Freie Universität Berlin

The Role of Long-Term Inflation Expectations for the Transmission of Monetary Policy Shocks

Max Diegel
Dieter Nautz

School of Business & Economics
Discussion Paper

Economics

2020/19

The Role of Long-Term Inflation Expectations for the Transmission of Monetary Policy Shocks

Max Diegel and Dieter Nautz*

Freie Universität Berlin

This Version: November 10, 2020

Abstract

This paper empirically investigates the role of long-term inflation expectations for the monetary transmission mechanism. In contrast to earlier studies, we confirm that U.S. long-term inflation expectations respond significantly to a monetary policy shock. In line with a re-anchoring channel of monetary policy, we find that long-term inflation expectations play an important role for the transmission of monetary policy shocks to the rate of inflation. Our results are robust with respect to the identification strategy and alternative monetary policy indicators applied during the zero lower bound period.

Keywords: Long-Term Inflation Expectations, Monetary Policy, Structural Vector Autoregression, Sign and Zero Restrictions
JEL-Classification: E31, E52, C32

*Corresponding author: Max Diegel (max.diegel@fu-berlin.de), Department of Economics, Boltzmannstr.20, D-14195 Berlin, Germany. Financial support from the Deutsche Forschungsgesellschaft through grant NA 365/6-1 (*The Anchoring of Inflation Expectations*) is gratefully acknowledged. We thank Jörg Breitung, Helmut Lütkepohl, Frank Schorfheide and participants of the 2020 seminar "Topics in Time Series Analysis" for helpful comments and suggestions.

1 Introduction

There is a general consensus among both, academics and central bankers that the anchoring of long-term inflation expectations is of crucial importance for monetary policy. As a result, a growing literature investigates the anchoring of inflation expectations assuming that well-anchored inflation expectations do not respond to macroeconomic news. Accordingly, any response of inflation expectations to a monetary policy shock is considered a sign of de-anchoring, and thus must be undesirable.[1]

However, the role of inflation expectations for the monetary transmission mechanism might be more complex than the early anchoring literature suggests. During the past decade, long-term inflation expectations have been persistently below official inflation targets. Consequently, central banks have discussed how monetary policy can contribute to *re-anchor* inflation expectations. In this case, the response of long-term inflation expectations to monetary policy might not be undesirable but is the intended policy outcome. Farmer (2012), Andrade et al. (2016), Ciccarelli et al. (2017) and Doh and Oksol (2018) provide first evidence on the *re-anchoring channel* of monetary policy for the European Central Bank and the U.S. Federal Reserve.

The aim of our paper is twofold. First, we use structural vector autoregressive (VAR) analysis to investigate if U.S. long-term inflation expectations respond to monetary policy shocks in line with the re-anchoring channel. Second, we propose a counterfactual analysis to shed more light on the quantitative importance of long-term inflation expectations and the re-anchoring channel for the transmission of monetary policy shocks to inflation and unemployment.

[1]Following Gürkaynak et al. (2005) the predominant approach in the empirical anchoring literature applies news-regressions where expected inflation is regressed on surprises in macroeconomic news announcements (MNA), see e.g. Nautz et al. (2017) and the literature cited therein. More recently, Hachula and Nautz (2018) use MNA surprises as external instruments in a structural VAR framework to estimate the response of inflation expectations to macroeconomic news shocks.

The focus of earlier contributions that include measures of inflation expectations into empirical macro models is typically not on the role of long-term inflation expectations for the monetary transmission mechanism and their response to monetary policy shocks. By contrast, the contemporaneous response of inflation expectations to macroeconomic shocks is often restricted to zero. This implicitly assumes that the contribution of structural shocks to changes in inflation expectations is small, see e.g. Leduc et al. (2007) and Geiger and Scharler (2020). To illustrate, Clark and Davig (2011) assume that neither shocks to short-term inflation expectations nor other macroeconomic shocks have a contemporaneous impact on long-term inflation expectations. Such a restriction of the reaction of long-term inflation expectations can be plausible if inflation expectations are perfectly anchored, but cannot account for the re-anchoring channel of monetary policy. Nautz et al. (2019) document an immediate response of long-term inflation expectations to macro news shocks in a bi-variate structural VAR. Yet, abstracting from economic key variables, bi-variate models of short- and long-term inflation expectations are not informative about the interaction of inflation expectations and monetary policy. To overcome these issues, the current paper identifies monetary policy shocks in a structural VAR that (i) includes inflation expectations, inflation, interest rates, and unemployment and (ii) exploits a minimal set of uncontroversial sign restrictions. Most importantly, the response of inflation expectations to a monetary policy shock is left unrestricted.

Our paper relates to studies that also avoid zero restrictions on the response of inflation expectations. Interestingly, the available evidence is mixed. While e.g. Gertler and Karadi (2015) find no response of longer-term inflation expectations to monetary policy shocks, Jarociński and Karadi (2020) confirm that inflation expectations decrease in response to a monetary policy tightening. Confirming Jarociński and Karadi (2020), our empirical results show that U.S. long-term inflation expectations respond significantly and plausibly signed to monetary policy shocks. In our benchmark model monetary policy shocks account for 16% of the variation of long-term inflation expectations on impact. In sharp contrast to the assumptions made by the earlier literature, this indicates that monetary policy has a sizable impact on the dynamics of long-term inflation expectations.

However, a plausibly signed and significant response of long-term inflation expectations to monetary policy shocks is only a necessary condition for the working of the re-anchoring channel of monetary policy. The question remains how important the estimated response of inflation expectations is for the transmission of monetary policy shocks to the ultimate target variables of monetary policy, i.e. to inflation and unemployment. In order to quantify the importance of the re-anchoring channel of monetary policy, we follow Wong (2015) and perform a counterfactual analysis where the transmission of monetary policy shocks via inflation expectations is shut down. While the response of unemployment to a monetary policy shock is only weakly affected by the assumption of constant long-term inflation expectations, the effects are much more pronounced for inflation. Confirming the re-anchoring channel of monetary policy, this suggests that monetary policy shocks are also transmitted to inflation via long-term inflation expectations. Moreover, we find that the contribution of monetary policy shocks to the variation of inflation rates is strongly reduced in the counterfactual scenario where long-term inflation expectations remain constant and the re-anchoring channel of monetary policy is shut down.

The rest of the paper is structured as follows. Section 2 presents the data and reduced-form evidence on the importance of long-term inflation expectations for monetary policy. Sections 3 presents our empirical model. We briefly review the identification problem of structural VARs, explain the identification strategy and introduce the underlying identifying assumptions. Section 4 presents the empirical results on i) the effect of monetary policy on long-term inflation expectations and ii) the role of inflation expectations for the transmission of monetary policy shocks to inflation and unemployment. This section also includes the counterfactual analysis as well as the robustness analysis regarding the choice of the shadow rate and the identifying assumptions. Section 5 provides some concluding remarks.

2 Long-term inflation expectations and monetary policy: Data, variables, and reduced-form evidence

2.1 Data and variables

Our empirical analysis on the role of inflation expectations for the transmission of monetary policy shocks is based on a structural VAR consisting of the three standard macro variables, i.e. an interest rate, inflation, and unemployment, as well as a measure of long-term inflation expectations. The vector of endogenous variables is

$$y_t = \begin{pmatrix} \pi_t, & u_t, & s_t, & \pi_t^e \end{pmatrix}.$$

Following the literature, we use the federal funds rate as the monetary policy instrument. For the period of the zero lower bound (2008m8 to 2015m11), the federal funds rate is replaced with the shadow rate of introduced by Krippner (2013). Therefore, our analysis should also capture shocks stirred by unconventional monetary policy measures. The spliced monetary policy indicator is denoted by s. In accordance with the ultimate targets of the Fed, we use the unemployment rate (u) as a measure of economic activity. Inflation (π) is defined as the annual percent change of the consumer price index. Long-term inflation expectations (π^e) are taken from the quarterly survey of professional forecasters (SPF) that is available from the Federal Reserve Bank of Philadelphia. Due to the availability of SPF data, we consider quarterly data and the sample period runs from 1991Q4 to 2019Q4. Time series plots and more detailed information about the data are provided in the appendix.

2.2 Long-term inflation expectations and monetary policy: Reduced form evidence

Before going into detail on how to assess the response of long-term inflation expectations to structural monetary policy shocks, we present reduced form evidence suggesting that inflation expectations are an informative variable for the transmission of monetary policy. Canova and Gambetti (2010) use Granger-causality tests to show that short-term inflation expectations are empirically relevant for actual inflation and the policy rate from 1960Q1 to 2005Q4. In this section, we follow Canova and Gambetti (2010) and employ our four-dimensional system to run Granger-causality tests. As a result, we test the null-hypothesis that long-term inflation expectations π_t^e do not Granger-cause inflation, the unemployment rate and the interest rate, respectively.

Two lags are selected by Bayesian (BIC) information criterion for the lag-length of the underlying VAR.[2] For sake of robustness we also present the results for three and four lags as well as for the alternative shadow rates by Lombardi and Zhu (2019) and Wu and Xia (2016). The results presented in Table 1 confirm that long-term inflation expectations could be an important variable for monetary policy analysis and should therefore not be ignored. In particular, the hypothesis that long-term inflation expectations can be omitted from the interest rate equation is rejected for most of the specifications. Similar results are obtained from the Granger-causality tests for inflation. By contrast, there seems to be no Granger-causality from π^e to unemployment.

Since long-term inflation expectations cannot be omitted from the interest rate and the inflation equation they are important for identification of monetary policy shocks and may

[2] Akaike (AIC) and Hannan-Quinn (HQ) criterion also select 2 lags.

Table 1: **The impact of long-term inflation expectations for inflation, unemployment and the monetary policy instrument: Results from Granger-causality tests**

Lags	dep. var	Krippner	Lombardi and Zhu	Wu and Xia
2	π	0.300	0.377	0.230
	u	0.115	0.108	0.179
	s	0.014	0.012	0.056
3	π	0.046	0.049	0.027
	u	0.220	0.156	0.291
	s	0.020	0.020	0.053
4	π	0.032	0.010	0.016
	u	0.350	0.320	0.665
	s	0.035	0.046	0.160

Notes: The table reports p-values of Wald tests for the null hypothesis that long-term inflation expectations π^e do not Granger-cause inflation π, the unemployment rate u and the shadow rate s. The rows show the results for different lag-lengths, the columns refer to different shadow rates. Common estimation sample for all lag orders: 1992Q4–2019Q4.

even play a role for transmitting changes of the monetary policy instrument to inflation. However, without further identifying assumptions, reduced form evidence cannot reveal (i) how monetary policy shocks affect inflation expectations and (ii) how important inflation expectations are for the transmission of monetary policy shocks. To shed more light on these questions, we proceed by introducing the structural VAR and our identification strategy.

3 The empirical model

We estimate the impact of monetary policy on long-term inflation expectations in a structural VAR framework. Exogenous shifts in monetary policy are identified in a standard empirical macro model consisting of an interest rate, inflation and unemployment that is augmented by a measure of long-term inflation expectations. The structural VAR accounts for the endogenous relations between the variables and allows to identify the exogenous sources of variations – in particular the monetary policy shock.

3.1 Structural VARs and the identification problem

The structural VAR with p lags of the $n \times 1$ vector y_t and a constant is given by

$$A_0 y_t = A_+ x_t + \varepsilon_t, \quad \varepsilon_t \sim N(0, I_n). \tag{1}$$

The regressor matrix $x_t = [1, y'_{t-1}, ..., y'_{t-p}]'$ is of dimension $(np+1) \times 1$ and the $n \times np+1$ matrix $A_+ = [c, A_1, ..., A_p]$ collects the structural coefficients on the lagged dependent variables and the constant c. The $n \times 1$ vector ε_t collects the structural economic shocks. The structural shocks are normally distributed with an identity covariance matrix. A_0 captures the contemporaneous relations between the variables in y_t. Its inverse A_0^{-1} represents the instantaneous impact of structural shocks on the variables in y_t. For estimation, the VAR is cast in reduced form

$$y_t = Bx_t + u_t, \quad u_t \sim N(0, \Sigma)$$

where u_t is the vector of reduced form errors and $B = A_0^{-1} A_+$. In contrast to the structural shocks, the reduced form errors are correlated with covariance matrix Σ. Reduced form errors are related to the structural shocks according to

$$u_t = A_0^{-1} \varepsilon_t.$$

The identification of the structural VAR amounts to finding A_0^{-1}, given the reduced form parameters B and Σ. The decomposition of the reduced form error variance matrix

$$\Sigma = A_0^{-1}(A_0^{-1})' \tag{2}$$

is at the heart of the identification problem (see e.g Kilian and Lütkepohl, 2017).

Identification via sign restrictions is based on the observation that the decomposition in (2) is not unique. For any orthonormal matrix Q there is another candidate impact matrix $\tilde{A}_0^{-1} = A_0^{-1}Q$ that satisfies (2). Each candidate decomposition yields different structural shocks $\tilde{\varepsilon}_t$. To make sure that the structural shocks are economically meaningful, shocks are required to satisfy a set of identifying restrictions. The next section introduces the identifying restrictions that are imposed on the matrix of contemporaneous relations A_0 and on the structural impact matrix A_0^{-1} in order to identify a monetary policy shock and the expectation shock.

3.2 The identification strategy

Our research agenda has implications for the identification strategy applied in the structural VAR analysis. First, since we focus on the transmission of monetary policy, the identification of monetary policy shocks is based on conventional, uncontroversial sign restrictions. Second, we rule out that monetary policy reacts to inflation expectations systematically in an implausible way. In particular, we assume that the central bank does not raise the interest rate in response to decreasing long-term inflation expectations and *vice versa*. Third, since the aim of the first part of the analysis is to estimate the impact of monetary policy shocks on inflation expectations, the identification of the monetary policy shock must not rely on restrictions regarding its impact on long-term inflation expectations.

The aim of the second part of our analysis is to assess the role of inflation expectations for the transmission of monetary policy shocks to inflation and unemployment. In a counterfactual analysis, we eliminate the role of inflation expectations in the transmission of monetary policy by assuming that a second shock, the expectation shock, neutralizes the impact of monetary policy such that inflation expectations remain constant. This counterfactual analysis requires the innocuous assumption that a shock to long-term inflation expectations does not hit inflation and unemployment on impact.

Finally, we avoid the dependence of our results on restrictions that are not essential for the analysis. Therefore, we base our analysis on a set-identified structural VAR that restricts the attention to the monetary policy and the expectation shock, and leaves the two remaining shocks unidentified.

3.3 The identifying assumptions

3.3.1 Sign restrictions on the structural impact matrix

In line with the identification strategy discussed in the previous section, we identify the monetary policy (MP) shock and the expectation (EXP) shock by imposing a combination of zero and sign restrictions on the structural impact matrix A_0^{-1}. Table 2 summarizes the restrictions. A contractionary monetary policy shock that increases the policy interest rate

Table 2: **Sign and zero restrictions to identify a monetary policy and an expectation shock**

	π_t	u_t	s_t	π_t^e
$\varepsilon_t^{\text{MP}}$	≤ 0	≥ 0	≥ 0	
$\varepsilon_t^{\text{EXP}}$	0	0		≥ 0

Notes: Restrictions to identify a monetary policy shock and an expectations shock: sign restrictions are indicated by weak inequalities, zero restrictions by 0, blanks indicate unrestricted elements.

s_t raises unemployment u_t and decreases inflation π_t on impact. This sign pattern for the impact of monetary policy shocks reflects consensus view of the literature (see e.g. Fry and Pagan, 2011; Geiger and Scharler, 2020). As the response of inflation expectations to a monetary policy shock is the object of interest, it is left unrestricted.

In accordance with Wong (2015) and the counterfactual exercise implemented in the second part of our analysis, the expectation shock does not affect inflation and unemployment on impact. We normalize the impact of the expectation shock on inflation expectations to be positive. The expectation shock can be interpreted as a change in agents' information set that is unrelated to current inflation and unemployment. Note that the response of the interest rate to expectation shocks cannot be assumed to be zero (e.g. Leduc et al., 2007).

3.3.2 Sign restrictions on the systematic component of monetary policy

Following Caldara and Kamps (2017), recent literature emphasizes the importance of the *systematic policy component* in SVARs for the identification of policy shocks. In particular, Arias et al. (2019) demonstrate how sign restriction on the systematic component of monetary policy in addition to sign restrictions on impulse responses can be informative about the otherwise unrestricted response of output in the identification scheme proposed by Uhlig (2005). They show that imposing a positive systematic monetary policy response to output consistently yields a negative output response to the monetary policy shock, regardless of other identifying assumptions.

A similar reasoning applies to the role of longer-term inflation expectations for the interest rate setting of the central bank. In the following, we incorporate the consensus view that central banks seek to stabilize long-term inflation expectations into our identification strategy. We do this by ruling out that the central bank systematically increases the policy rate in response to decreasing long-term inflation expectations. From a monetary policy perspective, a negative response of the central bank to long-term inflation expectations can be ruled out for various reasons. First, it can create a vicious circle of self-fulfilling inflationary or deflationary inflation expectations. Second, monetary policy decisions are often explained with reference to long-term inflation expectations. However, a negative response of monetary policy to long-term inflation expectations would be clearly at odds with typical FOMC statements. Third, the inflation target is specified for the medium term. Consequently, monetary policy should react to long-term inflation expectations to the extent that they reflect the unobservable trend in inflation, as suggested by e.g. Eusepi et al. (2019), Chan et al. (2018) or Mertens (2016).

Moreover, Wolf (2020) provides an important econometric argument in favor of the restriction we propose. He shows that linear combinations of shocks can be misidentified as a monetary policy shock when the response of one variable, e.g. π_t^e, to the monetary policy shock remains unrestricted. In our application, the identifying restrictions introduced in the previous section may not prevent that linear combinations of the expectation shock and the two other non-identified shocks are misidentified as monetary policy shock. In this case, conclusions about the response of π_t^e to the monetary policy shock would be misleading. However, Wolf (2020) shows that placing additional restrictions on the systematic component of monetary policy in A_0 solves the misidentification problem.

Therefore, imposing a sign restriction on the systematic response of monetary policy to long-term inflation expectations is also part of our identification scheme. The monetary policy rule is the first equation in the SVAR in (1) because the monetary policy shock is identified to be the first shock. After normalizing the coefficient on the monetary policy instrument s_t to unity, the monetary policy rule is obtained as

$$s_t = \psi_\pi \pi_t + \psi_u u_t + \psi_{\pi^e} \pi_t^e + A_{+,1} x_t + \varepsilon_t^{MP} \tag{3}$$

with $\psi_\pi = -\frac{a_{0,11}}{a_{0,13}}$, $\psi_u = -\frac{a_{0,12}}{a_{0,13}}$, $\psi_{\pi^e} = -\frac{a_{0,14}}{a_{0,13}}$ where $a_{0,1k}$ denotes the kth element in the first row of the structural impact matrix A_0, and $A_{+,1}$ is the first row of A_+. The sign restriction on the systematic component of monetary policy is given by

$$\psi_{\pi^e} \geq 0 \tag{4}$$

which we impose using the algorithm proposed by Arias et al. (2018).

In Section 4.3.2, we check the robustness of our results with respect to the identification scheme. We show that our main results remain unchanged if we leave the impact of the monetary policy shock on inflation and unemployment unrestricted and instead restrict the monetary policy reaction coefficients ψ_π and ψ_u in (3).

4 Empirical results

4.1 Priors and estimation algorithm

We estimate structural VAR using the Bayesian algorithm proposed by Arias et al. (2018) because it is flexible enough to allow combinations of sign and zero restrictions for identification. The Bayesian approach has the advantage of accounting for both, estimation uncertainty about the reduced form VAR-parameters and about the rotation matrices Q that satisfy a set of sign and zero restrictions. As a result, all statistics and high posterior density intervals (HPDI) for inference computed from the simulated draws from the posterior distribution also represent both types of uncertainty.

We specify an uninformative normal prior for the reduced form coefficients B and an inverse Wishart prior for the residual covariance matrix Σ. The algorithm of Arias et al. (2018) specifies a uniform prior for the rotation matrices Q. This means that under the prior all Q matrices are equally likely. To allow dependence of the variables within a year we use $p = 4$ lags for estimation for the quarterly data.[3] The results in the following section are based on 5000 accepted draws from the posterior distribution that jointly satisfy the restrictions in Table 2 and Equation (4).

4.2 The response of long-term inflation expectations to monetary policy shocks

This section presents our estimation results for the structural VAR introduced and identified in the previous section. Table 3 shows the estimates obtained for the contemporaneous reactions of monetary policy to the macro variables (π, u) and to long-term inflation expectations (π^e) implied by the Taylor-type monetary policy rule (3).

Table 3: **The monetary policy reaction coefficients on inflation, the unemployment rate and long-term inflation expectations**

Coefficient	ψ_π	ψ_u	ψ_{π^e}
median	0.51	-2.09	3.71
[16% 84%]	0.13 1.22]	[−4.02 −0.99]	[1.04 9.59]

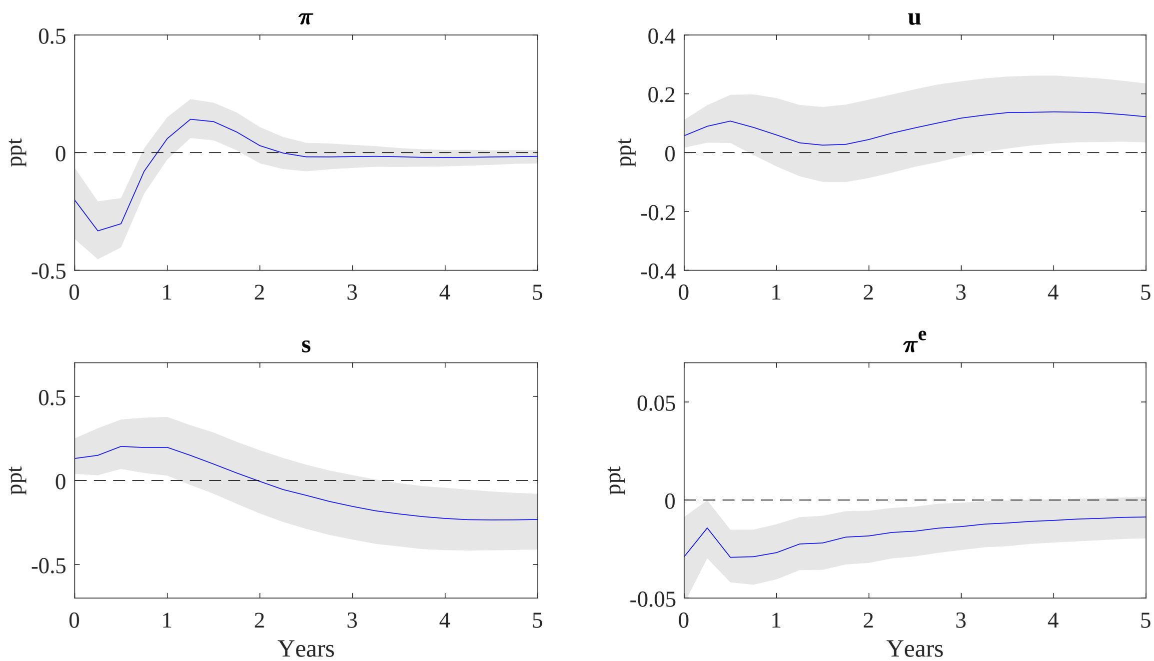
Notes: Estimated contemporaneous response coefficients of the systematic part of monetary policy in Equation (3) implied by the identifying restrictions in Table 2 and Equation (4)

While it is a direct consequence of the identifying sign restriction in (4) that the monetary policy response to π^e is non-negative, the estimated coefficient (3.71) is in fact well above zero. It is also worth emphasizing that – even though we did not restrict the monetary policy response to inflation and unemployment – the estimated signs are in line with economic intuition and the Fed's dual mandate of price stability and maximum employment.[4]

[3] LM test indicate that the reduced form residuals of a VAR(4) estimated with OLS are free of autocorrelation. The tests are available upon request.

[4] To assess the importance of the restriction on the systematic component of monetary policy in (3) we re-estimate the SVAR without the restriction in (4) and compute the relative frequency of the draws that for which $\psi_j > 0$ for $j \in \{\pi, u, \pi^e\}$. Table 7 in appendix A.2 shows that while ψ_π and ψ_u have the expected sign with near certainty, only 36% of the draws satisfy restriction (4).

Figure 1: **Impulse responses to a monetary policy shock**



Notes: The figure shows the estimated impulse responses of inflation π, the unemployment rate u, the shadow rate s and long-term inflation expectations π^e from a SVAR(4) to a one standard deviation monetary policy shock identified with sign restrictions as in Table 2 and Equation (4). Shaded areas are 68% high posterior density intervals (HPDI).

Having identified a monetary policy shock on the basis of a plausible monetary policy reaction function, we are now in the position to answer our first research question about the impact of monetary policy on long-term inflation expectations. To that aim, Figure 1 shows the estimated impulse responses of all four endogenous variables to a one standard deviation monetary policy shock. In line with the identifying sign restrictions, the contractionary monetary policy shock increases the shadow rate and unemployment but lowers inflation on impact. Note that the response to a monetary policy shock is much more pronounced for inflation than for unemployment.

The main result of this section is implied by the estimated impulse response of long-term inflation expectations. Figure 1 shows that long-term inflation expectations respond significantly and immediately to a monetary policy shock. Recall that this response is ruled out by the identification schemes used e.g. in Leduc et al. (2007), Clark and Davig (2011) and Geiger and Scharler (2020). In accordance with Jarociński and Karadi (2020), the expansionary monetary policy shocks during the past decade may have contributed to an increase and therefore to a re-anchoring of U.S. long-term inflation expectations. While the estimated response of long-term inflation expectations to a monetary policy shock is rather persistent, the effect is still transitory. This result is compatible with the view that only inflation target shocks can have a permanent impact on longer-term inflation expectations, see e.g. Nautz et al. (2019).

Table 4 shows the contribution of the monetary policy shock to the variation in long-term inflation expectations at different horizons h. On impact, monetary policy shocks account for 16% of the variation of long-term inflation expectations. In sharp contrast to the assumptions made by the earlier literature, this indicates that monetary policy has a sizable impact on the dynamics of long-term inflation expectations.

Table 4: **Monetary policy shocks and the variation of long-term inflation expectations**

h	0	1	2	4	8	40
median	16.07	15.40	21.40	26.64	28.16	25.62
[16% 84%]	[1.60 52.67]	[2.48 49.31]	[5.20 53.55]	[7.07 58.86]	[7.49 60.31]	[8.21 55.91]

Notes: Estimated relative contribution of the monetary policy shock to the total mean squared forecast error (MSFE) of long-term inflation expectations h quarters after the shock in percent.

4.3 Robustness analysis

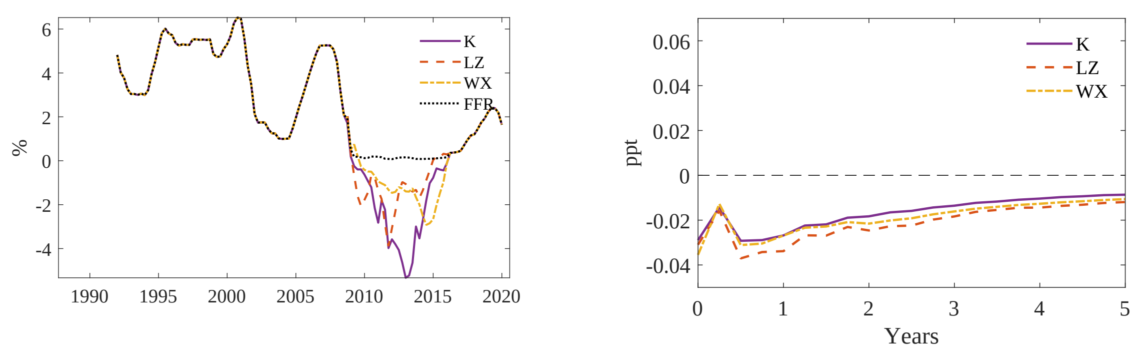
4.3.1 Alternative shadow rates

Identifying monetary policy shocks when interest rates are at the zero lower bound is not straightforward. In this paper, we follow the literature that replaces the federal funds rate with a shadow rate whenever the federal funds rate is stuck at the lower bound. However, the literature proposes multiple shadow rates and there is no clear consensus as to which of the instruments is the most accurate representation of monetary policy. Figure 2a plots the shadow rate by Krippner (2013) which we used for estimating the VAR against those proposed by Wu and Xia (2016), Lombardi and Zhu (2019), and the federal funds rate. In view of the remarkable differences, it is interesting to examine to what extent our results depend on the shadow rate used. To that aim, we re-estimate our structural VAR for the two alternative shadow rates. The results shown in Figure 2b demonstrate that the response of long-term inflation expectations is nearly unaffected by the choice of the shadow rate.

Figure 2: **The response of long-term inflation expectations to a monetary policy shock using alternative shadow rates**

(a) The alternative shadow rates

(b) Impulse responses of π^e



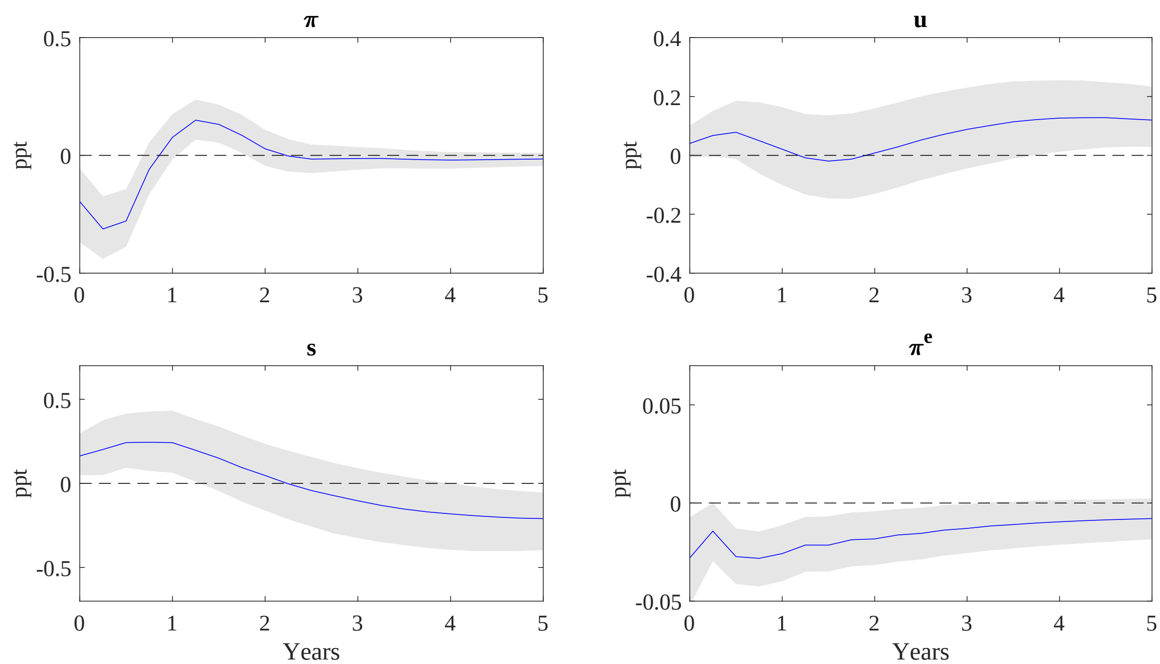
Notes: (a) The baseline shadow rate by Krippner (K) and those of Wu and Xia (WX), Lombardi and Zhu (LZ) and the fed funds rate (FFR). (b) median impulse responses of long-term inflation expectations to a monetary policy shock identified in a VAR with the alternative shadow rates of WX and LZ compared to the baseline case (K).

4.3.2 An alternative identification of monetary policy shocks

Since Uhlig (2005) has challenged the conventional view about the real effects of monetary policy, a large literature, including e.g. Antolín-Díaz and Rubio-Ramírez (2018) and Arias et al. (2019), has emerged that identifies the effect of monetary policy on real variables without a priori restricting the impact of monetary policy shocks on economic activity. In our application, one might be concerned that the sign restrictions of Table 2 rule out a sluggish response of the unemployment rate to a monetary policy shock and the so-called prize puzzle (i.e. a positive response of inflation to a contractionary monetary policy shock). To address this concern, we experimented with an alternative identification scheme that does not impose the sign restrictions on inflation and unemployment after a monetary policy shock.

In accordance with the Fed's dual mandate of maximum employment and price stability, we replace the restrictions on the impact of the shock with sign restrictions on the policy response to inflation ($\psi_\pi \geq 0$) and unemployment ($\psi_u \leq 0$) in the Taylor-type monetary policy equation (3). The resulting impulse responses are shown in Figure 3. The alternative identification does not support the immediate response of the unemployment rate to a monetary policy shock. However, the results regarding inflation and inflation expectations remain unaffected by the alternative identification scheme.

Figure 3: **Impulse responses to a monetary policy shock: Restrictions on the monetary policy rule**



Notes: The figure shows the estimated impulse responses from a VAR of y_t with 4 lags to a monetary policy shock identified with restrictions on the monetary policy rule. Shaded areas are 68% HPDIs.

4.4 Do inflation expectations transmit monetary policy shocks?

4.4.1 The counterfactual analysis

Having established that monetary policy shocks have a significant and plausibly signed impact on long-term inflation expectations, let us now quantify the role of inflation expectations for the transmission of monetary policy shocks. To this end, we construct counterfactual impulse responses to a monetary policy shock under the assumption that long-term inflation expectations remain constant. In this scenario, second round effects of monetary policy shocks that might occur via inflation expectations are set to zero. As a consequence, there is no room for a re-anchoring channel of monetary policy. This kind of counterfactual analysis is often used to quantify the various channels through which a specific shock affects variables of interest, see e.g. Kilian and Lewis (2011), Bachmann and Sims (2012), Wong (2015) or Bobeica et al. (2019). The impact of the re-anchoring channel for a specific variable can then be measured by the difference of the estimated impulse response and the corresponding counterfactual.

For $i = 1, ..., 4$ let $\theta_h^{\text{MP},i} = \frac{\partial y_{t+h}^i}{\partial \varepsilon_t^{\text{MP}}}$ be the impulse response of the ith variable to the monetary policy shock at horizon h. Since the monetary policy shock is the first shock, this corresponds to element $(i, 1)$ of the impulse response matrix Θ_h. π_t^e is the fourth variable in the VAR such that $\theta_h^{\text{MP},4}$ denotes the impulse response of π^e to the monetary policy shock. In order to implement that π_t^e remains constant after a monetary policy shock, we construct a counterfactual series of expectation shocks that offsets the response of π_t^e to a monetary policy shock for all horizons. For each horizon $h \in \mathbb{N}$ this implies

$$\theta_h^{\text{MP},4} \varepsilon_t^{\text{MP}} + \sum_{j=0}^{h} \theta_j^{\text{EXP},4} \tilde{\varepsilon}_{t+j}^{\text{EXP}} = 0 \tag{5}$$

To distinguish counterfactual from estimated values, the former are marked with a tilde. The sequence of counterfactual expectation shocks $\tilde{\varepsilon}_t^{\text{EXP}}$ can be computed recursively as

$$\tilde{\varepsilon}_{t+h}^{\text{EXP}} = -\frac{\theta_h^{\text{MP},4} \varepsilon_t^{\text{MP}} + \sum_{j=0}^{h-1} \theta_j^{\text{EXP},4}}{\theta_h^{\text{EXP},4}}. \tag{6}$$

Accordingly, one obtains the counterfactual impulse response $\tilde{\theta}_h^{\text{MP},i}$ of variable i to the monetary policy shock as

$$\tilde{\theta}_h^{\text{MP},i} = \theta_h^{\text{MP},i} \varepsilon_t^{\text{MP}} + \sum_{j=0}^{h} \theta_j^{\text{EXP},i} \tilde{\varepsilon}_{t+j}^{\text{EXP}}. \tag{7}$$

For the sake of comparability, we scale $\tilde{\theta}_h^{\text{MP},i}$ such that the counterfactual shock has the same impact effect on the monetary policy indicator as a one standard deviation monetary policy shock in the estimated model. Since $\sum_{j=0}^{h} \theta_j^{\text{EXP},i} \tilde{\varepsilon}_{t+j}^{\text{EXP}}$ exactly offsets the part of the monetary policy that is transmitted via long-term inflation expectations h quarters after the shock, the impact of the re-anchoring channel for variable i corresponds to the difference between $\tilde{\theta}_h^{\text{MP},i}$ (where the re-anchoring channel of monetary policy is shut down) and the estimated impulse response:

$$\theta_h^{\text{MP},i} \varepsilon_t^{\text{MP}} - \tilde{\theta}_h^{\text{MP},i} = - \sum_{j=0}^{h} \theta_h^{\text{EXP},i} \tilde{\varepsilon}_{t+j}^{\text{EXP}}. \tag{8}$$

We compute (8) for each draw of the impulse responses $\theta_h^{\text{MP},i} \varepsilon_t^{\text{MP}}$ of the SVAR (see Fig. 1).

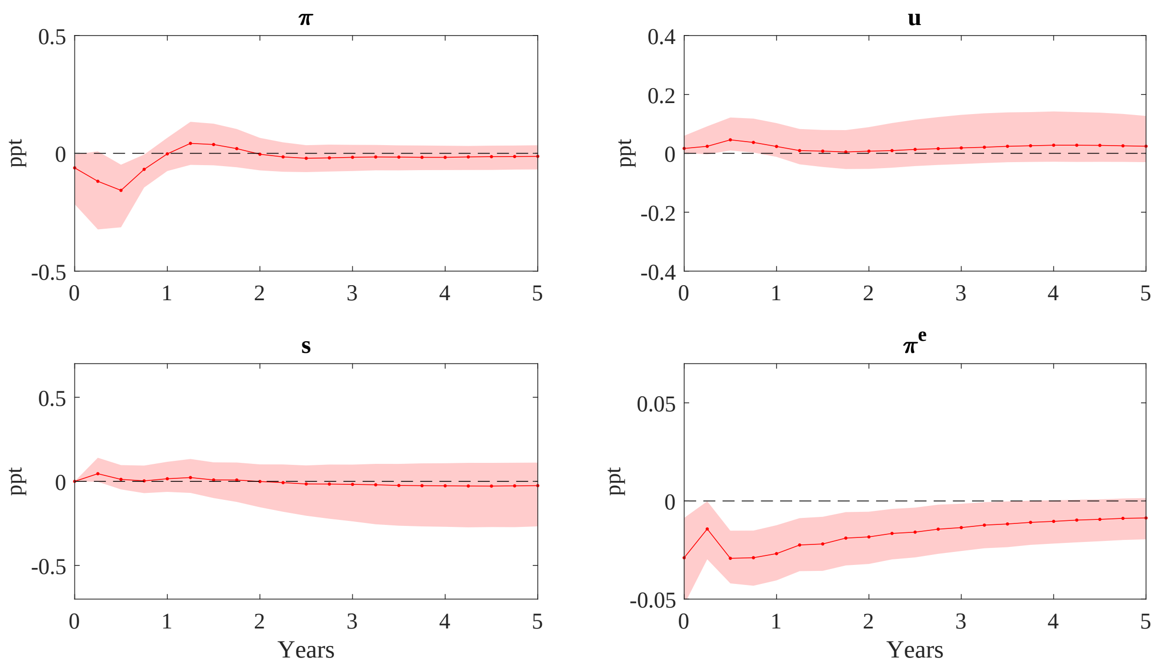
Figure 4 shows the posterior distribution of (8) for all four endogenous variables. By construction, the lower right panel simply replicates the impulse response of long-term inflation expectations. The remaining three panels reveal the impact of the re-anchoring channel of monetary policy for inflation, unemployment and the shadow rate. The larger the difference the more important are long-term inflation expectations for the transmission of monetary policy shocks.

The upper right and lower left panels of Figure 4 reveal that the counterfactual analysis has virtually no effect on the trajectories of the monetary policy instrument and the unemployment rate.[5] Therefore, long-term inflation expectations play no important role for the transmission of monetary policy shocks to the shadow rate and unemployment. By contrast, the role of the re-anchoring channel of monetary policy is much more pronounced for the rate of inflation.

According to the upper left panel, long-term inflation expectations contribute to the decrease in inflation for up to a year after the monetary policy shock. The peak impact is

[5] Note that the zero impact for the shadow rate is imposed by construction through the normalization of the counterfactual impulse responses.

Figure 4: **The re-anchoring channel of monetary policy: Results from a counterfactual analysis**



Notes: The figure plots the median of the difference between the impulse responses of the SVAR and the counterfactual where inflation expectations remain constant, compare (8). Shaded areas are 68% HPDIs.

reached after three quarters. Note that the overall impact of monetary policy shocks on inflation is negative (see Figure 1). Consequently, the impact of a monetary policy shock on inflation is muted if long-term inflation expectations do not react to monetary policy shocks. This supports the working of a re-anchoring channel of monetary policy where long-term inflation expectations help transmit a monetary policy shock to the rate of inflation.[6]

4.4.2 The economic significance of the re-anchoring channel of monetary policy

How important are long-term inflation expectations and, thus, the re-anchoring channel for the transmission of monetary policy shocks to inflation? In the following, we propose to quantify the re-anchoring channel for inflation through the lens of the mean squared forecast error (MSFE). The overall importance of the monetary policy shock for the variation in inflation at forecast horizon h is measured by its relative contribution to the total MSFE of inflation, i.e. $MSFE^{\pi}(h)$:

$$\frac{MSFE^{\pi}_{\mathrm{MP}}(h)}{MSFE^{\pi}(h)} \times 100 \tag{9}$$

where $MSFE^{\pi}_{\mathrm{MP}}(h)$ is the contribution of the monetary policy shock.

Let us now turn to the contribution of the monetary policy shock to the MSFE of inflation for the counterfactual where the re-anchoring channel is shut down. Based on the counterfactual impulse responses $\tilde{\theta}_h^{\mathrm{MP},\pi}$ we compute the contribution of the monetary policy

[6] Note that our findings regarding the impact of the re-anchoring channel for inflation and unemployment remain valid under the alternative identification strategy discussed in Section 4.3.2 and for the alternative shadow rates of Lombardi and Zhu, and Wu and Xia. In accordance with the insignificant response of the unemployment rate to a monetary policy shock, there is no evidence for the impact of the re-anchoring channel on the unemployment rate under the alternative identification. For brevity, these results are not presented but are available on request.

shock to the total MSFE of inflation under the counterfactual scenario, i.e. $\widetilde{MSFE}^{\pi}_{\text{MP}}(h)$:

$$\widetilde{MSFE}^{\pi}_{\text{MP}}(h) = \sum_{j=0}^{h-1} (\tilde{\theta}_j^{\text{MP},\pi})^2 \tag{10}$$

In analogy to (9), the counterfactual contribution of the monetary policy shock for the variation in inflation at forecast horizon h is obtained as

$$\frac{\widetilde{MSFE}^{\pi}_{\text{MP}}(h)}{MSFE^{\pi}(h)} \times 100. \tag{11}$$

Equation (11) measures the contribution of the monetary policy shock to the variation in inflation when the re-anchoring channel is shut down. Therefore, a comparison of (9) and (11) quantifies the contribution of the re-anchoring channel for the variation in the rate of inflation.

Table 5: **The re-anchoring channel and the transmission of monetary shocks to inflation**

H	0	1	2	4	8	40
(9)	15.24 [1.50 49.16]	28.10 [9.25 60.25]	33.15 [13.32 61.02]	30.45 [13.65 55.00]	32.87 [17.81 54.01]	33.14 [18.83 51.73]
(11)	2.16 [0.05 19.29]	7.39 [0.36 27.95]	7.57 [0.42 25.79]	8.22 [0.49 25.18]	10.75 [0.63 33.58]	15.94 [1.58 44.28]

Notes: The first column shows the percentage contribution of the monetary policy shock to inflation, see Equation (9). The second column shows the contribution under the counterfactual scenario where the re-anchoring channel is shut down, see Equation (11). Reported figures are medians and 16% and 84% quantiles in brackets.

Table 5 summarizes the estimated posterior distributions of (9) and (11). On impact ($h = 0$), we estimate that the monetary policy shock accounts for more than 15% of the variation of inflation. However, when the re-anchoring channel is shut down as counterfactual inflation expectations remain constant, the resulting counterfactual contribution of monetary policy is only about 2%. The results of Table 5 indicate that the role of long-term inflation expectations for the transmission of monetary policy shocks to inflation is economically relevant at all forecasting horizons (h).

5 Conclusions

This paper investigates the role of long-term inflation expectations for the transmission of monetary policy shocks. We identified the monetary policy shock by a mix of zero- and sign restrictions in a structural VAR consisting of the policy rate, inflation, unemployment and a measure of long-term inflation expectations. Since we replace the federal funds rate with the shadow rate during the zero lower bound period, the monetary policy shocks should also capture unconventional monetary policy measures.

In contrast to earlier studies, we confirm that U.S. long-term inflation expectations respond significantly to a monetary policy shock. In a counterfactual analysis, we find that long-term inflation expectations play an important role for the transmission of monetary policy shocks to inflation. We demonstrate that these findings are robust with respect to other shadow rates from the literature and alternative plausible identifying assumptions. In line with recent evidence found by Jarociński and Karadi (2020), our results provides new evidence on the economic significance of the re-anchoring channel and the importance of long-term inflation expectations for the conduct of monetary policy.

References

Andrade, P., J. Beckenfelder, F. De Fiore, and P. Karadi (2016). The Reanchoring Channel of QE The ECB's Asset Purchase Programme and Long-Term Inflation Expectations. ECB Working Paper 1956.

Antolín-Díaz, J. and J. F. Rubio-Ramírez (2018). Narrative Sign Restrictions for SVARs. *American Economic Review 108*(10), 2802–2829.

Arias, J. E., D. Caldara, and J. F. Rubio-Ramírez (2019). The Systematic Component of Monetary Policy in SVARs: An Agnostic Identification Procedure. *Journal of Monetary Economics 101*, 1–13.

Arias, J. E., J. F. Rubio-Ramírez, and D. F. Waggoner (2018). Inference Based on Structural Vector Autoregressions Identified With Sign and Zero Restrictions: Theory and Applications. *Econometrica 86*(2), 685–720.

Bachmann, R. and E. R. Sims (2012). Confidence and the Transmission of Government Spending Shocks. *Journal of Monetary Economics 59*(3), 235–249.

Bobeica, E., M. Ciccarelli, and I. Vansteenkiste (2019). The Link between Labor Cost and Price Inflation in the Euro Area. ECB Working Paper 2235.

Caldara, D. and C. Kamps (2017). Analytics of SVARs: A Unified Framework to Measure Fiscal Multiplier. *Review of Economic Studies 84*, 1015–1040.

Canova, F. and L. Gambetti (2010). Do Expectations Matter? The Great Moderation Revisited. *American Economic Journal: Macroeconomics 2*(3), 183–205.

Chan, J. C. C., T. E. Clark, and G. Koop (2018). A New Model of Inflation, Trend Inflation, and Long-Run Inflation Expectations. *Journal of Money, Credit and Banking 50*(1), 5–53.

Ciccarelli, M., J. A. Garcia, and C. Montes-Galdon (2017). Unconventional Monetary Policy and the Anchoring of Inflation Expectations. ECB Working Paper 1995.

Clark, T. E. and T. Davig (2011). Decomposing the Declining Volatility of Long-Term Inflation Expectations. *Journal of Economic Dynamics and Control 35*(7), 981–999.

Doh, T. and A. Oksol (2018). Has the Anchoring of Inflation Expectations Changed in the United States during the Past Decade? *Economic Review* (QI), 31–58.

Eusepi, S., E. Mönch, B. Preston, and C. Carvalho (2019). Anchored Inflation Expectations. CEPR Discussion Paper DP13900.

Farmer, R. E. A. (2012). The Effect of Conventional and Unconventional Monetary Policy Rules on Inflation Expectations: Theory and Evidence. *Oxford Review of Economic Policy 28*(4), 622–639.

Fry, R. and A. Pagan (2011). Sign Restrictions in Structural Vector Autoregressions: A Critical Review. *Journal of Economic Literature 49*(4), 938–960.

Geiger, M. and J. Scharler (2020). How Do People Interpret Macroeconomic Shocks? Evidence from U.S. Survey Data. *Journal of Money, Credit and Banking*. doi: 10.1111/jmcb.12747.

Gertler, M. and P. Karadi (2015). Monetary Policy Surprises, Credit Costs, and Economic Activity. *American Economic Journal: Macroeconomics 7*(1), 44–76.

Gürkaynak, R. S., B. Sack, and E. Swanson (2005). The Sensitivity of Long-Term Interest Rates to Economic News: Evidence and Implications for Macroeconomic Models. *American Economic Review 95*(1), 425–436.

Hachula, M. and D. Nautz (2018). The Dynamic Impact of Macroeconomic News on Long-Term Inflation Expectations. *Economics Letters 165*, 39–43.

Jarociński, M. and P. Karadi (2020). Deconstructing Monetary Policy Surprises - The Role of Information Shocks. *American Economic Journal: Macroeconomics 12*(2), 1–43.

Kilian, L. and L. T. Lewis (2011). Does the Fed Respond to Oil Price Shocks?*. *The Economic Journal 121*(555), 1047–1072.

Kilian, L. and H. Lütkepohl (2017). *Structural Vector Autoregressive Analysis*. Cambridge University Press.

Krippner, L. (2013). Measuring the Stance of Monetary Policy in Zero lower Bound Environments. *Economics Letters 118*(1), 135–138.

Leduc, S., K. Sill, and T. Stark (2007). Self-fulfilling Expectations and the Inflation of the 1970s: Evidence from the Livingston Survey. *Journal of Monetary Economics 54*(2), 433–459.

Lombardi, M. and F. Zhu (2019). A Shadow Policy Rate to Calibrate U.S. Monetary Policy at the Zero Lower Bound. *International Journal of Central Banking*, 305–346.

Mertens, E. (2016). Measuring the Level and Uncertainty of Trend Inflation. *The Review of Economics and Statistics 98*(5), 950–967.

Nautz, D., L. Pagenhardt, and T. Strohsal (2017). The (De-)Anchoring of Inflation Expectations: New Evidence from the Euro Area. *The North American Journal of Economics and Finance 40*, 103–115.

Nautz, D., T. Strohsal, and A. Netšunajev (2019). The Anchoring of Inflation expectations in the long and in the short run. *Macroeconomic Dynamics*, 1959–1977.

Uhlig, H. (2005). What Are the Effects of Monetary Policy on Output? Results from an Agnostic Identification Procedure. *Journal of Monetary Economics 52*(2), 381–419.

Wolf, C. K. (2020). SVAR (Mis-)Identification and the Real Effects of Monetary Policy Shocks. *American Economic Journal: Macroeconomics 12*(4), 1–32.

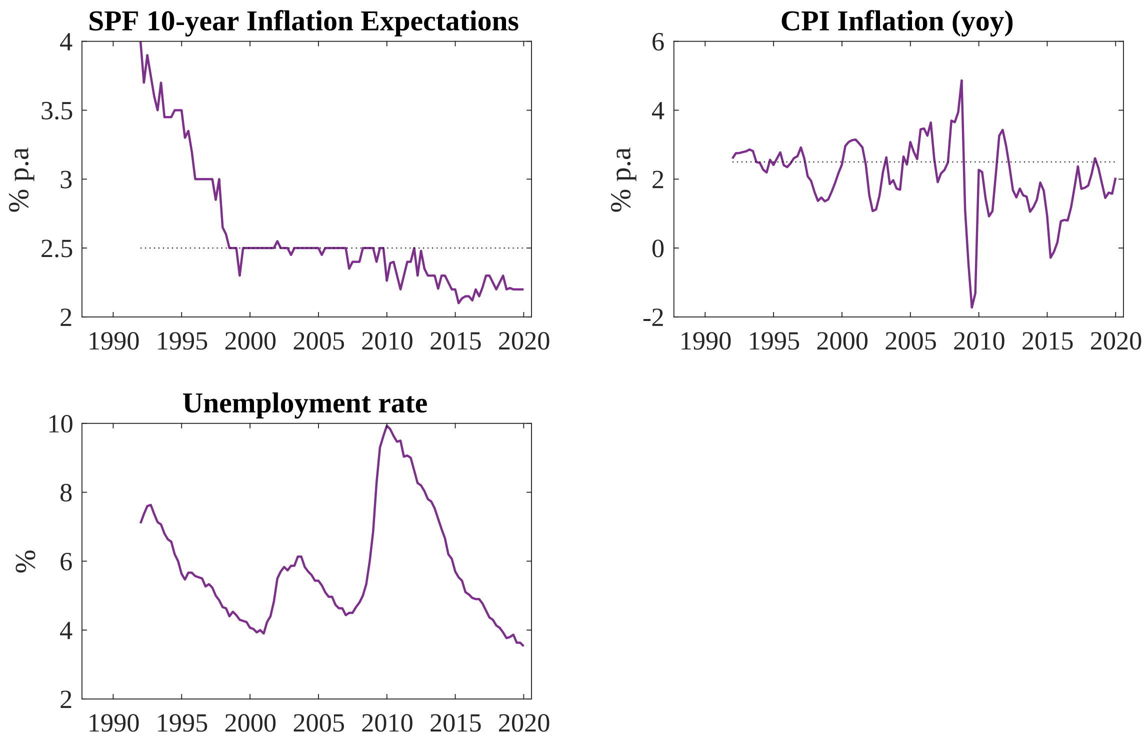
Wong, B. (2015). Do Inflation Expectations Propagate the Inflationary Impact of Real Oil Price Shocks?: Evidence from the Michigan Survey. *Journal of Money, Credit and Banking 47*(8), 1673–1689.

Wu, J. C. and F. D. Xia (2016). Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound. *Journal of Money, Credit and Banking 48*(2-3), 253–291.

A Appendix

A.1 Time series and data sources

Figure 5: **Quarterly US Data**



Notes: The dotted line at 2.5% p.a in indicates the Feds inflation target taking into accounted that CPI is on average about 0.5 percentage points above PCE inflation for which the original target is specified (see e.g. Doh and Oksol, 2018). 10-year inflation expectations are taken from the Survey of Professional Forecasters available from the Philadelphia Fed. CPI and the Unemployment rate are obtained from FRED.

Table 6: **Data sources**

	Variable	Source	Transformation
π	annual CPI year-on-year inflation rate	FRED, code: CPIAUCSL	$(\ln(x_t) - \ln(x_{t-12})) \times 100$, quarterly average
u	unemployment rate	FRED, code: UNRATE	quarterly average
s	shadow rate, 2008M8 to 2015M11 fed funds rate, else	author's website[a] FRED, code: EFFR	quarterly average quarterly average
π^e	median 10 year inflation expectations	Philadelphia Fed[b]	none

[a] `https://www.ljkmfa.com/test-test/united-states-shadow-short-rate-estimates/`
[b] `https://www.philadelphiafed.org/research-and-data/real-time-center/survey-of-professional-forecasters/historical-data/inflation-forecasts`

A.2 The systematic component of monetary policy

In order to assess the importance of the restriction (4) on the systematic component of monetary policy, we identify the VAR without this restriction. To that aim, we only apply the sign and zero restrictions restrictions on the structural impact matrix as in Table 2 and estimate the model without the restriction on the systematic component. We then compute the probability that the coefficients of the monetary policy rule on inflation ψ_π, unemployment ψ_u and long-term inflation expectations ψ_{π^e} are positive from the draws of the posterior. Table 7 reports these probabilities.

With near certainty the signs of ψ_π and ψ_u are in accordance with the consensus view of a Taylor-type monetary policy rule. However, the coefficient ψ_{π^e} has the expected positive sign only with low probability. Hence, following the discussion in Arias et al. (2019), we conclude that imposing (4) significantly shrinks the identified set and improves identification.

Table 7: **Probability that the coefficient ψ_j is positive**

$P(\psi_\pi > 0)$	$P(\psi_u > 0)$	$P(\psi_{\pi^e} > 0)$
1.00	0.01	0.36

Notes: Figures are relative frequencies of accepted draws that satisfy $\psi_j > 0$ for the monetary policy response coefficient in Equation (3).

Diskussionsbeiträge - Fachbereich Wirtschaftswissenschaft - Freie Universität Berlin
Discussion Paper - School of Business & Economics - Freie Universität Berlin

2020 erschienen:

2020/1	ASSEYER, Andreas: Wholesale price discrimination with regulatory asymmetry *Economics*
2020/2	JESSEN, Robin und Johannes KÖNIG: Hours Risk and Wage Risk: Repercussions over the Life-Cycle *Economics*
2020/3	ASSEYER, Andreas: Collusion and Delegation under Information Control *Economics*
2020/4	ADAM, Marc Christopher: Liquidating Bankers' Acceptances: International Crisis, Doctrinal Conflict and American Exceptionalism in the Federal Reserve 1913-1932 *Economics*
2020/5	BÖNKE, Timm; Rick GLAUBITZ; Konstantin GÖBLER; Astrid HARNACK; Astrid PAPE und Miriam WETTER: Die Entwicklung und Prognose von Lebenserwerbseinkommen in Deutschland *Economics*
2020/6	HUNDSDOERFER, Jochen und Eva MATTHAEI: Gender Discriminatory Taxes, Fairness Perception, and Labor Supply *FACTS*
2020/7	ZHU, Junbing und Theocharis GRIGORIADIS: Chinese Dialects, Revolutionary War & Economic Performance *Economics*
2020/8	POLUGODINA, Maria und Theocharis GRIGORIADIS: East Prussia 2.0: Persistent Regions, Rising Nations *Economics*
2020/9	DOMBI, Akos; Theocharis GRIGORIADIS und Junbing ZHU: Antiquity and capitalism: the finance-growth perspective *Economics*
2020/10	AHMED LAHSEN, Amina; Alan T. PIPER und Ida-Anna THIELE: Kim Jiyoung, Born 1982, and the Labour Market: Overeducation, Gender, Income and Life Satisfaction. Panel evidence from Korea *Economics*

2020/11 COLEMAN, Winnie und Dieter NAUTZ: The Credibility of the ECB's Inflation Target in times of Corona: New Evidence from an Online Survey
Economics

2020/12 SYDOW, Jörg; Georg SCHREYÖGG und Jochen KOCH: Current interest in the theory of organizational path dependence. a short update on the occasion of the 2019 AMR Decade Award
Management

2020/13 DIECKELMANN, Daniel: Cross-Border Lending and the International Transmission of Banking Crises
Economics

2020/14 WOLF, Tobias: Welfare while working: How does the life satisfaction approach help to explain job search behavior?
Economics

2020/15 PIPER, Alan: Temps dip deeper: temporary employment and the midlife nadir in human well-being
Economics

2020/16 OLSEN, Nils: A Literature Overview on Scheduling Electric Vehicles in Public Transport and Location Planning of the Charging Infrastructure
Information Systems

2020/17 WINKELMANN, Lars und Wenying YAO: Cojump Anchoring
Economics

2020/18 MARTÍNEZ-HERNÁNDEZ, Catalina: Disentangling the effects of multidimensional monetary policy on inflation and inflation expectations in the euro area
Economics