New evidence on monetary transmission: interest rate versus inflation target shocks[*]

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Abstract

We present empirical evidence on monetary transmission from estimated New Keynesian and empirical VAR models, that allow for a standard nominal interest rate shock and an inflation target shock. In response to the highly persistent inflation target shock we largely find evidence of a Neo-Fisher effect: the nominal interest rate co-moves positively with inflation and output. In an estimated model version where agents do not have full but only imperfect information about the nature of monetary shocks, Neo-Fisherian effects arise only with a lagged effect and not in the immediate short-run, because, in such case, inflation expectations do not adjust immediately to the target shock. We then use these insights to inform our VAR, adopting a methodology that allows to account for the uncertainty about identifying assumptions with respect to the target shock, i.e., that economic agents *might* need time to learn whether a monetary shock is temporary or persistent. We again find that nominal interest rates and inflation increase significantly and co-move positively in the short aftermath of the target shock, and output increases immediately.

Keywords: Monetary policy; Neo-Fisher effect; Time-varying inflation target; DSGE; VAR; full information; imperfect information; learning
JEL-Codes: E12, F31, E52, E58

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1 Introduction

For a long time researchers interested in understanding the monetary transmission mechanism have studied temporary shocks to the nominal interest rate. In theoretical New Keynesian models, monetary policy shocks are typically captured by a temporary shock to the Taylor rule; similarly, in empirical vector autoregressive (VAR), a monetary policy shock is understood as a temporary innovation to the short-term nominal interest rate in the VAR system. This type of monetary policy shock, 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, that a current active academic and policy debate on the existence of Neo-Fisher effects deems important in understanding inflation dynamics. The Neo-Fisherian hypothesis postulates that, in response to permanent monetary policy shocks, the nominal interest rate is positively associated with inflation, already in the short run. It thus challenges the conventional view that low nominal interest rates are necessarily expansionary and associated with increases in inflation; the argument put forward is that central banks may need to raise interest rates to raise inflation, and that, similarly, extended periods of low interest rates may be deflationary (cf. Cochrane (2016); Williamson (2016); Uribe (2021); Cochrane (2018)).

In the theoretical frameworks of dynamic stochastic general equilibrium models one way to capture such long-term natured monetary policy shifts is to allow for a time-varying inflation target (cf. Ireland (2007); Cogley et al. (2010)). Alternatively, more recent contributions explicitly include permanent nominal interest rate shocks in the theoretical model framework, in addition to the conventional temporary nominal interest rate shocks (cf. Uribe (2021); Cochrane (2018)). We follow the first strand of the literature and estimate the established small-scale New Keynesian model of Ireland (2007) and Cogley et al. (2010) with Bayesian methods to derive impulse responses to the two types of monetary policy shocks: (i) the standard nominal interest rate shock and (ii) a persistent inflation target shock. A contribution of our paper is to show that the approach of modeling long-term natured monetary shocks through persistent inflation target shocks may yield similar results as explicitly incorporating permanent interest rate shocks, in the sense that they give rise to positive short-run dynamics of nominal interest rates and inflation, consistent with the Neo-Fisherian hypothesis. In addition, we consider different model versions in our estimations to account for the crucial role of how agents form inflation expectations: we estimate a model version where agents have rational expectations and full information about the nature of monetary policy shocks, but also a model version where agents have imperfect information about the type of the monetary policy shock. In the latter version, private agents have limited information about the central bank's objectives and need to learn the nature of the monetary shock over time to disentangle persistent shifts in the inflation target from transitory disturbances to the monetary policy rule, as in Erceg and Levin (2003). The assumptions on full versus imperfect information have important bearings for how agents form their inflation expectations, which is at the heart of the question of whether a persistent monetary policy shock like an inflation target increase results in model dynamics in line with the Neo-Fisherian hypothesis. In particular, in the estimated model under full information a positive target shock raises inflation expectations, increasing economic activity, and thus actual inflation immediately, leading to a rise in the nominal interest rate. This provides evidence in favor of a Neo-Fisher effect. In the case of the estimated model under imperfect information, inflation expectations (and actual inflation) adjust upward only with a lag in response to the target increase; because agents may initially misinterpret a target increase with an expansionary interest rate shock (and need to learn the true nature of the shock over time) interest rates co-move negatively with inflation and output initially, and Neo-Fisherian effects come into play only with a lag of about four to five quarters.

In addition to the empirical evidence from our estimated DSGE models we provide evidence from empirical VAR models, where we augment a widely-used small-scale monetary VAR on output growth, inflation and the nominal interest rate[1] with a low-frequency measure of inflation, with the goal to capture the inflation target shock. For this purpose we use a number of alternative measures: we consider the off-the-shelf measure of the Federal Reserve Board's own inflation target estimate (cf. Brayton et al. (2014)); long-run inflation forecasts from the Survey of Professional Forecasters; the DSGE-based implicit inflation target series obtained as a side-product from the Bayesian estimation of our New Keynesian model; or, measures of the trend inflation component from purely empirical models.

In terms of the empirical framework, we adopt the novel methodology introduced by Baumeister and Hamilton (2015, 2018, 2019). Their approach is particularly suitable for our setting, as it allows to obtain inference in structural vector autoregressions when the identifying assumptions are not fully believed or uncertain. It thus allows us to address the concern that agents, in reality, are not able to distinguish the two types of monetary shocks right away, but may need to learn their nature over time. Similarly to the theoretical model, we study the transmission of a persistent monetary shock by looking at the responses to an innovation of our measure that proxies the inflation target – in addition to the standard nominal interest rate shock. We make use of the two versions of the theoretical New Keynesian model (full versus imperfect information) in informing the VAR and in specifying identification assumptions that insure that the inflation target shock is as disentangled as possible from other structural shocks of the system. As the estimated versions of the DSGE models under full or imperfect information have left us with the insight that there are important differences in response to the inflation target shock, we employ an empirical methodology that allows us to incorporate this uncertainty without imposing anything too dogmatically and letting the data speak. In particular, we choose priors of the structural VAR parameters as being based on an average of

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

what is implied by the two theoretical DSGE models, and are relatively uninformative about those parameters where full and imperfect information scenarios differ more strongly. We therefore explicitly account for the uncertainty in identifying assumptions and leave it to the data to infer what is more realistic. Based on these identification assumptions our impulse responses to an inflation target shock provide a consistent picture, both for the various target-proxy measures considered, as well as for the different time-splits over subsample periods. In response to a positive target shock, inflation and the nominal interest rate both rise, while output typically expands. The increase in inflation is small and includes zero on impact, so that the story of the imperfect information model that agents need to learn the nature of the shock appears to find some support in the data. Nonetheless, the increase becomes significant in the short aftermath of the shock, so that inflation and nominal interest rates do comove positively in the short run, which we interpret as evidence in favor of a Neo-Fisher effect.

Our paper builds on and connects to a large literature that has deemed a time-varying inflation target important in understanding macroeconomic dynamics, particularly inflation dynamics.[2] It is also one way to reflect and capture long-term shifts in monetary policy, and, in particular, is an alternative to the route taken by Uribe (2018), who explicitly distinguishes between temporary and permanent interest rate shocks. Our paper thus also more narrowly connects to a new wave of macroeconomic studies on Neo-Fisherian effects (Cochrane (2016); Williamson (2016); Uribe (2021); Schmitt-Grohè and Uribe (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 leads to a positive co-movement of the nominal interest rate and inflation *already in the short-run*, which is dubbed the Neo-Fisher effect. The debate up until recently exists mostly on theoretical grounds. Theoretical models where agents have rational expectations typically deliver strong support for a Neo-Fisher effect: agents fully understand when a raise in the interest rate is permanent, and, accordingly, adjust their inflation expectations upwards. Interest rates, actual inflation, and output –because of a drop in real rates– all increase. However, a number of contributions criticize this view and are much more sceptical about the existence of a Neo-Fisher effect (Garcìa-Schmidt and

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[2] On the theoretical side, prominent examples include Ireland (2007); Cogley et al. (2010), Erceg and Levin (2003), Smets and Wouters (2003), De Graeve et al. (2009), De Michelis and Iacoviello (2016). On the empirical side Kozicki and Tinsley (2005), Andrle and Bruha (2014), Mumtaz and Theodoridis (2018) and Bauer and Rudebusch (2019).

Woodford (2018); Evans and McGough (2018); Garin et al. (2018)): if agents do not fully understand that a given interest rate increase reflects a permanent change, but need to learn about the nature of the interest rate increase (temporary or permanent) over time inflation expectations may not react the same way. This could be the case in a setting where agents form expectations in an explicit adaptive learning environment, or, as is the case we consider, where agents remain rational but imperfectly observe and need to learn the type of monetary shock.[3,4]

Given this theoretical ambiguity, we consider it particularly important to provide empirical insights on the matter. Prior to us, there are only few empirical contributions on the Neo-Fisher effect, among which, most prominently, is Uribe (2021). 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 that a shock that permanently increases the nominal interest rate is associated with a rise in inflation and output.[5] We obtain similar results in response to a shock that increases the inflation target, which –for most of our specifications– similarly leads to a rise and positive co-movement of interest rates and inflation and output. While we thus obtain similar results compared to Uribe (2021), we want to emphasize two major differences compared to his approach. The first difference is methodological, but this should be seen as an advantage: reaching similar conclusion despite the different methodological approach corroborates the evidence in favor of the existence of the Neo-Fisher effect. In particular, our methodological approach is to take the inflation target as the measure that captures long-term monetary policy shifts, a conventional approach to understand low-frequency inflation dynamics, following the long tradition of DSGE models with time-varying inflation target. This approach allows us to analyze our question in a simple extension to a very standard and simple monetary VAR, thus connecting directly to one of the most widely used frameworks in which monetary transmission has been studied in economics empirically: a VAR in output growth, inflation, and nominal interest rate, now augmented by a proxy for the inflation target process. Instead, Uribe in his empirical model with temporary and permanent monetary (and non-monetary) shocks imposes (and needs to impose) much more structure on the VAR. While elegant and plausible, identification in his setup requires more assumptions, namely that output is cointegrated with the nonstationary non-monetary shock, that inflation and the interest rate are cointegrated with the nonstationary monetary shock. The advantage of

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[3] A similar point has been made already in contributions on the period of the Volcker disinflation. In particular, Erceg and Levin (2003) show that in a model where private agents have limited information about the central bank's objectives and need to disentangle persistent shifts in the inflation target from transitory disturbances to the monetary policy rule, output costs of disinflation are substantially higher.

[4] The theoretical discussion also makes clear that central bank communication has an important role to play. When central banks inform the public about the nature of a policy shift, this should help contribute to affecting inflation expectations accordingly.

[5] Uribe finds permanent monetary policy shocks very important for inflation dynamics, attributing more than 40% of the variation in inflation to permanent monetary shocks.

our approach is that we do not need to impose any assumptions (e.g. on the causality of the long-run Fisher effect running from nominal interest rate shocks to inflation), but are able to let the data speak in a more direct way. A second difference, and a major novel contribution over and above the existing work by Uribe (2021), is that we provide empirical evidence on the Neo-Fisher effect in a framework that explicitly addresses the critical theoretical literature arguing against the existence of a Neo-Fisher effect: in our estimation of the New Keynesian model with imperfect information we explicitly account for the fact that agents in the economy cannot distinguish between different types of monetary shocks (short-term or long-term natured) but need to learn their nature over time. Our findings show that, indeed, this is consequential also for the evidence on the Neo-Fisher effect, as emphasized in the theoretical discussions. In the theoretical model (and to a lesser degree also in the empirical model), a Neo-Fisher effect, in the sense of positive co-movement of nominal interest rates with inflation (and output) does arise in the 'short-run', but not immediately, only with a lag of around five quarters (or, respectively one quarter in the empirical VAR), once agents have sufficiently learned about the monetary disturbance being a target shock.

Our paper is also closely related to the papers by Kozicki and Tinsley (2005), De Michelis and Iacoviello (2016) and Mumtaz and Theodoridis (2018). Before the advent of the discussion on the Neo-Fisher effect, Kozicki and Tinsley (2005) propose an empirical model in which they similarly distinguish between target shocks and transitory perturbations to the short-term interest, confirming that sizable movements in inflation are attributable to (perceptions of) shocks in target inflation. De Michelis and Iacoviello (2016) study Japan's experience with increasing the inflation target during a liquidity trap, in an empirical and theoretical setting. In their theoretical model, they emphasize the importance of imperfect credibility in explaining the behavior of real and nominal variables. In contrast to De Michelis and Iacoviello (2016) we use the structural DSGE model not only as a framework to understand the precise transmission mechanism of interest rate versus inflation target shocks, but, since our aim is to provide empirical evidence on the subject, we explicitly estimate it on US data, as well as using the predictions of the theoretical models to inform our empirical VAR model. Mumtaz and Theodoridis (2018) 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.

The paper is organized as follows. In section 2 we provide a brief description of the New Keynesian model that we take to the data, in its full information and in its imperfect information version. We discuss Bayesian impulse responses and implied inflation target series from the estimated models. Section 3 discusses the VAR model and the data used to estimate it, with particular emphasis on the various low-frequency inflation measures used as a proxy for the central bank's implicit inflation target. Section 3.3 lays out our main empirical results and extensive sensitivity analysis. Finally, section 4 concludes.

2 Evidence from an estimated New Keynesian model

2.1 A model with temporary interest rate and inflation target shocks

Over the past 70 years US inflation time series exhibit 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.

This section adopts and extends the influential contribution of Ireland (2007) and Cogley et al. (2010), who model the central bank's inflation target as a time-varying process in a small-scale New Keynesian model. In the model monetary policy shocks thus take on two forms: (i) a temporary interest rate shock, or (ii) an inflation target shocks with a long-lasting effect. We estimate the model with Bayesian methods, to be able to provide empirical evidence on the relevance of the two types of monetary shocks, and on the existence of a Neo-Fisher effect in response to the persistent monetary policy shock. To address the controversies and ongoing discussions on the existence of a Neo-Fisher effect in the theoretical literature, we estimate the model in two versions: in a model version where agents have full information and in a version where agents have imperfect information and need to learn the nature of a monetary policy change. The estimated models are then used to derive impulse responses to the two types of monetary policy shocks. In addition, we use the model to obtain an estimate for the implicit central bank's inflation target measure, the main, generally unobserved, determinant in inflation trends, which we later employ, among other measures, in the VAR model of section 3. We choose to stick to a small-scale theoretical model[6], both for the sake of simplicity but also to be consistent with our later empirical setup, i.e. we only use the same three

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[6] Other contributions (e.g. De Graeve et al. (2009) or Smets and Wouters (2003)) use medium-scale DSGE models or more elaborate approaches to model the way the inflation target counteracts with monetary policy (e.g. Fève et al. (2010))

macroeconomic time series for the estimation of our inflation target 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 complete model description and here focus on laying out the key aspects only (see Appendix A.1). In particular, 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-linearized terms):

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

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 $\widehat{\bar{\pi}}_{4,t} \equiv (\widehat{\pi}_t + \widehat{\pi}_{t-1}+ \widehat{\pi}_{t-2} + \widehat{\pi}_{t-3})/4$, π^*_t is the time-varying inflation target, Y_t is the output level, Y^{flex}_t is the output level in a hypothetical flexible price economy, and u_t captures a (temporary) shock to the policy rate. In the simplest case, as adopted by Cogley et al. (2010), $\rho_u = 0$ and u_t can directly be understood as the disturbance $\varepsilon_{R,t}$. More generally, u_t is described by the exogenous process:

$$u_t = \rho_u u_{t-1} + \varepsilon_{R,t}, \qquad \varepsilon_{R_t} \sim N\left(0, \sigma^2_R\right). \tag{2}$$

According to the above rule the central bank considers three factors in deciding on the current nominal interest rate: (a) the previous value of the nominal interest rate R_{t-1}, i.e. there is interest rate smoothing; (b) 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^{flex}_t; and (c) 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 textbook treatment of the 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:[7]

$$\log \pi^*_t = (1-\rho_{\pi^*})\log \pi + \rho_{\pi^*} \log \pi^*_{t-1} + \varepsilon_{\pi^*,t}, \qquad \varepsilon_{\pi^*,t} \sim N\left(0, \sigma^2_{\pi^*}\right). \tag{3}$$

To introduce the full information versus the imperfect information version of the model,

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[7] 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 in practice. The setting in equations (1)-(3) provide an empirically more suitable generalization.

let us rewrite the above Taylor rule, equation (1), slightly as:

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

and define

$$\varepsilon_t \equiv (1-\rho_R)(-\rho_\pi)\,\widehat{\pi}_t^* + u_t. \tag{5}$$

When agents are rational and have full information, agents in the economy observe both $\widehat{\pi}_t^*$ and u_t individually, and fully understand what is behind an interest rate movement at any point in time. Under imperfect information, while agents are still rational, they are only able to observe ε_t, but cannot observe $\widehat{\pi}_t^*$ and u_t individually (c.f. Erceg and Levin (2003)). However, they learn over time what is behind a particular observed movement in ε_t, that varies the interest rate. In particular, their learning problem is a linear problem, featuring an observation equation, $o_t = H'\xi_t$, and a state transition equation, $\xi_{t+1} = F\xi_t + B\epsilon_{t+1}$, so that the learning problem can be described using the Kalman filter:

$$\underbrace{(\varepsilon_t)}_{o_t} = \underbrace{\begin{bmatrix} (1-\rho_R)(-\rho_\pi) & 1 \end{bmatrix}}_{H'} \underbrace{\begin{bmatrix} \widehat{\pi}_t^* \\ u_t \end{bmatrix}}_{\xi_t}, \tag{6}$$

$$\underbrace{\begin{bmatrix} \widehat{\pi}_{t+1}^* \\ u_{t+1} \end{bmatrix}}_{\xi_{t+1}} = \underbrace{\begin{bmatrix} \rho_{\pi^*} & 0 \\ 0 & \rho_u \end{bmatrix}}_{F} \underbrace{\begin{bmatrix} \widehat{\pi}_t^* \\ u_t \end{bmatrix}}_{\xi_t} + \underbrace{\begin{bmatrix} \varepsilon_{\pi^*,t+1} \\ \varepsilon_{R,t+1} \end{bmatrix}}_{B\epsilon_{t+1}}, \tag{7}$$

where we denote with Q the variance-covariance matrix of the innovation $B\epsilon_{t+1}$, $Q = BB' = \begin{bmatrix} \sigma_{\pi^*}^2 & 0 \\ 0 & \sigma_R^2 \end{bmatrix}$.

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.[8] We use U.S. data from 1947Q2 to 2019Q1, taken from the Federal Reserve Bank of St. Louis database. We refer the reader to Appendix A.4 for a table that summarizes prior choice (where we largely follow Cogley et al. (2010)) and the parameter estimates of both the full information and imperfect information versions of our New Keynesian model. Here, we only want to briefly comment on the estimation results of the inflation target process. In both model versions we find a very high autoregressive coefficient, ρ_{π^*}, equal to 0.9908 (0.9918) and a low standard deviation, σ_{π^*}, of 0.1146 (0.0828) in the full

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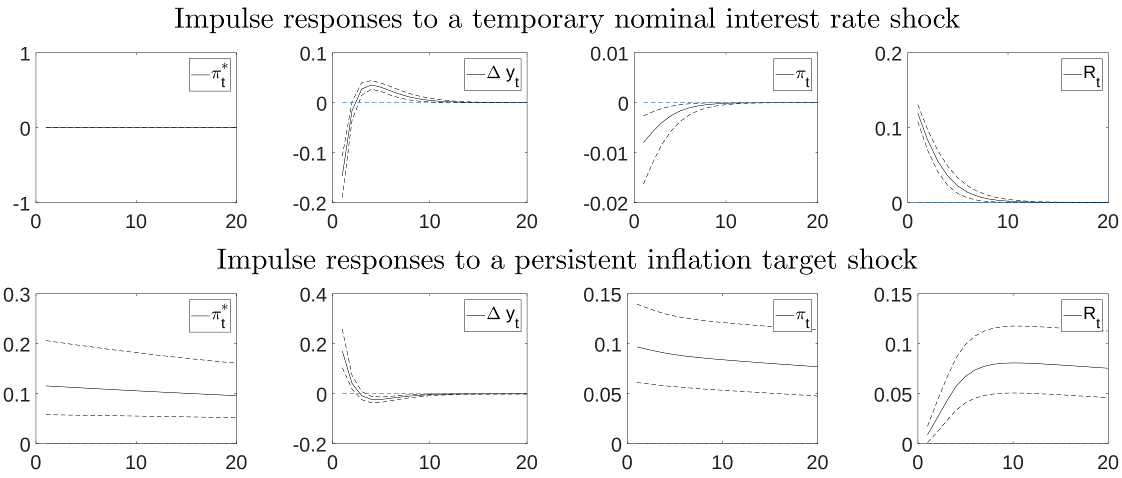
[8] In addition, we estimate the model including an additional observable time series of long-run inflation expectations. Once we include inflation expectations the model fits model parameters, particularly the ones of the inflation target process, π_t^*, to closely match this time series. This means that the resulting model-implied (smoothed or filtered) inflation target series closely resembles the actual inflation expectations time series. The results in terms of Bayesian impulse responses from these extended model estimations remain intact. More details can be found in section 2.4.



Impulse responses to a temporary nominal interest rate shock

Impulse responses to a persistent inflation target shock

Figure 1: Impulse responses in the *full information* model. The Figure plots Bayesian impulse responses (at the posterior mean of the estimated parameters and at their 10% and 90% percentiles) of inflation target (π^*_t), output growth (Δy_t), inflation (π_t), and nominal interest rate (R_t). Row 1: responses to a temporary monetary shock, $\varepsilon_{R,t}$. Row 2: responses to an inflation target shock, $\varepsilon_{\pi^*,t}$.

(imperfect) information version.[9] These statistical properties of our inflation target process imply that target shocks can indeed be viewed as long-lasting shifts in monetary policy, even though it should be noted that, unlike in Uribe (2021), shocks to the inflation target are not, strictly speaking, permanent but only highly persistent.

2.2 Impulse responses

Figure 1 reports impulse responses to the standard nominal interest rate shock, $\varepsilon_{R,t}$, and to the inflation target shock, $\varepsilon_{\pi^*,t}$, for the model version under *full information.* The responses to the nominal interest rate shock, displayed in row 1 of Figure 1, summarize the conventional wisdom from decades of New Keynesian macro models: a contractionary monetary shock ($\varepsilon_{R,t} \uparrow$) that temporarily raises the nominal interest rate, translates, because of sticky prices, into an increase also in the real interest rate. This decreases consumption demand, as agents increase their saving and delay their consumption to future periods. As a result of the temporarily depressed demand, firms sell less of their goods produced (output falls), despite lowering their prices to attract customers (inflation falls). That is, the short-term dynamics generated are that the nominal interest rate ($\widehat{R}_t$) co-moves negatively with output ($\widehat{Y}_t$) and inflation ($\widehat{\pi}_t$). In contrast, the short-run co-movement properties of the nominal interest rate

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[9] Cogley et al. (2010) do not estimate ρ_{π^*} but set it close to a unit root, 0.995. Ireland (2007) even considers a unit coefficient on lagged inflation target values, π^*_{t-1}. We performed sensitivity checks of our Bayesian estimation, adding ρ_{π^*} to the list of calibrated parameters, following Cogley et al. (2010) in setting $\rho_{\pi^*} = 0.995$. Results are essentially unaffected.

with output and inflation differ markedly in response to an inflation target shock, displayed in row 2 of Figure 1. In response to the target shock the inflation target rises persistently. Because agents fully understand the nature of this monetary policy shock (under full information), they adjust their inflation expectations on impact, leading to a fall in the real interest rate and an expansionary effect on output[10]. The jump in inflation expectations, together with the expansion in output imply that actual inflation jumps up strongly as well. Finally, the nominal interest rate responds positively to the inflation gap and the output gap: while the former is actually slightly negative (because the inflation target goes up by more than actual inflation), the strongly positive output gap implies that the central bank responds with a nominal interest rate increase. Summarizing, in response to the inflation target shock, the short-term dynamics of the nominal interest rate ($\widehat{R}_t$) are positively related with output ($\widehat{Y}_t$) and inflation ($\widehat{\pi}_t$), in support of a Neo-Fisher effect and in contrast to the co-movement properties of $\widehat{R}_t$ and $\widehat{\pi}_t$ in response to the conventional temporary interest rate shock.

Figure 2 moves on to report the same impulse responses in our *imperfect information* model version, where agents do not have full knowledge about the type of monetary policy shock, but only can observe ε_t, which could move either because the economy was subjected to a temporary interest rate shock or because of a persistent target shock. In particular, at the heart of the discussion of theoretical contributions on the existence of the Neo-Fisher effect stands exactly this question, and several contributions have cast doubts on agents fully being able to understand the nature of a monetary shock (Garcìa-Schmidt and Woodford (2018); Evans and McGough (2018); Garin et al. (2018); De Michelis and Iacoviello (2016); Erceg and Levin (2003)). Our estimation results from the imperfect information model version indeed show that the transmission of monetary policy shocks is sensitive to this assumption. The upper panels of Figure 2 report again the case of a temporary nominal interest rate rise: in row 1, the responses to the inflation target, output growth, inflation and the nominal rate; row 2 reports also the response of ε_t, the only thing agents can in fact observe, as well as the responses of the actual and perceived inflation target and temporary shock, on impact and as agents learn over time. As can be seen, the interest rate shock in the imperfect information model continues to give rise to a short-term negative co-movement of nominal interest rate ($\widehat{R}_t$) with output ($\widehat{Y}_t$) and inflation ($\widehat{\pi}_t$) in the very short-run, however, a few quarters after the shock hit the nominal interest rate turns negative (in terms of deviations from its steady state value), suggesting that even such traditional monetary policy shock may be able to give rise to a positive co-movement of the nominal interest rate with inflation and economic activity. Most importantly, the lower panels of Figure 2, rows 3-4, display the responses to the inflation target increase in the imperfect information setup. As the increase in $\widehat{\pi}_t^*$ is unobserved, and agents only observe a drop in ε_t (implied by the increase in $\widehat{\pi}_t^*$), they

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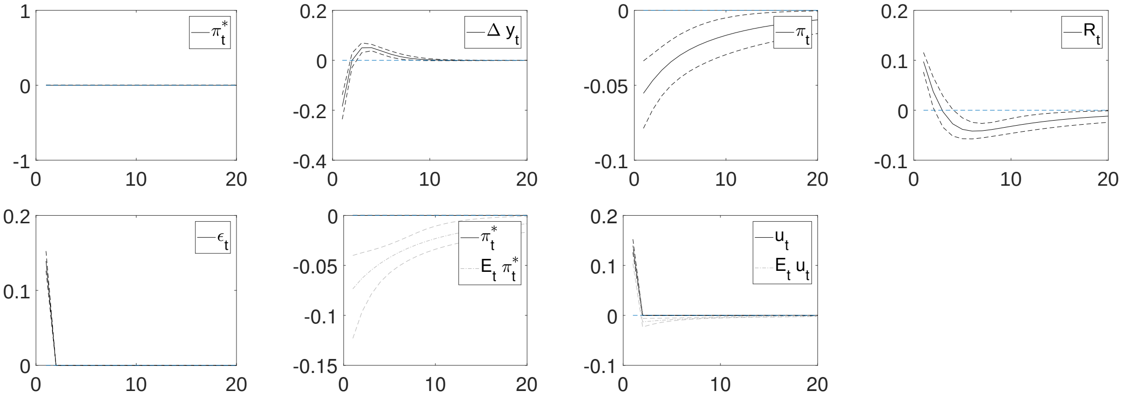
[10] Note that what is plotted in Figure 1 is not the *level* of output, but output growth, Δy_t. The effect on the level of output is undoubtedly expansionary and the response of output (in % deviation from its steady state) never falls below zero in response to the target shock.

Impulse responses to a temporary nominal interest rate shock



Impulse responses to a persistent inflation target shock

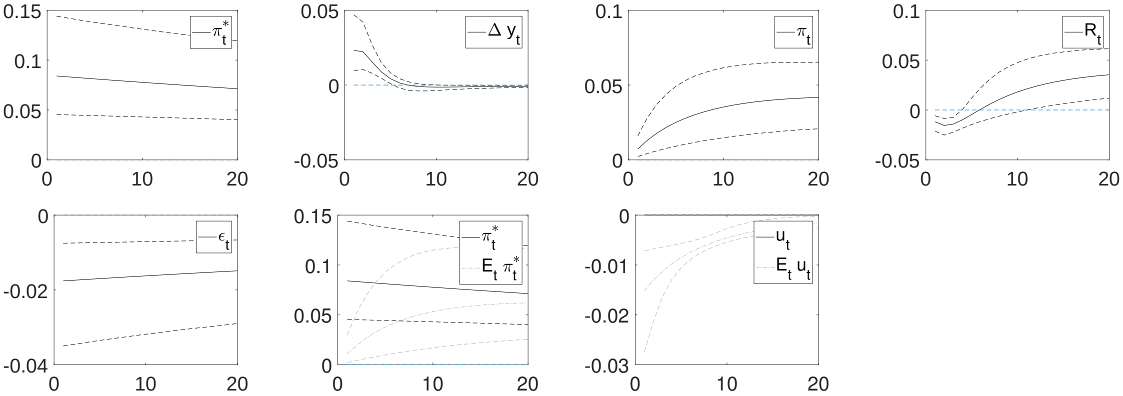


Figure 2: Impulse responses in the *imperfect information* model. The figure plots Bayesian impulse responses (at the posterior mean of the estimated parameters and at their 10% and 90% percentiles) of (π^*_t), output growth (Δy_t), inflation (π_t), and nominal interest rate (R_t), as well as the observed (composite) monetary shock (ε_t), the target shock and perceived target (π^*_t and $E_t\pi^*_t$), and the temporary interest rate shock and the perceived temporary shock (u_t and $E_t u_t$). Row 1-2: responses to a temporary monetary shock, $\varepsilon_{R,t}$. Row 3-4: responses to an inflation target shock, $\varepsilon_{\pi^*,t}$.

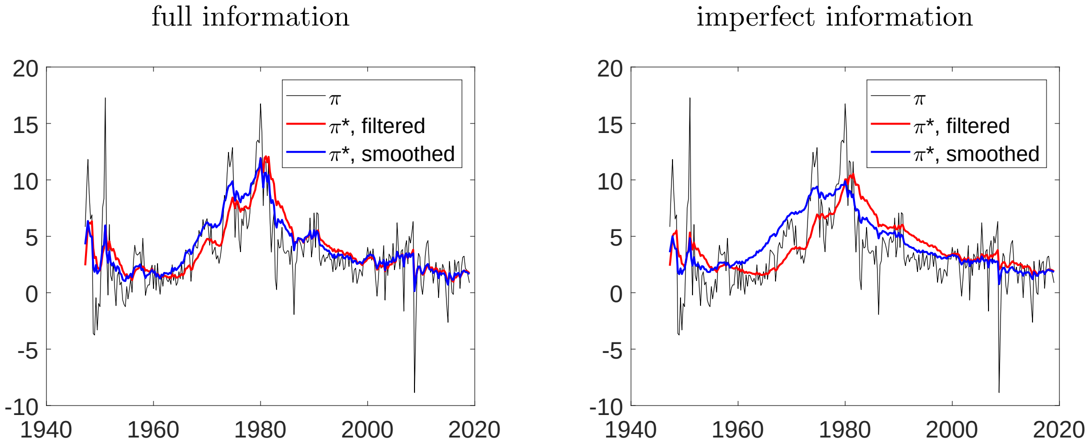


Figure 3: Dynamics of the inflation target series from the estimated New Keynesian DSGE model and actual inflation. Left panel: case of full information. Right panel: case of imperfect information. Black line: actual inflation. Blue line: smoothed inflation target estimate. Red line: filtered inflation target estimate.

may mistake a target increase with a temporary expansionary shock, believing that a drop in the temporary component u_t could be behind the drop in ε_t. That is, instead of reacting to an inflation target increase, they react to a perceived temporary expansionary interest rate decrease. As a result, agents do not update their inflation expectations and the rise in inflation is very modest initially. Since the inflation gap is now strongly negative in the first couple of quarters after the target shock, the nominal interest rate falls. Summarizing, the imperfect information assumption and the fact that agents need to learn the nature of the monetary policy shock indeed implies that we do not observe a Neo-Fisher effect in the very short-term, with $\widehat{R}_t$ co-moving negatively with with output $(\widehat{Y}_t)$ and inflation $(\widehat{\pi}_t)$ for the first 5 quarters. Only thereafter, agents have sufficiently learned the nature of the shock (i.e. that it was indeed an inflation target shock) and respond accordingly, so that a Neo-Fisher effect is present from around period five onwards.

2.3 Implicit inflation target series from estimated DSGE-model

We also make use of our estimated New Keynesian model to derive model-implied time series of the latent series of the implicit central bank's inflation target, a main variable of interest also for our empirical VAR analysis. Figure 3 presents the estimated smoothed and filtered series of the inflation target, plotted on the actual inflation series, for both the full information model version (left panel) and the imperfect information learning model version (right panel). In both cases, the inflation target is much smoother than actual inflation, 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 followed 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.

Our estimates are consistent with the literature. As we closely follow Ireland (2007) and Cogley et al. (2010) to derive the inflation target, our full information inflation-target measure also looks fairly similar to theirs, and the small differences that do arise stem mostly from a consideration of different time periods of estimation. Our full information inflation-target measure also squares well with other rational expectations (full information) 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). It also bears a close resemblance to both the permanent component of inflation estimated by Uribe's empirical SVAR or in his theoretical model (Figure 5 and 7 in Uribe (2021)). A similar statement 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). Contrasting the estimated inflation target from full information and imperfect information model versions, the latter similarly tracks actual inflation realizations, but to a somewhat more lagged degree, reflecting agents' learning process.[11]. 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.

2.4 Extended model estimations

In addition to estimating our (full and imperfect information) models on the three observable time series of output growth, inflation and nominal interest rate, we also experiment with estimating them on an extended dataset that includes a time series of long-run inflation expectations. We do so using the 10-year ahead inflation forecasts from the Survey of Professional Forecasters, or, alternatively, the 5-year ahead household inflation forecasts from the Michigan survey. Once we include inflation expectations as an additional observable the model fits the model parameters, particularly the ones of the inflation target process, π_t^*, to closely match this time series. This means that the resulting model-implied (smoothed or filtered) inflation target series (the equivalents to the ones reported in Figure 3) closely resembles the actual inflation expectations time series. The results in terms of Bayesian impulse responses from these extended model estimations remain intact. In the full information

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[11] We are not aware of any other inflation target estimates from rational expectations imperfect information models. Deviating from the assumption of rational expectations, the working paper version of Milani (2007), or the estimate of Kozicki and Tinsley (2005) report inflation target series estimated within an adaptive learning setting

model, the impulse responses to a target shock always produce dynamics of inflation, output and nominal interest rate consistent with Neo-Fisherian effects. Similarly, in the imperfect information model version, the result that the nominal interest rate does not necessarily increase on impact in response to a target shock remains intact. To save space, we do not report the results of our estimations with inflation-expectations-augmented datasets in detail.

3 VAR model

In this section we continue our empirical assessment of the Neo-Fisher effect by employing empirical VAR methods. Our baseline empirical model directly connects to one of the most widely used frameworks to study monetary transmission: a three-variable VAR model in output growth, inflation and the nominal interest rate; a simple and tractable framework, widely used in the literature. Such three variable VAR can be thought of as a reduced-form that reflects dynamics similar to that of a simple theoretical New Keynesian model, i.e. model variables being driven by an aggregate demand (AD) shock, an aggregate supply (AS) shock and a (short-term) monetary policy shock to the nominal interest rate. A contribution of this section lies in the way we introduce an inflation target shock in this simple framework: in particular, we augment the three-variable VAR by a measure of low-frequency inflation dynamics, which is closely related to the implicit inflation target of the theoretical model. This four-variable set-up allows us to keep up the interpretation of the VAR model dynamics as being driven by standard AD, AS and nominal interest rate shocks, but, in addition, allows us to also examine the transmission of long-lasting, persistent monetary policy shifts arising from the inflation target shock. Our estimated versions of the DSGE models of the previous section have left us with the insight that there are important differences in response to the inflation target shock across the model versions under full or imperfect information, with the question of evidence for the presence of a Neo-Fisherian short-run comovement of inflation and nominal interest rate at its very heart. The goal of our empirical analysis is thus to employ an empirical methodology that allows us to use the results of our theoretical model(s) to inform the VAR, but to not impose anything too dogmatically and let the data speak. To do so we follow the recent approach of Baumeister and Hamilton (2018) to obtain inference in structural vector autoregressions when the identifying assumptions are not fully believed or uncertain. Section 3.1 below describes their empirical methodology, and how we adopt it to the setting of our extended monetary VAR with persistent shocks. Section 3.2 describes in detail the data we employ. Section 3.3 presents results.

3.1 Empirical methodology

In our choice to obtain Bayesian inference and identification we adopt the approach of Baumeister and Hamilton (2015, 2018, 2019), which has the benefit of imposing sign restrictions that are less restrictive than the conventional approach to estimating sign-identified VAR models (as discussed in, e.g., Uhlig (2005), and Rubio-Ramirez, Waggoner and Zha (2010)), and, in addition allows to account for uncertainty about the identifying assumptions themselves. Baumeister and Hamilton (2018, 2019) show how explicit prior information can be used about both structural coefficients and the impacts of shocks, proposing to incorporate prior beliefs about the signs of equilibrium impacts in a non-dogmatic way. The goal of adopting this methodology is that it allows us to derive guidance about the implied structural VAR parameters from our theoretical DSGE models, but also explicitly allows us to account for the uncertainty of our structural parameters that comes from the fact that the full information or the imperfect information structure imply different structural VAR coefficients and that we do not know which provides a more accurate description of the data. By adopting this empirical methodology we aim to infer what is more realistic by letting the data speak. To explain our approach in greater detail, consider the 4-variable SVAR model:

$$Ay_t = Bx_t + u_t, u_t \sim \mathbb{N}(0, D),$$

where vector y_t contains our endogenous variables, a vector of four macroeconomic time series: a proxy for the inflation target, π_t^*, output growth, Δy_t, inflation, π_t, and the nominal interest rate, R_t. Vector x_t is the vector of lagged endogenous variables and an intercept, u_t is the vector of structural shocks. We employ AIC and BIC information criteria to assess the optimal number of lags for our model. The BIC criterion strongly supports a model specification with two lags (across various time samples and measures of the inflation target), while the AIC criterion suggests four lags. We thus specify our baseline model to include two lags, but we confirm that our results are robust with respect to considering four lags. Results with 4 lags can be found in appendix B.3. Additionally, we check all employed time series for stationarity using the augmented Dickey-Fuller test. Our DSGE model can be represented using the above SVAR model formulation. Now, we will set up a simple empirical VAR system to be able to draw inference on the identification of structural shocks from our DSGE models. The four variable VAR can be thought of as reflecting dynamics similar to that of a simple theoretical New Keynesian model with time-varying inflation target, i.e. model variables being driven by an aggregate demand (AD) shock, an aggregate supply (AS) shock, a (short-term) monetary policy shock to the nominal interest rate and, in addition, a persistent inflation target shock (IT).[12]

The reduced-form empirical VAR takes the following form:

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[12] Our approach is thus quite different from the three-variable VAR set-up of Uribe (2021): in order to identify a permanent monetary policy shock, the author assumes that output is cointegrated with the nonstationary non-monetary shock and that inflation and the interest rate are cointegrated with the nonstationary monetary shock. Implicit in this identification is thus the assumption that the Fisher effect, the long-run comovement of interest rates and inflation, runs causally from interest rate shocks to inflation. Our approach does not require theses assumptions making our results more general.

$$y_t = \Psi x_t + \epsilon_t,$$

where $\Psi = A^{-1}B$, and $\epsilon_t = A^{-1}u_t$ is the vector of reduced-form innovations that are some linear combination of the structural shocks. To estimate impulse responses to structural shocks we need to know the elements of the A matrix. At this point, the VAR literature typically suggests various restrictions to identify elements of the A matrix and to recover the structural shocks of the model. Often such restrictions are based on the predictions of theoretical models (for example, as in the sign restrictions approach pioneered by Uhlig (2005)). If we were to follow this approach, we would be faced with a dilemma about the identification assumptions to the inflation target shock, as the contemporaneous responses to the target shock are different across DSGE models under full and imperfect information. Instead, we want to let data guide us by incorporating uncertainty about our identification assumptions when estimating the VAR. Let

$$A = \begin{vmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{vmatrix} \tag{8}$$

and $A^{-1} = \frac{1}{det(A)}H$, where H is the adjugate matrix of A. We follow Baumeister and Hamilton (2018) and Baumeister and Hamilton (2019) and assume that all elements of the A matrix are distributed according to a t-distribution with some prior parameters. In imposing these parameters we use information from our theoretical models and set the prior mode in accordance with the implied values from DSGE models.[13] Our approach includes the following three steps.

One, we estimate the distribution of the parameters of the A matrix from the full and imperfect information DSGE models. To do so we note that we can make use of the DSGE model's policy functions of the (data-consistently defined) model variables of inflation target, output growth, inflation and nominal interest rate, denoted by y_t^{DSGE}, which are linear functions of the DSGE model's state variables and an impact matrix times the structural shocks of the DSGE model. Formally, we can write $y_t^{DSGE} = g_x x_t^{DSGE} + g_u u_t^{DSGE}$, where x_t^{DSGE} is the vector of DSGE state variables, and u_t^{DSGE} is the vector of structural DSGE shocks.[14]

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[13] In appendix B.6 we present another approach, where we follow the choice of A-matrix coefficients of the 3x3 example monetary model of Baumeister and Hamilton (2018) (based on the standard 3-equation NK model) and extend it to an inflation-target-measure augmented VAR, being relatively uninformative about the additional (inflation-target related) coefficients of the A-matrix.

[14] Two further aspects deserve mention. First, the variance matrix of the structural shocks in the DSGE model is determined by the estimated shock volatilities given in table A.1. While we recognize that this will generally not be identical to the structural covariance matrix in the SVAR, we base our choice for the priors of the coefficients of the $A = g_u^{-1}$ matrix on having the same format across DSGE model and SVAR. Second, our DSGE model cannot be directly mapped into the 4-equation VAR model, thus we combine the DSGE markup and technology shocks to one VAR supply shock with their contributions scaled by relative weights.

In this case, we notice that $A^{-1} = g_u$ and are thus able to derive a full distribution for the elements of the A matrix as a byproduct from the Bayesian estimation of the DSGE model. Figures B.1 and B.2 in Appendix B.6 depict the distributions of the elements of the A matrix implied by the full and imperfect information setting, respectively.

Two, we set up priors in a way that reflects our uncertainty about the responses to inflation target shocks across DSGE models under full and imperfect information. We refer to this identification strategy as "hybrid". In particular, we set the prior means of the t-distributed elements of the A matrix to a weighted average of the full and imperfect models predictions. The distribution of the elements of the A matrix implied by our DSGE models can be found in appendix B.6, figures B.1 and B.2. To stress the uncertainty across the two models the weight of each model's prediction is set to 0.5. We then set the prior variances in a way that there is a positive mass of the prior attributed to cases implied by full and by imperfect information DSGE models. We are rather uninformative about A elements that differ substantially across the two models and set high precision for elements that do not deviate much across the two models. More precisely we set the prior variance equal to 0.4 (following Baumeister and Hamilton (2018)) for all coefficients of the A matrix apart for row 3, where we set the prior variance equal to 2, reflecting the much wider distributions for coefficients a_{31}, a_{32}, a_{33} and a_{34} on figures B.1 and B.2. Prior and posterior distributions of the elements of the A matrix are presented on figure 4.

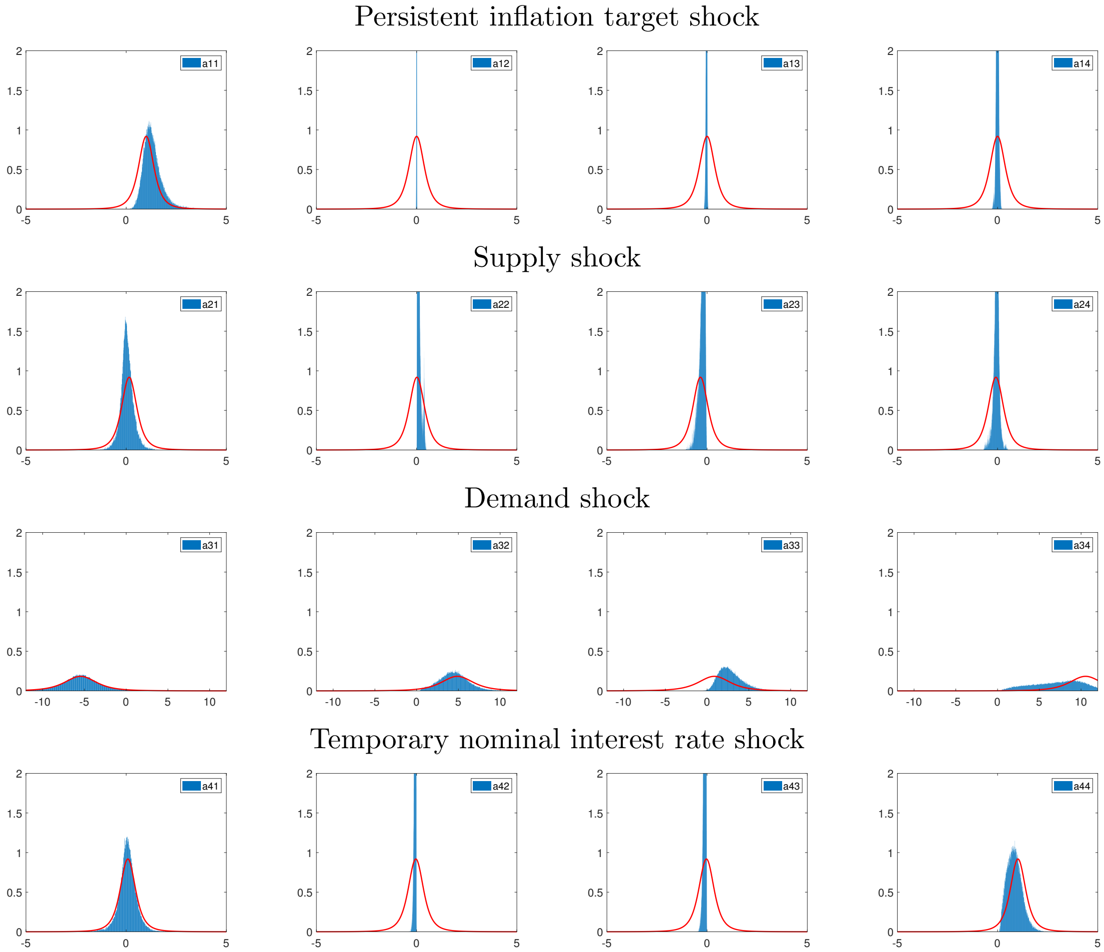

Figure 4: Prior and posterior distributions of the coefficients of the A matrix. Baseline model with perceived inflation target rate (PTR) measure from the FRB/US model (Brayton, Laubach, Reifschneider, 2014) and hybrid identification. Red line - prior distribution, blue line - posterior mass. Sample: 1962Q1 to 2019Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.

Finally, three, we impose sign restrictions in a way that allows us to be à priori agnostic about the identification. Following Baumeister and Hamilton (2018), we do so by imposing an asymmetric t-distribution over the parameters of the H matrix. Our sign restrictions are summarized in the table 1. Plus and minus signs in table 1 reflect the location of the prior mode, i.e. the fact that the largest mass of the distribution will be allocated to either positive or negative numbers. Yet, these are not hard restrictions as in the case of conventional sign restrictions. The full prior distribution imposed on the elements of the H matrix can be found on figure 5, together with their respective posterior distributions.

	IT shock	AS shock	AD shock	NIR shock
π^*	+			-
Δy	+	+	+	-
π		-	+	-
R			+	+

Table 1: Sign restrictions for the hybrid identification approach. IT shock - inflation target shock, AD shock - aggregate demand shock, AS shock - aggregate supply shock, NIR shock - nominal interest rate shock.

The signs imposed on the aggregate supply (AS), the aggregate demand (AD) and the nominal interest rate shocks are quite standard: the AS shock moves prices and output into opposite directions, while the AD shock moves prices and output, and, as a result, the nominal interest rate into the same direction, the latter reflecting the logic of a standard Taylor rule. The signs imposed on the inflation and output reactions in response to the nominal interest rate shock are also conventional, an increase in the nominal rate leading to a decrease in those variables. In addition, we impose that in our hybrid identification strategy the (perceived) inflation target response be can negative to a nominal interest rate shock, as this is the response obtained in the imperfect information model, while it can also be zero, as this is under full information. In response to the the inflation target shock, we only suggest that the target measure itself and output growth respond positively. Since the responses of the interest rate, and, to a lesser degree, inflation differ across full and imperfect information model versions we leave the signs of these variables in response to the target shock unrestricted.

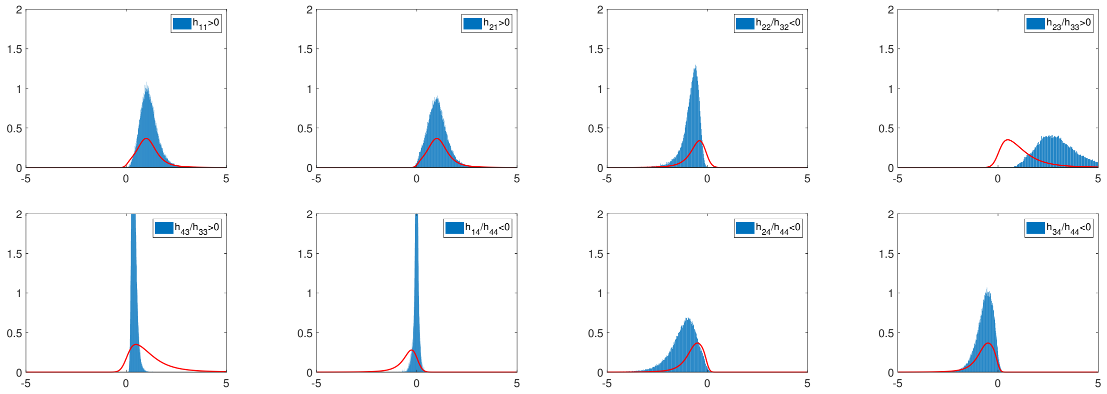

Figure 5: Sign restrictions imposed on the elements of the H matrix, prior and posterior distributions. Baseline model with perceived inflation target rate (PTR) measure from the FRB/US model (Brayton, Laubach, Reifschneider, 2014) and hybrid identification. Red line - prior distribution, blue line - posterior mass. Sample: 1962Q1 to 2019Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.

3.2 Data

We use U.S. data from 1947Q2 to 2019Q1 taken from the Federal Reserve Bank of St.Louis as our baseline period. All data is on quarterly basis. The variables in our VAR include 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, as well as a proxy for the central bank's inflation target. Below we discuss the various measures we use as a proxy in detail.[15]

To introduce long-run inflation we use observable time series that capture the low-frequency dynamics of inflation. As the measure of the central bank's implicit inflation target is not directly observable, it is crucially important to check the robustness of our results with respect to the choice of these long-run inflation measures. We consider several alternative measures that capture long-term inflation trends and serve as a suitable proxy for the inflation target: (i) the Federal Reserve Board of Governors' own inflation target estimate (PTR), (ii) long-run inflation expectations from the Survey of Professional Forecasters, (iii) our DSGE-based estimates of the implicit inflation target process, and (iv) empirical estimates of trend inflation. Figure 6 plots these time series, together with the actual inflation time series.[16,17]

The Federal Reserve Board's PTR measure (the acronym being an abbreviation for $p$erceived inflation $t$arget $r$ate) is displayed in the left panel of Figure 6, and corresponds to the FRB's own inflation target estimate from the FRB/US-model, described in (Brayton et al., 2014). The FRB/US-model is a medium-scale model, estimated on macro data, including observables for forward-looking inflation expectations. The time series is publicly available on a quarterly basis from 1962Q1, taken from the website of the Boards of Governors of the Federal Reserve System.[18] Visual assessment of the PTR measure suggests that the time series is very persistent with low volatility.

An alternative measure proxying for the central bank's inflation target is long-run inflation

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[15] 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, an average of monthly time series over each quarter. The data used in our VAR models thus corresponds to the data used for the Bayesian estimation of the theoretical models of section 2. Also, we check all employed time series for stationarity using the augmented Dickey-Fuller test. For the time samples starting in 1979 this can be undoubtedly confirmed. For time series ranging over the full postwar sample, a unit root cannot be rejected for inflation, the nominal interest rate, and our inflation target proxy measures. To ensure that the invertibility of the VAR model is not at risk we check and confirm that all eigenvalues of the companion matrix of x_t lie within the unit circle. We further, for the postwar sample, experiment with a version of the VAR where inflation, the nominal interest rate and inflation target proxy enter in first differences and obtain qualitatively similar results.

[16] Time series for the implicit inflation target generated from the DSGE model are presented in figure 3 in section 2.

[17] We are aware that our long-run inflation measures are only proxies for the central bank's inflation target, which might contain errors. We address this issue precisely through providing robustness of our results with respect to various measures. Our candidates for proxying the inflation target come from very different backgrounds and, hence, might contain different amounts of information on the inflation target. The fact that we observe very similar impulse responses across different models indicates that we identify the same shock, i.e. the inflation target shock.

[18] Mumtaz and Theodoridis (2018) also employ the PTR measure in VAR estimations.

expectations, which is conceptually very close to the central bank's target when inflation expectations are well anchored in the long-run. Our measure of inflation forecasts is directly observable from the Survey of Professional Forecasters (Livingstone survey), denoted as SPF, and depicted in the center panel of Figure 6. Specifically, we use the 10-year ahead inflation forecast which starts in 1991Q4. To extend the number of observations we augment the forecast with observations from the Blue Chip Economic Indicators, a survey of top business economists, available from 1979Q4.[19] Apart for the shorter time period covered, the SPF measure closely resembles the PTR measure.

The implicit inflation target series obtained as a side-product from the Bayesian estimation of our New Keynesian model of section 2 constitute another set of measures to employ in our VAR. We have already presented the evolution of these time series in Figure 3, plotting the smoothed and filtered versions of the estimates for the model-based π_t^* process, both under full and imperfect information. The DSGE-based measures also show a clear resemblance to the two previous measures, indicating that they all capture well low-frequency inflation dynamics.

Finally, we also consider trend inflation estimates proposed in the empirical literature, reported in the right panel of Figure 6. Measures of trend inflation similarly reflect the long-term low-frequency movements in inflation dynamics. Stock and Watson (2007) is a key reference in decomposing inflation dynamics into trend and cyclical components, using an unobserved components stochastic volatility model. In addition we look at the contribution of Chan et al. (2018), who build on Stock and Watson (2007).[20] It turns out that the Stock and Watson measure of trend inflation captures much higher frequencies in inflation dynamics compared to our other proxies of inflation target measures, tracking the actual inflation series much more closely. This leaves us to conclude that the Stock and Watson trend inflation measure may not be a good proxy for the inflation target. However, Chan et al. (2018) estimate trend inflation in a similar set-up as Stock and Watson (2007), but augment the Stock and Watson trend inflation measure by considering actual inflation, together with the PTR measure of long-run 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 than the trend inflation measure of Stock and Watson, and, again, resembles our other, earlier presented measures. The measures by Stock and Watson (2007) and Chan et al. (2018) are, respectively, abbreviated as $S\&W$ and UCE in Figure 6.

To sum up, the measures of low-frequency inflation dynamics introduced in this section and used, in the following, as our proxy variable for the central bank's inflation target in

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[19] The Blue Chip Economic Indicators are available on biannual basis, the missing observations are interpolated.

[20] We estimate trend inflation based on Stock and Watson (2007) using inflation based on the quarterly CPI index, for the period of 1947Q2 to 2019Q1. Trend inflation as in Chan et al. (2018) is taken from Joshua Chan's website; it starts in 1960Q2.

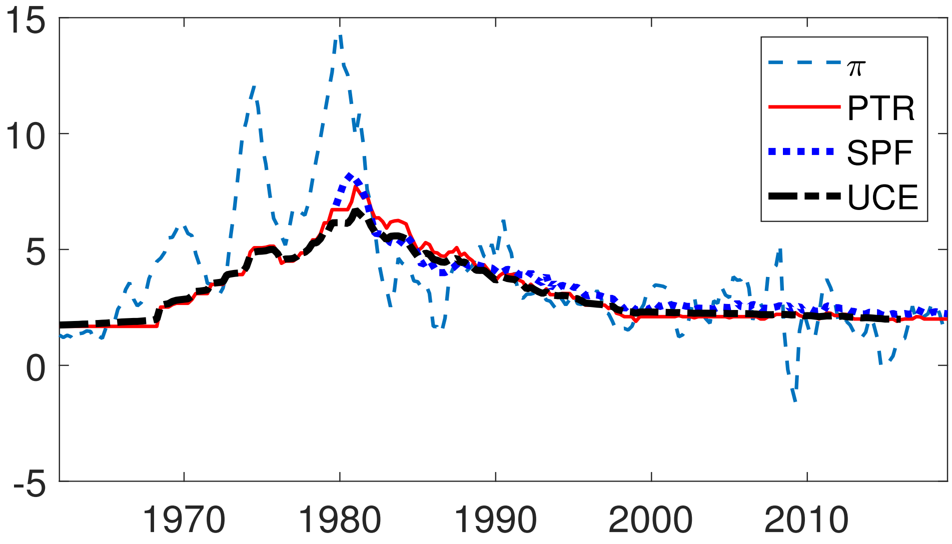

Figure 6: Measures serving as proxy for the inflation target from 1962Q1 to 2019Q1, plotted on actual inflation. Red line: Federal Reserve Board's perceived inflation target rate (PTR) measure. Blue dotted line: Survey of Professional Forecasters (SPF) long-run inflation expectations. Black dashed line: trend inflation as in Stock and Watson (2007) ($S\&W$) and trend inflation as in Chan et al. (2018) (UCE).

our VAR models all share similar characteristics: high persistence and low volatility. From a macroeconomic perspective, long-term inflation trends and long-term inflation expectations are conceptually closely related to the concept of a time-varying perceived inflation target. We thus think of a shock to these measures, in a VAR setting, as reflecting a systematic shift in monetary policy, much like a shift in the Fed's preferences over an inflation target.

We experiment with alternative time samples in our empirical analysis. As a baseline, we present results for the maximum length of available data, referred to as the 'postwar' sample.[21] In addition we estimate the VAR for the following periods: we start in 1979Q3 (as to start from the period of the Volcker chairmanship of the Fed) and end in 2008Q3 (to exclude the period of interest rates at the zero lower bound) or in 2019Q1.[22] 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. By looking at different subsample periods, we are able to conclude that the dynamics of the identified nominal interest rate and inflation target shocks are similar across the postwar period and the shorter subsample periods.

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[21] Depending on the precise measure we use as a proxy for the implicit inflation target the 'postwar' period differs somewhat. For the PTR measure it runs from 1962Q1-2019Q1. The $S\&W$ and the DSGE-based measures run from 1947Q2 to 2019Q1. Coverage of SPF is over the period 1979Q4-2019Q1, coverage of UCE over the period 1960Q2-2019Q1.

[22] It could be argued that our use of the 3-month T bill series for the nominal interest rate ignores possible problems related to the zero lower bound. We therefore re-estimate our VAR models with samples until 2019Q1 also with the alternative measure of the shadow interest rate of Wu and Xia (2016), and obtain virtually identical results (see appendix B.4).

3.3 Estimation results

Our baseline empirical specification is the VAR model in output growth, inflation and nominal interest rate, augmented with the PTR measure, the FRB's estimate of the perceived inflation target. This setting allows us, like in the theoretical model of section 2, to look at the two types of monetary policy shocks: the temporary monetary policy shock to the short-term nominal interest rate, as standard in the literature; and, the inflation target shock, a persistent shock to the long-run inflation goal of the Fed, identified as the shock to an innovation to the PTR variable. Our estimations suggest that both shocks have significant effects over various time samples, proving to be important channels for monetary policy transmission into the US economy.

The main goal of this exercise is to gain insights from the data on the effects of inflation target shocks: specifically if they are consistent with predictions of the DSGE model estimated under full information or under imperfect information. In particular, the full information DSGE model suggest that output growth, inflation, and the nominal interest rate all increase after a positive inflation target shock already on impact. The imperfect information DSGE model predicts a negative response of the nominal rate on impact of the shock that quickly increases afterward. It also suggests that inflation almost does not respond on impact and starts growing from period two onward. The response of output growth is positive right after the inflation target shock, yet with a smaller magnitude compared to the response of output under full information. To understand which of the two DSGE models produces more realistic results we allow the data to guide us through the identification assumptions. In particular, we adopt a hybrid identification strategy described in detail above that a priori allows for responses consistent with both full and imperfect information DSGE models.

Figure 7 presents posterior impulse responses of the baseline model estimated over the full horizon, starting in 1962Q1 and ending in 2019Q1. The responses to the nominal interest rate shock are summarized in row 1 of Figure 7. By imposing our identifying restrictions, we suggest that the nominal interest rate response is negatively correlated with output growth and inflation. The intuition behind these restrictions comes from transitional dynamics generated by theoretical New Keynesian models, such as the one discussed in detail in section 2. In particular, a positive nominal interest rate shock leads to an increase in the nominal rate and, due to sticky prices, to an increase in the real rate. The higher real rate translates into a drop in demand and a corresponding drop in output and inflation. Consistent with our understanding that the nominal interest rate shock captures temporary monetary disturbances, we observe that the effect on macro variables is short-lived. Because the effects are only temporary, there are virtually no differences in results across full and imperfect information DSGE models, and our VAR estimation results with hybrid identification are also in line with our expectations.

One variable that does respond differently compared to the theoretical predictions is the (perceived) inflation target. In the full information DSGE model its response is zero, while in the imperfect information DSGE model the perceived inflation target declines on impact of a positive nominal interest rate shock. We use this information to inform our prior and suggest that the response of long-run inflation might be negative after a temporary interest rate shock. In line with the hybrid identification strategy, we impose a mild prior, allowing for both negative and zero response. Panel 1 of row 1 on Figure 7 documents that the inflation target variable is not significantly affected throughout. Therefore, our estimations suggest that long-run inflation does not respond to temporary monetary policy shocks, consistent with predictions of the DSGE model under full information.

Row 2 of Figure 7 displays impulse responses to a positive inflation target shock. In contrast to the nominal interest rate shock, where responses converge back to zero quickly, the responses to the inflation target shock remain away from zero for a prolonged period of time, indicating that our identification strategy is successful at distinguishing the two types of monetary shocks – temporary versus long-lasting. In response to this persistent monetary policy shock, we observe that the nominal interest rate response is positive on impact withing the 68% confidence bound, and it never turns negative. The mean response of inflation is positive and while the 68% confidence bound does include zero, the posterior mass is concentrated above zero on impact of the shock and it turns significantly positive from period two onward. Thus, our empirical VAR, where the responses of macro variables to the target shock are left to be determined by the data, indicates support for Neo-Fisher like effects, i.e. persistent changes in the inflation target induce a positive co-movement of inflation and nominal interest rate dynamics already in the short-run, at no output cost.[23]

The theoretical model of section 2 helps us interpreting the transmission mechanism economically. There, an outcome of the shock is a decline in the real rate, which stimulates output and inflation. This seems to be consistent with the data. The effects of the inflation target shock are also found to be very persistent. Even 20 quarters after the shock the responses of inflation and the interest rate do not die out. This is due to the high persistence of the inflation target shock, but also due to the nature of the shock: as it moves forward-looking variables, long-term inflation expectations, it creates long-lasting effects. The effect on output growth is least persistent, starting to die out after the first year. This is consistent with the Fisher equation: as the dynamics between inflation and the interest rate adjust and reach similar levels, the real rate becomes unaffected by changes in these nominal variables.

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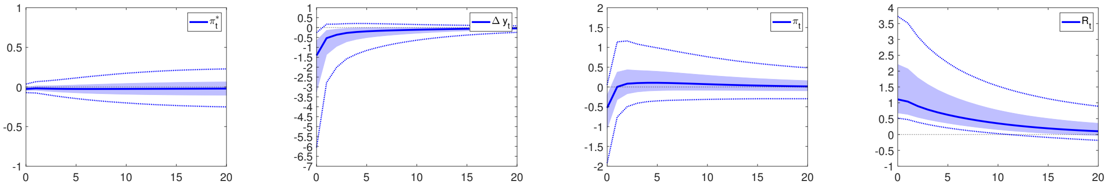
[23] A robustness check with the same data and identification via a standard set of sign restrictions also provides proof of the Neo-Fisherian effects in US data. Following the sign restrictions approach, we impose zero restrictions on the response of the long-run inflation on demand and supply shocks, and we impose no sign restrictions in response to the target shock. When we impose zero restriction on long-run inflation in response to the temporary monetary shocks, consistently with the DSGE model under full information, we observe strong empirical support for the Neo-Fisher effects on impact of the inflation target shock. In absence of this last zero restriction, consistently with the DSGE model under imperfect information, Neo-Fisherian effects come with a delay of a few quarters. Thus, accounting for a possibility of imperfect information *jointly* with full information already in the identification allows us to uncover the true empirical effects of the target shock.

As a result, output growth returns to its pre-shock value.

Our results are qualitatively in line with the results from other related empirical studies. Uribe (2021) finds that in response to a permanent nominal interest rate raise, inflation and the interest rate increase. Mumtaz and Theodoridis (2018) study the effects of an inflation target shock using an SVAR model and similarly report an increase in nominal rate and inflation. De Michelis and Iacoviello (2016) report a positive response of inflation to a positive inflation target shock for Japanese data for the late sample which runs from 1994 to 2015. Uribe (2021), Mumtaz and Theodoridis (2018) and De Michelis and Iacoviello (2016) also find evidence in favour of an increase in economic activity, consistent with our results. In contrast to this literature, we are able to use our identification strategy to account for a potential confusion between persistent inflation target shocks and temporary interest rate shocks which might affect decisions of economic agents, and therefore the outcomes of a persistent inflation target shock. We find that the response of inflation does include zero on impact of a positive inflation target shock yet inflation and the nominal interest rate comove positively and rise already in the short-run.

Impulse responses to a temporary nominal interest rate shock



Impulse responses to a persistent inflation target shock

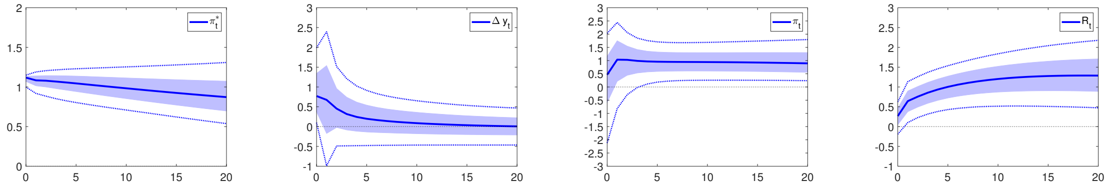


Figure 7: Baseline model with perceived inflation target rate (PTR) measure from the FRB/US model (Brayton, Laubach, Reifschneider, 2014) and hybrid identification. First row: shaded area - 68% confidence interval and blue dotted line 90% confidence interval to a nominal interest rate shock. Second row: shaded area - 68% confidence interval and blue dotted line 90% confidence interval to a persistent inflation target shock. Sample: 1962Q1 to 2019Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.

We further provide extensive robustness checks. First, with respect to the measure of long-run inflation. Second, with respect to the number of lags used in the VAR model and different time samples. And finally, with respect to the prior specification for our VAR methodology.

First, we substitute the PTR measure with our other inflation target proxy measures: the survey-based inflation forecasts of professional forecasters (SPF), the estimated inflation target series from our full and imperfect information versions of the DSGE model, and the Chan et al. (2018) trend inflation measure (UCE). To save space, we relegate all impulse responses for these alternative VAR models to Appendix B.5.[24]

The VAR models with all alternative measures deliver robust results, with dynamics similar to our baseline model. In response to a positive nominal interest rate shock, inflation and output contract, with effects being relatively short-lived. The inflation target measure is not affected. In contrast, in response to the inflation target shock, inflation, output growth and nominal rate all typically increase, with a significantly higher degree of persistence in the co-movement of inflation and nominal interest rate. Overall, the differences across the specifications with with alternative inflation target measures are not large, and the results are quite robust across various measures of the low-frequency inflation.

Then we consider different time samples, to study if our findings on the presence of Neo-Fisher effects are robustly found also for more recent time periods. Appendix B.2 contains impulse responses of our VAR model estimated over various time horizons: 1962Q1 to 2008Q3, 1979Q4 to 2019Q1 and 1979Q4 to 2008Q3. We also estimate the VAR model with shadow rates to address potential non-linearity introduced by the binding zero lower bound constraint reflected in the behavior of the nominal rate time series in the aftermath of the 2007/08 financial crisis (impulse responses can be found in appendix B.4). Arguably, with the beginning of the Volcker chairmanship, US monetary policy became much more committed to the goal of price stability, and, under the chairmanship of Bernanke, even adopted an explicit publicly announced inflation target. As a result, the inflation target became more credible. We also estimate our baseline model with four lags instead of two. Nonetheless, the overall picture obtained in the baseline model on the full postwar time series remains: short-run effects of inflation target shocks remain significant across all subsample periods (as well as in the model with shadow rates), and continue to introduce inflation and nominal interest rate dynamics in line with the Neo-Fisher effect, which stand in contrast to the dynamics in response to a standard temporary shock to the nominal interest rate.

Finally, we provide robustness checks with respect to the choice of the prior identification parameters that guide us through the identification of structural shocks. We do so by setting the parameters for the distribution of the elements of the A matrix as suggested by the simple three-equation New Keynesian model Baumeister and Hamilton (2018), augmented with a time-varying inflation target. Therefore, we center the prior distribution for the parameters of the A matrix as suggested in Baumeister and Hamilton (2018) for the three structural shocks present in the 3-equation NK model, i.e. supply-, demand-, and the nominal interest rates shocks. We are then quite uninformative about the way the inflation target shock affects the VAR. We center the prior modes for the response of inflation target at zero and allow for relatively wide prior variances. The results, displayed on figure B.12 in Appendix B.6, are

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[24] The impulse responses reported are for the full sample period. We again check robustness with respect to a higher number of lags and subsample periods.

again robust to the presence of the Neo-Fisherian effects.

4 Conclusions

This paper presents new empirical evidence on monetary policy transmission by distinguishing between long-run and short-run monetary policy shocks. We do so both by estimating a theoretical New Keynesian DSGE model and by studying empirical VAR models. Both approaches suggest that the two shocks are important sources of fluctuations in inflation, interest rates and output growth in the close aftermath of the shock, but each shock represents a different channel through which the central bank affects the economy and implies different co-movement properties of the nominal interest rate with inflation and output. In response to a temporary nominal interest rate shock, a rise in the interest rate is associated with a fall in inflation and economic activity, as is the conventional wisdom of generations of monetary macro models. In response to a persistent inflation target increase, we find evidence that the nominal interest rate, inflation, and economic activity all rise, in line with a recent literature on Neo-Fisherian effects. A key novel aspect of our paper is that we also estimate a version of the New Keynesian model in which agents have imperfect information about the nature of a monetary policy shock, and need to learn over time if a change in monetary policy reflects a temporary interest rate shock or a shock to the inflation target. We show that this is indeed consequential, as agents do not adjust their inflation expectations upwards immediately in response to a target increase. We find that, in such case, Neo-Fisherian effects arise only with a lagged effect and not in the immediate short-run, in the sense that the nominal interest rate may not immediately rise but initially falls in response to a target increase. We use the two versions of the theoretical models to inform our empirical VAR model, accounting explicitly for the uncertainty in terms of the identification assumptions regarding the inflation target shock, using the novel methodology of Baumeister and Hamilton (2015,?, 2019). In such setting an inflation target shock gives rise to a strong positive co-movement of nominal interest rates and inflation in the short run, even if this increase is significantly positive only from quarter two after the shock onwards. However, the delay in our empirical macro models is very brief only, so that our empirical VAR results strongly point towards the presence of the Neo-Fisherian inflation-interest rate co-movement in the data.

References

Andrle, M. and Bruha, J. (2014). Learning about monetary policy using (s)vars? some pitfalls and possible solutions. *mimeo.*

Bauer, M. D. and Rudebusch, G. D. (2019). Interest rates under falling stars. *American Economic Review (forthcoming)*, 6571.

Baumeister, C. and Hamilton, J. D. (2015). Sign restrictions, structural vector autoregressions, and useful prior information. *Econometrica*, 83(5):1963–1999.

Baumeister, C. and Hamilton, J. D. (2018). Inference in structural vector autoregressions when the identifying assumptions are not fully believed: Re-evaluating the role of monetary policy in economic fluctuations. *Journal of Monetary Economics*, 100:48–65.

Baumeister, C. and Hamilton, J. D. (2019). Structural interpretation of vector autoregressions with incomplete identification: Revisiting the role of oil supply and demand shocks. *American Economic Review*, 109(5):1873–1910.

Bjørnland, H., Leitemo, K., and Maih, J. (2011). Estimating the natural rates in a simple New Keynesian framework. *Empir Econ*, 40:755–777.

Boivin, J. and Giannoni, M. (2006). Has monetary policy become more effective? *The Review of Economics and Statistics*, 88(3):445–462.

Brayton, F., Laubach, T., and Reifschneider, D. (2014). The FRB/US Model: A Tool for Macroeconomic Policy Analysis. *FEDS Notes. Washington: Board of Governors of the Federal Reserve System.*

Calvo, G. (1983). Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics*, 12(3):383 – 398.

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

Cochrane, J. (2016). Do higher interest rates raise or lower inflation? *Manuscript, Hoover Institution, Standford University.*

Cochrane, J. (2018). Michelson-Morley, Fisher, and Occam: The Radical Implications of Stable Quiet Inflation at the Zero Bound. *Chapter in NBER book NBER Macroeconomics Annual 2017*, 32.

Cogley, T., Primiceri, G., and Sargent, T. (2010). Inflation-Gap Persistent in the US. *American Economic Journal: Macroeconomics*, 2(1):43–69.

Cogley, T. and Sargent, T. (2005). Drifts and volatilities: monetary policies and outcomes in the post wwii us. *Review of Economic Dynamics*, 8(2):262 – 302. Monetary Policy and Learning.

De Graeve, F., Emiris, M., and Wouters, R. (2009). A structural decomposition of the US yield curve. *Journal of Monetary Economics*, 56(4):545 – 559.

De Michelis, A. and Iacoviello, M. (2016). Raising an inflation target: The japanese experience with abenomics. *European Economic Review*, 88(C):67–87.

Erceg, C. J. and Levin, A. T. (2003). Imperfect credibility and inflation persistence. *Journal of Monetary Economics*, 50(4):915–944.

Evans, G. W. and McGough, B. (2018). Interest-Rate Pegs in New Keynesian Models. *Journal of Money, Credit and Banking*, 50(5):939–964.

Fève, P., Matheron, J., and Sahuc, J.-G. (2010). Inflation target shocks and monetary policy inertia in the euro area. *The Economic Journal*, 120(547):1100–1124.

Friedman, M. (1968). In *Inflation: Causes and Consequences.*, *Dollars and Deficits: Living With America's Economic Problems*, page 21–71. Englewood Cliffs, NJ: Prentice-Hall.

Galí, J. (2008). Monetary policy, inflation, and the business cycle: An introduction to the new keynesian framework. *Princeton University Press.*

Garcìa-Schmidt, M. and Woodford, M. (2018). Are Low Interest Rates Deflationary? A Paradox of Perfect-Foresight Analysis. *Working Paper.*

Garin, J., Lester, R., and Sims, E. (2018). Raise Rates to Raise Inflation? Neo-Fisherianism in the New Keynesian Model. *Journal of Money, Credit and Banking*, 50(1):243–259.

Herbst, E. P. and Schorfheide, F. (2016). Bayesian estimation of dsge models. *Princeton University Press.*

Ireland, P. (2007). Changes in the Federal Reserve's Inflation Target: Causes and Consequences. *Journal of Money, Credit and Banking*, 39(8):1851–1882.

Kozicki, S. and Tinsley, P. (2005). Permanent and transitory policy shocks in an empirical macro model with asymmetric information. *Journal of Economic Dynamics and Control*, 29(11):1985–2015.

Lütkepohl, H. (1991). Introduction to Multiple Time Series Analysis. *Springer-Verlag, Berlin.*

Lütkepohl, H. (1999). Vector Autoregressions. *unpublished manuscript, Institut für Statistik und Ökonometrie, Humboldt-Universität zu Berlin.*

Milani, F. (2007). Expectations, learning and macroeconomic persistence. *Journal of Monetary Economics*, 54(7):2065–2082.

Mumtaz, H. and Theodoridis, K. (2018). The Federal Reserve's implicit inflation target and Macroeconomic dynamics. A SVAR analysis. *Working Paper.*

Primiceri, G. (2005). Time varying structural vector autoregressions and monetary policy. *The Review of Economic Studies*, 72:821–852.

Schmitt-Grohé, S. and Uribe, M. (2017). Open economy macroeconomics. Princeton University Press.

Schmitt-Grohè, S. and Uribe, M. (2018). The Neo Fisher Effect and Exiting a Liquidity Trap. *European Central Bank Conference on Monetary Policy.*

Sims, C. (1980). Macroeconomics and Reality. *Econometrica*, 48(1):1–48.

Smets, F. and Wouters, R. (2003). An estimated dynamic stochastic general equilibrium model of the euro area. *Journal of the European Economic Association*, 1(5):1123–1175.

Stock, J. and Watson, M. (2007). Why has U.S. inflation become harder to forecast? *Journal of Money, Credit and Banking*, 39(1):3–33.

Uhlig, H. (2005). What are the effects of monetary policy on output? Results from an agnostic identification procedure. *Journal of Monetary Economics*, 52(2):381 – 419.

Uribe, M. (2021). The Neo-Fisher Effect: Econometric Evidence from Empirical and Optimizing Models. *AEJ: Macroeconomics*, forthcoming.

Waggoner, D. F. and Zha, T. (1999). Conditional forecasts in dynamic multivariate models. *Review of Economics and Statistics*, 81(4):639–651.

Watson, M. (1994). Chapter 47 vector autoregressions and cointegration. volume 4 of *Handbook of Econometrics*, pages 2843 – 2915. Elsevier.

Williamson, S. (2016). Neo-Fisherism: A Radical Idea, or the Most Obvious Solution the the Low-Inflation Problem? *Federal Reserve Bank of St. Louis Regional Economist*, 24(3):5–9.

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

FOR ONLINE PUBLICATION

Appendix A The DSGE model

A.1 Brief model description

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:

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

subject to the budget constraint:

$$\int_0^1 P_t(i) C_t(i) di + B_t + T_t \leqslant R_{t-1} B_{t-1} + \Pi_t + \int_0^1 W_t(i) L_t(i) di. \tag{A.2}$$

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:

$$\log(b_t) = \rho_b \log(b_{t-1}) + \varepsilon_{b,t}, \tag{A.3}$$

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

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, $Y_t(i)$:

$$Y_t(i) = A_t L_t(i), \tag{A.4}$$

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:

$$z_t = (1-\rho_z)\gamma + \rho_z z_{t-1} + \varepsilon_{z,t}. \tag{A.5}$$

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:

$$\max E_t \sum_{s=0}^{\infty} \zeta^s \Lambda_{t,t+s} \left[\tilde{P}_t(i)\pi Y_{t+s}(i) - W_{t+s}(i) L_{t+s}(i)\right], \tag{A.6}$$

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:

$$\frac{R_t}{R} = \frac{R_{t-1}}{R}^{\rho_R} \left[\left(\frac{\bar{\pi}_{4,t}}{(\pi_t^*)^4}\right)^{\rho_\pi} \left(\frac{Y_t}{Y_t^*}\right)^{\rho_Y}\right]^{1-\rho_R} e^{\varepsilon_{R,t}}, \tag{A.7}$$

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^*:

$$\log \pi_t^* = (1-\rho_{\pi^*}) \log \pi + \rho_{\pi^*} \log \pi_{t-1}^* + \varepsilon_{\pi^*,t}. \tag{A.8}$$

A.2 List of log-linearized first order and equilibrium conditions

This section lists the system of first order and equilibrium conditions to be coded.
First-order and equilibrium conditions of the sticky price economy:
Phillips curve:

$$\widehat{\pi}_t = \beta E_t \widehat{\pi}_{t+1} + \widehat{\lambda}_{P,t} + \frac{(1-\beta\zeta)(1-\zeta)}{\zeta\left(1-\nu\left(1+\frac{1}{\lambda_P}\right)\right)} \widehat{w}_t, \tag{A.9}$$

Marginal utility of consumption

$$(\gamma - h\beta)(\gamma - h)\widehat{\lambda}_t + \left(\gamma^2 + \beta h^2\right)\widehat{Y}_t = \left[\begin{array}{c} (\gamma h \beta) E_t \widehat{Y}_{t+1} + \gamma h \widehat{Y}_{t-1} + \\ (\gamma - h\beta\rho_b)(\gamma - h)\widehat{b}_t + (\beta h \gamma \rho_z - h\gamma)\widehat{z}_t \end{array}\right], \tag{A.10}$$

Euler equation

$$\widehat{\lambda}_t = \beta E_t \widehat{\lambda}_{t+1} + \widehat{R}_t - \widehat{\pi}_{t+1} - \rho_z \widehat{z}_t \tag{A.11}$$

Labor supply equation

$$\widehat{w}_t + \widehat{\lambda}_t = \widehat{b}_t + \nu \widehat{Y}_t \tag{A.12}$$

Monetary policy rule

$$\widehat{R}_t = \rho_R \widehat{R}_{t-1} + (1-\rho_R)\left[\rho_\pi\left(\frac{\widehat{\pi}_t + \widehat{\pi}_{t-1} + \widehat{\pi}_{t-2} + \widehat{\pi}_{t-3}}{4}\right) + \rho_Y\left(\widehat{Y}_t - \widehat{Y}_t^{flex}\right)\right] + \varepsilon_t, \tag{A.13}$$

First-order and equilibrium conditions of the flexible price economy:
Marginal utility of consumption

$$(\gamma - h\beta)(\gamma - h)\widehat{\lambda}_t^{flex} + \left(\gamma^2 + \beta h^2\right)\widehat{Y}_t^{flex} = \left[\begin{array}{c} (\gamma h \beta) E_t \widehat{Y}_{t+1}^{flex} + \gamma h \widehat{Y}_{t-1}^{flex} + \\ (\gamma - h\beta\rho_b)(\gamma - h)\widehat{b}_t + (\beta h \gamma \rho_z - h\gamma)\widehat{z}_t \end{array}\right], \tag{A.14}$$

Euler equation

$$\widehat{\lambda}_t^{flex} = \beta E_t \widehat{\lambda}_{t+1}^{flex} + \widehat{R}_t^{flex} - \rho_z \widehat{z}_t, \tag{A.15}$$

Labor supply equation

$$\widehat{w}_t^{flex} + \widehat{\lambda}_t^{flex} = \widehat{b}_t + \nu \widehat{Y}_t^{flex}, \tag{A.16}$$

Observables

$$o\_\Delta Y_t = \gamma^{100} + \widehat{Y}_t - \widehat{Y}_{t-1} + \widehat{z}_t, \tag{A.17}$$

$$o\_\pi_t = \pi^{100} + \widehat{\pi}_t, \tag{A.18}$$

$$o\_R_t = \left(\pi^{100} + r^{100}\right) + \widehat{R}_t. \tag{A.19}$$

Exogenous processes

$$\widehat{z}_t = \rho_z \widehat{z}_{t-1} + \varepsilon_{z,t}, \tag{A.20}$$

$$\widehat{b}_t = \rho_b \widehat{b}_{t-1} + \varepsilon_{b,t}, \tag{A.21}$$

$$\widehat{\theta}_t = \rho_\theta \widehat{\theta}_{t-1} + \varepsilon_{\theta,t}, \tag{A.22}$$

$$\widehat{\pi}^*_t = \rho_{\pi^*} \widehat{\pi}^*_{t-1} + \varepsilon_{\pi^*,t}, \tag{A.23}$$

$$u_t = \rho_u u_{t-1} + \varepsilon_{R,t} \tag{A.24}$$

Definition of ε_t

$$\varepsilon_t \equiv (1-\rho_R)\,(-\rho_\pi)\,\widehat{\pi}^*_t + u_t. \tag{A.25}$$

A.3 The solution in the imperfect information setup

Solving and estimating the model version under full information is straightforward, the system of equations in section A.2, equations (A.9)-(A.25) needs to be coded up and solved with any of the many available packages to solve linear rational expectation systems.[25] It can be shown, that in the model solution of the full information model version, the policy functions are a function of the state vector $x_t = \left[\widehat{R}_{t-1}, \widehat{\pi}_{t-1}, \widehat{\pi}_{t-2}, \widehat{\pi}_{t-3}, \widehat{Y}_{t-1}, \widehat{Y}^{flex}_{t-1}, \widehat{z}_t, \widehat{b}_t, \widehat{\theta}_t, \widehat{\pi}^*_t, u_t\right]$.

Obtaining a solution to the model version under imperfect information and learning is somewhat more involved, and the steps needed to derive a solution are laid out in detail below.[26] Recall from the main text that the Taylor rule describing the central banks's policy actions could be written as:

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

---

[25] E.g., Dynare is particularly convenient.

[26] An excellent exposition of a imperfect information and learning model is in chapter 5 of Schmitt-Grohé and Uribe (2017) (despite being on the very different application of a small open economy needing to learn the source of technology disturbances, temporary versus permanent). Our solution approach follows the same steps. Since obtaining the model solution is non-standard, we cannot use Dynare for estimation. Instead, for estimating the imperfect information model, we adopt (and adapt) the Bayesian estimation codes that accompany the example model of chapters 1 and 2 of Herbst and Schorfheide (2016, https://web.sas.upenn.edu/schorf/files/2017/07/DSGE-Estimation-ueds33.zip) to our model. Rigorous checks for correct implementation were successful, e.g., we also implement the full information model version in the Herbst and Schorfheide (2016) set of Bayesian estimation codes; we verify that our implementation and Dynare yields (for a particular draw of parameters) identical policy function coefficients and model log-likelihood, as well as virtually the same estimated parameters from the Metropolis-Hastings MCMC.

where we defined

$$\varepsilon_t \equiv (1-\rho_R)(-\rho_\pi)\widehat{\pi}_t^* + u_t.$$

Under imperfect information, agents are only able to observe ε_t, but cannot observe the components $\widehat{\pi}_t^*$ and u_t individually. However, they learn over time what is behind a particular movement of ε_t. In particular, their learning problem is a linear problem and features an observation equation, $o_t = H'\xi_t$, and a state transition equation, $\xi_{t+1} = F\xi_t + B\epsilon_{t+1}$, so that the learning problem can be described using the Kalman filter:

$$\underbrace{(\varepsilon_t)}_{o_t} = \underbrace{\left[\begin{array}{cc}(1-\rho_R)(-\rho_\pi) & 1\end{array}\right]}_{H'}\underbrace{\left[\begin{array}{c}\widehat{\pi}_t^* \\ u_t\end{array}\right]}_{\xi_t}, \tag{A.26}$$

$$\underbrace{\left[\begin{array}{c}\widehat{\pi}_{t+1}^* \\ u_{t+1}\end{array}\right]}_{\xi_{t+1}} = \underbrace{\left[\begin{array}{cc}\rho_{\pi^*} & 0 \\ 0 & \rho_u\end{array}\right]}_{F}\underbrace{\left[\begin{array}{c}\widehat{\pi}_t^* \\ u_t\end{array}\right]}_{\xi_t} + \underbrace{\left[\begin{array}{c}\varepsilon_{\pi^*,t+1} \\ \varepsilon_{R,t+1}\end{array}\right]}_{B\epsilon_{t+1}},$$

where we denote with Q the variance-covariance matrix of the innovation $B\epsilon_{t+1}$, $Q = BB' = \left[\begin{array}{cc}\sigma_{\pi^*}^2 & 0 \\ 0 & \sigma_u^2\end{array}\right]$. The Kalman filter yields

$$\begin{aligned} E_t o_{t+1} &= H' E_t \xi_{t+1}, \\ E_t\xi_{t+1} &= FE_{t-1}\xi_t + \kappa\left(o_t - H'E_{t-1}\xi_t\right), \end{aligned} \tag{A.27}$$

where κ is the Kalman gain matrix, $\kappa \equiv FPH\left(H'PH\right)^{-1}$, and P is implicitly given by the Riccati equation $P = F\left[P - PH\left(H'PH\right)^{-1}H'P\right]F' + Q$, and represents the steady state mean square error of the forecast of ξ_{t+1}, that is $P = E\left[(\xi_{t+1} - E_t\xi_{t+1})(\xi_{t+1} - E_t\xi_{t+1})'\right]$.

Given this setup, the model version with imperfect information and learning can be solved in two stages. In the first stage, one needs to code up equations (A.9) to (A.22), that is, all model equations apart from the ones describing the exogenous processes of $\widehat{\pi}_t^*$ and u_t, and the definition of ε_t. In addition, the variable ε_t (the observable) is treated as a state variables, and expectations in period t are taken, given the agent's information in period t, which does not include $\widehat{\pi}_t^*$ and u_t. In particular, agents only know $E_{t-1}\widehat{\pi}_t^*$ and $E_{t-1}u_t$. Defining auxiliary (state) variables $\eta_{1t} = E_{t-1}\widehat{\pi}_t^*$ and $\eta_{2t} = E_{t-1}u_t$, we can write their law of motion as:

$$\left[\begin{array}{c}\eta_{1t+1} \\ \eta_{2t+1}\end{array}\right] = \left(F - \kappa H'\right)\left[\begin{array}{c}\eta_{1t} \\ \eta_{2t}\end{array}\right] + \kappa\left[\varepsilon_t\right], \tag{A.28}$$

and the conditional expectation of ε_{t+1} is given by

$$[E_t\varepsilon_{t+1}] = H' \begin{bmatrix} \eta_{1t+1} \\ \eta_{2t+1} \end{bmatrix}. \tag{A.29}$$

Solving system (A.9)-(A.22) together with (A.28) and (A.29) yields a solution as a function of the state vector $x_t = \left[\widehat{R}_{t-1}, \widehat{\pi}_{t-1}, \widehat{\pi}_{t-2}, \widehat{\pi}_{t-3}, \widehat{Y}_{t-1}, \widehat{Y}^{flex}_{t-1}, \widehat{z}_t, \widehat{b}_t, \widehat{\theta}_t, \eta_{1t}, \eta_{2t}, \varepsilon_t\right]$, and concludes the first step in the solution procedure. This is not the end of the computation algorithm though, because in equilibrium, the variable ε_t is not a primitive exogenous state variable, but a control variable, determined by the truly exogenous states $\widehat{\pi}^*_t$ and u_t. Luckily, this second step of the solution is easily done and consists of rewriting the solution obtained in step 1 as a function of $x_t = \left[\widehat{R}_{t-1}, \widehat{\pi}_{t-1}, \widehat{\pi}_{t-2}, \widehat{\pi}_{t-3}, \widehat{Y}_{t-1}, \widehat{Y}^{flex}_{t-1}, \widehat{z}_t, \widehat{b}_t, \widehat{\theta}_t, \eta_{1t}, \eta_{2t}, \widehat{\pi}^*_t, u_t\right]$ (by using the solution of ε_t from the first step), and appending equations $\xi_{t+1} = F\xi_t + B\epsilon_{t+1}$ and $o_t = H'\xi_t$ to the system.

A.4 Prior setup and posterior estimates

Table A.1 presents estimation results for the model parameters of the New Keynesian model described in Appendix A.1, reporting information on the chosen prior distributions, prior means and variances, as well as the estimated posterior means and 10% and 90% intervals.

				Full information		Imperfect information	
param.	prior density	prior mean	prior var.	post. mean	10% and 90% intervals	post. mean	10% and 90% intervals
γ^{100}	Normal	0.475	0.025	0.482	[0.451,0.514]	0.483	[0.452,0.514]
π^{100}	Normal	0.500	0.100	0.511	[0.386,0.635]	0.520	[0.396,0.645]
$\frac{1}{\beta} - 1$	Gamma	0.250	0.100	0.147	[0.079,0.225]	0.151	[0.080,0.232]
h	Beta	0.500	0.100	0.469	[0.405,0.532]	0.457	[0.393,0.521]
ζ	Beta	0.660	0.100	0.768	[0.703,0.831]	0.783	[0.718,0.843]
ρ_π	Normal	1.700	0.200	1.260	[1.005,1.525]	1.193	[0.941,1.458]
ρ_Y	Gamma	0.300	0.150	1.110	[0.829,1.410]	1.252	[0.948,1.577]
ρ_R	Beta	0.600	0.200	0.877	[0.840,0.910]	0.825	[0.761,0.880]
ρ_z	Beta	0.400	0.200	0.608	[0.507,0.707]	0.545	[0.450,0.640]
ρ_θ	Beta	0.600	0.200	0.507	[0.431,0.581]	0.538	[0.465,0.610]
ρ_b	Beta	0.600	0.200	0.940	[0.907,0.967]	0.935	[0.901,0.964]
ρ_{π^*}	Beta	0.980	0.015	0.991	[0.984,0.997]	0.992	[0.986,0.997]
σ_R	Inv.Gam.	0.150	1.000	0.139	[0.130,0.148]	0.139	[0.129,0.149]
σ_z	Inv.Gam.	1.000	1.000	0.709	[0.587,0.834]	0.807	[0.696,0.921]
σ_θ	Inv.Gam.	0.150	1.000	0.260	[0.222,0.299]	0.253	[0.213,0.294]
σ_b	Inv.Gam.	1.000	1.000	4.142	[3.032,5.528]	3.973	[2.836,5.392]
σ_{π^*}	Inv.Gam.	0.100	0.050	0.115	[0.065,0.177]	0.084	[0.051,0.125]

Table A.1: Prior parameters and posterior estimates

Appendix B Sensitivity checks in empirical models

B.1 Distributions of the elements of A matrix implied by DSGE models

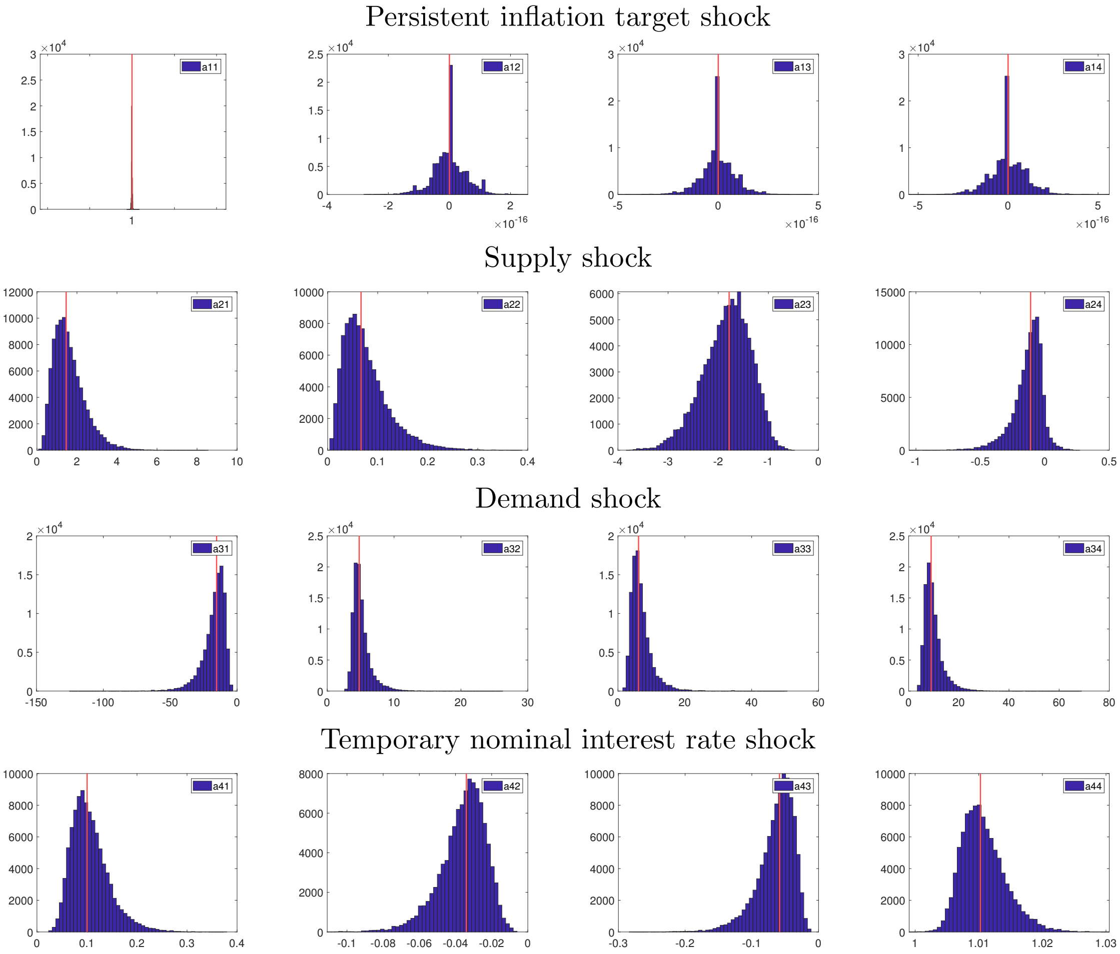
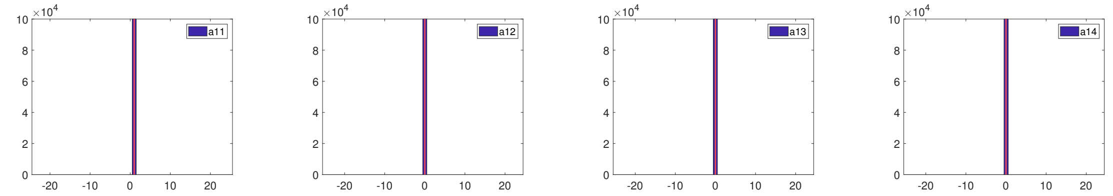
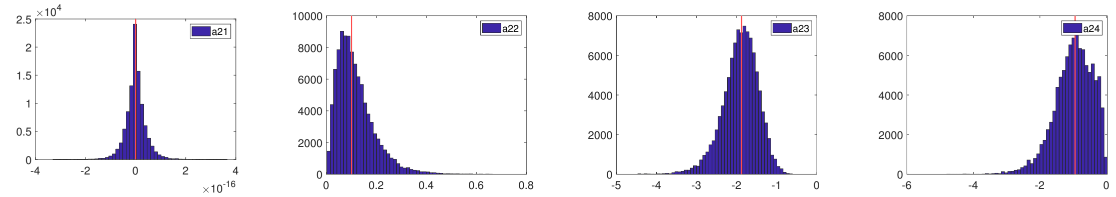


Figure B.1: Distribution of the elements of the A matrix implied by the DSGE model estimated under full information. Red line - median.

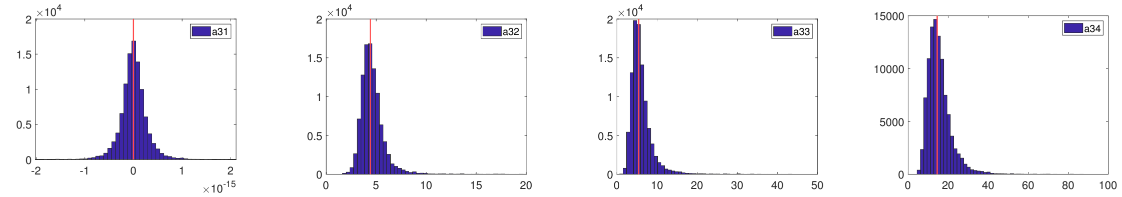
Persistent inflation target shock



Supply shock



Demand shock



Temporary nominal interest rate shock

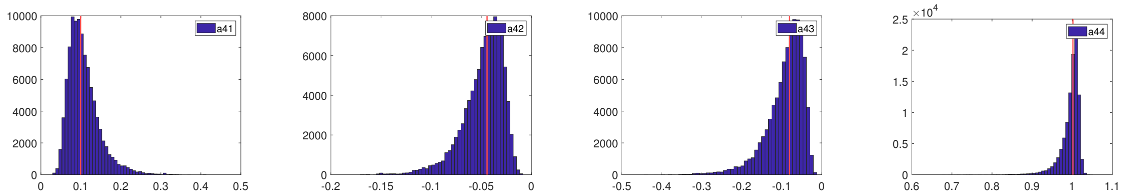
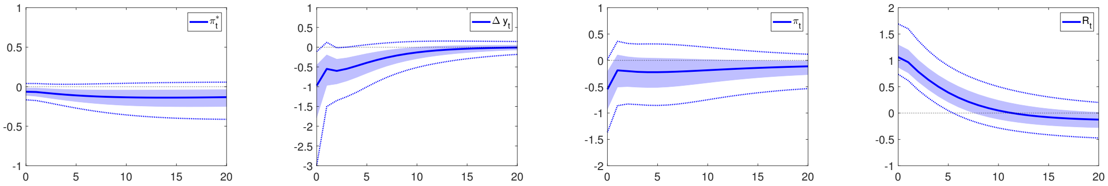


Figure B.2: Distribution of the elements of the A matrix implied by the DSGE model estimated under imperfect information. Red line - median.

B.2 Sensitivity checks: different time samples

Impulse responses to a temporary nominal interest rate shock



Impulse responses to a persistent inflation target shock

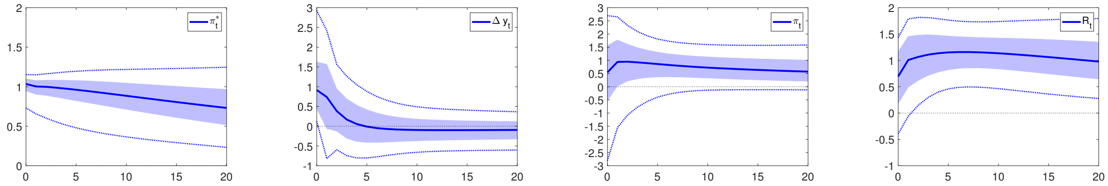
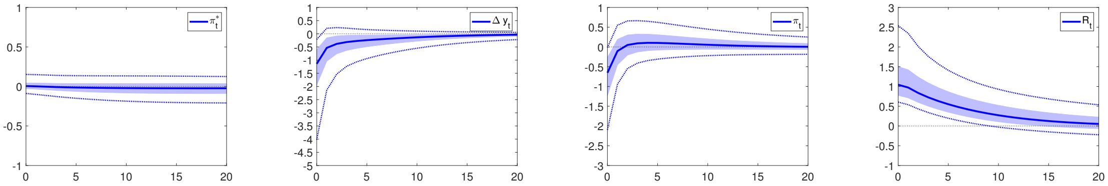


Figure B.3: Baseline model with perceived inflation target rate (PTR) measure from the FRB/US model (Brayton, Laubach, Reifschneider, 2014) and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock. Second row: 90% confidence interval to a persistent inflation target shock. Sample: 1962Q1 to 2008Q3. Horizontal axis: periods after the shock. Vertical axis: percentage change.

Impulse responses to a temporary nominal interest rate shock



Impulse responses to a persistent inflation target shock

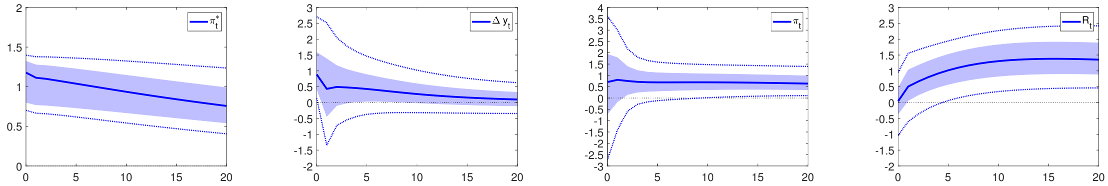
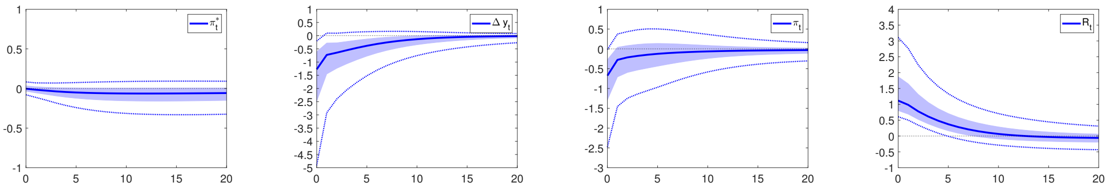


Figure B.4: Baseline model with perceived inflation target rate (PTR) measure from the FRB/US model (Brayton, Laubach, Reifschneider, 2014) and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock. Second row: 90% confidence interval to a persistent inflation target shock. Sample: 1979Q4 to 2019Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.

Impulse responses to a temporary nominal interest rate shock



Impulse responses to a persistent inflation target shock

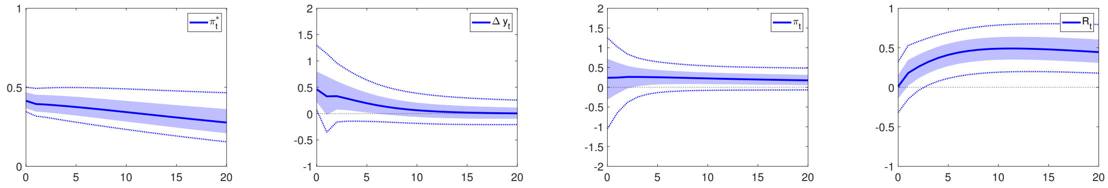
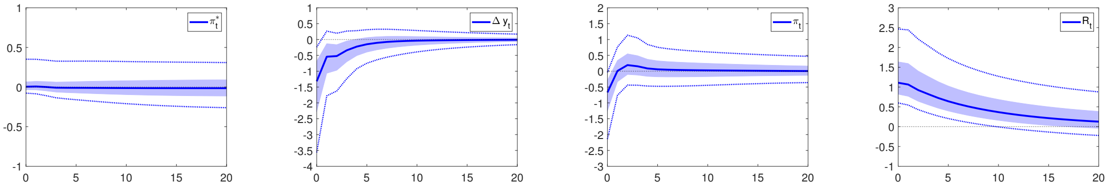


Figure B.5: Baseline model with perceived inflation target rate (PTR) measure from the FRB/US model (Brayton, Laubach, Reifschneider, 2014) and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock. Second row: 90% confidence interval to a persistent inflation target shock. Sample: 1979Q4 to 2008Q3. Horizontal axis: periods after the shock. Vertical axis: percentage change.

B.3 Sensitivity checks: four lags

Impulse responses to a temporary nominal interest rate shock



Impulse responses to a persistent inflation target shock

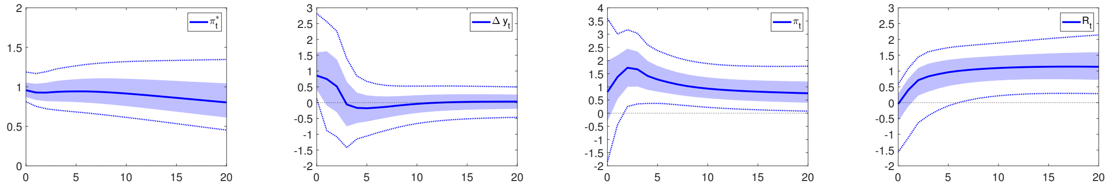
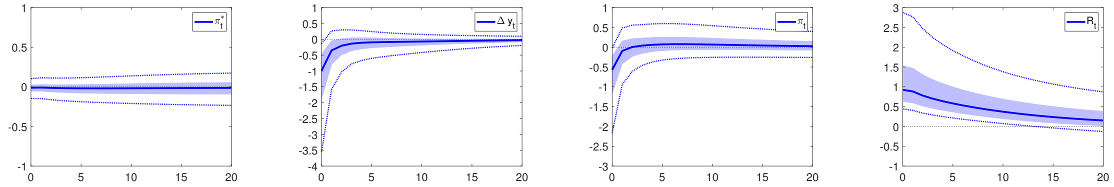


Figure B.6: Baseline model with perceived inflation target rate (PTR) measure from the FRB/US model (Brayton, Laubach, Reifschneider, 2014), 4 lags and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock. Second row: 90% confidence interval to a persistent inflation target shock. Sample: 1962Q1 to 2019Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.

B.4 Sensitivity checks: model with shadow rates

Impulse responses to a temporary nominal interest rate shock



Impulse responses to a persistent inflation target shock

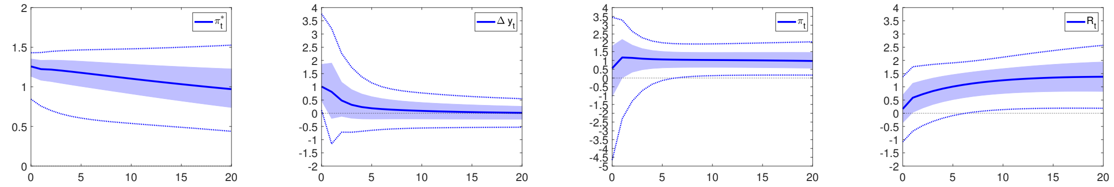
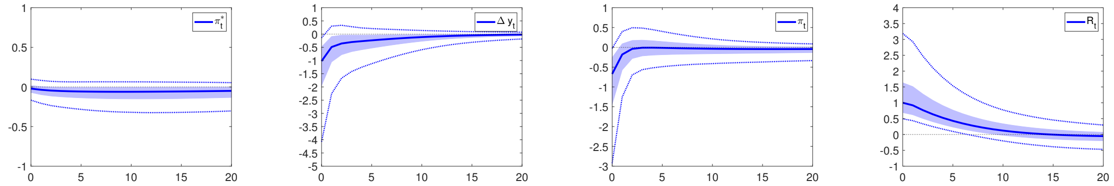


Figure B.7: Model with shadow rates and perceived inflation target rate (PTR) measure from the FRB/US model (Brayton, Laubach, Reifschneider, 2014), hybrid identification. First row: 90% confidence interval to a nominal interest rate shock and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock. Second row: 90% confidence interval to a persistent inflation target shock. Sample: 1962Q1 to 2019Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.

B.5 Sensitivity checks: alternative inflation target measures

Impulse responses to a temporary nominal interest rate shock



Impulse responses to a persistent inflation target shock

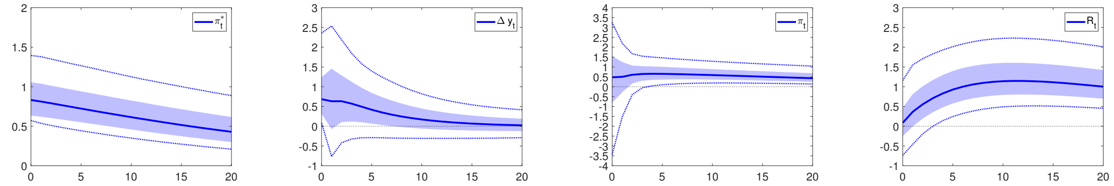
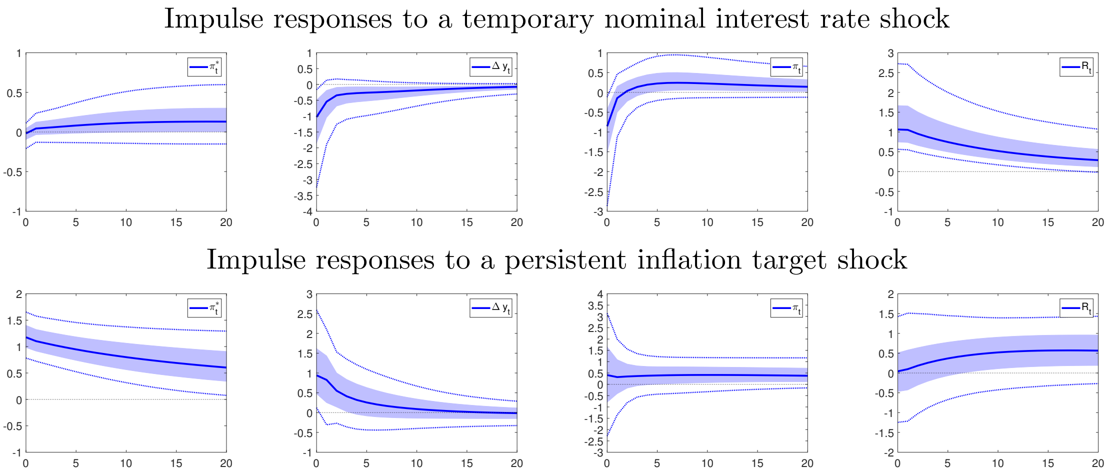
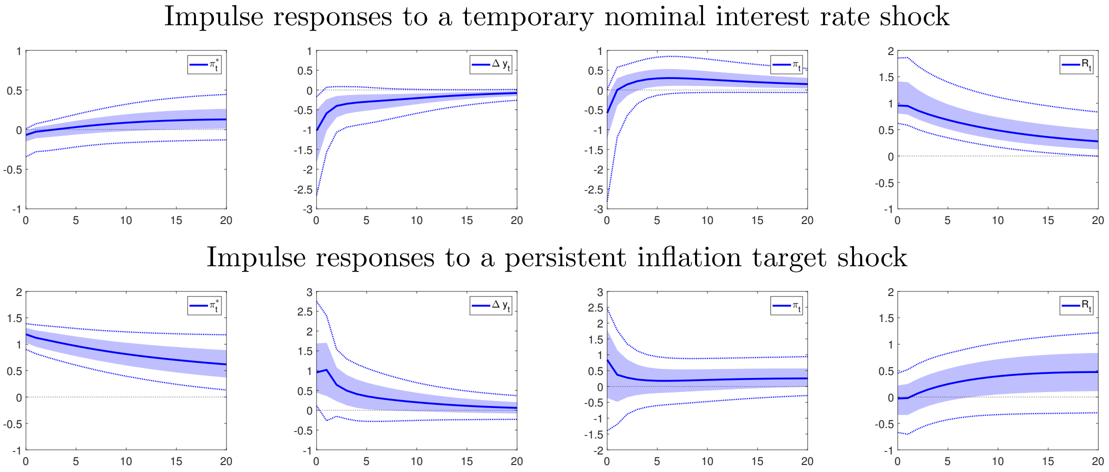


Figure B.8: Model with inflation forecasts taken from the Survey of Professional Forecasters, SPF, and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock. Second row: 90% confidence interval to a persistent inflation target shock. Sample: 1979Q4 to 2019Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.


Impulse responses to a temporary nominal interest rate shock

Impulse responses to a persistent inflation target shock

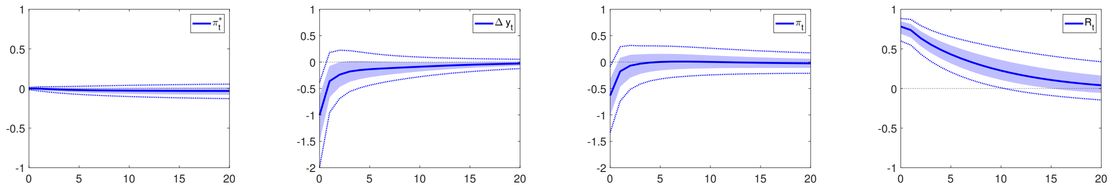
Figure B.9: Model with inflation target estimated from the DSGE model with full information and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock. Second row: 90% confidence interval to a persistent inflation target shock. Sample: 1947Q2 to 2019Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.


Impulse responses to a temporary nominal interest rate shock

Impulse responses to a persistent inflation target shock

Figure B.10: Model with inflation target estimated from the DSGE model with imperfect information and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock. Second row: 90% confidence interval to a persistent inflation target shock. Sample: 1947Q2 to 2019Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.

Impulse responses to a temporary nominal interest rate shock



Impulse responses to a persistent inflation target shock

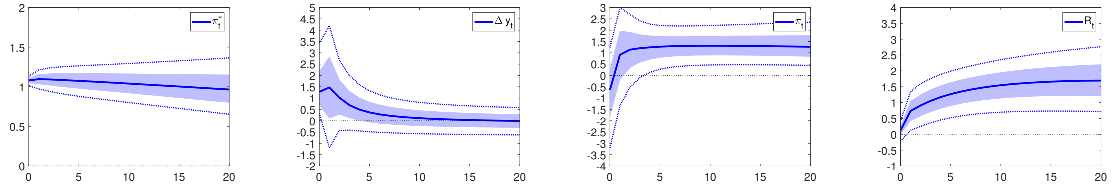


Figure B.11: Model with trend inflation taken from Chan et al. (2018), UCE, and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock and hybrid identification. First row: 90% confidence interval to a nominal interest rate shock. Second row: 90% confidence interval to a persistent inflation target shock. Sample: 1962Q1 to 2016Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.

B.6 Sensitivity checks: alternative prior for identification

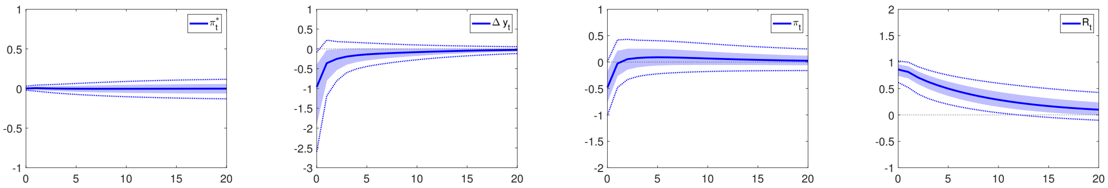
Here the prior for the responses of output growth, inflation dn the nominal interest rate are governed by the standard 3-equation NK model described in detail in Baumeister and Hamilton (2018). Effectively, the A matrix now takes the following form:

$$A = \begin{vmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} := -\alpha^S & a_{24} \\ a_{31} & a_{32} & a_{33} := -\beta^D & a_{34} := -\gamma^D \\ a_{41} & a_{42} := -(1-\rho)\psi^Y & a_{43} := -(1-\rho)\psi^\pi & a_{44} \end{vmatrix} \tag{A.30}$$

And we set the prior mode at (some elements are truncated as in Baumeister and Hamilton (2018)):

$$mode(A) = \begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 > 0 & -2 < 0 & 0 \\ 0 & 1 > 0 & -0.75 & 1 > 0 \\ 0 & -0.25 < 0 & -0.75 < 0 & 1 > 0 \end{vmatrix} \tag{A.31}$$

Impulse responses to a temporary nominal interest rate shock



Impulse responses to a persistent inflation target shock

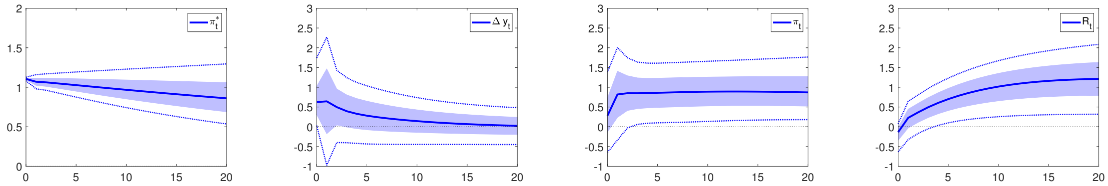


Figure B.12: Baseline model with perceived inflation target rate (PTR) measure from the FRB/US model (Brayton, Laubach, Reifschneider, 2014) and hybrid identification. First row: shaded area - 68% confidence interval and blue dotted line 90% confidence interval to a nominal interest rate shock. Second row: shaded area - 68% confidence interval and blue dotted line 90% confidence interval to a persistent inflation target shock. Sample: 1962Q1 to 2019Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.