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New VAR evidence on monetary transmission channels: temporary interest rate versus inflation target shocks

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New VAR evidence on monetary transmission channels: temporary interest rate versus inflation target shocks*

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ABSTRACT

We augment a standard monetary VAR on output growth, inflation and the nominal interest rate with the central bank's inflation target, which we estimate from a New Keynesian DSGE model. Inflation target shocks give rise to a simultaneous increase in inflation and the nominal interest rate in the short run, at no output expense, which stands at the center of an active current debate on the Neo-Fisher effect. In addition, accounting for persistent monetary policy changes reflected in inflation target changes improves identification of a standard temporary nominal interest rate shock in that it strongly alleviates the price puzzle.

Keywords: Monetary policy; Neo-Fisher effect; Time-varying inflation target; DSGE; VAR
JEL classification: E12, E31, E52, E58.

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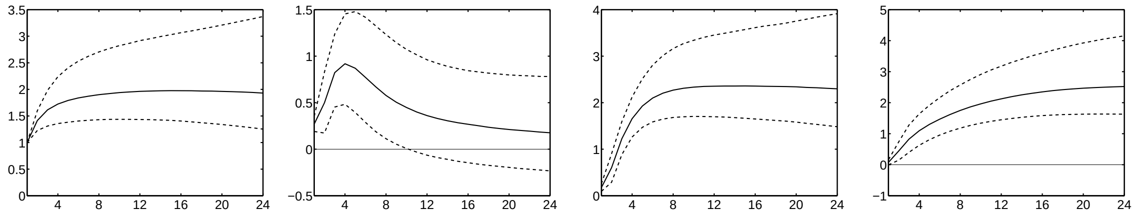
1 Introduction

A large literature investigates the transmission mechanism of monetary policy in empirical vector autoregression (VAR) models, among the most widely used a three variable VAR that studies the effects of a temporary nominal interest rate shock on output growth and inflation.[1] In such setting, a monetary policy shock is understood as a temporary innovation to the short-term nominal interest, which, however, provides an only incomplete description of the monetary stance. The large and persistent swings in inflation in US postwar data likely reflect also changes in monetary conduct of more permanent and systematic nature, such as shifts in the Federal Reserve's inflation target. We follow Ireland (2007) and Cogley et al. (2010) in estimating the otherwise unobserved time series of the central bank's time-varying inflation target from a small scale New Keynesian model, and add this time series to our VAR. This way, we are able to study the transmission mechanism in response to an inflation target shock – a monetary policy change of high persistence – as well as the standard temporary short-term nominal interest rate shock. We find that in response to an inflation target shock, inflation and the nominal interest rate both rise, even in the short-run, while output expands. These findings are reminiscent of the so-called Neo-Fisher effect, whose importance is currently being emphasized by recent contributions in the literature, which we relate to below. The presence of the inflation-target process in our VAR system also helps identification of the traditional temporary monetary policy shock of an increase in the short-term nominal interest rate, in that it strongly alleviates the existence of a price puzzle, i.e. a counterintuitive increase in inflation in response to an interest rate increase.

Figure 1 previews our main results, plotting the impulse responses to a shock to the inflation target: in response to such shock, which can be viewed as a persistent shift in monetary policy, our VAR predicts that inflation and the nominal interest rate rise, co-moving positively over the entire duration of the persistent shock, including in the short run. These results closely connect to and are consistent with a new wave of macroeco-

[1] See, e.g., Sims (1980); Lütkepohl (1991, 1999); Watson (1994); Waggoner and Zha (1999).



Inflation target Output growth Inflation Interest rate

Figure 1. Impulse responses to an inflation target shock

nomic studies on Neo-Fisherian effects (Schmitt-Grohè and Uribe (2014); Uribe (2018); Cochrane (2018); Garcìa-Schmidt and Woodford (2018)). To gain an understanding of the key insights of these studies, let us first review the economic consensus on the monetary transmission mechanism even prior to these studies.

In particular, according to theory, a temporary shock, such as a temporary increase in the short-term interest rate, indisputably decreases inflation in the short run, but has no long run effects. Similarly, it is also quite undisputed that there is empirical evidence for the existence of a Fisher effect, according to which in the long run inflation moves one-to-one with the nominal interest rate, while the real interest rate is determined by non-monetary factors.

There is less consensus, and this is the topic of debate of this recent literature whether a permanent monetary policy shock has a positive effect both on inflation and nominal interest rate *already in the short-run*, which is dubbed the Neo-Fisher effect. The debate exists mostly on theoretical grounds with a few empirical contributions among which is Uribe (2018). He constructs both an empirical VAR model and a theoretical DSGE model with temporary and permanent monetary shocks (as well as temporary and permanent non-monetary shocks). He finds support for the Neo-Fisher effect in response to permanent monetary policy shocks and deems them very important for inflation dynamics, attributing about 45% of the variation in inflation to permanent monetary shocks. Because there is no increase in real rates, the nominal interest increase comes at no cost of an output loss, but on the contrary output expands.

Despite using a quite different approach we similarly find strong evidence for a short-run positive co-movement of inflation and the nominal interest rate, at no output cost.

Unlike Uribe (2018) we do not introduce permanent shocks to the interest rate, but our results arise from shocks to the Federal Reserve's inflation target, which similarly capture macroeconomic dynamics in response to more systematic, persistent monetary policy changes.[2] With our approach, we are able to obtain an additional interesting result (not shown in figure 1, but in the main text in section 4), when estimating our VAR model over a subsample period starting with the Volcker chairmanship: we find that in the more recent time sample of a much more stable and credible inflation target the identified inflation target shock appears to be much less persistent and therefore contributes less to inflation dynamics. In choosing our approach we build upon and connect to previous existing work that attributes an important role of movements in the inflation target for inflation dynamics in theoretical model frameworks (Ireland (2007); Cogley and Sargent (2005); De Graeve et al. (2009); Cogley et al. (2010)), or that decomposes inflation dynamics into trend components and cyclical components in empirical frameworks (Stock and Watson (2007); Chan et al. (2018)). We consider it a main advantage that our results arise from very standard and simple methodological frameworks. The inflation target process itself is estimated from a small-scale New Keynesian model, that is not much more complicated than the textbook workhorse New Keynesian model of, e.g., Woodford (2003) or Galí (2008). Similarly, the VAR specification we propose directly connects to the most simple and widely used framework in which monetary transmission has been studied in economics. Nevertheless, the model predictions are strong.

Our paper is also related to a recent contribution by Mumtaz and Theodoridis (2018) who similarly study the macroeconomic dynamics of an inflation target shock. In their SVAR, they identify an inflation target shock as VAR innovations that make the largest contribution to future movements in long-horizon inflation expectations. Despite our much simpler setup, the resulting behavior of inflation, nominal interest rate and output (growth) is qualitatively the same.

Our second main result is summarized in figure 2, where we depict the impulse re-

[2]Note that our estimated process for the inflation target follows a highly persistent, yet stationary process.

sponse to a standard temporary nominal interest shock, based on a basic 3-variable VAR in output growth, inflation, and the nominal interest rate, and from our 4-variable, inflation target augmented, VAR model. While both approaches are consistent in predicting a contractionary effect on demand and thus a drop in output growth in response to a nominal interest rate increase, the results differ with respect to the responses of inflation, where the 3-variable model produces a large and very persistent increase in inflation: this is in stark contrast to theory, which predicts that in response to a temporary interest rate hike inflation declines. This counterintuitive inflation response is a very typical result obtained in empirical VAR models and is known as the 'price puzzle' in the literature (Sims (1992)). Our impulse response from the inflation target augmented VAR shows that the price puzzle is much alleviated once one disentangles effects of persistent monetary policy changes in the inflation target from transitory shocks, which both affect inflation in the short-run in an opposing direction.[3] Accounting for inflation fluctuations that arise from inflation target changes, thus helps a clean identification of the effects of a temporary shock to the nominal interest rate, leading to a more theory-consistent price response.[4]

We subject our findings to a number of robustness checks. In particular, we make direct use of our New Keynesian DSGE model that we used to obtain the estimated inflation target series, and consider theoretical model impulse responses from the estimated model. We consider impulse responses with respect to an inflation target shock and to a temporary nominal interest rate shock, and find that the theoretical model im-

[3]The price puzzle has since its original finding by Sims (1992) been addressed and was removed, e.g., when fast moving commodity prices were included (Christiano et al., 1996). Alternatively, Del Negro and Otrok (2007) utilize house prices. Bernanke et al. (2005) and Forni and Gambetti (2010) use factor model with information from a large set of time series. Gertler and Karadi (2015) employ high frequency shock identification schemes in a VAR with financial variables. Sign restrictions were also actively employed to solve the puzzle (Canova and De Nicolò, 2002; Uhlig, 2005; Liu and Theodoridis, 2012), in which case the price puzzle is solved by disregarding the theory-inconsistent responses. Our findings suggest that carrying our measure of the inflation target in the VAR contains important information, much like commodity prices, house prices, or the information content of factors from large datasets. However, our approach has the additional advantage that we remain within a very parsimonious setup of a VAR and that our additional measure included, the inflation target, has a straightforward economic interpretation and is of clear monetary policy relevance.

[4]Uribe (2018) finds that in his empirical setup, the introduction of permanent and temporary policy shocks similarly help in addressing the price puzzle, in his case, completely removing it. These results suggest, that the price puzzle might simply be a result of model misspecification when more permanent influences of monetary policy are disregarded from the empirical analysis.

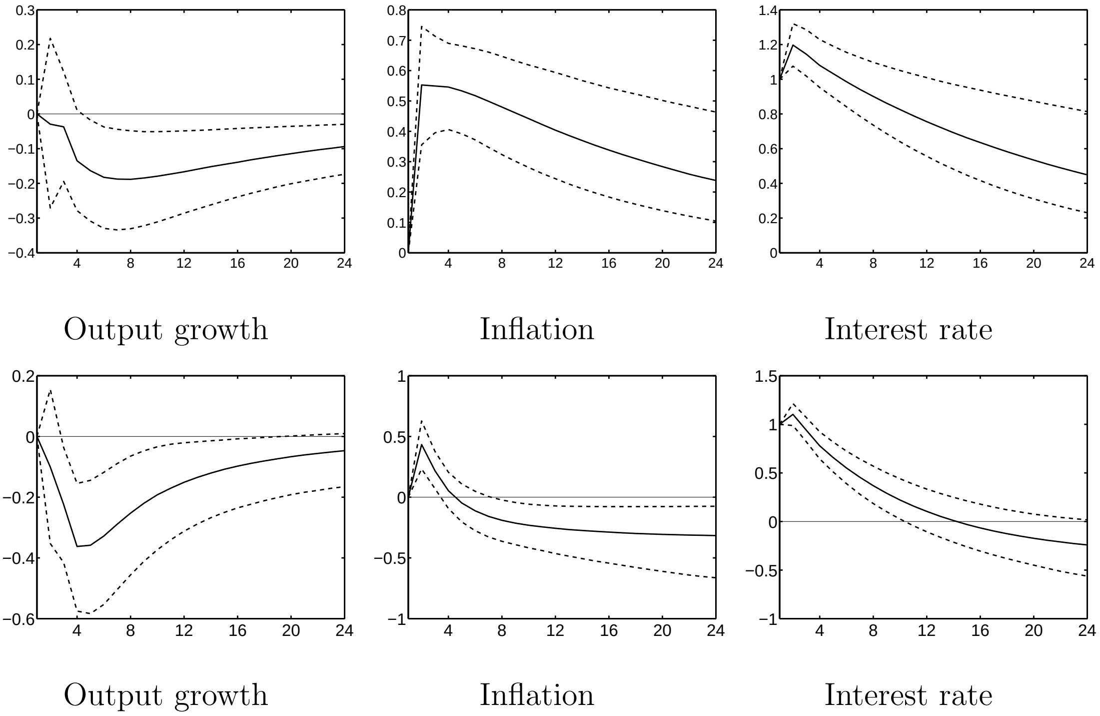


Figure 2. Impulse responses to a temporary nominal interest rate shock. First row: 3-variable VAR. Second row: 4-variable VAR.

pulse responses behave qualitatively the same as in our VAR. We then turn to robustness checks of our empirical VAR model. Both our findings of the positive short and long-run co-movement in inflation and the nominal interest rate in response to an inflation target shock, as well as the alleviation of the price puzzle in our 4-variable VAR are robust to looking at different time samples and at different lag lengths of our VAR specification.[5]

Similarly, to check sensitivity with respect to the DSGE-based estimated measure of the unobservable inflation target, we look at VAR specifications in which we replace our measure with other related measures from the empirical literature. In particular, we consider the trend-inflation measure of Stock and Watson (2007) and of Chan et al. (2018). We find that in response to a trend-inflation shock, the impulse responses of inflation and the nominal interest rate behave similarly, especially in the early quarters of the responses to the shock; in the medium run, the Stock and Watson trend-inflation measure works less well in proxying for the inflation target, since it is a significantly less

[5]In addition to our baseline period of the entire postwar period (1947Q3-2017Q3), we consider sample splits of 1947Q3-2008Q2, 1979Q3-2017Q3, 1979Q3-2008Q2, 1983Q1-2017Q3, and 1983Q1-2008Q2. We also consider at 4-lag and 5-lag specifications in addition to our baseline 2-lag specification.

persistent and more volatile measure (tracking very closely the actual inflation process itself) and reflects long-run shifts in inflation less well. The trend-inflation measure by Chan et al., which expands the Stock and Watson measure by incorporating forward-looking information on inflation expectations, is conceptionally closer to what we want to capture via our DSGE-based time-varying inflation target and is better suited to reflect the central bank's inflation goals; carrying this measure in our VAR produces impulse responses that are very close to the ones from our DSGE-based target process, both to the target shock, as well as in terms of the alleviation of the price puzzle to a temporary interest rate shock.

The paper is organized as follows. In section 2 we discuss in detail our measures of the inflation target, the economic intuition behind this variable and our approach to estimate it. Section 3 discusses the VAR model and the data used to estimate it. Section 4 lays out our main empirical results and extensive sensitivity analysis. Finally, section 5 concludes.

2 The inflation target

2.1 Intuition behind the inflation target

Figure 3 plots the time paths of various inflation measures for the U.S. economy over the period 1947-2017. Inflation exhibits large and persistent swings, reaching levels of above 10 percent annually in the period of the Great Inflation in the 1970s and early 1980s, falling to substantially lower levels during the 1980s and 1990s in the Great Moderation, and falling further in and succeeding the period of the Great Recession. Observing these large swings one is reminded of the famous quote by Milton Friedman (1968, p.39) that "inflation is always and everywhere a monetary phenomenon": while fluctuations in inflation at any point in time may reflect a myriad of factors, such as reactions to purely temporary shocks, large and persistent movements in inflation typically reflect the conduct of monetary policy. The economics discipline has spent considerable efforts to understand these swings in inflation dynamics, estimating an underlying inflation target process or trend inflation, both with theoretical, dynamic stochastic general equilibrium (DSGE), models as well as with empirical models.

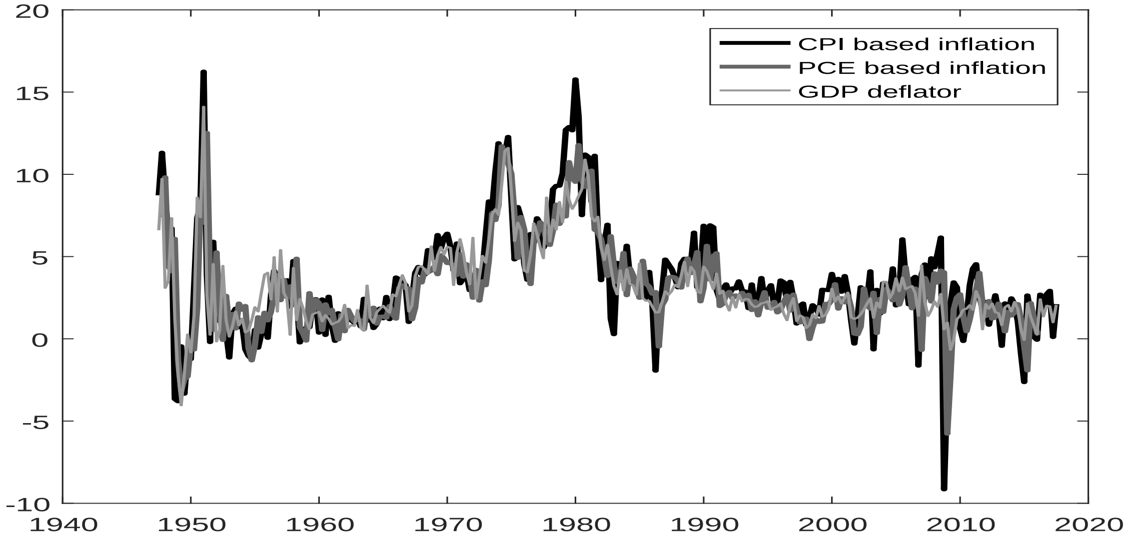


Figure 3. Different inflation measures

This section introduces the inflation target measure we employ in the VAR model of section 3. The central bank's inflation target, the main determinant in inflation trends, is generally unobserved. We follow the influential contribution by Ireland (2007) in choosing to estimate it from a small-scale New Keynesian model. In more recent work Cogley et al. (2010) also employ Ireland's small-scale New Keynesian model to estimate the inflation target, while other contributions (e.g. De Graeve et al. (2009)) use medium-scale DSGE models or more elaborate approach to model the way inflation target counteracts with monetary policy (e.g. Fève et al. (2010)). We choose to stick to a small-scale theoretical model, both for the sake of simplicity but also to be consistent with our later empirical setup, i.e. we only use the same three macroeconomic time series for the estimation of our trend inflation measure from the DSGE model that we will later use in our VAR. Because the model is standard and has been previously employed in the literature we relegate readers to the appendix for a model description and only focus on laying out the key aspects here (see appendix A).

The model is a standard New Keynesian setting, in which monopolistically competitive firms face nominal rigidities and produce with a labor-only production technology.

Households derive utility from consumption, assumed to be of the habit form, and disutility from working. The monetary authority is modelled as setting the short-term nominal interest rate according to a Taylor rule of the form (in log lineralized terms):

$$\widehat{R}_t = \rho_R \widehat{R}_{t-1} + (1-\rho_R)\left[\rho_\pi(\widehat{\bar{\pi}}_{4,t} - \widehat{\pi}_t^*) + \rho_Y(\widehat{Y}_t - \widehat{Y}_t^*)\right] + \varepsilon_{R,t}, \tag{1}$$

where for any variable, $\widehat{X}_t$ denotes percentage deviations from its steady state, i.e., $\widehat{X}_t \equiv \log(X_t/X)$. R_t is the nominal interest rate, $\bar{\pi}_{4,t}$ is actual average inflation over the year, defined as $\bar{\pi}_{4,t} \equiv (\pi_t + \pi_{t-1} + +\pi_{t-2} + \pi_{t-3})/4$, π_t^* is a time-varying inflation target, Y_t is the output level, Y_t^* is the output level in a hypothetical flexible price economy, and $\varepsilon_{R,t}$ is an exogenous disturbance meant to capture a (temporary) shock to the policy rate.

According to the above rule the central bank considers three factors in deciding on the current nominal interest rate: (1) the previous value the nominal interest rate R_{t-1}, i.e. there is interest rate smoothing; (2) the output gap, defined as the deviation of the actual level of output, Y_t from its potential, i.e. the level of output that would prevail in an economy with flexible prices, Y_t^*; and (3) the inflation gap, defined as the deviation of inflation, $\bar{\pi}_{4,t}$, from the target inflation, π_t^*.

The key aspect of the Taylor rule described here, and in contrast to the more standard Taylor rule featured in a standard New Keynesian model such as, e.g., described in chapter 3 of Galí (2008), the inflation target, π_t^*, is not required to be fixed at a constant level, but is allowed to be time-dependent and vary over time according to following exogenous process for π_t^*:[6]

$$\log \pi_t^* = (1-\rho_{\pi^*})\log \pi + \rho_{\pi^*} \log \pi_{t-1}^* + \varepsilon_{\pi^*,t}, \qquad \varepsilon_{\pi^*,t} \sim N(0, \sigma_{\pi^*}). \tag{2}$$

We estimate the DSGE model using Bayesian methods using three observable time series: real output growth, inflation, expressed as the quarterly change in the consumer price index, and the 3-months Treasury Bill rate. We use U.S. data from 1947Q3 to 2017Q3, taken from the Federal Reserve Bank of St. Louis database. We refer the reader

[6] In particular, in the standard New Keynesian model of, e.g., Galí (2008), the central bank aims at eliminating the distance between the actual inflation and a constant inflation target. Moreover, the steady state inflation is often assumed to be constant at a net rate of zero. However, this does not have a direct correspondence to the way the central bank appear to be choosing the inflation target in practice.

to Appendix A for a table that summarizes the parameter estimates of our New Keynesian model other than the ones related to the inflation target process, equation (2), which we discuss below. Our main variable of interest is the time series of the smoothed variable for π_t^*, which represents the model-implied evolution of the central bank's inflation objective, which is presented in figure 4.

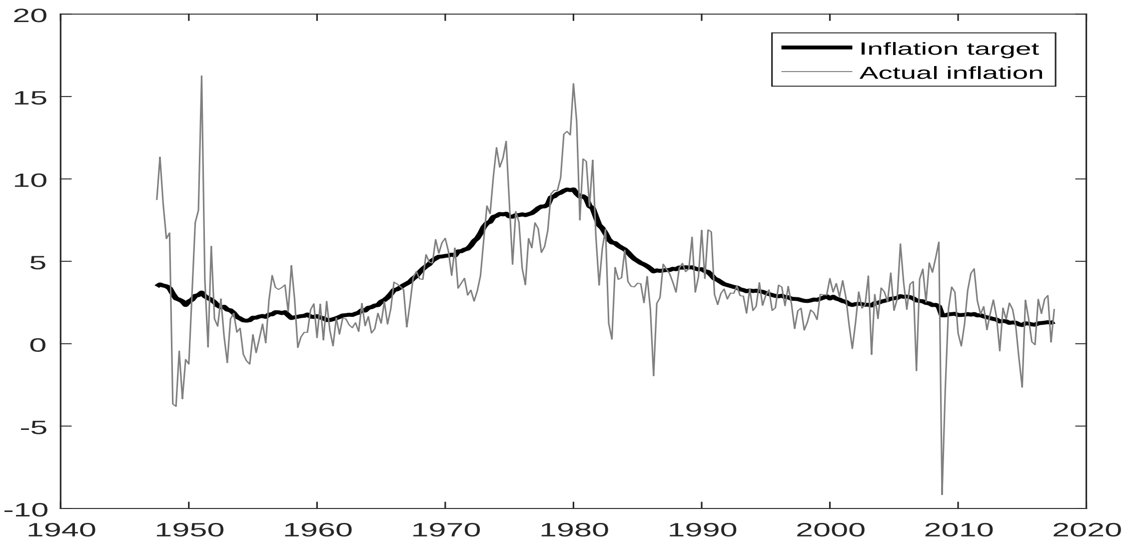


Figure 4. Dynamics of the inflation target – estimated from the New Keynesian DSGE model – and actual inflation.

The inflation target is much smoother than actual inflation, however, largely following its patterns, mimicking the high inflation episode of the 1980s, and becoming relatively stable after the 1990s. The inflation target is also quite stable in the low inflation episode that was triggered by the 2007/08 financial crisis and its aftermath, reflecting the strong dedication of the Federal Reserve to avoid deflation and bring inflation back up again quickly. The estimated inflation target process is highly persistent, with a posterior mean value for the autoregressive coefficient ρ_{π^*} of 0.9889, and a (small) shock standard deviation of σ_{π^*} = 0.1095. These statistical properties of our inflation target process imply that there are, on average, not many changes in the target, but if, that these reflect systematic and persistent changes in monetary policy. This is somewhat different to how – in the work on the presence of a Neo-Fisher effect that we relate to – Uribe (2018) thinks of systematic changes in monetary policy, which he models as permanent shocks to the nominal interest rate. Our systematic monetary policy shifts of the inflation target shocks are highly persistent, but unlike in Uribe, not, strictly speaking, permanent.

2.2 Comparison to other measures

Since the inflation target is unobserved and our approach to utilize a New Keynesian DSGE model is just one possible way to estimate this latent series, we find it of particular importance to provide a thorough comparison of our measure to alternative approaches in the literature, both theoretical, that use DSGE-models to estimate the inflation target, and empirical, that aim to disentangle permanent from cyclical components in inflation dynamics.

The first set of comparisons is easily done. The small scale New Keynesian model that underlies the estimation of our inflation target measure is the model that has been previously used by Ireland and Cogley, thus the inflation-target measures of these contributions are very similar, and the small differences that arise stem mostly from a consideration of different time periods of estimation. Our inflation-target measure also squares well with other DSGE-based estimations that we are aware of, such as the also small-scale New Keynesian model of Bjørnland et al. (2011) or the medium-scale model of De Graeve et al. (2009). The common feature of DSGE-based estimates for the inflation target is that the resulting inflation target series are all slow-moving, highly persistent measures that track (and to some degree lag) the big trends in actual inflation, but are substantially smoother than actual inflation. This is consistent with the nature of an inflation target, as it represents a long-term objective of the Fed. Although the inflation target is time-dependent, we do not expect it to react to short-term economic shocks, but to be subject to changes only infrequently.

On the side of the empirical literature the contribution of Stock and Watson (2007) is a key reference in decomposing inflation dynamics into trend and cyclical components, using an unobserved components stochastic volatility model, which is our first reference for comparison. In addition we look at the contribution of Chan et al. (2018)[7], who build

[7] We estimate trend inflation based on Stock and Watson (2007) using inflation based on the quarterly CPI index, for the period of 1947Q3 to 2017Q3. The trend inflation as in Chan et al. (2018) is taken

on Stock and Watson (2007). Measures of trend inflation can reasonably be expected to, similarly to our inflation target measure, reflect the long-term low frequency movements in inflation dynamics. It turns out though that the Stock and Watson measure of trend inflation very closely resembles movements in actual inflation, and appears to capture much higher frequencies in inflation dynamics compared to our inflation target measure (left panel of figure 5). As we do not think that the Federal reserve's preferences on the current level of target inflation change that frequently, we conclude that the Stock and Watson trend inflation measure may not be a good proxy for the inflation target after all. Chan et al. (2018) estimate trend inflation in a similar setup and building up on Stock and Watson (2007), considering actual inflation together with the forward-looking measure of long run survey-based inflation expectations in the estimation process. The additional information of forward-looking inflation expectations gives rise to an estimated trend inflation that is considerably less volatile and more persistent, and that more closely resembles our DSGE-based inflation target (right panel of figure 5). Also, introducing inflation expectations into the estimation process to obtain trend inflation brings the resulting measure conceptually much closer, as the inflation target and inflation expectations, if well anchored, are closely related. We thus expect the trend inflation measure of Chan et al. (2018) to serve as a good proxy for the central bank's inflation target. We will make use of the trend inflation measures of both Stock and Watson (2007) and Chan et al. (2018) for robustness checks of our baseline VAR model, discussed in section 4.

Contrasting our inflation target measure to the permanent component of inflation estimated by Uribe's empirical SVAR (figure 5 in Uribe (2018)), the two measures appear to follow largely similar dynamics, with our measure being somewhat more persistent and less volatile. A similar statements can me be made about the estimated inflation target of a recent contribution by Mumtaz and Theodoridis (2018), depicted in figure 5 of Mumtaz and Theodoridis (2018). They use inflation expectations and identify a shock to the inflation target as the largest contribution to the future variation of long-run inflation expectations. Similarly to our measure, their inflation target measure aims to capture

from Joshua Chan's website; it starts in 1960Q2 due to the availability of the data for the long run survey-based inflation expectations.

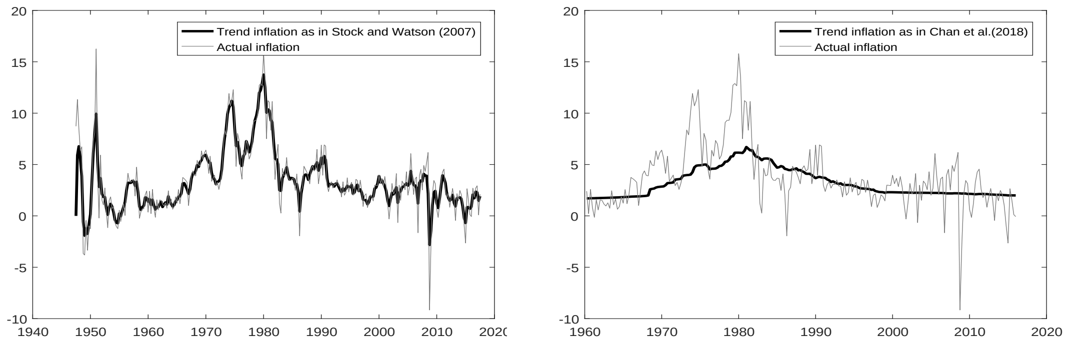


Figure 5. Estimated trend inflation and actual inflation: relative dynamics

the long-term component of monetary policy. Like our DSGE-based measure, it is much less volatile and more persistent than the actual inflation series.

To sum up, there are two characteristics of the inflation target that stand out: high persistence and low volatility. Alternative measures which are conceptually close and which attempt to capture low-frequency inflation dynamics, share similar characteristics. We think of a shock to these measures as reflecting a systematic shift in monetary policy, much like a shift in the Fed's preferences over an inflation target.

2.3 Nominal interest rate and inflation target shocks in the New Keynesian model

Figure 6 presents impulse responses to an inflation target and a short-term nominal interest rate shock from the theoretical New Keynesian DSGE model. This informs us about the qualitative behavior we expect to observe also in the empirical VAR model. The figure plots Bayesian impulse responses, at the posterior mean of the estimated parameter distributions, and at their 10% and 90% percentiles, taking into account the uncertainty over the parameter estimates. The response to the nominal interest rate shock (second row of figure 6) is standard: the increase in nominal interest rate in the New Keynesian model lowers inflation and – because nominal rigidities imply that the increase in nominal translate into an increase in the real interest rate – output growth. The inflation target shock persistently raises inflation and the nominal interest rate and is associated with short-run gains in output growth, this time resulting from a fall in the real interest rate, because of the more pronounced increase in inflation relative to the short rate.

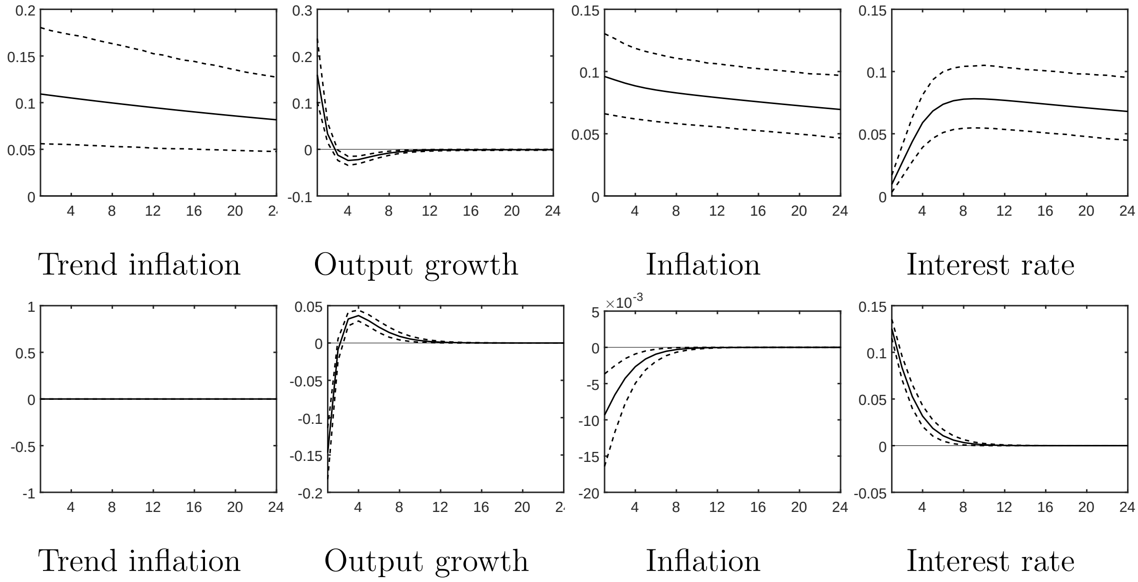


Figure 6. DSGE model-implied impulse responses. Horizontal axis: periods after the shock, vertical axis: percentage change.

3 VAR model

This section presents the empirical model. A major goal is to keep the framework simple and tractable. Our baseline model directly connects to one of the most widely used frameworks to study monetary transmission: a 3-variable VAR model in output growth, inflation and the nominal interest rate. Our baseline model is precisely this 3-variable VAR, augmented by our inflation target series, estimated from the DSGE model. This setup allows us to examine the transmission of monetary policy shocks, both in terms of the standard temporary shocks to the nominal interest rate, but also in terms of more persistent monetary policy shifts from shocks to the inflation target. We further provide a number of robustness checks by changing time samples and changing number of lags of the baseline VAR model.

3.1 Data

We use U.S. data from 1947Q3 to 2017Q3 taken from the Federal Reserve Bank of St.Louis. All data is on quarterly basis. The 3-variable VAR consists of the growth rate of real GDP, inflation, expressed as the rate of change of the consumer price index, and the 3-month Treasury bill rate[8]. The data for the VAR model is chosen in order to make a direct correspondence to our DSGE model, i.e. we use the same time series in the VAR as we use for the estimation of the DSGE model.

We experiment with alternative time samples. In addition to our baseline period of 1947Q3 to 2017Q3, we estimate the VAR for the following periods: 1979Q3-2017Q3 (as to start from the Volcker period of the Fed's chairmanship), 1979Q3-2008Q2 (to exclude the period of zero interest rates) and 1947Q3 -2008Q2 for the same reason.[9] We choose the breakpoint at the end of 1979 as it marks the period of Volcker's disinflation. Some studies (Primiceri, 2005; Cogley and Sargent, 2005; Cogley et al., 2010) point towards a decline in inflation gap persistence from 1980 onwards. We are interested in whether the dynamics of the identified nominal interest rate and inflation target shocks differ across the postwar period and the shorter subsample periods.

3.2 Estimation

We estimate the VAR with Bayesian methods using an independent Normal-Wishart prior. This prior family allows priors on the autoregressive parameters of the VAR to be specified independently of priors on the covariance. We do not impose a strong belief on the values of the autoregressive coefficients, setting the prior for the autoregressive coefficients at zero, with a value of the prior precision of 10. This way we leave it up to the data to identify the non-zero coefficients important to capture the dynamics of our four variables. The prior for the covariance matrices is set equal to an identity matrix, similarly uninformative. As there is no analytical solution for this choice of prior distributions, we employ a Gibbs sampler for the estimation of posterior densities (Koop and Korobilis (2010) provide an extensive discussion on this topic). Our baseline model

[8] Real GDP was calculated using nominal GDP and the GDP deflator, the CPI index is Consumer Price Index for All Urban Consumers All Items, CPIAUCSL, and the treasury bill rate is 3-Month Treasury Bill Secondary Market Rate, TB3MS, average of monthly time series over each quarter.

[9] It could be argued that our use of the 3-month T bill series for the nominal interest rate may ignore possible problems related to the zero lower bound. We therefore re-estimated our VAR models with samples until 2017Q3 with the alternative measure of the shadow interest rate of Wu and Xia (2016), and obtain virtually identical results.

includes 2 lags, as, e.g. in Mumtaz and Theodoridis (2018). This allows us to reduce the number of parameters to estimate in the setup with four endogenous variables. We check robustness for versions of the VAR with 4 or 5 lags, and find that our results are indeed robust to these changes.

The model set up consists of:

$$y_t = A_0 + \sum_{j=1}^{p} A_j y_{t-j} + e_t, \tag{3}$$

$$e_t \sim \mathbb{N}(0, \Sigma).$$

where y_t is a vector of consisting of the inflation target, output growth, inflation and the nominal interest rate. A_0 is a vector of intercepts, p is the number of lags, A_j is the matrix of autoregressive coefficients of lag j, and Σ is the covariance matrix of the residuals.

Our identification strategy follows the most standard approach in the literature, namely, we employ a Cholesky identification.[10] The variables in our VAR are ordered in the following way: inflation target, output growth, inflation and nominal interest rate. The inflation target is ordered first as it is a highly persistent variable and we expect it not to react on impact of a shock to any other variable in the system. In order to offset short-run variations in the economy, the Fed shifts the interest rate, not the target. The ordering across the remaining three variables (output growth, inflation, nominal interest rate) is standard in the literature.

[10]We are aware that imposing structure through a Cholesky decomposition brings with it a certain inconsistency between the DSGE model assumptions and the VAR model. However, the Cholesky decomposition still remains the most widely used identification strategy and we intentionally refrain from more elaborated identification approaches for the sake of simplicity.

4 Results

4.1 Results from the baseline model

We are primarily interested in using our empirical VAR model to study the effects of monetary policy shocks. In particular, we look at a temporary shock to the short-term nominal interest rate, as standard in the literature. However our main contribution comes from studying the inflation target shock, a persistent shock to the long-run goal of the Fed. This inflation target shock is similar in spirit to a permanent monetary shock, about which there is controversy in the recent literature on the effects of monetary policy on inflation dynamics.

Schmitt-Grohè and Uribe (2014) and Cochrane (2018) argue a permanent monetary policy shock has a positive effect both on inflation and nominal interest rate, not only in the long run, but already in the short run, the Neo-Fisher effect. They call for disentangling the effects of permanent and transitory shocks which jointly affect inflation dynamics in the short-run. According to this view, the price puzzle might be a result of a model misspecification when effects from permanent monetary shocks are overlooked in the empirical analysis.

Another side of the literature argues against the existence of a Neo-Fisher effect. Garcìa-Schmidt and Woodford (2018) claim that the existence of a Neo-Fisher effect in response to a persistent lowering of the nominal rate is a consequence of an unreasonable setup of the theoretical model, i.e. the assumption of a perfect-foresight. They show that under an alternative assumption of a reflective equilibrium there is no evidence of Neo-Fisherian effects.

This paper contributes to this literature by providing missing empirical evidence. Using our empirical model setup we are able to distinguish between temporary monetary policy shocks and monetary policy shocks of more permanent nature, represented by shifts in the short-term nominal interest rate and shift in the inflation target, respectively.

Figure 7 presents the posterior mean responses of our baseline model estimated for four time samples, starting in 1947Q3 or 1979Q3 and ending in 2017Q3 or 2008Q2 (appendix C contains the impulse responses in terms of posterior mean and 90% confidence intervals for each time sample separately).[11] We look at the effects of a shock to the inflation target (first row) and a shock to the nominal interest rate (second row). In the third row we supply the impulse responses to the nominal rate shock in a standard three-variable VAR without inflation target. This allows us to 1) provide evidence on the transmission of inflation target shock, 2) compare and contrast the effects of two different types of monetary policy shocks, and, finally, 3) contrast the transmission of the nominal interest rate shock in our baseline VAR with inflation target to the standard three-variable VAR without such information.

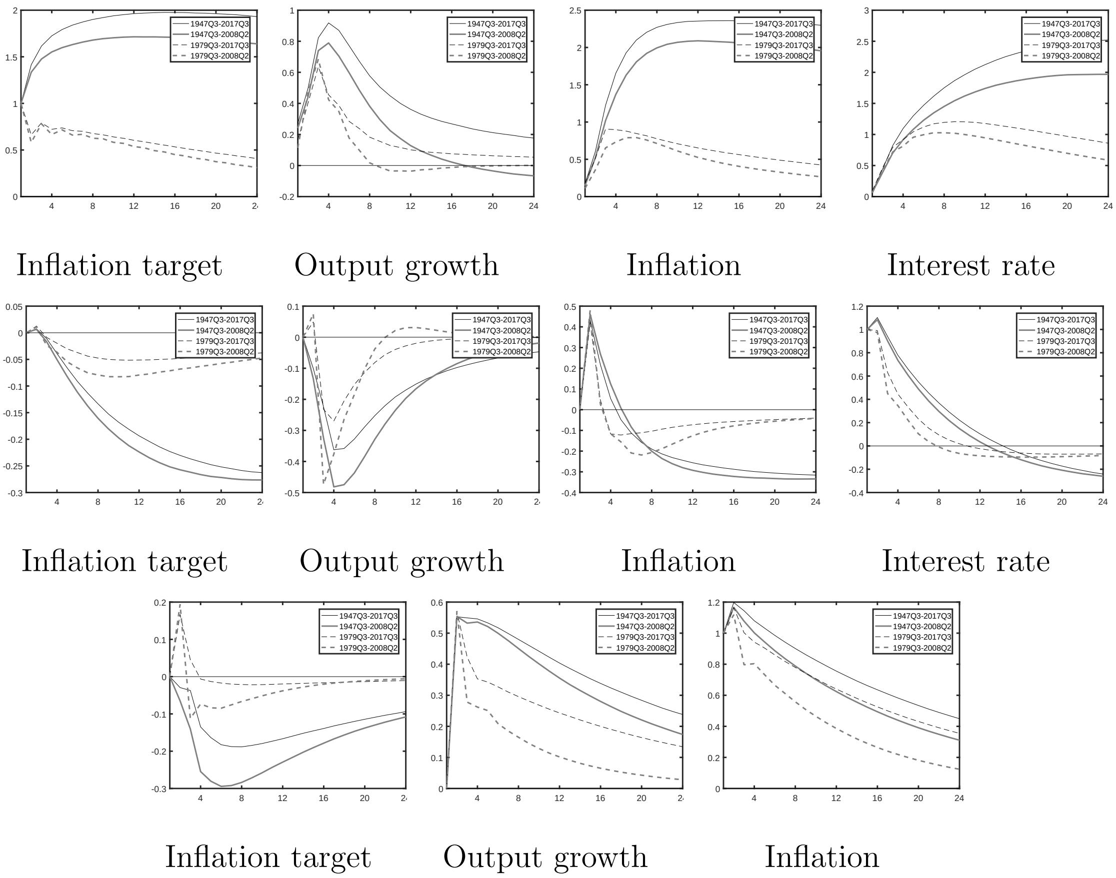


Figure 7. First row: Posterior mean impulse responses to an inflation target shock. Second row: Posterior mean impulse responses to a temporary nominal interest rate shock. Third row: Posterior mean impulse responses to a temporary nominal interest rate shock in the 3-variable VAR. Black solid line: 1947Q3 to 2017Q3, gray solid line: 1947Q3 to 2008Q2, black dotted line: 1979Q3 to 2017Q3, gray dotted line: 1979Q3 to 2008Q2. Horizontal axis: periods after the shock, vertical axis: percentage change.

We observe a positive response of inflation and the nominal interest rate on impact

[11] We also estimate over the samples 1983Q1-2008Q2 and 1983Q1-2017Q3 and receive similar results.

of a one percent increase in the inflation target. Inflation increases by about 2% and the nominal interest rate increases by 1.5% after a few quarters, as indicated by the posterior means of these variables. These results indicate that we do find support for Neo-Fisher like effects, i.e. persistent changes in the inflation target affect inflation and nominal interest rate dynamics in the short-run, the two variables co-moving positively.

Our results are in line with the results from other related empirical studies. Uribe (2018) finds, in response to a permanent nominal interest rate increase, similar maximum responses of inflation and the interest rate, with inflation reacting by a 1% increase on impact and going up to a peak of about 1.3%, and with the nominal interest rate increasing more gradually, starting at zero on impact of the shock, and reaching similar peak responses. Mumtaz and Theodoridis (2018) find a 1.6% increase in inflation on impact and a peak response of about 3% for the policy rate (with a 1% increase on impact of the shock).

In our model both inflation and the interest rate require considerable time to attain their peak responses, because of the nature of the highly persistent inflation target. The reaction of inflation is more pronounced, implying that the real interest rate goes down. This in turn stimulates real activity and we observe an increase in output growth. Both Uribe (2018) and Mumtaz and Theodoridis (2018) also find evidence in favor of an increase in economic activity. This effect is least persistent however and output growth starts to die out after the first year. This is consistent with the Fisher equation: as the dynamics between inflation and interest rate adjust and reach similar levels, the real rate becomes unaffected by changes in these nominal variables. As a result, output growth returns to its pre-shock value.

Figure 7 (row 1) documents substantial quantitative differences in the effects of the inflation target shock, depending on the sample period. We observe a pronounced decrease in the persistence of the inflation target in the more recent subsamples that start from 1979Q3 (see figures 13 and 14 in appendix C, for the impulse response plots with confidence bounds), compared to the time period of the entire postwar period (figures 11 and 12 in appendix C). In more recent times the Federal reserve placed a large value on the commitment to its polices, and, under the chairmanship of Bernanke even adopted an explicit, publicly announced inflation target. As a results, the inflation target became more credible. This is also clearly reflected in the much smoother time path of our estimated inflation target series in more recent times. Because of this, the inflation target shock is identified as much less persistent and more quickly mean-reverting by the VAR estimated on the recent subsamples, and, consequently this also holds for inflation itself. This result suggests the policy implication that the long-run commitment to an inflation target helps reducing inflation persistence, making the implementation of monetary policy more effective.

Here we emphasize a divergence between the nature of an inflation target shock, as in our setting, and a permanent interest rate shock, as in Uribe (2018). One of the critical arguments against the Neo-Fisherian intuition proposed by Garcìa-Schmidt and Woodford (2018) was an unreasonably high and persistent predicted reaction of the economy towards a long-lasted reduction in the nominal interest rate in recent times. As in our setting, the inflation target shock is not equivalent to a permanent nominal interest rate shock, and in fact, the data suggests that the inflation target shock has become less persistent, our setting predicts also that the reaction of the economy to such shock is more contained. That is, we observe that the effects of shifts in the inflation target are dependant on the monetary style adopted by the Federal Reserve, i.e. on the "era" of its chairmanship. Under a very credible inflation target, the effects of changes in the target are less pronounced compared to postwar data. Nevertheless, there are still short-run effects of inflation target shocks that introduce inflation and nominal interest rate dynamics in line with the Neo-Fisher effect, and that clash with those in response to temporary shocks to the nominal interest rate.

In particular, contrasting the transmission mechanism implied by the inflation target and the nominal interest rate shock (row 2 of figure 7), one can see that they bring about opposite effects on interest rates and on real output and inflation. A raise in the inflation target stimulates the economy, increasing output growth, and raises the nominal interest rate; a raise in the nominal interest rate on the other hand has a contractionary effect on output and decreases inflation after a few quarters, consistent with the theoretical predictions outlined in section 2. To be precise, and this observation deserves a deeper discussion, we still find that inflation exhibits an increase on impact of the nominal interest rate shock. As discussed, this is counter to the intuition of a basic theoretical (New Keynesian) model, which predicts that inflation reacts negatively already on impact of the monetary contraction. However, this counterfactual price increase in response a temporary interest rate increase is a very usual finding in the empirical VAR literature, and is regarded as the 'price puzzle'. In fact, row 3 of figure 7 plots the impulse responses to the nominal interest rate shock for the case of the standard three-variable VAR without inflation target. As can be seen, the price puzzle in this case is very pronounced, with the response of inflation to the interest rate shock remaining positive for the entire 24 quarter horizon plotted. [12]

One approach to addressing the price puzzle is the use sign restrictions as in (Canova and De Nicolò, 2002; Uhlig, 2005; Liu and Theodoridis, 2012), in which case the price puzzle is solved by disregarding the theory-inconsistent responses. Uribe (2018) also employs sign restrictions in order to identify impulse responses. As we only impose time restrictions via the Cholesky decomposition, the fact that the price puzzle is strongly alleviated comes purely from economic intuition, from disentangling the effects of temporary interest rate shocks from the effects of persistent shifts in the inflation target, in our baseline four-variable VAR. We see that the inflation is highly persistent in response to the inflation target shock, i.e. the price puzzle was the side effect of an omitted variable, of not having accounted for the presence of persistent monetary policy shifts. As for policy implementation, a temporary raise in the nominal interest rate should still be viewed as a shock that triggers a fall in inflation within the first year after the implementation. In order to predict an unbiased effect of any monetary policy action, we suggest to use the model version that explicitly accounts for both types of policies.

[12] The price puzzle was first documented by Sims (1992), and has since been addressed by a large literature. The puzzle was removed, e.g., when fast moving commodity prices were included (Christiano et al., 1996). Alternatively, Del Negro and Otrok (2007) utilize house prices. Bernanke et al. (2005) and Forni and Gambetti (2010) use factor model with information from a large set of time series. Gertler and Karadi (2015) employ high frequency shock identification schemes in a VAR with financial variables.

The improvement of the identification of the inflation response under a temporary monetary shocks also holds throughout all subsamples. The fact that separating more permanent-natured from temporary effects improves inflation identification in different periods, including the most recent one, and suggests that Neo-Fisher like effects seem to importantly contribute to inflation dynamics.

4.2 Sensitivity analysis

We perform a number of checks to assess the robustness of our results. First we check the sensitivity of our baseline model by increasing the number of lags. We further check how our baseline model behaves with alternative measures of the inflation target.

Appendix C includes detailed results of the baseline model with 4 and 5 lags. Figure 8 presents the mean responses of the baseline model with 4 lags over four different subsamples. Our previous results continue to hold: on impact of a shock to the inflation target, inflation and the nominal interest rate increase in the short-run, there is a pronounced decrease in persistence of the inflation target shock after 1980s, and the price puzzle is strongly alleviated compared to the three-variable VAR.

Figures 9 and 10 present the results of models in which we replace the DSGE-based measure of the inflation target series with the measure of trend inflation as in Stock and Watson (2007), or the measure of trend inflation as in Chan et al. (2018), respectively. In section 2 we mention that trend inflation as estimated in Stock and Watson (2007) is much less persistent compared to the inflation target and more volatile. Hence, it is less likely to be a good proxy for persistent monetary policy shifts, and we expect the 'persistent' shock in the model with the Stock-Watson trend inflation measure to behave more like a temporary interest rate shock rather than the inflation target shock. This is apparent from figure 9: inflation explodes on impact of inflation target shock. The nominal interest rate is expected to bring the inflation down eventually. As the real interest rate declines, output growth quickly drops below zero. We conclude that the trend inflation measure of Stock&Watson misses information on the more long lasting changes monetary policy stance, as the reaction of inflation to an increase in the policy

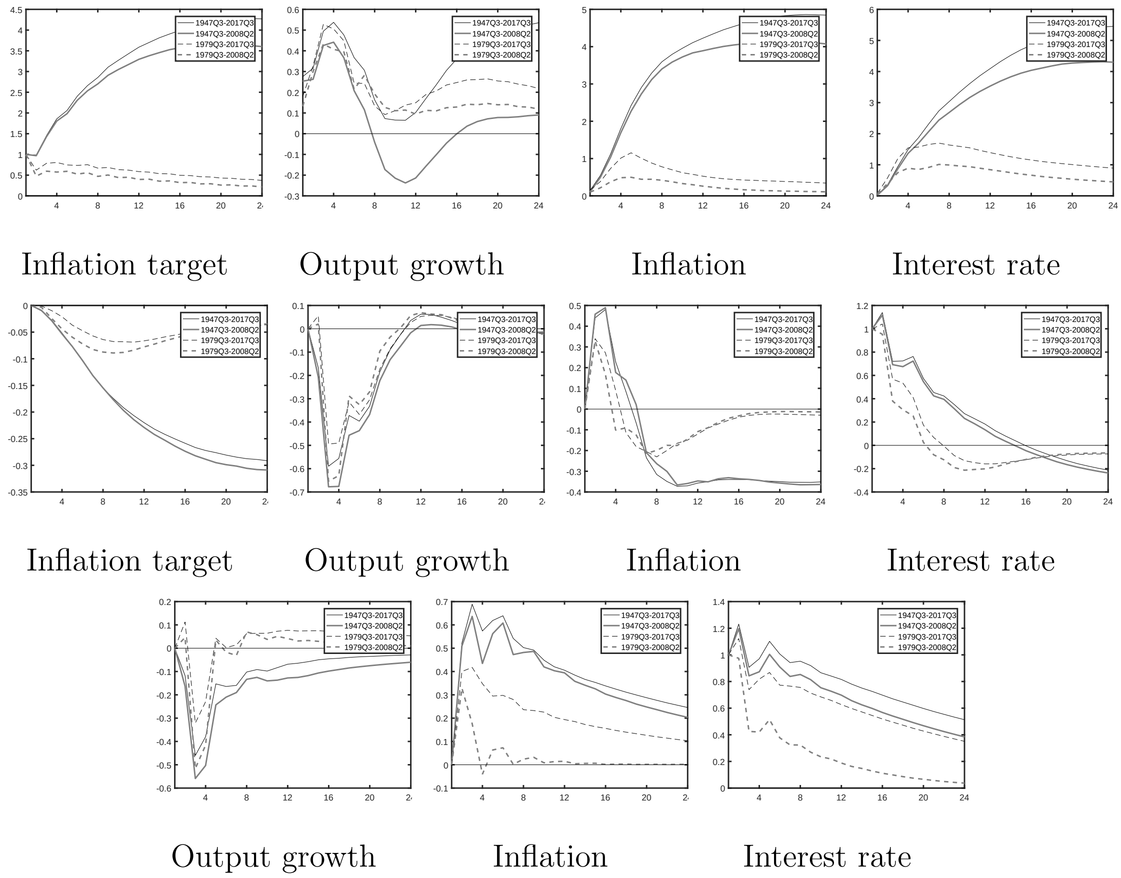


Figure 8. Baseline model with 4 lags. First row: Posterior mean impulse responses to an inflation target shock. Second row: Posterior mean impulse responses to a temporary nominal interest rate shock. Third row: Posterior mean impulse responses to a temporary nominal interest rate shock in the 3-variable VAR. Black solid line: 1947Q3 to 2017Q3, gray solid line: 1947Q3 to 2008Q2, black dotted line: 1979Q3 to 2017Q3, gray dotted line: 1979Q3 to 2008Q2. Horizontal axis: periods after the shock, vertical axis: percentage change.

rate is positive and persistent much like the price puzzle in the three-variable VAR.

The trend inflation measure as estimated in Chan et al. (2018) incorporates forward-looking time series of inflation expectations, making this variable conceptionally more alike to the our DSGE-based inflation target measure. The results of the model with this trend inflation measure are closer to the results of our baseline model, both in terms of a shock to trend inflation and a temporary nominal interest rate shock. There is a clear support for the Neo-Fisher-like effects as inflation and interest rate show positive responses to the raise in the trend inflation, triggering again an increase in output growth; inflation reacts positively to the temporary shock, however, the price puzzle is reduced compared to the three-variable VAR.

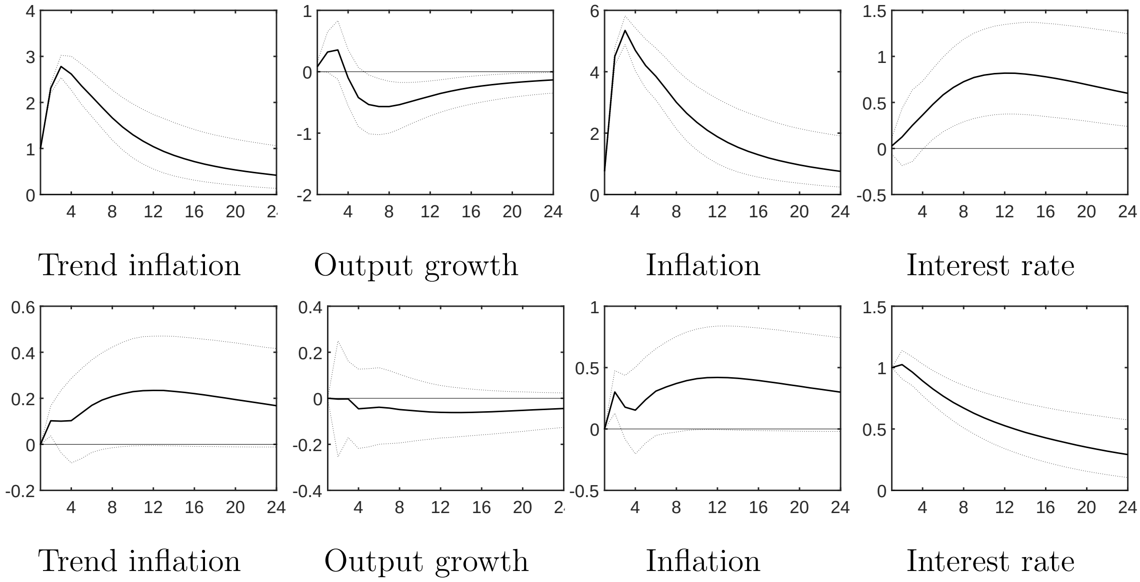


Figure 9. Model with trend inflation as in Stock&Watson (2007). First row: Impulse responses to an inflation target shock. Second row: Impulse responses to a temporary nominal interest rate shock. Sample: 1947Q3 -2017Q3. Horizontal axis: periods after the shock, vertical axis: percentage change.

Importantly, those measures of the inflation target that contain similar information as our DSGE-based measure bring up similar results when added to the standard three-variable VAR. This suggests that using a theoretical model to estimate the unobservable forward-looking variable of the inflation target, is reasonable and can compete with empirically estimated measures of the target.

5 Conclusions

This paper proposes a simple empirical framework to study the transmission mechanisms of monetary policy, allowing to distinguish between long-run and short-run monetary policies. In particular, we estimate a time-varying inflation target from a theoretical DSGE model, which we then use to augment a standard three-variable VAR in output growth, inflation and the nominal interest rate. With this model we are able to study effects of inflation target shock which represents shifts in the long-run policy objectives of the Fed, and effects from a nominal interest rate shock, which is used by the Fed to mitigate short-run fluctuations in the economy.

Our results suggest that both shocks are important sources of fluctuations in inflation

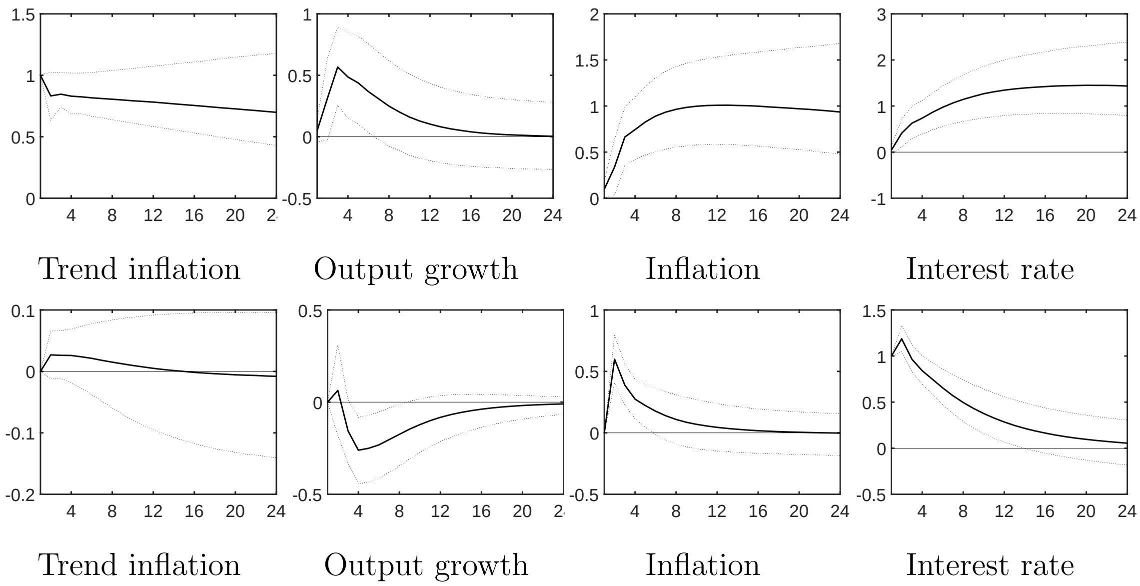


Figure 10. Model with trend inflation as in Chan et al.(2018). First row: Impulse responses to an inflation target shock. Second row: Impulse responses to a temporary nominal interest rate shock. Sample: 1947Q3 -2017Q3. Horizontal axis: periods after the shock, vertical axis: percentage change.

and output growth in the close aftermath of the shock and the Fed has two channels to affect the economy. Hence, we provide empirical evidence in favour of the existence of Neo-Fisher-like effects: in response to systematic monetary policy changes, inflation and the nominal interest rate co-move positively, even in the short run. Our empirical model also informs us that, in recent times, the persistence of the inflation target shock is reduced, which likely contributes to a reduction in inflation persistence. Lastly, introducing the inflation target helps in the identification of temporary nominal interest rate shock in that the resulting price puzzle is strongly alleviated. In this sense, the inflation target can be interpreted as a previously omitted variable, whose absence in the VAR led to biased impulse responses.

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A The DSGE model

This section presents the DSGE model which we employ to estimate the unobserved time series for the inflation target. We intend to stay within a simple and commonly acknowledged framework. We follow closely the approach taken by Cogley et al. (2010): a standard New Keynesian model (Boivin and Giannoni, 2006) with a time-varying inflation target process as in (Ireland, 2007). We give a brief description of the model below.

Our economy is populated by households who consume, supply their labor services in the labor market and decide on their savings. Imperfectly competitive firms supply goods to the market and face nominal rigidities in their price setting decisions. Monetary policy is described by a central bank that follows a Taylor rule in setting the nominal interest rate every period.

The household's faces habit preferences in consumption, that is, period utility depends positively on consumption relative to past consumption with a weight h, and negatively on labor effort, with ν being the inverse Frisch elasticity of labor supply. The representative household solves the following maximization problem:

$$\max E_t \sum_{s=0}^{\infty} \beta^s b_{t+s} \left[\log(C_{t+s} - hC_{t+s-1}) - \psi \int_0^1 \frac{L_{t+s}(i)^{1+\nu}}{1+\nu} di \right], \tag{4}$$

subject to the budget constraint:

$$\int_0^1 P_t(i) C_t(i) di + B_t + T_t \leqslant R_{t-1} B_{t-1} + \Pi_t + \int_0^1 W_t(i) L_t(i) di. \tag{5}$$

L_t is the household's labor supply, W_t the nominal wage rate, B_t indicate holdings of government bonds, R_t is the nominal gross interest rate, T_t are taxes and transfers received. b_t represents a preference shock. C_t is a final consumption index, modelled as a Dixit-Stiglitz aggregator over the different varieties of consumption goods, that are substitutable with each other at elasticity of substitution θ_t:

$$C_t = \left[\int_0^1 C_t(i)^{\frac{1}{1+\theta_t}} di \right]^{1+\theta_t}.$$

The substitution elasticity θ_t is allowed to vary over time according to an exogenous process, which gives rise to fluctuations in firms' markup over marginal cost. The exogenous processes of the preference shock, b_t, and the markup shock, θ_t, evolve according to the following stochastic processes:

$$\log(b_t) = \rho_b \log(b_{t-1}) + \varepsilon_{b,t}, \tag{6}$$

$$\log(\theta_t) = (1 - \rho_\theta) \log(\theta) + \rho_\theta \log(\theta_{t-1}) + \varepsilon_{\theta,t},$$

The production side is represented by monopolistically competitive firms. Each firm i produces a differentiated good taken as given the demand for its variety from households and facing a a linear production function, $Y_t(i)$:

$$Y_t(i) = A_t L_t(i), \tag{7}$$

where A_t is the level of aggregate total factor productivity. The level of productivity is allowed to grow over time, and the growth rate of the economy, defined as $z_t \equiv \log \frac{A_t}{A_{t-1}}$, follows an exogenous process and is subject to stochastic shocks:

$$z_t = (1 - \rho_z)\gamma + \rho_z z_{t-1} + \varepsilon_{z,t}. \tag{8}$$

Firm i optimally sets the price for its variety, but cannot do so every period, following the setup of staggered prices as in Calvo (1983). In particular, each period only a fraction of $1 - \zeta$ of firms is allowed to optimally re-set their price, while the remaining fraction ζ of firms is not allowed to re-optimize their prices. In setting the price the firm aims to maximize the lifetime expected discounted stream of profits (revenue minus costs) subject to the demand schedule from households, and subject to its production technology:

$$\max E_t \sum_{s=0}^{\infty} \zeta^s \Lambda_{t,t+s} \left[\tilde{P}_t(i) \pi Y_{t+s}(i) - W_{t+s}(i) L_{t+s}(i) \right], \tag{9}$$

where $\Lambda_{t+s} = \beta^s \frac{\lambda_{t+s}}{\lambda_t}$ is the household's discount factor (the appropriate discount factor for firms' decision as firms are owned by households), and π is the steady state gross inflation rate.

Finally, the monetary authority sets the gross nominal interest rate according to the following Taylor rule:

$$\frac{R_t}{R} = \frac{R_{t-1}}{R}^{\rho_R} \left[\left(\frac{\bar{\pi}_{4,t}}{(\pi_t^*)^4} \right)^{\rho_\pi} \left(\frac{Y_t}{Y_t^*} \right)^{\rho_Y} \right]^{1-\rho_R} e^{\varepsilon_{R,t}}, \tag{10}$$

where R is the steady state level of the nominal interest rate, and where $\varepsilon_{R,t}$ is an exogenous disturbance meant to capture (temporary) nominal interest rate shock to the policy rate. According to the rule the central bank considers three factors in deciding on the current level of the nominal interest rate: (1) the previous level of the nominal interest rate R_{t-1}, i.e. there is interest rate smoothing; (2) the output gap, defined as the deviation of the actual level of output, Y_t from its potential, i.e. the level of output that would prevail in an economy with flexible prices, Y_t^*; and (3) the inflation gap, defined as the deviation of inflation, $\bar{\pi}_{4,t}$, from the level of target inflation. In particular, it is defined as $\bar{\pi}_{4,t} \equiv (\pi_t + \pi_{t-1} + \pi_{t-2} + \pi_{t-3})/4$. In contrast to the more standard Taylor rule featured in a standard New Keynesian model such as, e.g., described in chapter 3 of Galí (2008), the inflation target, π_t^*, is not required to be fixed at a constant level, but is allowed to be time dependent and vary over time according to following exogenous process for π_t^*:

$$\log \pi_t^* = (1 - \rho_{\pi^*}) \log \pi + \rho_{\pi^*} \log \pi_{t-1}^* + \varepsilon_{\pi^*,t}. \tag{11}$$

B Prior setup and posterior estimates

Table 1 presents estimation results for the model parameters of the New Keynesian model described in appendix A, reporting information on the chosen prior distributions, prior means, and prior variances, as well as the estimated posterior means and posterior variances.

Parameter name	Prior density	Prior mean	Prior variance	Starting value	Lower bound	Upper bound	Posterior mean	Posterior variance
γ_q	Normal	0,475	0,025	0,465	0,001	1,000	0,4632	0,00
π	Normal	0,500	0,100	0,506	0,001	1,000	0,512	0,010
$\rho = \frac{1}{\beta} - 1$	Gamma	0,250	0,100	0,159	0,001	1,000	0,132	0,003
h	Beta	0,500	0,100	0,458	0,00001	0,990	0,450	0,003
ζ	Beta	0,660	0,100	0,772	0,00001	0,990	0,738	0,003
ρ_π	Normal	1,700	0,200	1,362	1,050	10,000	1,292	0,025
ρ_Y	Gamma	0,300	0,150	1,068	0,010	2,000	1,134	0,053
ρ_R	Beta	0,600	0,200	0,736	0,010	0,999	0,859	0,001
ρ_z	Beta	0,400	0,200	0,439	0,010	0,999	0,547	0,007
ρ_θ	Beta	0,600	0,200	0,469	0,010	0,999	0,505	0,004
ρ_b	Beta	0,600	0,200	0,870	0,010	0,999	0,906	0,000
ρ_{π^*}	Beta	0,950	0,400	0,990	0,001	0,999	0,989	0,000
$\sigma(\epsilon_R)$	Inverse Gamma	0,150	1,000	0,162	0,0001	4,000	0,148	0,000
$\sigma(\epsilon_z)$	Inverse Gamma	1,000	1,000	0,806	0,0001	4,000	0,730	0,009
$\sigma(\epsilon_\theta)$	Inverse Gamma	0,150	1,000	0,197	0,0001	4,000	0,265	0,000
$\sigma(\epsilon_b)$	Inverse Gamma	1,000	1,000	3,218	0,0001	4,000	3,195	0,191
$\sigma(\epsilon_{\pi^*})$	Inverse Gamma	0,075	0,043	0,110	0,000	1,000	0,110	0,003

Table 1 Prior parameters and posterior estimates

C Sensitivity analysis

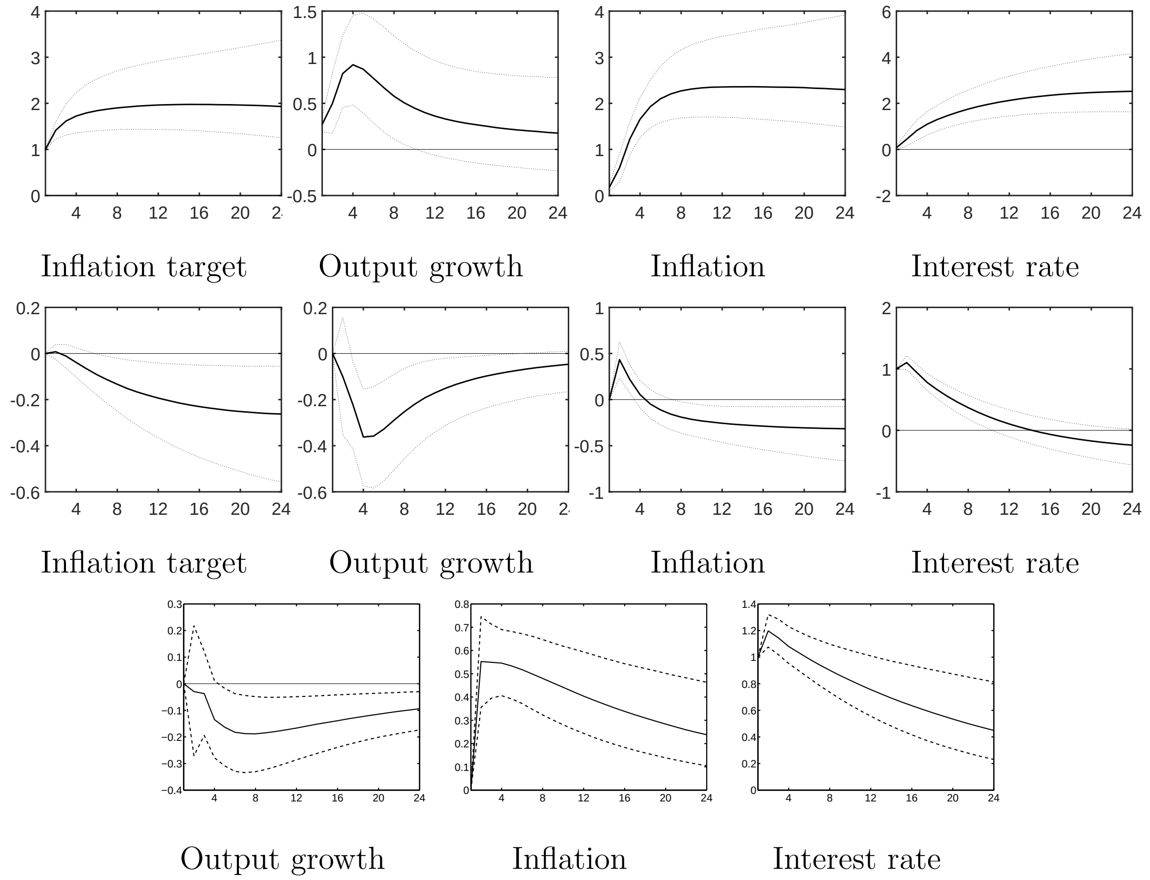

Figure 11. First row: Impulse responses to an inflation target shock. Second row: Impulse responses to a temporary nominal interest rate shock. Third row: Impulse responses to a temporary nominal interest rate shock in the 3-variable VAR. Sample: 1947Q3 -2017Q3. Horizontal axis: periods after the shock, vertical axis: percentage change.

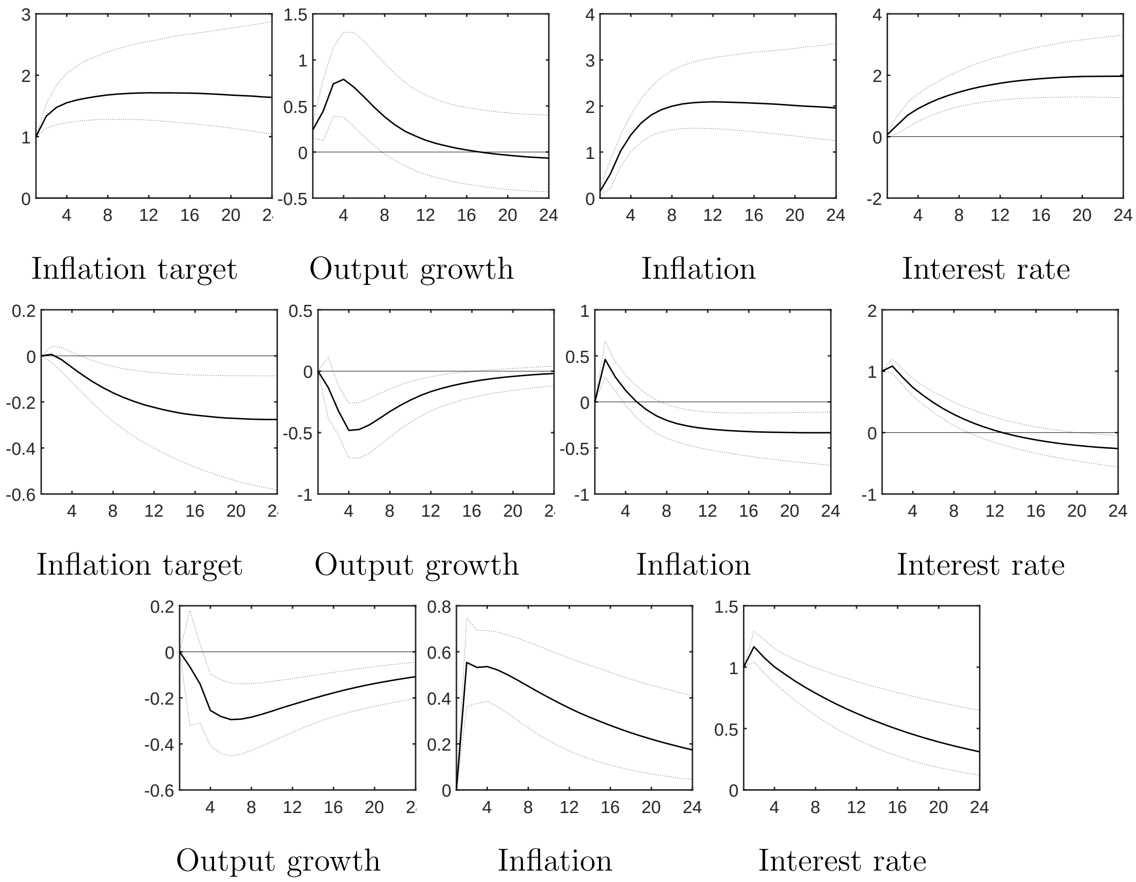

Figure 12. First row: Impulse responses to an inflation target shock. Second row: Impulse responses to a temporary nominal interest rate shock. Third row: Impulse responses to a temporary nominal interest rate shock in the 3-variable VAR. Sample: 1947Q3 -2008Q2. Horizontal axis: periods after the shock, vertical axis: percentage change.

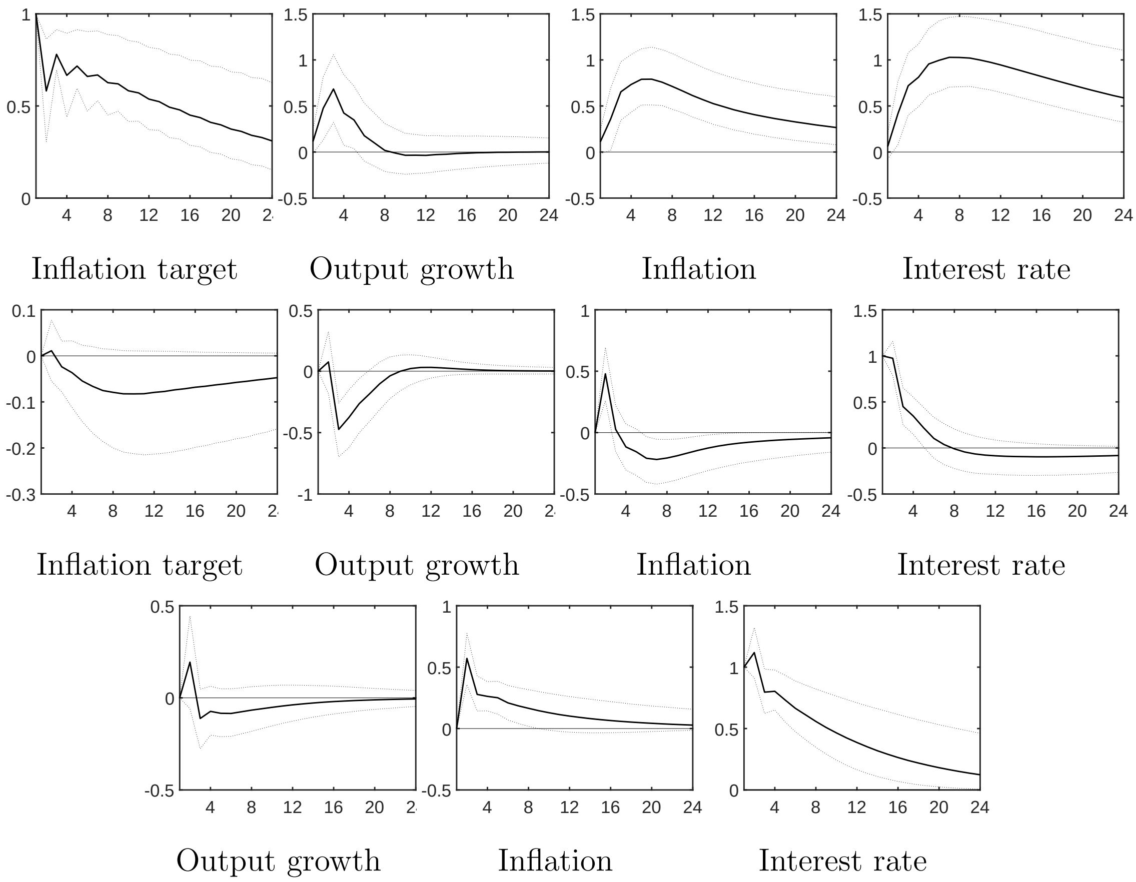

Figure 13. First row: Impulse responses to an inflation target shock. Second row: Impulse responses to a temporary nominal interest rate shock. Third row: Impulse responses to a temporary nominal interest rate shock in the 3-variable VAR. Sample: 1979Q3 -2008Q2. Horizontal axis: periods after the shock, vertical axis: percentage change.

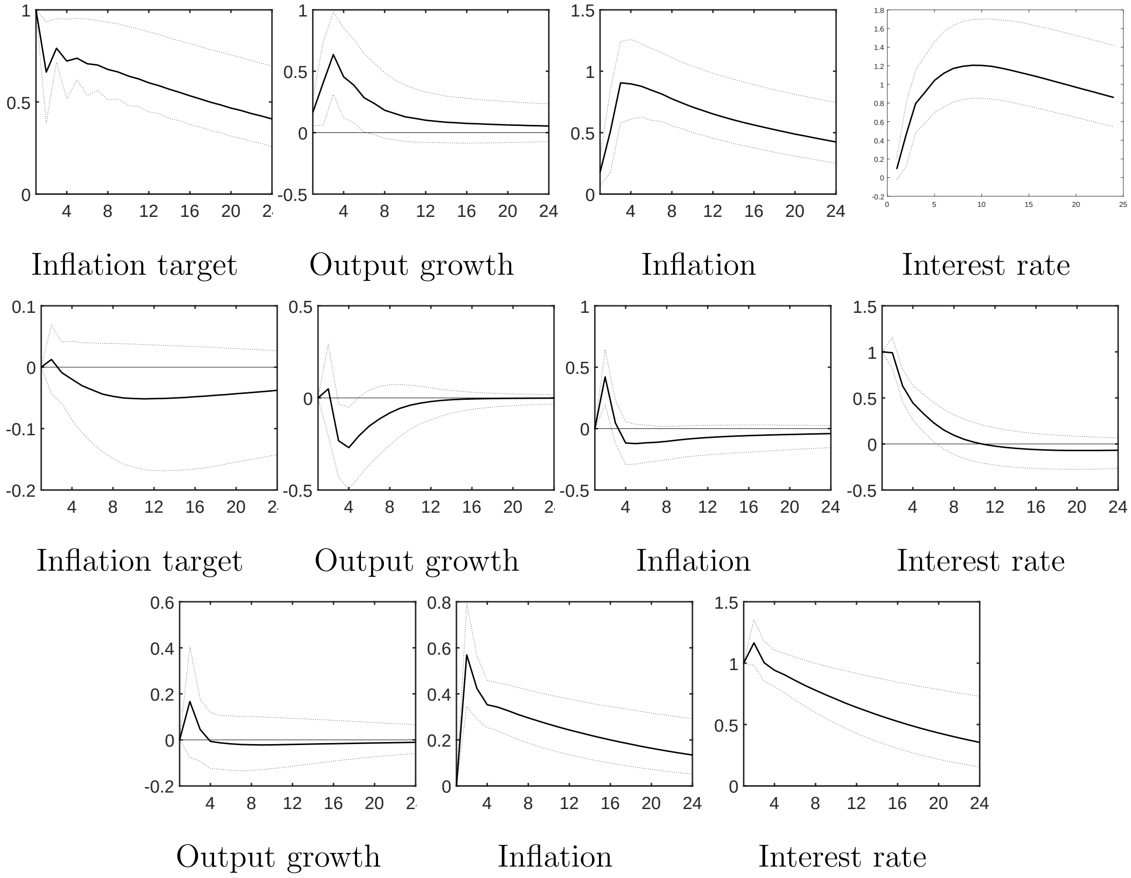

Figure 14. First row: Impulse responses to an inflation target shock. Second row: Impulse responses to a temporary nominal interest rate shock. Third row: Impulse responses to a temporary nominal interest rate shock in the 3-variable VAR. Sample: 1979Q3 -2017Q3. Horizontal axis: periods after the shock, vertical axis: percentage change.

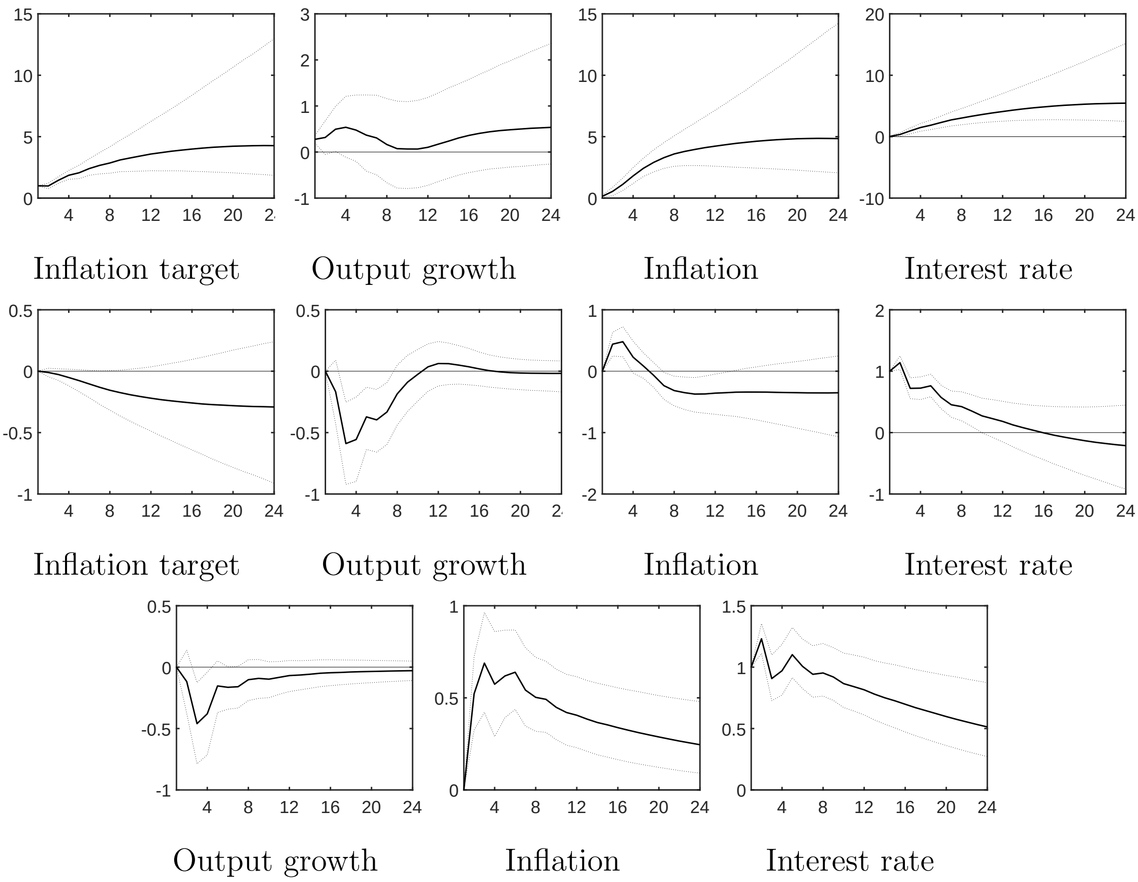

Figure 15. Baseline model with 4 lags. First row: Impulse responses to an inflation target shock. Second row: Impulse responses to a temporary nominal interest rate shock. Third row: Impulse responses to a temporary nominal interest rate shock in the 3-variable VAR. Sample: 1947Q3 -2017Q3. Horizontal axis: periods after the shock, vertical axis: percentage change.

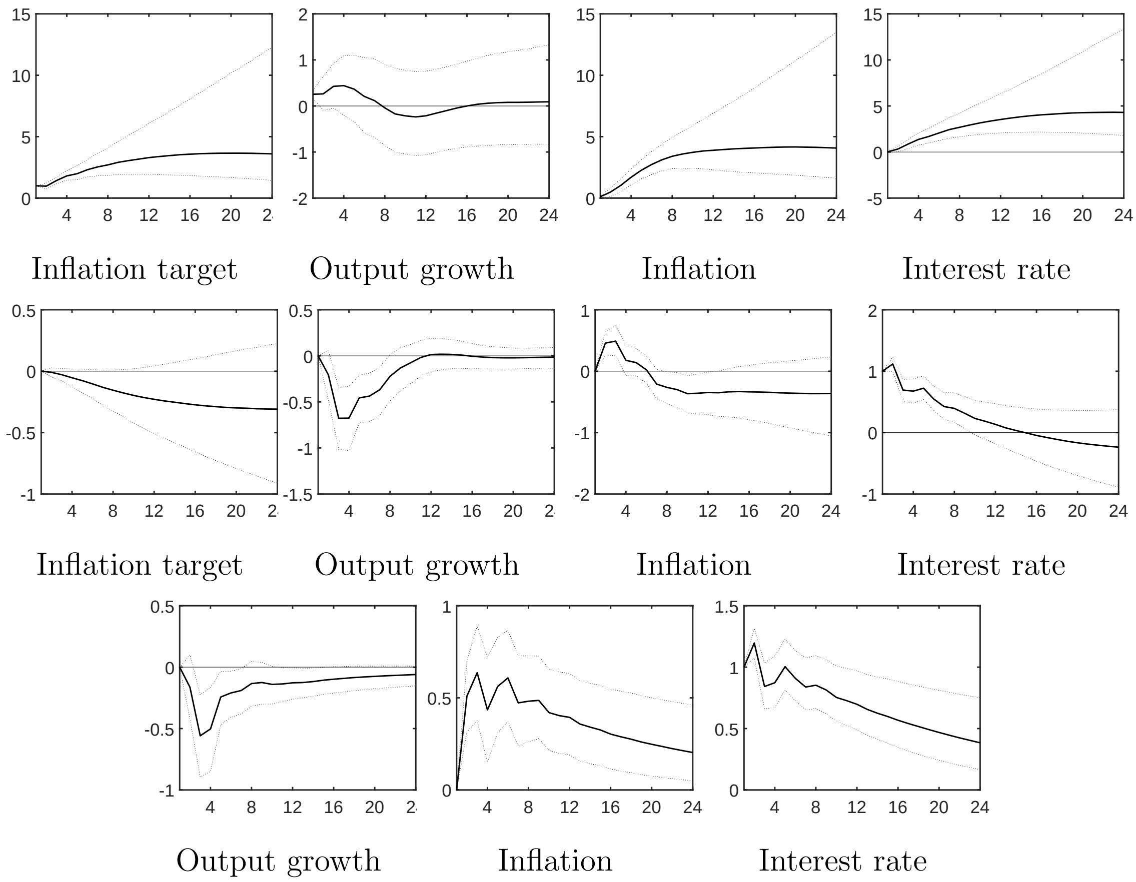

Figure 16. Baseline model with 4 lags. First row: Impulse responses to an inflation target shock. Second row: Impulse responses to a temporary nominal interest rate shock. Third row: Impulse responses to a temporary nominal interest rate shock in the 3-variable VAR. Sample: 1947Q3 -2008Q2. Horizontal axis: periods after the shock, vertical axis: percentage change.

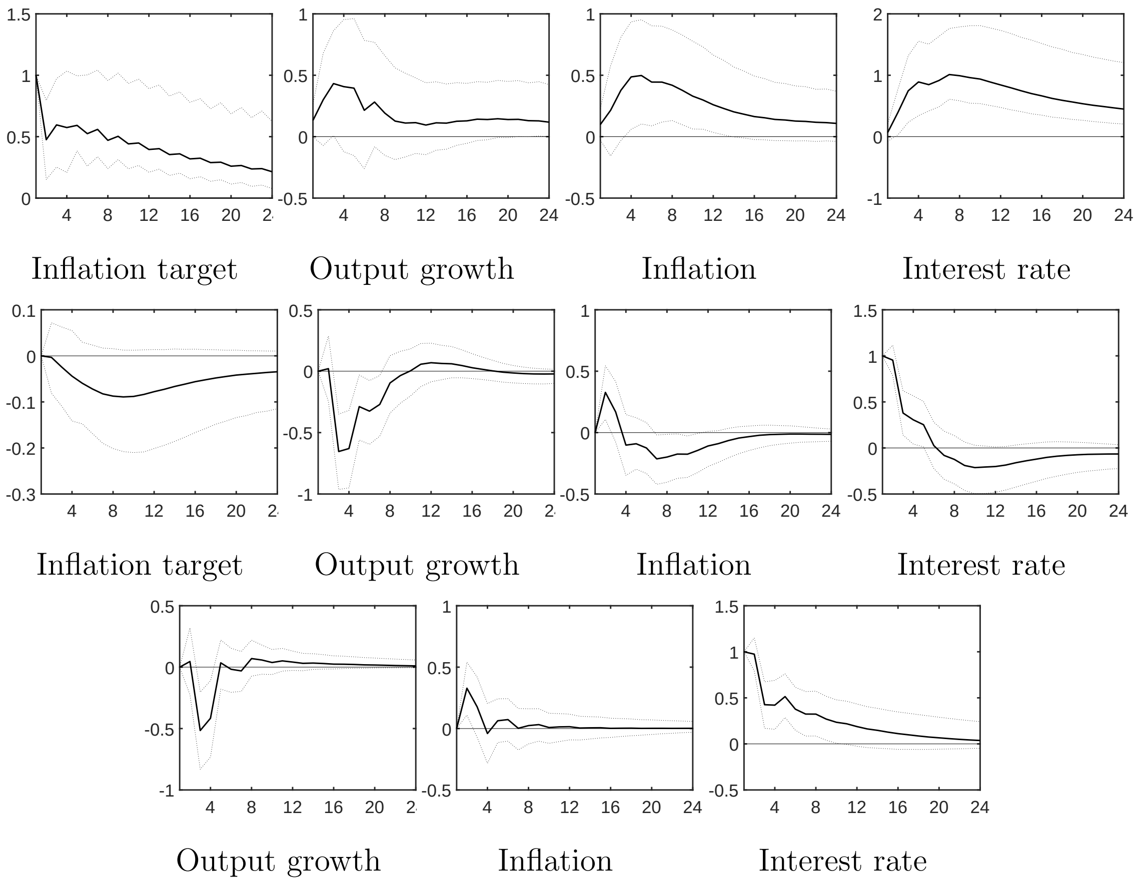

Figure 17. Baseline model with 4 lags. First row: Impulse responses to an inflation target shock. Second row: Impulse responses to a temporary nominal interest rate shock. Third row: Impulse responses to a temporary nominal interest rate shock in the 3-variable VAR. Sample: 1979Q3 -2008Q2. Horizontal axis: periods after the shock, vertical axis: percentage change.

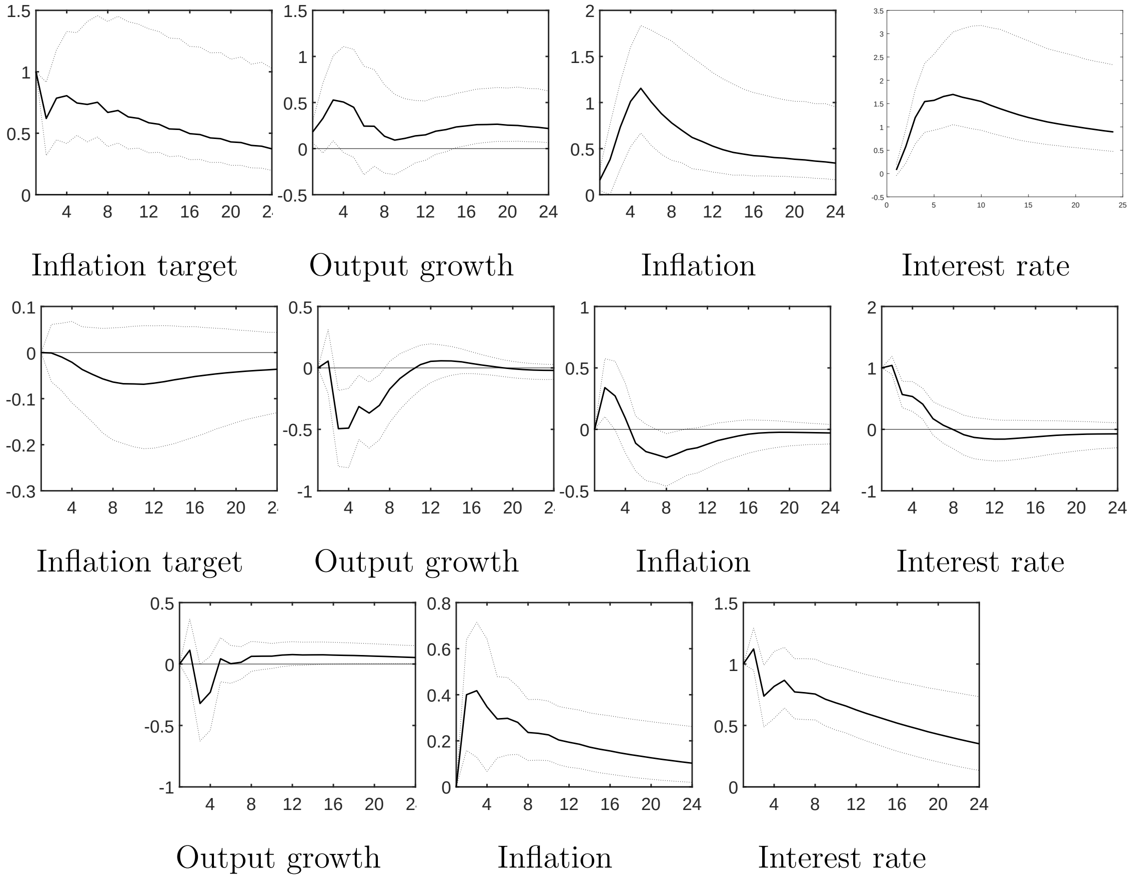

Figure 18. Baseline model with 4 lags. First row: Impulse responses to an inflation target shock. Second row: Impulse responses to a temporary nominal interest rate shock. Third row: Impulse responses to a temporary nominal interest rate shock in the 3-variable VAR. Sample: 1979Q3 -2017Q3. Horizontal axis: periods after the shock, vertical axis: percentage change.