THE EFFECT OF UNCONVENTIONAL MONETARY POLICY ON INFLATION EXPECTATIONS: A STRUCTURAL VAR ANALYSIS

by

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Abstract

This essay compares the behaviour of inflation expectations in the United States after both standard and unconventional monetary policy shocks. The reaction of inflation expectations matters since they can influence real interest rates by the Fisher equation. The question is answered by use of structural vector autoregressions with two identification schemes: the recursive Cholesky decomposition and the recent sign restrictions agnostic procedure with a single zero restriction. Unconventional monetary policy is represented as a decrease in the expected federal funds rate which leaves the federal funds rate itself unchanged. I find that both the standard and the unconventional monetary policy shock have a negative effect on inflation expectations and that this effect is stronger for the latter. Similar results are found using alternative measures of unconventional monetary policy.

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1 Introduction

In December 2008, the US Federal Reserve lowered its target for the federal funds rate to a range of 0–25 basis points and hit the zero lower bound, where it could not use its main policy instrument to further stimulate the economy. Facing a disastrous financial crisis that led to rising unemployment and plunging output, there was a need for further stimulus. This led the Federal Reserve to try unconventional monetary policy in the form of forward guidance and large-scale asset purchases (LSAPs), also known as quantitative easing (QE).

Forward guidance is the act of trying to steer market expectations of future Federal Reserve actions by adding conditional guidance to Federal Open Market Commitee (FOMC) statements. For example, in its June 2014 FOMC statement the Federal Reserve wrote that "the Committee continues to anticipate [...] that it likely will be appropriate to maintain the current target range for the federal funds rate for a considerable time...". It is important to understand that the central bank commits itself to a certain path in the future even if at the time it will not be optimal for the central bank to act in that way. In the case of forward guidance the central bank tries directly to lower expectations of future short-term rates which should then reflect into lower longer-term rates by the expectations hypothesis. By committing itself to a certain path, the central bank sends a credible signal that could mitigate the effect of the zero lower bound.

LSAPs, on the other hand, involve buying long-term financial securities, mainly bonds, and crediting bank reserves with the objective of directly influencing yields. There are two channels through which LSAPs can have an impact on yields. The first is the portfolio balance channel. When the central bank purchases long-term assets, it decreases the supply of long-term assets and increases the supply of short-term, risk-free bank reserves. If the two assets are not perfect substitutes then the expected return on long-term assets has to fall in order for investors to be willing to accept these changes. This lowers the risk premium on the asset (Gagnon *et al.*, 2011). The second is the signalling channel: if LSAPs send a credible signal to markets that the central bank will have a more stimulative stance than previously expected then this will lower expectations of future short-term rates and lower rates across the yield curve according to the expectations theory.

The objective of this essay is to compare the impact of standard and unconventional monetary policy on inflation expectations. In order to answer this question, vector autoregressions (VARs) will be estimated and two identification procedures will be used to recover the structural innovations. The first is the Cholesky decomposition which results in a recursive VAR in which shocks to variables ordered last do not have a contemporaneous impact on variables ordered before them. The second is the relatively recent sign restrictions procedure where economic theory is (usually) referred to in order to restrict the sign of the impulse responses of some variables. Additionally, a single zero restriction is imposed to model monetary policy at the zero lower bound.

Furthermore, I study three different specifications. The first two arise from the need to measure unconventional monetary policy. It is represented either as a decrease in the expected federal funds rate or as a decrease in the spread between long-term and short-term yields which leaves the federal funds rate unchanged. A third specification combines standard and unconventional monetary into a single indicator of the stance of monetary policy with a measure known as the shadow federal funds rate. This indicator tracks closely the federal funds rate in normal times but can be negative when the federal funds rate is at the zero lower bound.

On the question of this essay, there can be three possible reactions of inflation expectations after an expansionary monetary policy shock. The first is that people expect the central bank's actions to succeed in boosting growth and inflation which would then lead them to revise their expectation of inflation upward. The second alternative is that people believe the central bank has private information not available publicly. An expansionary monetary policy shock would then signal that the central bank has received new information on the future state of the economy, such as forecasts of inflation below its target, which justifies stimulative policy. People then revise their private forecast of inflation downward to incorporate this new information. Yet another alternative is that inflation expectations do not react to the shock. The interpretation would be that inflation expectations are persistent and do not change much, as a result perhaps of the credibility of the central bank and the anchoring of inflation expectations that has taken place in the United States since the Volcker disinflation.

It is important for the central bank to have knowledge on how its policies affect inflation expectations since a change in expected inflation should transmit into a change in real interest rate by the Fisher equation which could then have an influence on consumption, investment and net exports and thus aggregate demand. This is especially important at the zero lower bound since the federal funds rate cannot be used anymore to lower short-term real interest rates and only higher inflation expectations can lead to lower short-term real interest rates.[1] Furthermore

[1]Although long-term real interest rates can still drop following forward guidance, a change in the composition of the central bank's balance sheet and/or an increase in the size of the central

inflation expections can be a useful indicator of future inflation since the public's forecast of future inflation is an important variable for wage and price decisions.

I find that in most cases inflation expectations decrease after both monetary policy shocks, but that the effect of unconventional monetary policy is stronger than that of standard monetary policy. This provides evidence in support of the second scenario mentioned above, where expansionary monetary policy sends a signal that the economic outlook of the central bank has worsened and people revise their expectations accordingly. It also supports the hypothesis that the novelty of unconventional monetary policy and the relative rarity of its use mean that it sends a stronger signal than standard monetary policy, which explains the larger effect on expected inflation.

The rest of the paper is structured as follows. Section 2 reviews the literature on the economic and financial impact of unconventional monetary policy as well as empirical research on inflation expectations. Section 3 describes the financial and macroeconomic data used in this paper. Section 4 introduces the VAR and explains the two identification schemes. Section 5 discusses the impulse responses obtained from the VAR for a conventional and an unconventional monetary policy shock and compares the two identification schemes. Section 6 examines if the inference is robust to the measure of policy by computing impulse responses for two other specifications. Section 7 discusses the results in more detail and concludes.

bank's balance sheet.

2 Related Research

2.1 Empirical Research on Unconventional Monetary Policy

The first wave of studies on the effects of LSAPs examined their financial market impact. For the United States, Gagnon *et al.* (2011) have found using the event study method that LSAPs had a significant impact on long-term interest rates, even for securities that were not purchased by the Federal Reserve. Krishnamurthy and Vissing-Jorgensen (2011) also applied the event-study method to QE1 and QE2 and investigated the channels through which LSAPs operate. They found that LSAPs had significant impact on the yields of securities purchased, with QE2 having a more moderate effect than QE1. Hamilton and Wu (2012) found with a term-structure model that LSAPs at the zero lower bound could lower 10-year Treasury yields without raising short-term interest rates. Swanson (2011) performed an event-study of the Federal Reserve's 1961 Operation Twist (which was similar in size to QE2) to obtain potential estimates of this second round of LSAPs. This method showed that QE2 should lead to to declines in long-term Agency and Treasury yields. For the United Kingdom, Joyce *et al.* (2010) relied on an event study of financial market prices to conclude that LSAPs in that country depressed yields on 10-year government bonds by 100 basis points, similar to what Gagnon *et al.* (2011) found for the United States.

The second wave of studies on LSAPs mostly relied on the VAR method to obtain estimates of their effect on output and inflation. This contribution is important because although there had been many studies on the effects of conventional monetary policy shocks on output and inflation, Christiano *et al.* (1999)

being an excellent survey, there was little known about the effect of unconventional monetary policy prior to the financial crisis of 2007–2008. Moreover, output and inflation are what the central bank ultimately cares about so it is important to know if LSAPs can influence them. This especially matters since there are potential costs to these operations such as distorting financial markets and leading to search-for-yield behaviour that results in the purchases of riskier securities and could lead to financial instability. It also favors borrowers over savers and it has even been argued that because LSAPs lead to rising stock prices, a category of assets that is held in greater proportion by the wealthy, they can be associated with rising inequality.

Baumeister and Benati (2013) investigated the economic impact of LSAPs in the United States by estimating a time-varying parameter VAR identified with a mix of sign restrictions and a single zero restriction. They model the unconventional monetary policy shock as a term spread shock which lowers long-term interest rates while leaving the short-term rate unchanged. Their first result indicated that a decline in the term spread leads to significant positive effects on output growth and inflation at the zero lower bound. Their second result came from a counterfactual analysis of what would have happened if the Federal Reserve had not reacted to the financial crisis. This scenario showed that without LSAPs, inflation would have been 1 percentage point lower, output growth would have been lower by 0.9 percentage points and unemployment higher by 0.75 percentage points.

Also for the United States, instead of relying on a VAR, Chen, Curdia and Ferrero (2012) simulated a DSGE model with preferred-habit and market segmentation and showed that the effect of LSAPs on macroeconomic variables is "moderate". A program similar in size to QE2 results in an increase in GDP growth of less than 0.5 percentage point and its effect on inflation is "very small". Chung *et al.* (2012) used the Federal Reserve Board macroeconomic model to run counterfactual simulations and found that LSAPs were succesful at limiting the increase in unemployment and avoiding deflation.

For the Euro area, Lenza *et al.* (2010) estimated a Bayesian VAR on a large-scale model. They identified unconventional monetary policy as an interest spread shock. Their counterfactual exercise of what would have happened without the policy indicated that unemployment would have been higher by 0.5 points and that it had a positive impact of 1.5 percentage points on the growth of loans. Another study on the effect of unconventional monetary policy in the Euro area is by Peersman (2011). He estimated a structural VAR for which he identified three credit supply shocks with sign restrictions, including an unconventional monetary policy shock. He concluded that unconventional monetary policy had a significant effect on economic activity and inflation but with a more sluggish response than a standard monetary policy shock.

For the United Kingdom, Kapetanios *et al.* (2012) represented LSAPs as a long-term yield spread shock and compared three VARs: a Bayesian VAR, a Markov switching structural VAR and a time-varying parameter structural VAR. Based on a counterfactual scenario with no policy, they found that the average of the three models suggests that LSAPs had a peak effect of 1.5 percentage points on GDP and 1.25 points on inflation.

Finally, Schenkelberg and Watzka (2013) looked at post-1995 Japanese data, when the policy rate was at the zero lower bound, and estimated a Bayesian VAR identified with sign restrictions to examine the effects of LSAPs, represented as an increase in reserves, on industrial production and inflation. They concluded that quantitative easing in Japan was successful at stimulating economic activity in the short run but not inflation. Ugai (2007) provides a survey of empirical studies on the effect of quantitative easing in Japan.

2.2 Empirical Research on Inflation Expectations

We have seen so far that most studies have concluded that unconventional monetary policy has a positive impact on output and inflation. However, this literature has not determined empirically the channels through which policy operates. The objective of this essay is to determine if unconventional monetary policy has a significant impact on inflation expectations and if this relationship differs from the case of standard monetary policy.

Early studies on inflation expectations examined if they became more stable and better-anchored since the high inflation of the 1970s and the disinflation that followed. In their review of empirical evidence on this issue, Cunningham *et al.* (2010) concluded that past research has shown that inflation expections have become more stable but are still imperfectly anchored and that inflation expectations are better-anchored in inflation targeting countries.

Several studies relied on the VAR method to examine the relationship between inflation expectations and monetary policy. Berk (2002) converted qualitative survey data on inflation expectations to quantitative data and looked at the effect of monetary policy on inflation expectations in European countries with the hope of finding differences based on the credibility of the national central banks. He estimated a vector error correction model (VECM) and found that an unexpected monetary policy shock has no significant effect on inflation expectations in all the countries included. Ueda (2010) investigated the determinants of households' inflation expectations in Japan and the United States using survey data. He estimated a structural VAR identified by zero restrictions in a non-recursive scheme taking into account the simulatenous co-dependence of inflation and inflation expectations. His results indicated that households' inflation expectations not only react to food and energy prices but also to monetary policy, as a contractionary monetary policy shock results in a declining inflation expectations. The study by Nakazono *et al.* (2012) is very similar to that of Ueda (2010) with the main difference being that they also include the United Kingdom in the countries examined and their estimates of inflation expectations are based on a survey of professional forecasters instead of a household survey.

Closer to this essay, Neuenkirch (2013) has compared the impact of monetary policy and central bank communications on inflation expectations in the Euro area. Using a VAR identified with the Cholesky decomposition, he found that communications by the European Central Bank have a similar effect on inflation expectations to standard monetary policy.

This essay differs from previous studies on the relationship between inflation expectations and monetary policy by comparing the response of inflation expectations to monetary policy and unconventional monetary policy for the United States as well as including an identification scheme that does not rely on zero restrictions: the sign restrictions procedure. Moreover, it is different from past empirical research on unconventional monetary policy by studying additional specifications of policy.

3 Financial and Macroeconomic Data

3.1 Description of Data

The federal funds rate is used as the indicator of the stance of monetary policy, which is a widely accepted measure since Bernanke and Blinder (1992) concluded that it is "a good indicator of monetary policy actions" and that it is "extremely informative about future movements of macroeconomic variables" (Bernanke and Blinder, 1992, 1). However the federal funds rate loses most of its informative content at the zero lower bound, hence I include the 8-month expected federal funds rate as an indicator of current expectations of future monetary policy. Changes in this indicator reflect aspects of monetary policy which are not captured by the federal funds rate, such as communications by the central bank. In other words it is a proxy for unconventional monetary policy. This is yet another way in which this essay differs from the literature on unconventional monetary policy as no study so far has focused on the expected federal funds rate as an indicator of unconventional monetary policy. Inflation and industrial production are also included in order to be able to distinguish the 4 shocks which the sign restrictions procedure has to identify (see section 4.2). The last variable, expected inflation, is the main focus of this essay.

More precisely, the financial and macroeconomic time series used are the effective federal funds rate (r_t), the expected federal funds rate 8 month ahead (r_t^e)

as extracted from the 8-month federal funds rate futures contract, inflation computed as the annual percentage change in the CPI (π_t), the Federal Reserve Bank of Cleveland estimates of 10-year inflation expectations (π_t^e) and industrial production annual growth (y_t). I use monthly data from January 2000 to April 2014.

Industrial production and expected inflation are already monthly variables so no modifications were needed. The other time series are daily. To transform them into monthly series I take their average level for the month. The federal funds rate, inflation and industrial production are obtained from the Federal Reserve Bank of Saint Louis economic database, expected inflation is available on the Federal Reserve Bank of Cleveland website[2] while the expected federal funds rate series is retrieved from Bloomberg. Figures of each variable appear in Appendix A.

The federal funds rate, inflation and industrial production are typical macroeconomic time series. The expected federal funds rate and inflation expectations are less standard data so more explanation is needed. Federal funds rate futures contracts have been traded daily since October 1988 at the Chicago Board of Trade (CBOT). A contract is based on the average of the effective federal funds rate during the month of the contract and the settlement price is 100 minus this average. Contracts are available from the current month to 24 months ahead (Robertson and Thornton, 1997, 1). This allows us to extract market expectations of the federal funds rate in the future. For example, if today the price of the 8-month contract is 98 this implies that market participants expect the federal funds rate to average 2% in 8 months.

[2] http://www.clevelandfed.org/research/data/inflation_expectations/

Gurkaynak, Sack and Swanson's (2005) event study has shown that, in normal times, FOMC statements have an impact on federal funds rate futures prices and Treasury yields and that market participants believe that they contain information about future monetary policy. Based on unanticipated changes in expected future rates, they found that two factors explain most of the innovation variance of the expected federal funds rate: the target factor and the path factor. The target factor reflects a surprise change in the current federal funds rate while the path factor conveys changes in expected future rates. Campbell *et al.* (2012) applied the same method after 2008 to determine if the zero lower bound changed these relationships and found that FOMC statements can still have an influence on federal funds futures prices at the zero lower bound. They also replicated Gurkaynak *et al.* (2005)'s study with newer observations and concluded that the innovation variance in the expected federal funds rate is mostly due to the target factor for the current quarter to two quarters ahead series while it is mostly accounted for by the path factor for the three to four quarters ahead series. For example, for the period 1994–2007, 90% of the innovation variance in the four quarters ahead expected federal funds rate is accounted by the path factor. In other words, futures contract with longer time to expiration are more responsive to unconventional monetary policy. Their findings justifiy using the 8-month contract.[3]

As for inflation expectations, most of the commonly used estimated come either from surveys or are market measures.[4] However, the Cleveland Fed estimates

[3]Ideally, I would have opted for the 12-month or the 9-month contract but there were considerably fewer observations (4 years) for these contracts.

[4]For example, some of the most known survey measures in the United States are the University of Michican Survey of Consumers, the Federal Reserve Bank of Philadelphia Survey of Professional Forecasters and Consensus Economics' international survey of professional forecasters. The usual market measure is the break-even inflation rate, defined below. See Cunningham *et al.* (2010) for a detailed description of survey and market based measures of inflation expec-

of expected inflation are obtained from the the term structure model of Haubrich *et al.* (2008) where the parameters are based on nominal Treasury yields, survey forecasts of inflation and inflation swaps. The 10-year expected inflation is interpreted as the expected average rate of inflation for the next 10 years. Haubrich (2009) argues that it provides better estimates than other measures. For instance, surveys only provide expected inflation for a few horizons while market measures such as break-even inflation, usually defined as the difference between the 10-year Treasury rate and the 10-year Treasury inflation-linked rate, contain a risk and a liquidity premium which tend to overstate expected inflation.[5] For this essay, monthly data is needed since the VAR requires a large number of parameters to be estimated, therefore this requirement disqualifies measures of expected inflation that are estimated from quarterly surveys such as the Federal Reserve Bank of Philadelphia's Survey of Professional Forecasters (SPF). Moreover, a long horizon is needed in order to obtain better estimates for the VAR. Because break-even inflation is available only from 2003 it was preferable to adopt the Cleveland Fed measure since it is available from 1982, even though it would have been interesting to compare the VAR estimates based on the two expected inflation measures, especially since the correlation between the two series is only 0.32.

3.2 Testing for Non-Stationarity

When dealing with time series data it is important to test for non-stationarity. To test for unit roots, I apply the augmented Dickey-Fuller (ADF) test without drift

tations as well as a list of their advantages and inconvenients

[5]Although they have shown that the inflation risk premium has been stable across time so a change in break-even inflation should reflect a change in expected inflation rather than a change in the inflation risk premium.

or trend on each series as nothing in the theory would justify their inclusion. The ADF involves the following regression on a variable y_t:

$$\Delta y_t = a_0 + \gamma y_{t-1} + \sum_{i=2}^{p} \beta_i \Delta y_{t-i+1} + \epsilon_t$$

The null hypothesis is that $\gamma = 0$, *i.e.* there is a unit root, while the alternative is that the series is stationary. The regression is estimated for each variable using data from January 2000 to April 2014. The number of lags to include in the regression was chosen so as to minimize the Bayesian Information Criterion. This procedure resulted in the selection of 1 lag for expected inflation and the federal funds rate, 2 lags for the expected federal funds rate and inflation and 3 lags for industrial production. The results from the ADF test are that the federal funds rate, the expected federal funds rate and expected inflation are $I(1)$ while inflation and industrial production are stationary at the 5% significance level. The p-values are respectively 0.1053, 0.3767, 0.0150, 0.1635 and 0.0086. Changing the number of lags does not alter the conclusion.

The previous finding could lead to another important non-stationarity issue. Indeed, since there are three $I(1)$ variables, it is possible that a linear combination of some pairs results in a $I(0)$ variable, in other words that there is cointegration. To investigate this issue, I apply the Johansen (1988) test for cointegration with no trend to find the number of cointegrating equations, r, and use the trace statistic at the 5% significance level. The procedure of this test is to start with the null hypothesis of $r = 0$ and increase r by one each time the the null hypothesis is rejected. The trace statistic at $r = 0$ (84.40) is greater than its critical value (59.46), so I reject the null hypothesis of no cointegrating equation. Moving the null hypothesis of $r = 1$, the trace statistic (43.19) is greater than its critical value (39.89) and the null hypothesis of one cointegrating equation can be rejected. For $r = 2$ the trace statistic (23.78) is less than its critical value (24.31) and the the null hypothesis of 2 cointegration equations cannot be rejected.

Even though there appears to be cointegration in the data, it can nonetheless be appropriate to estimate a VAR in levels instead of a VECM since the former allows for implicit cointegration in the data (Sims, Stock and Watson, 1990). Moreover, even if the endogenous variables are not stationary it can still be appropriate to estimate a VAR in levels if the residuals appear to be stationary (Canova, 2005, p.115).

4 VAR and Identification

4.1 VAR Model

The structural VAR is[6]

$$AY_t = c + B(L)Y_{t-1} + \epsilon_t \tag{1}$$

where $Y_t = [r_t, r_t^e, \pi_t, \pi_t^e, y_t]$, A is a matrix of coefficients, $B(L)$ is a matrix of coefficients of the lagged values of Y_t, c is a vector of constants and ϵ_t is a vector of structural errors with $\epsilon_t \sim \mathcal{N}(0, I)$. Equation (1) cannot be estimated by OLS since the regressors are correlated with the error term and this would produce inconsistent estimates and impulse responses. The solution is to pre-multiply by A^{-1} each side of (1) to obtain the reduced-form VAR. Leaving the constant for

[6]This subsection draws on the lecture notes of Ambrogio Cesa-Bianchi "A Primer on Vector Autoregressions" which are an intuitive presentation of how VARs work and are available on his personal page: `https://sites.google.com/site/ambropo/LectureNotes`.

simplicity of exposition:

$$Y_t = A^{-1}B(L)Y_{t-1} + A^{-1}\epsilon_t \tag{2}$$

which can be written

$$Y_t = \Gamma(L)Y_{t-1} + u_t \tag{3}$$

where $\Gamma(L) = A^{-1}B(L)$, $u_t = A^{-1}\epsilon_t$ and $u_t \sim \mathcal{N}(0, \Sigma_u)$ Note that the reduced form errors are now correlated:

$$\Sigma_u = E[u_t u_t'] = E[A^{-1}\epsilon_t \epsilon_t'(A^{-1})'] = A^{-1}\Sigma_\epsilon (A^{-1})' = A^{-1}(A^{-1})'$$

To specifiy the VAR, the number of lags to include has to be chosen. The smallest number of lags for which the residuals are not autocorrelated, based on an LM test, is 4 and is the one chosen to estimate the VAR. This also corresponds to the number of lags that minimizes the Akaike information criteria and is standard for monthly data.

4.2 Identification of the VAR

Since the residuals for each equation in the reduced-form VAR are correlated, direct analysis of impulse responses from this VAR would not be meaningful as each residual is a linear combination of the structural errors. To produce meaningful impulse response functions, we need to make the shocks orthogonal and recover the structural innovations, which are uncorrelated, from the reduced-form VAR. This is done with identifying restrictions. In this essay, two identification schemes are compared: the Cholesky decomposition and sign restrictions.

Starting with the Cholesky decomposition, recall that $\Sigma_u = A^{-1}(A^{-1})'$. The problem with this system of equations is that there are more unknowns than there are equations. In order to identify A^{-1}, $n(n-1)/2$ restrictions need to be specified. Sims (1980) suggested the Cholesky decomposition which results in a recursive VAR with exactly this number of restrictions as it decomposes Σ_u into the product of a lower triangular matrix P and its transpose P'. Formally, $\Sigma_u = P'P$. This implies that $P'P = A^{-1}(A^{-1})'$ and thus that A^{-1} is lower triangular. The model is now identified since we have the same number of equations and unknowns.

When using this identification scheme, explict assumptions are made on the contemporaneous effect of a shock in each variable on the others since the triangular structure of the impact matrix A^{-1} implies, for example, that a shock to the first variable has a contemporaneous impact on all the other variables but is not affected immediately by shocks to the other variables. In other words, the Cholesky decomposition makes the ordering of the variables very important and assumes specific relationships between the variables.

More recently, Uhlig (2005) suggested making the theoretical assumptions explicit by using economic theory to directly constrain the impulse responses of some variables while leaving the variable(s) of interest unconstrained. This approach involves sign restrictions on the impact matrix A^{-1}. It is referred to as an agnostic procedure, because "the central question [of interest] is left agnostically open by design of the identification procedure: the data will decide" (Uhlig, 2005, 384). For instance, Uhlig used this approach, which had been pioneered by Faust (1998) and Canova and de Nicolo (2002)[7], to investigate the effect of a contractionary mon-

[7]See Fry and Pagan (2011) for a survey of studies that employ the sign restrictions procedure.

etary policy shock on output. To identify the shock, he constrained the federal funds rate impulse responses to be positive while those for prices and non-borrowed reserves were restricted to be negative. Most importantly, he did not constrain the impulse responses of output as this is the central question of his paper. Although this approach seems to be more appropriate regarding identifying assumptions, it needs to be said that even with this agnostic procedure, one must still make assumptions on the length of the restriction period.

For this essay, the sign restrictions for the monetary policy, unconventional monetary policy, demand and supply shocks are summarized in table 1 and are based on theory and empirical evidence. All restriction must hold only on impact. The restrictions for the monetary, demand and supply shock are based on standard New-Keynesian model results. A positive demand shock increases inflation and output, to which the central bank reacts by raising its policy rate. In the case of a supply shock, output and inflation move in opposite directions and the central bank faces a tradeoff which could lead it to either increase or decrease its policy rate depending on the rule it follows. For the monetary shock, New-Keynesian models find that a decrease in the policy rate leads to higher output and inflation. The 8-month expected federal funds rate is restricted to have the same sign as the federal funds rate.

The sign restrictions for the unconventional monetary policy shocks are based on the empirical findings summarized in section 2 that unconventional monetary policy has a positive impact on inflation and output. Here unconventional monetary policy is represented as a negative shock to the expected federal funds rate which leaves the federal funds rate unchanged. Hence the zero restriction to the

Table 1: Sign Restrictions
Expected Federal Funds Rate Specification

Title of variable	Monetary policy	Unconventional	Demand	Supply
Federal funds rate	−	0	+	
Expected federal funds rate	−	−		
Inflation	+	+	+	−
Expected inflation				
Industrial production	+	+	+	+

federal funds rate, which is a convenient way to represent monetary policy at the zero lower bound. The justification for the negative restriction on the expected federal funds rate is the finding of Campbell *et al.* (2012) that communications by the Federal Reserve have an impact on federal funds rate futures prices. For all the shocks, inflation expectations are not restricted as the objective of this essay is to find the effect of each shock on inflation expectations. Moreover, no additional restrictions are needed so that each shock has a unique sign pattern.

The procedure for the sign restrictions with a zero restriction is a bit different from the standard one, as a zero restriction need to be imposed in the impact matrix in order to constrain the federal funds rate not to respond on impact to the unconventional monetary policy shock. This restriction is required to distinguish the standard monetary policy shock from the unconventional one. The procedure was suggested by Baumeister and Benati (2013) and has been generalized to more than one zero restriction and to zero restrictions for more than one period by Haberis and Sokol (2014). The algorithm works in the following way:[8]

1. Start by taking the Cholesky decomposition of the covariance matrix of the

[8]The explanation of this algorithm draws from Haberis and Sokol (2014, pp. 7-8). and the MatLab code of Christiane Baumeister used for Baumeister and Benati (2013).

VAR residuals Σ_u:

$$\Sigma_u = A^{-1}(A^{-1})' = P'P$$

2. Perform the Householder transformation: draw a random Normal matrix W and take its QR decomposition $W = QR$ where Q is an orthogonal matrix such that $Q'Q = I$ and R is a triangular matrix. Decompose Σ_u in the following way:

$$\Sigma_u = P'Q'QP$$

to obtain the candidate impact matrix $A_0 = (P'Q)^{-1}$ with orthogonal shocks.

3. Multiply A_0 by a deterministic rotation matrix R to put a zero in the $(1, 2)$ position of the candidate impact matrix, which corresponds to the reaction of the federal funds rate to the unconventional monetary policy shock. The deterministic rotation matrix in this case is the 5×5 Givens matrix:

$$R = \begin{bmatrix} cos(\theta) & -sin(\theta) & 0 & 0 & 0 \\ sin(\theta) & cos(\theta) & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

so that

$$\tilde{A}_0 = A_0 R = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix} \begin{bmatrix} cos(\theta) & -sin(\theta) & 0 & 0 & 0 \\ sin(\theta) & cos(\theta) & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

The angle θ is calculated such that it puts a zero in the $(1, 2)$ position of the rotated impact matrix $\tilde{A}_0$. Formally, it is the angle θ that solves $a_{11}cos(\theta) - a_{12}sin(\theta) = 0$ which results in $\theta = tan^{-1}(a_{12}/a_{11})$ (Baumeister and Benati, 2013, 176). The resulting candidate impact matrix $\tilde{A}_0$ now satisfies the zero restriction. Note that this step can be skipped if no zero restriction needs to be imposed.

4. Check if the sign restrictions are satisfied. This involves looking at every column of $\tilde{A}_0$ and being able to identify jointly the 4 shocks by looking at the sign of the entries. Note that we have to take into account that the signs might be switched. For example, we do not want to keep only expansionary monetary policy shocks but also contractionary shocks, so it is important to look for both positive and negative shocks. This is done by a normalization procedure involving the division of each column (except the second) by its first element. Another important thing to note is that the ordering of the shocks does not matter, so apart from the unconventional monetary policy shock which always has to be in the second column (since this is where the zero restriction is), all the other shocks can be in any other column of $\tilde{A}_0$. If the four shocks can be jointly identified by looking at $\tilde{A}_0$ the matrix is retained, if not it is discarded.

5. Repeat until the desired number of succesful draws is obtained. In this

paper I choose 1000.[9]

6. Keep the median impulse response and the 16% and 84% quantile impulse responses to compute the impulse responses and the one standard error confidence intervals.

5 Results

5.1 Conventional Monetary Policy Shock

This section presents the impulse responses of all the variables to an expansionary monetary policy shock and compares the results from the Cholesky decomposition and the sign restrictions identification procedures.[10]

In the case of the Cholesky decomposition, the ordering of the variables is the following: industrial production, inflation, federal funds rate, expected federal funds rate and expected inflation. It is well known that monetary policy shocks have a lagged impact on output and inflation, so these two variables are ordered before the federal funds rate. As a result, the contemporaneous impact of inflation and industrial production after a shock to the federal funds rate is null. The expected federal funds rate is ordered after the federal funds rate so the federal funds rate cannot react on impact to a shock to the expected federal funds rate, which is how I approximate monetary policy at the zero lower bound. Expected

[9]Note that this can involve a lot of simulations. For example, to obtain 1000 full identifications for the specification with the spread it took approximately 300000 draws and rotations.

[10]The impulse responses associated with the Cholesky decomposition were produced using Ambrogio Cesa Bianchi's VAR and Figures toolboxes available on his personal page. The MatLab code of Christiane Baumeister which she used for her 2013 paper with Luca Benati was used to produce the sign restrictions impulse responses.

inflation is ordered last as a result of the assumption that all the other variables can affect inflation expectations.

The VAR is estimated with 4 lags from January 2000 to April 2014. The standard monetary policy shock is a one standard deviation decrease in the federal funds rate. The results are presented in figure 1 where the solid line represents the mean impulse response of the variable and the dashed lines delimit the one standard error confidence interval obtained by the boostrap with 1000 draws. I find that there is no significant effect on expected inflation after the monetary policy shock. The behaviour of the expected federal funds rate is very similar to the federal funds rate itself. Inflation decreases for 12 months which is the price puzzle of Sims (1992) that a contractionary monetary policy shock raises inflation. Industrial production growth rises after 17 months.

The results for the sign restrictions identification scheme appear in figure 2. The solid line is the median impulse response for the variable while the dashed lines are the 16% and 84% median impulse responses which is equivalent to the one standard error confidence interval. The results are that a one standard deviation drop in the federal funds rate results in declining inflation expectations for the median impulse response but the whole confidence band becomes negative only after 10 months. There is a negative impact on inflation after 15 months which turns positive after 24 months. Industrial production growth only rises after approximately 2 years.

Figure 1: Impulse Responses to a Monetary Policy Shock (Cholesky Decomposition Identification)

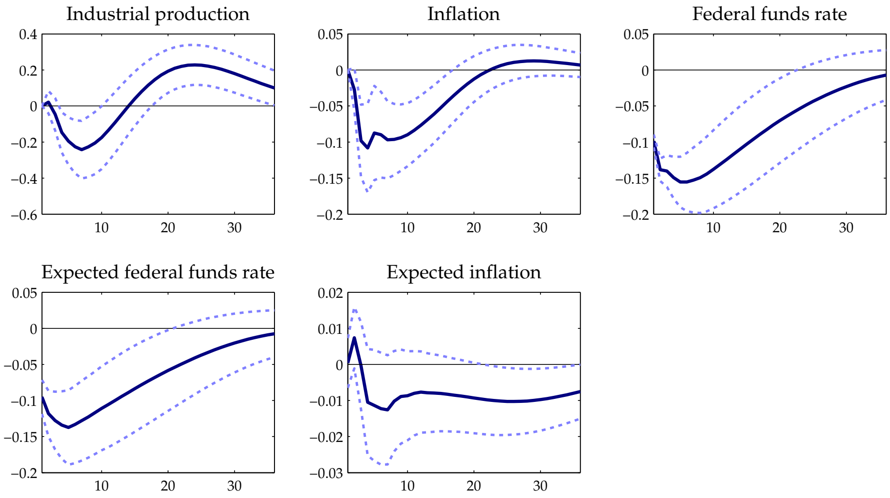
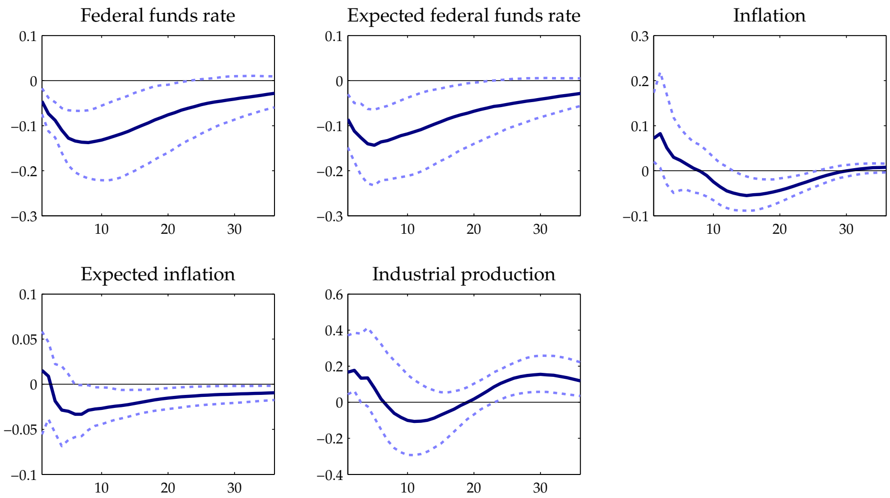


Figure 2: Impulse Responses to a Monetary Policy Shock (Sign Restrictions Identification)



5.2 Unconventional Monetary Policy Shock

Turning now to the question of how inflation expectations react after an unconventional monerary policy shock, the shock is represented as a one standard deviation decrease in the 8-month expected federal funds rate. Other measures of policy are discussed in section 6.

The impulse responses from the Cholesky identification are shown in figure 3. As opposed to the standard case which found no significant effect, inflation expectations decline after the unconventional monetary policy shock and the effect is permanent. There is no significant impact on inflation and a positive impact on industrial production growth after approximately 2 years.

Figure 4 shows the impulse responses to an unconventional monetary policy shock identified by sign restrictions. Inflation expectations could increase or decrease on impact, as the median impulse response is positive but the 16% quantile impulse response is negative. Nevertheless, the confidence band becomes negative after 5 months so it is possible to say that there is a lagged negative effect on inflation expectations. Comparison with the standard monetary policy shock based on the median impulse response shows that the effect is larger in the case of unconventional monetary policy. As for the other variables, their impulse responses show that inflation decreases after 12 months while the effect on industrial production growth is only significantly positive close to impact and after about 24 months.

To summarize the findings of this section, the impulse responses obtained with the Cholesky decomposition and the sign restrictions procedure agree on the effect of unconventional monetary policy on inflation expectations as both show that they decrease following the shock. This corresponds to the hypothesis that people believe the central bank has received new private information that influences its forecast of inflation negatively and they adjust their expectations accordingly. The two identification schemes also agree that the unconventional monetary policy shock has a larger effect on inflation expectations than the standard monetary policy shock, especially for the Cholesky decomposition. The only difference between the two identification schemes is that the Cholesky decomposition does not find a significant effect of standard monetary policy on inflation expectations while the sign restrictions identification shows that they decrease. The finding that unconventional monetary policy has a stronger effect on inflation than standard monetary policy could be due to the novelty of unconventional monetary policy. Because it is rarely used it could send a stronger signal on the Federal Reserve economic outlook than a change in the federal funds rate. This will be discussed in more detail in section 7.

6 Alternative Specifications

This section examines whether the results found in section 5 are robust to the measure of unconventional monetary policy. Comparison between impulse responses for standard and unconventional monetary policy shocks will be made on the basis of an alternative measure of policy used in the literature: the spread between the ten-year interest rate and the federal funds rate. An indicator of both standard and unconventional monetary policy, the shadow federal funds rate, then will provide impulse responses for a monetary policy shock where the instrument is not constrained by the zero lower bound.

Figure 3: Impulse Responses to an Unconventional Monetary Policy Shock (Cholesky Decomposition Identification)

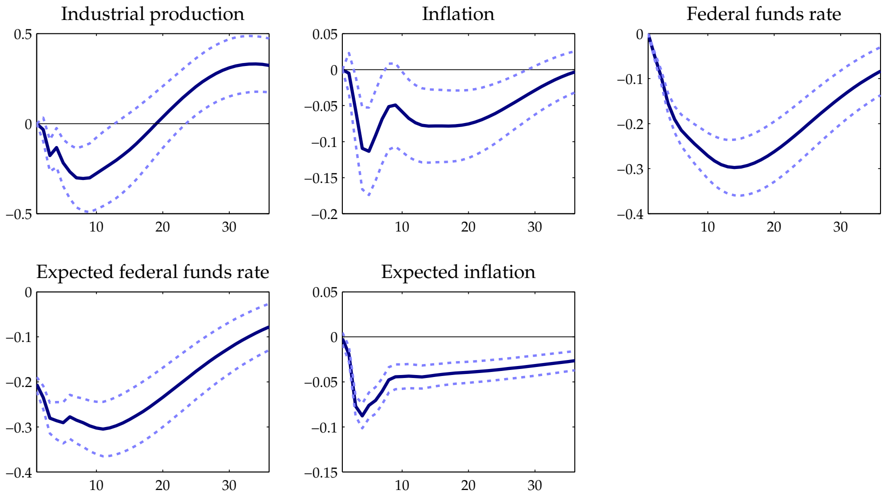


Figure 4: Impulse Responses to an Unconventional Monetary Policy Shock (Sign Restrictions Identification)

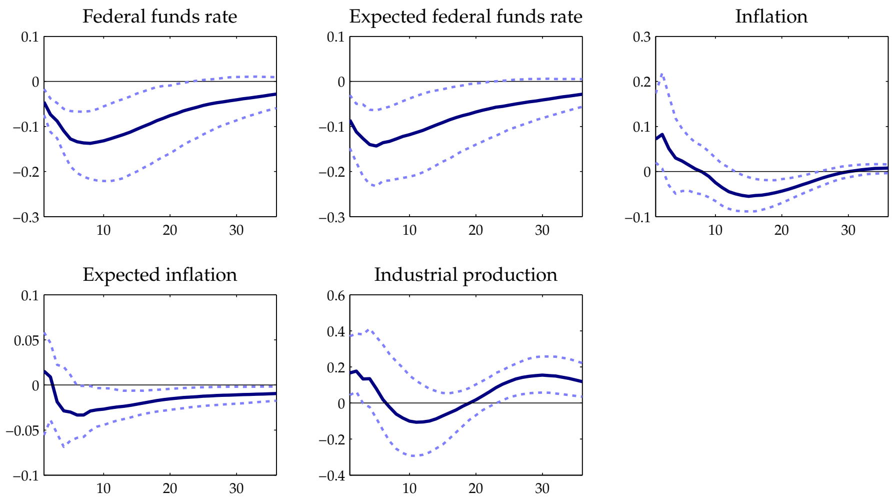


Table 2: Sign Restrictions
Spread Specification

Variable	Monetary policy	Unconventional	Demand	Supply
Federal funds rate	−	0	+	
Spread	+	−		
Inflation	+	+	+	−
Expected inflation				
Industrial production	+	+	+	+

6.1 Spread

The expected federal funds rate is now replaced with the spread between the yield on the US 10-year Treasury bond and the federal funds rate. This alternative measure of unconventional monetary policy is based on the findings that LSAPs by central banks were able to lower the spread between the yields on long-term and short-term bonds during the global financial crisis, as mentioned in section 2. Moreover, this measure of policy has been the one most commonly used in research on the effects of unconventional monetary policy on inflation and output. The VAR is estimated with 4 lags from January 1992 to March 2014. The decision not to start the sample earlier is based on the fact that the volatiliy and the level of inflation became lower in the 1990s compared to the previous decade as inflation expectations became better-anchored.

Regarding the identification, in the case of the Cholesky decomposition the variables are ordered in the following way: industrial production, inflation, federal funds rate, spread and inflation expectations. The reasoning is the same as when the expected federal funds rate was included instead of the spread.

As for the second identification scheme, the sign restrictions for the 4 shocks are similar to those in table 1 with the exception that the spread now replaces the expected federal funds rate. The spread is not restricted to react in a particular way after demand and supply shocks. The monetary policy shock is modelled as a decrease in the federal funds rate, which all else equal should increase the spread between long-term and short-term yields. The unconventional monetary policy shock is represented as a decrease in long-term yields that leaves the federal funds rate unchanged, hence the negative sign restriction on the spread and the zero restriction on the federal funds rate. Restrictions are summarized in table 2 and are based on Baumeister and Benati (2013, 176).

Turning to the results for the standard monetary policy shock, figure 5 shows that when the VAR is identified with the Cholesky decomposition, a one standard deviation drop in the federal funds rate leads to a decline in inflation expectations. Note however that this effect is nearly insignificant as the edge of the confidence interval is close to zero. There is no significant impact on industrial production and the effect on inflation is negative for a short period only.

When the sign restrictions are instead used as the identification scheme, the results are notably different. Most importantly, figure 6 shows that the impulse responses of inflation expectations are positive, as people expect the policy to increase inflation as a result of increasing economic activity. This is also different from the results with the expected federal funds rate included in the VAR instead of the spread. The price puzzle is not present in this case, as median impulse responses show that inflation rises for 12 months and the effect on industrial production is positive also for 12 months.

In brief, it appears that the two VAR identification schemes do not agree on the effect of an expansionary monetary shock on expected inflation, as the Cholesky decomposition finds that it decreases while the sign restrictions show an increase.

Continuing with the unconventional monetary policy shock, measured as a decline in the spread, the Cholesky decomposition finds that a one standard deviation drop in the spread results in lower inflation expectations, which can be seen in figure 7, and the effect is stronger than in the case of a conventional monetary policy shock. The effect on inflation is negative after 15 months while industrial production growth decreases.

The results from the sign restriction identification are different from those found for the monetary policy shock as, instead of increasing, expected inflation decreases after the shock according to its impulse responses in figure 8. It thus appears that the two types of policies have different effects on inflation expectations. For the other variables, there is a positive effect on inflation for 12 months and positive impact on industrial production growth followed by a decline after approximately a year.

To summarize, the Cholesky decomposition and the sign restriction identification procedures find similar results for the effect of unconventional monetary policy on expected inflation as both impulse responses show a decrease in inflation expectations that is larger in comparison with the standard monetary policy shock. This is a similar result to what was found in section 5 when the expected federal funds rate was used as the measure of unconventional monetary policy. The main difference is that inflation expectations increase after a standard monetary policy shock when the sign restriction identification procedure is used.

Figure 5: Impulse Responses to a Monetary Policy Shock (Cholesky Decomposition Identification)

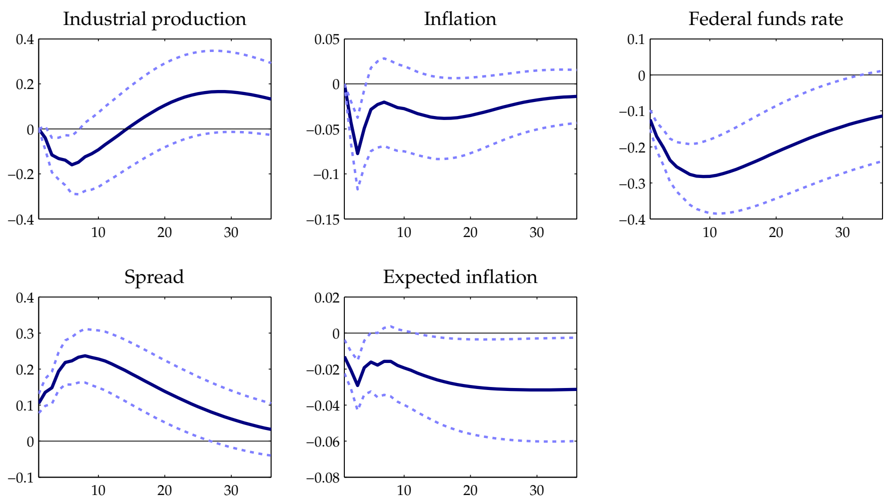


Figure 6: Impulse Responses to a Monetary Policy Shock (Sign Restrictions Identification)

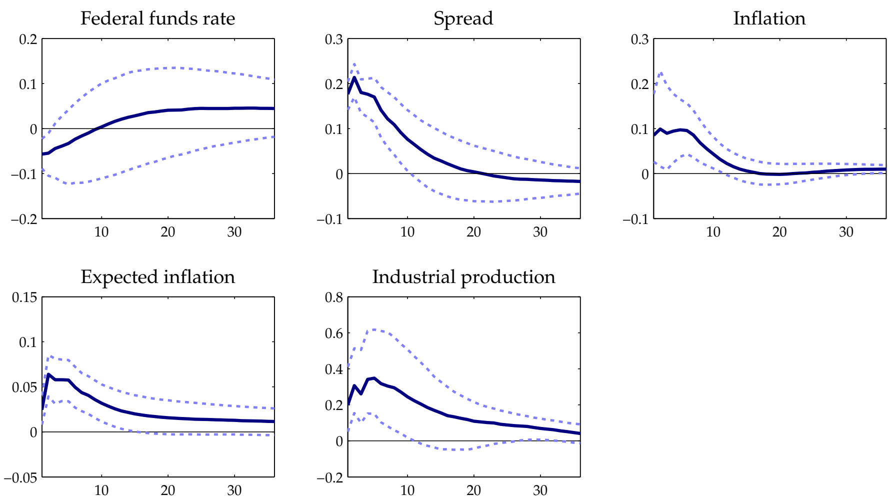


Figure 7: Impulse Responses to an Unconventional Monetary Policy Shock (Cholesky Decomposition Identification)

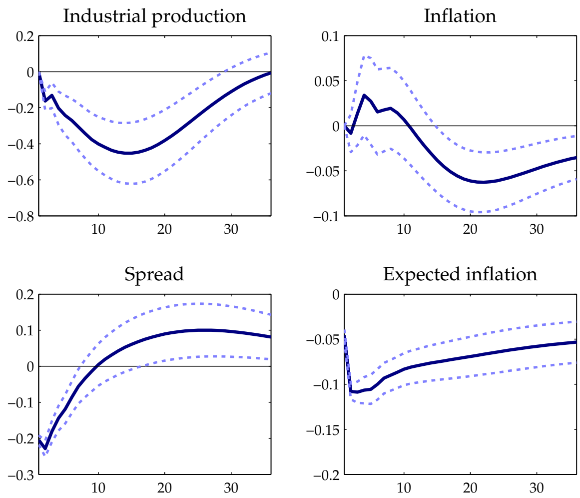
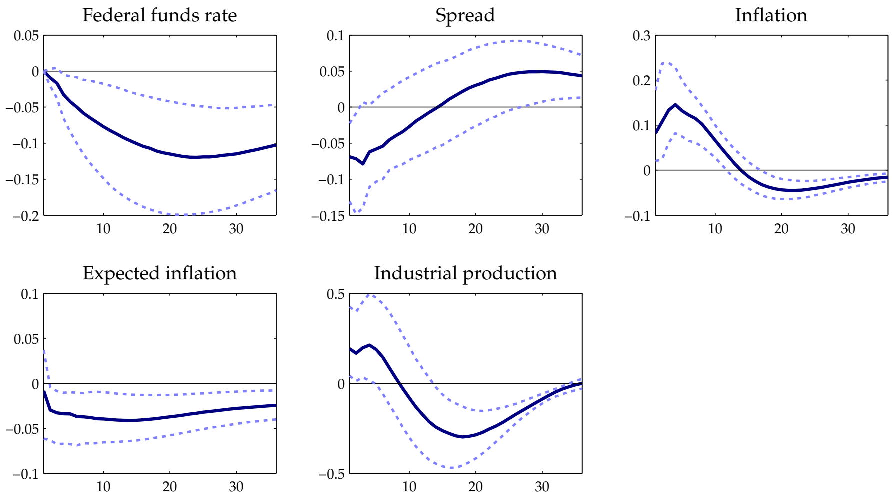


Figure 8: Impulse Responses to an Unconventional Monetary Policy Shock (Sign Restrictions Identification)



6.2 Shadow federal funds rate

Lombardi and Zhu (2014) recently developped an interesting measure of the stance of monetary policy which is not constrained by the zero lower bound and reflects unconventional monetary policy. They call it the shadow federal funds rate. It is constructed from a dynamic factor model with missing data. By including measures of interest rates, monetary aggregates, the Federal Reserve's assets and liabilities, it reflects information on standard monetary policy and unconventional monetary policy. As the authors write, "[their] 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" (Lombardi and Zhu, 2014, 7). Before the financial crisis, the shadow federal funds rate closely tracked the federal funds rate. When the federal funds rate hit the zero lower bound, the shadow federal funds rate became negative as a result of the Federal Reserve LSAPs.

Since the shadow federal funds rate summarises information on the stance of monetary policy beyond the federal funds rate, there is no need to compare standard and unconventional monetary policy as the shadow federal funds rate includes both. Therefore, in this sub-section only the impulse responses to an expansionary monetary policy shock, represented as a one standard deviation decrease in the shadow federal funds rate, will be presented.

Moreover, because no indicator of unconventional monetary policy needs to be included, the VAR is now estimated with 4 variables: the shadow federal funds rate, inflation, expected inflation and industrial production annual growth. The sample period is from January 1992 to December 2013, the last observation of the

Table 3: Sign Restrictions
Shadow Federal Funds Rate Specification

Variable	Monetary policy	Demand	Supply
Shadow federal funds rate	−	+	
Inflation	+	+	−
Expected inflation		+	−
Industrial production	+	+	+

shadow federal funds rate available at this time.

Another consequence of the fact that the shadow federal funds rate reflects standard and unconventional monetary policy is that in the sign restrictions procedure only three shocks need to be identified as the standard monetary and unconventional monetary policy are pooled into a single monetary policy shock. The restrictions are summarized in table 3. Note that this time the impulse response of expected inflation are constrained to be positive on impact for the demand and supply shocks. This extra assumption was required to identify the shocks.

On the sign restrictions procedure, because there is no longer a zero restriction, the third step of the algorithm (multiplying the impact matrix by the Givens matrix to impose a zero in the $(1, 2)$ position) is no longer needed. The rest of the algorithm works in a similar way, except that now it has to jointly identify 3 shocks which can be in any of the 4 columns since no zero is imposed in one of them.[11]

The impulse responses from the Cholesky decomposition identification, shown in figure 9, demonstrate that a one standard deviation decrease in the shadow federal funds rate results in lower inflation expectations. There is no significant

[11] Recall that originally the unconventional monetary policy shock was restricted to be in the second column.

Figure 9: Impulse Responses to a Monetary Policy Shock (Cholesky Decomposition Identification)

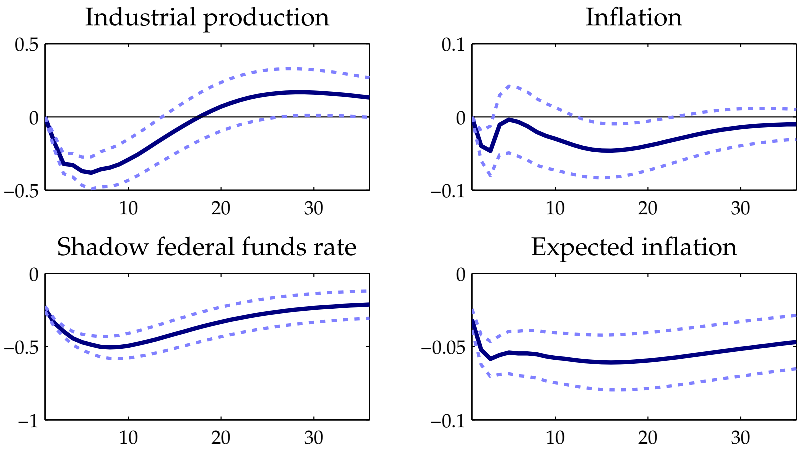
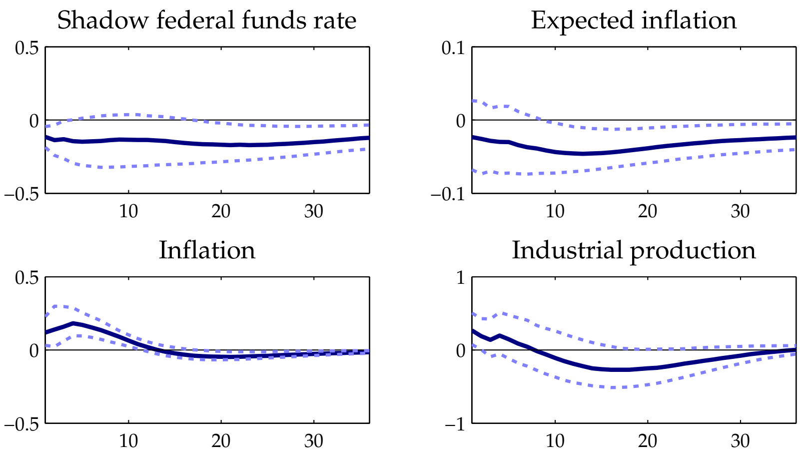


Figure 10: Impulse Responses to a Monetary Policy Shock (Sign Restrictions Identification)



effect on inflation and a decrease in industrial production growth that lasts for a year. The results from the sign restrictions identification procedure show that according to the median impulse response there is a decline in inflation expectations after 10 months. Inflation increases for 10 months while there is no clear effect on industrial production growth. The results are in figure 10. Thus the results for inflation expectations from both identification schemes are similar to what was found in section 5.

7 Discussion and Conclusion

This essay has compared the response of expected inflation after standard and unconventional monetary policy shocks by estimating a VAR with two identification schemes: the Cholesky decomposition and sign restrictions. Unconventional monetary policy was represented by two different measures: a decline in the expected federal funds rate as extracted from the 8-month federal funds rate futures prices and a decline in the spread between long-term and short-term yields. The shadow federal funds rate, a third specification, combined indicators of standard and unconventional monetary policy into a single measure of the stance of monetary policy.

When the Cholesky decomposition was chosen as the identification scheme, most measures found that inflation expectations decline after both monetary shocks. This finding supports the hypothesis that people believe that the central bank has private information which is not available to them. An expansionary monetary policy sends a signal that the central bank anticipates a worse outlook for inflation and output growth than previously expected. People realize this and adjust their forecasts accordingly. Furthermore, the effect on expected inflation was larger and more significant (in the sense that the edge of the confidence interval was farther from zero) for the unconventional monetary policy shock. This is an intuitive result: because unconventional monetary policy is rarely used it sends a stronger signal than a standard change in the target for the federal funds rate and hence the effect on inflation expectations should be stronger. In other words, for the central bank to try unconventional monetary policy, the inflation forecast of the central bank must be very pessimistic.

The sign restrictions identification procedure found similar results. Inflation expectations decline after both shocks and the effect is stronger in the unconventional case. Interestingly, when the spread replaced the expected federal funds rate as the measure of unconventional monetary policy, there was an important difference between the results from the standard and unconventional monetary policy shocks. I found that a monetary policy shock has a positive effect on inflation expectations, which corresponds to the hypothesis that people expect the central bank actions to have a positive impact on economic activity and inflation, while for the unconventional shock inflation expectations decrease. Again this provides support for the hypothesis that unconventional monetary policy sends a stronger signal on the central bank's private forecasts of inflation.

The shadow federal funds rate is an interesting way to summarize the overall stance of monetary policy by combining indicators of standard and unconventional monetary policy into a single measure. As in the other cases, I found with this measure of policy that a monetary policy shock leads to a decline in inflation expectations. A summary of all the findings on inflation expectations is presented

Table 4: Summary of Changes in Expected Inflation

Measure of policy	Shock	Cholesky	Sign restrictions
Expected federal funds rate	Conventional (r_t)	Not significant	Negative
	Unconventional (r_t^e)	Negative	Negative
Spread	Conventional (r_t)	Negative	Positive
	Unconventional (s_t)	Negative	Negative
Shadow federal funds rate	Monetary policy ($\tilde{r}_t$)	Negative	Negative

Note: r_t is the federal funds rate, r_t^e is the 8-month expected federal funds rate, s_t is the spread between the 10-year US Treasury yield and the federal funds rate and $\tilde{r}_t$ is the shadow federal funds rate.

in table 4.

The finding that in most cases inflation expectations decrease after both monetary shocks has important implications for the real interest rate. For the standard monetary policy shock, the decline in the federal funds rate was, in all cases, larger than that in expected inflation, which shows that the Federal Reserve has historically been succesful in lowering short-term real interest rates by changing its target for the federal funds rate. However, at the zero lower bound it is not possible for the Federal Reserve to lower short-term real interest rates by decreasing its target for the federal funds rate. The other option to exert downward pressure on short-term real interest rates[12] is to increase inflation expectations by, for example, using unconventional monetary policy.[13] Yet I found that unconventional monetary policy is associated with decreasing inflation expectations which should lead to higher

[12]The discussion is on short-term rates but LSAPs can be used to lower long-term rates.

[13]Other actions to steer inflation expectations upwards are a rise in the Federal Reserve's inflation target and nominal GDP targeting.

real interest rates, the opposite of what the central bank is trying to achieve.

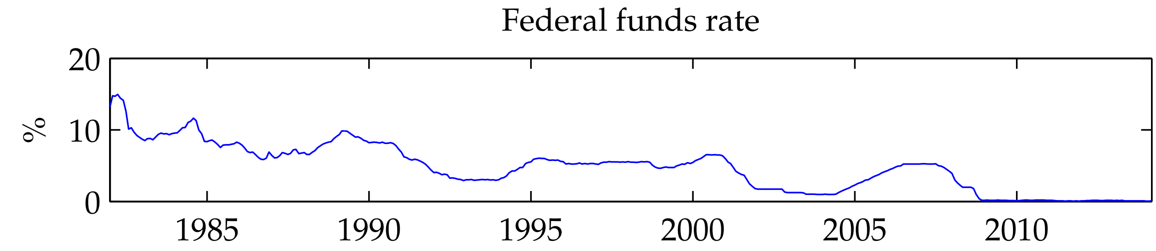
A policy recommendation that emerges from this analysis is that in order to undo this rise in the short-term real interest rate, the Federal Reserve should write in its FOMC statements that it expects its unconventional monetary policy to increase inflation in the future. The effect would be even more powerful if the Federal Reserve would state that it is willing to tolerate inflation above target for some time. It must be said however that this recommendation assumes that the public would actually believe that unconventional monetary policy would have a positive effect on economic growth and inflation. It is therefore important for the Federal Reserve to communicate why this would be the case.

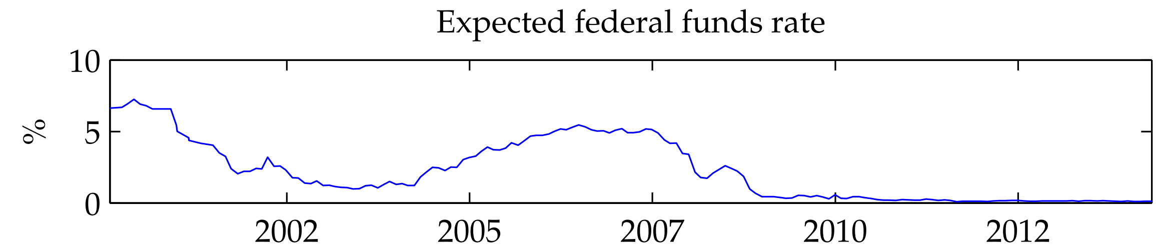
To elaborate on the warning above, there appears to be some kind of self-fulfilling prophecy here. If people expect that the central bank will be successful at stimulating the economy with unconventional monetary policy, inflation expectations will increase which will lower real interest rates and boost aggregate demand and the unconventional policy will be deemed to have been successful. Conversely, if people do not expect the central bank to succeed at boosting the economy, inflation expectations will decrease and real interest rates will rise which would provide headwinds to economic growth and the unconventional monetary policy would be considered a failure. Note also that this is not only important for the current round of unconventional monetary policy but also for future ones. If it has been deemed that unconventional monetary policy was a success, people will be more inclined in the future to believe that the policy will be successful.

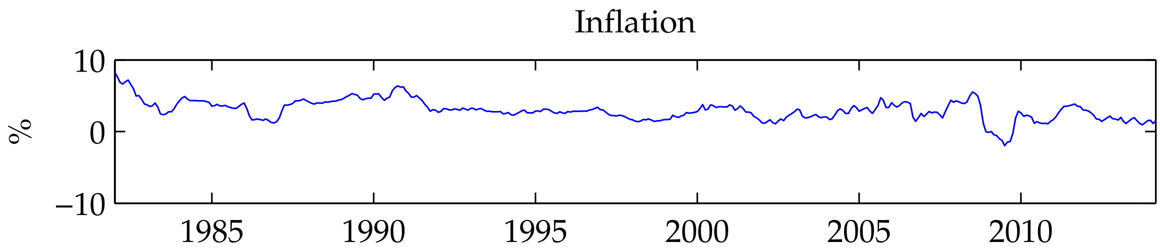
In any case, section 2 showed that there is considerable evidence that unconventional monetary policy was successful at raising inflation and output growth which implies that there must be other and stronger channels for unconventional monetary policy than the expected inflation channel. Most probable is that unconventional monetary policy causes a decline in long-term yields that is larger than the decrease in inflation expectations. This results in lower long-term real interest rates, which are more important for consumption and investment decisions than short-term rates. In future research it would be interesting to study VARs with interest rates of various maturities, to test for this effect. However, adding variables to the VAR also creates challenges in identifying shocks under sign restrictions.

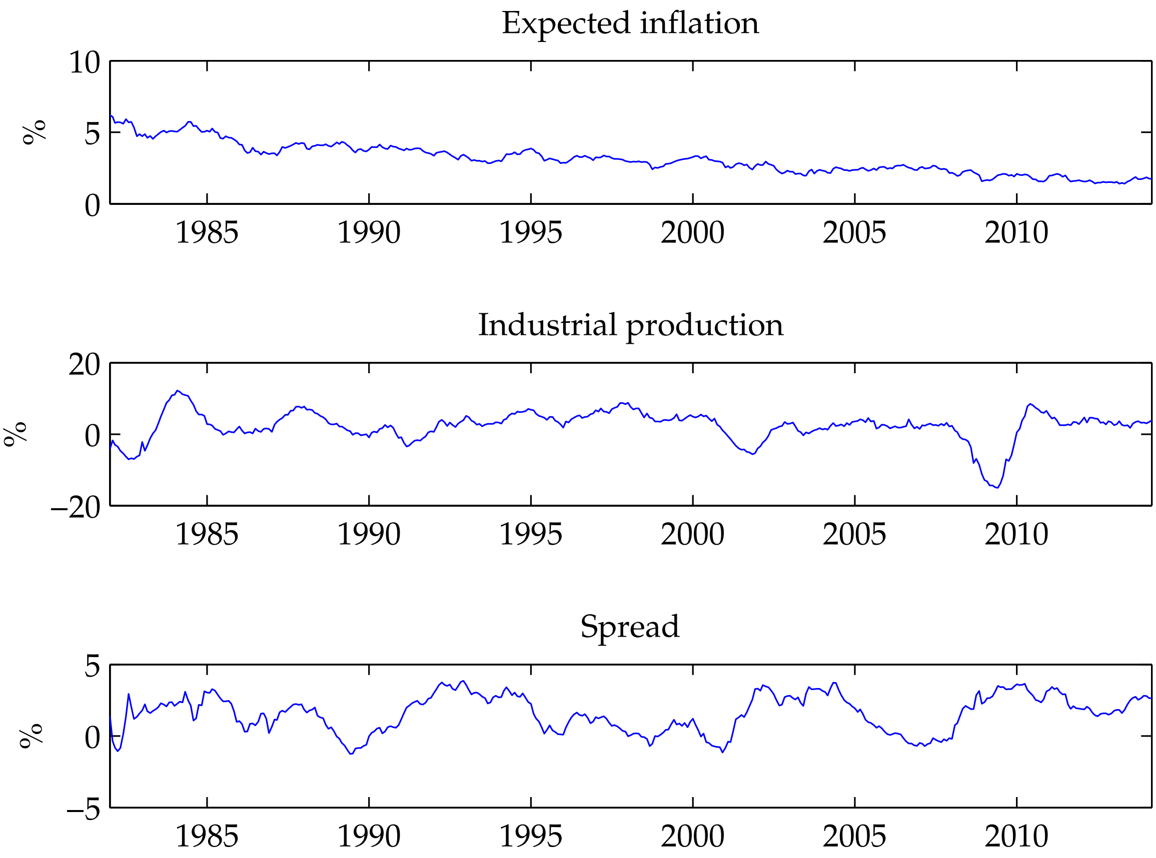
One important assumption implicit so far in this essay is that structural relationships in the economy did not change during the financial crisis. This assumption underlies the use of the VAR with constant coefficients. However this assumption is rather strong and it would have been interesting to compare the results to other types of VARs, with Markov-switching or time-varying parameters, that account for structural changes. On future research, the identification scheme with a mix of sign restrictions and zero restrictions can be used to analyze any issue where one variable cannot react on impact. An interesting area of empirical research would be on the link between financial risk-taking and unconventional monetary policy in order to have an idea of how much financial instability the central bank has created with its unconventional monetary policy.

A Figures of Time Series









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