Long-Term Inflation Expectations and the Transmission of Monetary Policy Shocks: Evidence from a SVAR Analysis

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Abstract

This paper investigates the role of long-term inflation expectations for the monetary transmission mechanism and the conduct of monetary policy in a structural VAR framework. In contrast to earlier studies, we find that U.S. long-term inflation expectations respond significantly to a monetary policy shock. In line with a re-anchoring channel of monetary policy, long-term inflation expectations play an important role for the transmission of monetary policy shocks to the rate of inflation. Structural scenario analysis suggests that the response of monetary policy to expectations shocks contributes to the stabilization of inflation and unemployment.

Keywords: Long-Term Inflation Expectations, Monetary Policy, Re-anchoring Channel, Structural VAR, Structural Scenario Analysis
JEL-Classification: C32, E31, E52

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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. However, the empirical relevance of the re-anchoring channel of monetary policy is still under debate, see e.g. Andrade et al. (2016), Ciccarelli et al. (2017) and Gambetti and Musso (2020).

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 counterfactual analysis to assess the quantitative importance of long-term inflation expectations for the conduct and transmission of monetary policy.

The focus of earlier contributions that include measures of inflation expectations into

[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.

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 and expectations shocks in a structural VAR that (i) includes inflation expectations, inflation, the monetary policy rate, and unemployment and (ii) exploits a minimal set of sign and zero restrictions. To identify the monetary policy shock we use uncontroversial sign restrictions for inflation and unemployment. Moreover, in the spirit of Arias et al. (2019) we rule out that monetary policy reacts to inflation expectations systematically in an implausible way. The expectations shock is identified as an increase in long-term inflation expectations that has no instantaneous effect on inflation and unemployment. As a result, the expectations shock is interpreted as a change in agents' information set that is unrelated to current inflation and unemployment. Most importantly for our purpose, the identification scheme leaves both, the response of inflation expectations to a monetary policy shock and the monetary policy response to expectations shocks unrestricted.

Our paper relates to studies that avoid zero restrictions on the response of inflation expectations by using Proxy SVARs. Interestingly, the available evidence is mixed. While Gertler and Karadi (2015) and Gambetti and Musso (2020) 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. However, the studies do not consider the monetary policy response to expectations shocks. 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. Therefore, we perform a counterfactual analysis where the transmission of monetary policy shocks via inflation expectations is shut down, see Wong (2015). 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.

The estimated SVAR implies that expectations shocks are an important driver of the policy rate. Following Antolín-Díaz et al. (2020), we employ structural scenario analysis to demonstrate that the response of U.S. monetary policy to expectations shocks has contributed to the stabilization of the economy and the anchoring of inflation expectations. In particular, inflation would have been 36 basis points lower and unemployment 74 basis points higher on average if monetary policy had not responded to expectations shocks since 2012.

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 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.

For sake of robustness we also present the results 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 policy rate or the inflation equations is rejected for most of the specifications. By contrast, there is no Granger-causality from π^e to unemployment.

Table 1: **The impact of long-term inflation expectations for inflation, unemployment and the policy rate: 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. Two lags are selected by Bayesian (BIC), Akaike (AIC) and Hannan-Quinn (HQ) information criteria for the underlying VAR. Common estimation sample for all lag orders: 1992Q4–2019Q4.

Since long-term inflation expectations cannot be omitted from the interest rate and the inflation equation they are important for identifying monetary policy shocks and may even play a role for transmitting changes of the policy rate 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 expectations 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 expectations 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 expectations 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 expectations shock**

	π_t	u_t	s_t	π_t^e
$\varepsilon_t^{\mathrm{MP}}$	≤ 0	≥ 0	≥ 0	$*$
$\varepsilon_t^{\mathrm{EXP}}$	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, asterisks 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 the 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 Section 4.4, the expectations shock does not affect inflation and unemployment on impact. We normalize the impact of the expectations shock on inflation expectations to be positive. Following Leduc et al. (2007), the response of the monetary policy to expectations shocks cannot be assumed to be zero.

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 consistently yields a negative output response to a contractionary 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. 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 do not prevent that linear combinations of the expectations 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.[2] 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).

[2] 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.

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)

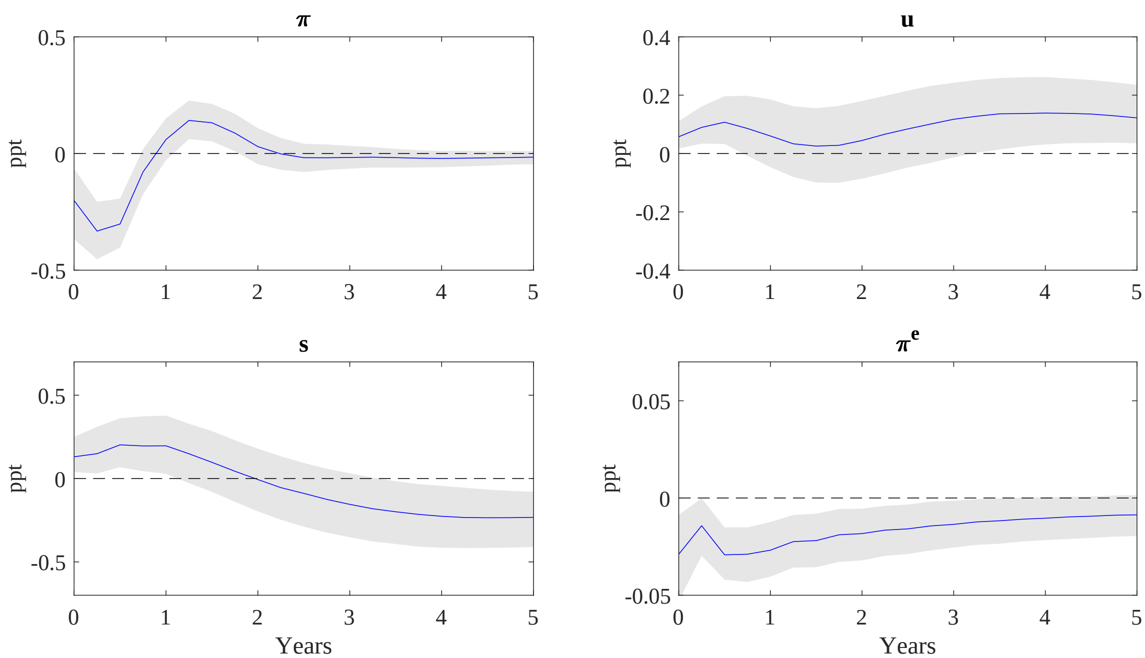
While it is a direct consequence of the identifying sign restriction in (4) that the monetary policy response to π^e is non-negative, the estimated coefficient (3.71) is in fact well above zero. It is also worth emphasizing that – even though we did not restrict the monetary policy response to inflation and unemployment – the estimated signs are in line with economic intuition and the Fed's dual mandate of price stability and maximum employment.[3]

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

[3]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).

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: **Contribution of monetary policy shocks to 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.

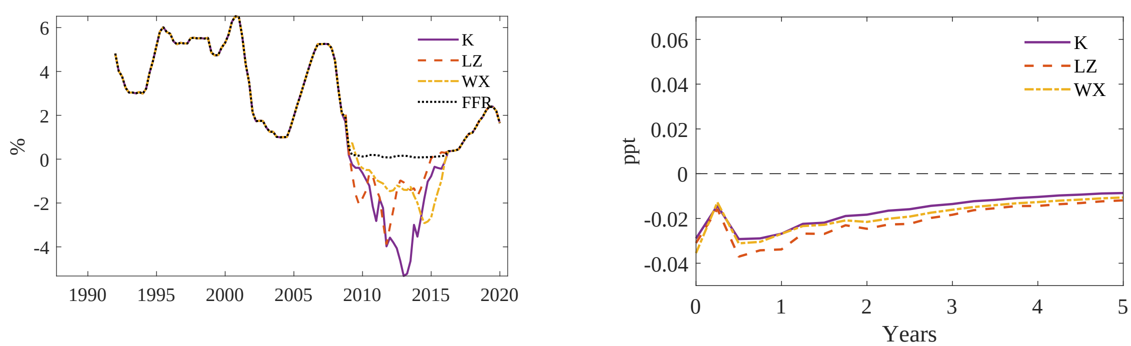
4.3 Robustness analysis

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

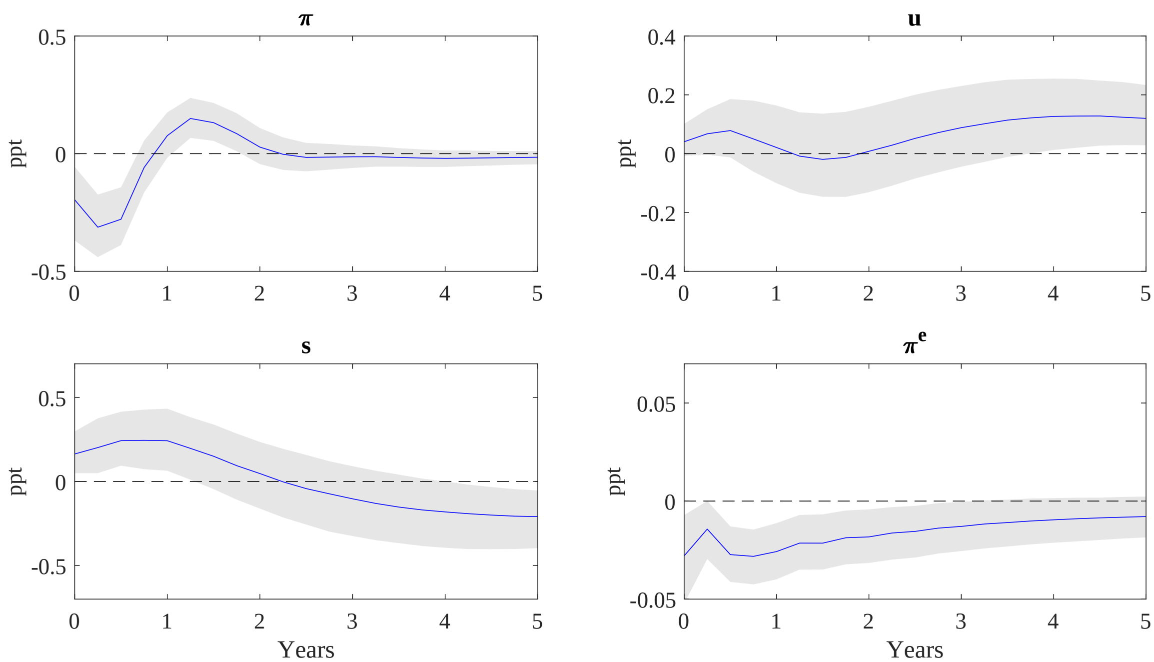


Notes: (a) The baseline shadow rate by Krippner (K) and those of Wu and Xia (WX), Lombardi and Zhu (LZ) and the fed funds rate (FFR). (b) median impulse responses of long-term inflation expectations to a monetary policy shock identified in a VAR with the alternative shadow rates of WX and LZ compared 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 sluggish responses of the unemployment rate and inflation to a monetary policy shock. To address this concern, we apply an alternative identification scheme that does not impose sign restrictions on the response of inflation and unemployment after to a monetary policy shock.

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.

In accordance with the Fed's dual mandate of maximum employment and price stability, the alternative identification replaces 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.

4.4 Do inflation expectations transmit monetary policy shocks?

4.4.1 A 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 expectations 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

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

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

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

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

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

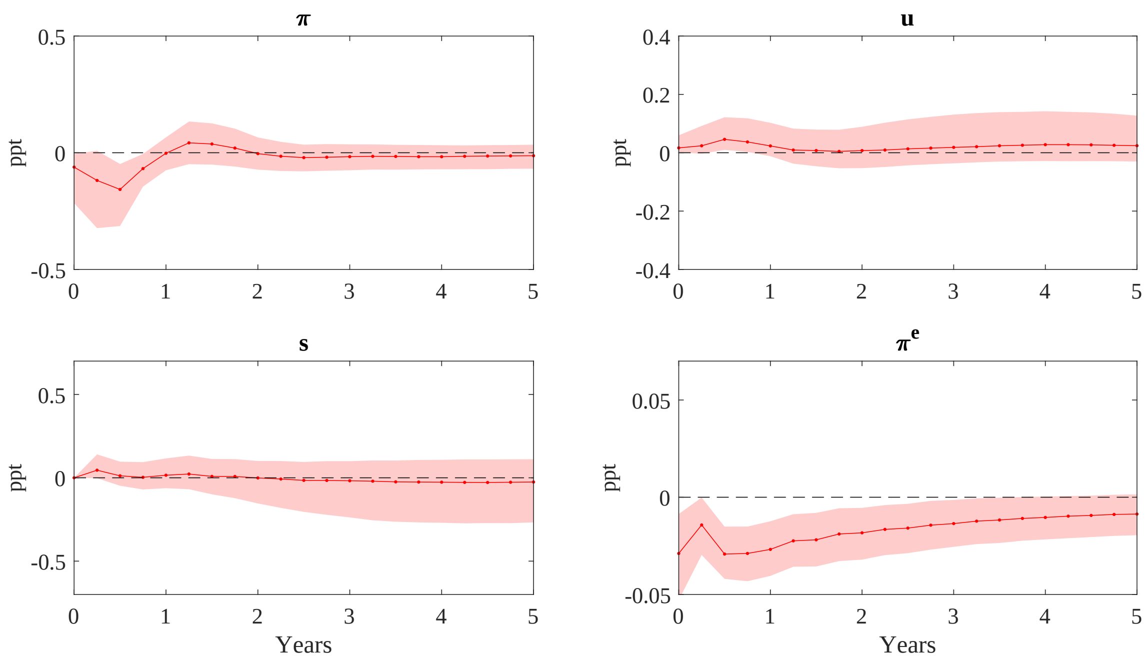
For the sake of comparability, we scale $\tilde{\theta}_h^{\mathrm{MP},i}$ such that the counterfactual shock has the same impact effect on the monetary policy indicator as a one standard deviation monetary policy shock in the estimated model. Since $\sum_{j=0}^{h} \theta_j^{\mathrm{EXP},i} \tilde{\varepsilon}_{t+j}^{\mathrm{EXP}}$ 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 $\tilde{\theta}_h^{\mathrm{MP},i}$ (where the re-anchoring channel of monetary policy is shut down) and the estimated impulse response:

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

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

Figure 4 shows the posterior distribution of the difference between the estimated and

Figure 4: **The effect of the re-anchoring channel on impulse responses to a monetary policy shock**



Notes: The figure plots the median of the difference between the impulse responses to a monetary policy shock of the SVAR and the counterfactual where inflation expectations remain constant, compare (8). Shaded areas are 68% HPDIs. Due to the normalization of the counterfactual impulse responses, the impact effect of the re-anchoring channel on the shadow rate equals zero.

counterfactual impulse responses for all four endogenous variables, see (8). 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. 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 reached after three quarters. Since the overall impact of monetary policy shocks on inflation is negative (see Figure 1), the impact of a monetary policy shock on inflation is muted if long-term inflation expectations do not react to monetary policy shocks. Therefore, in line with the working of a re-anchoring channel of monetary policy, long-term inflation expectations transmit a monetary policy shock to the rate of inflation.[4]

[4] 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.

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. $MSFE^{\pi}(h)$:

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

where $MSFE^{\pi}_{\text{MP}}(h)$ 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 $\tilde{\theta}_h^{\text{MP},\pi}$ we compute the contribution of the monetary policy 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

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

(11) measures the contribution of the monetary policy shock to the variation in inflation when the re-anchoring channel is shut down. 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 contribution of monetary policy shocks to the variation of inflation with and without the re-anchoring channel**

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]

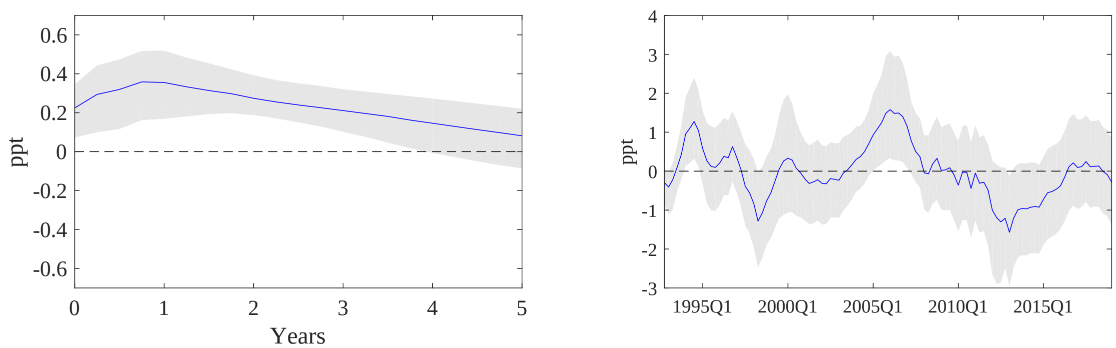
Notes: The first row shows the percentage contribution of the monetary policy shock to inflation, see Equation (9). The second row shows the contribution under the counterfactual scenario where the re-anchoring channel is shut down, see Equation (11). Reported figures are medians and 16% and 84% quantiles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

4.5 How important is the monetary policy reaction to expectations shocks?

The counterfactual impulse response analysis in the previous section shows that inflation expectations play a key role for the monetary transmission process. In turn, this suggests that monetary policy should also respond to unexpected movements in long-term inflation expectations and thus to expectations shocks. Leduc et al. (2007) and Clark and Davig (2011) document a strong response of the Federal Reserve to expectations shocks for earlier periods. Our estimation results confirm this finding for the more recent period: Figure 5 (left panel) shows that the the shadow rate increases strongly in response to a positive expectations shock. The cumulative contribution of the expectations shocks to the shadow rate, shown in the right panel of Figure 5, reveals that the monetary policy reaction to expectations shocks has contributed significantly to historical movments of the shadow rate.

Figure 5: **The impact of expectations shocks on the shadow rate: Impulse response and historical contribution**



Notes: Left: Impulse response of the shadow rate s to the (expectations increasing) expectations shock; Right: Cumulative historical contribution of the expectations shock to s. Blue lines are posterior medians and shaded areas represent the 68% HPDIs.

Yet the question remains: how important is the response of monetary policy to expectations shocks for inflation, unemployment and inflation expectations? To answer this question, we employ a structural scenario analysis. Specifically, we assume that monetary policy has not responded to expectations shocks. Since this corresponds to a policy counterfactual, the scenario is implemented by means of counterfactual monetary policy shocks. Following Antolín-Díaz et al. (2020), we take into account the uncertainty of the scenario. However, in distinction, the uncertainty of our scenario for the shadow rate itself is implied by the estimation uncertainty. Consequently, estimation uncertainty affects the counterfactual for inflation, unemployment and inflation expectations twice. Firstly, through the estimation uncertainty of the historical shock contributions. And secondly, when using draws from the posterior of the parameters to simulate the model. Therefore, uncertainty is accurately accounted for by computing the counterfactual for each draw from the posterior. The counterfactual monetary policy shocks that offset the cumulative contribution of the expectations shocks on the shadow rate are obtained by a straightforward application of the formulas in Section 4.4.1 to the cumulative contribution of the expectations shock to the shadow rate.

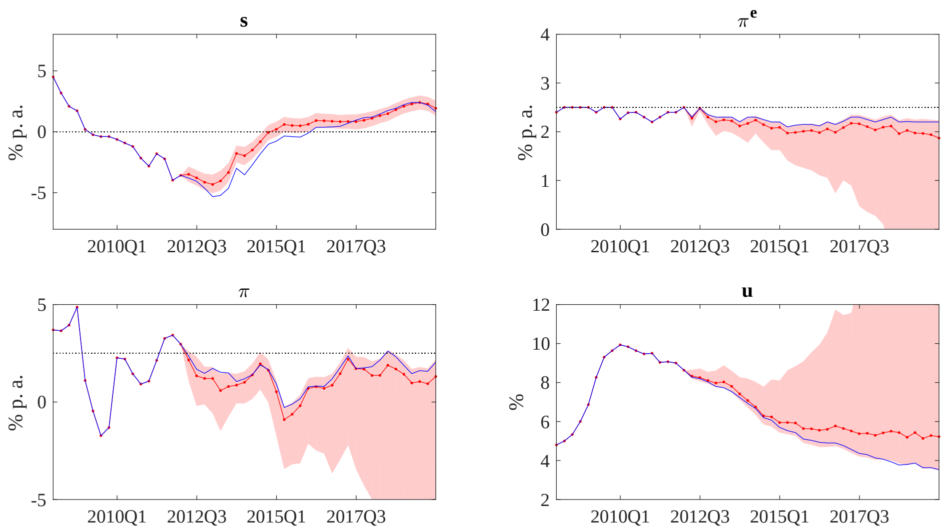
Since the announcement of the official inflation target in January 2012, the Federal Reserve has repeatedly emphasized the prominent role of anchored inflation expectations for the conduct of monetary policy. In the following, we therefore choose January 2012 as the starting point of the structural scenario analysis. Ever since, long-term inflation expectations have been below-target. This may explain the negative contribution of expectations shocks to the shadow rate since 2012. Accordingly, the resulting counterfactual path for the shadow rate will be higher than the actually observed one, implying a tighter monetary policy stance.[5]

Figure 6 compares the median counterfactual trajectories (red) with the observed data (blue). The top left panel shows the more restrictive path for the shadow under the restriction that the Federal Reserve does not react to expectations shocks. The median results clearly indicate the direction for the impact of the policy change. Figure 6 indicates that if monetary policy had not responded to the expectations shocks, this would have had sizable adverse effects on the distributions of inflation and unemployment. In fact, since 2012 median inflation would have been 36 basis points lower and unemployment 74 basis points

[5]Since this exercise assumes that markets are repeatedly surprised by the Fed not reacting to expectations shocks, the counterfactual is in principle not immune to the Lucas' critique. However, Sims and Zha (2006) argue that agents may take some time to incorporate the altered monetary policy reaction into account. Under this consideration, the counterfactual is valid at least for a certain limited number of periods. For this line of argument to hold, the counterfactual shocks should not be 'too implausible'. Antolín-Díaz et al. (2020) propose to measure the plausibility of the counterfactual shocks using the Kullback-Leibler divergence which requires an analytical expression for the density of the shocks. In our case the distribution of counterfactual shocks depends on the posterior estimates of a historical shock contribution and no closed form solution is available. Therefore, Figure 8 in appendix A.3 plots medians of the distribution of the counterfactual and the estimated monetary policy shocks. The counterfactual shocks largely remain within the range of 3 standard deviations the estimated shock. We conclude that the counterfactual shocks are not too large to render the exercise invalid.

higher on average. Finally, the bottom right panel indicates that the response of monetary policy to expectations shocks has prevented long-term inflation expectations from drifting even further away from the inflation target.

Figure 6: **The importance of expectations shocks for the conduct of monetary policy: Results from a structural scenario analysis**



Notes: The scenario assumes that the impact of expectations shocks on the shadow rate is neutralized by counterfactual monetary policy shocks. Observed variables in blue, median counterfactual path in red. Following Antolín-Díaz et al. (2020), red shaded areas represent 40% point-wise credible sets for the counterfactual series. Dotted lines in the panels for π^e and π indicate the Fed's target for CPI inflation of 2.5%.

5 Conclusion

This paper investigates the role of long-term inflation expectations for the conduct and transmission of monetary policy. We identify the monetary policy and expectations shocks 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 show that U.S. long-term inflation expectations respond instantaneously to a monetary policy shock. We explore the quantitative implications of the estimation results for monetary policy using structural scenario analysis. First, 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 identifying assumptions. Second, our analysis strongly suggests that the response of U.S. monetary policy to expectations shocks has contributed to the stabilization of the economy and the anchoring of inflation expectations. In line with Jarociński and Karadi (2020), our results provide new evidence on the re-anchoring channel and the importance of long-term inflation expectations for the conduct of monetary policy.

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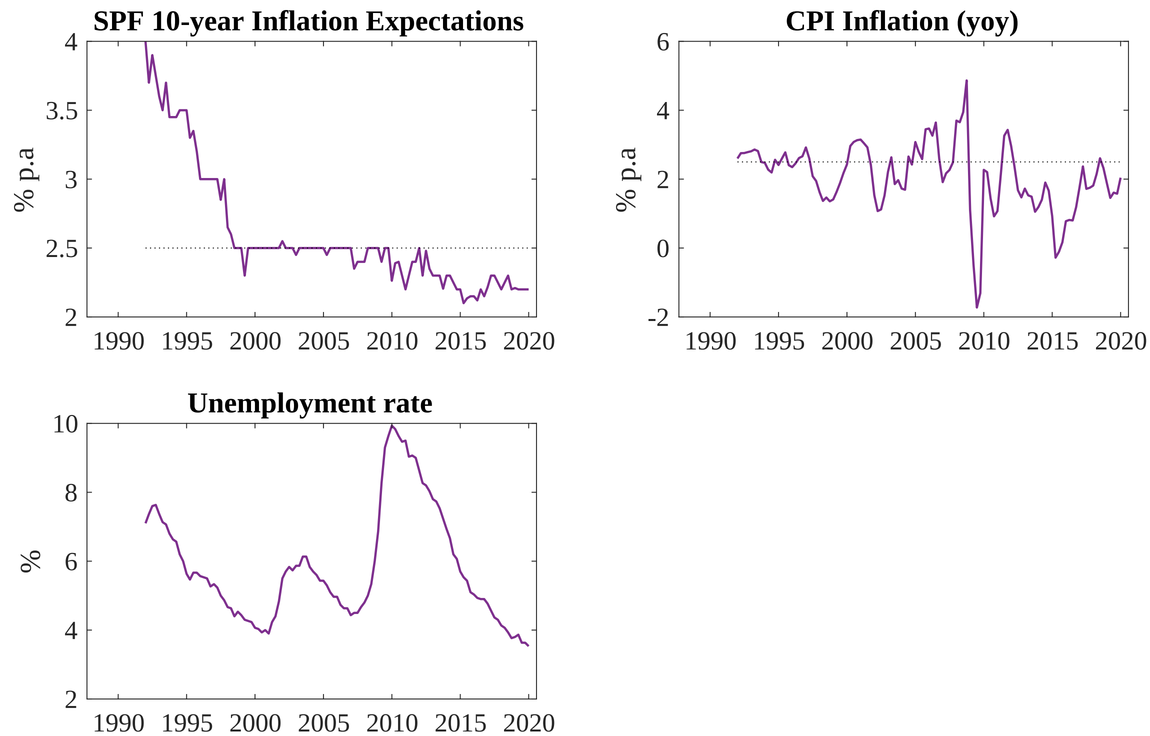
A Appendix

A.1 Time series and data sources

Figure 7: **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.

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

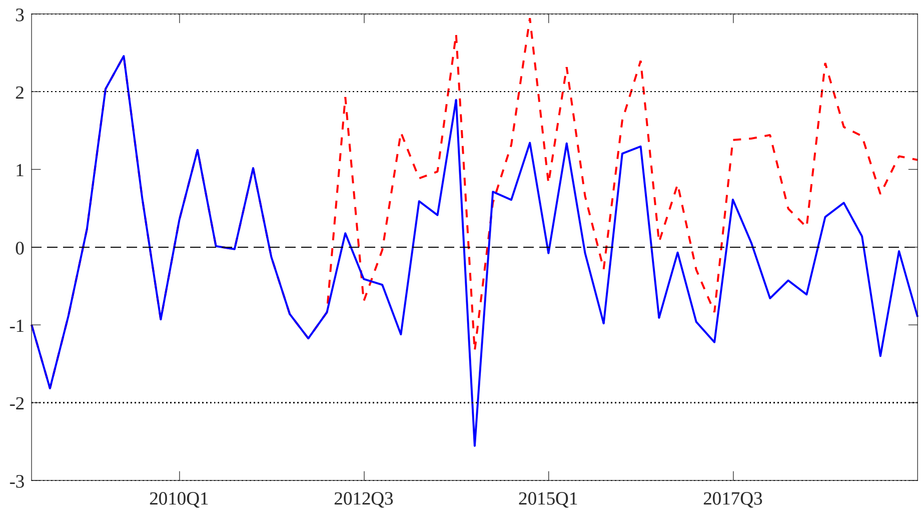
$P(\psi_\pi > 0)$	$P(\psi_u > 0)$	$P(\psi_{\pi^e} > 0)$
1.00	0.01	0.36

Notes: Figures are relative frequencies of accepted draws that satisfy $\psi_j > 0$ for the monetary policy response coefficient in the Taylor rule implied by the SVAR: $s_t = \psi_\pi \pi_t + \psi_u u_t + \psi_{\pi^e} \pi^e_t + A_{+,1} x_t + \varepsilon^{MP}_t$

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.

A.3 Counterfactual monetary policy shocks

Figure 8: **Estimated and counterfactual monetary policy shocks**



Notes: Median estimated MP shocks in blue, median counterfactual shocks for the scenario analysis in Section 4.5 in red. Black dotted lines indicate 3 and 2 standard deviations. Recall that the structural shocks have unit variance. Since the contribution of expectations shocks to the shadow rate has been negative since 2012Q1, the counterfactual monetary policy shocks to offset this impact are positive on average.