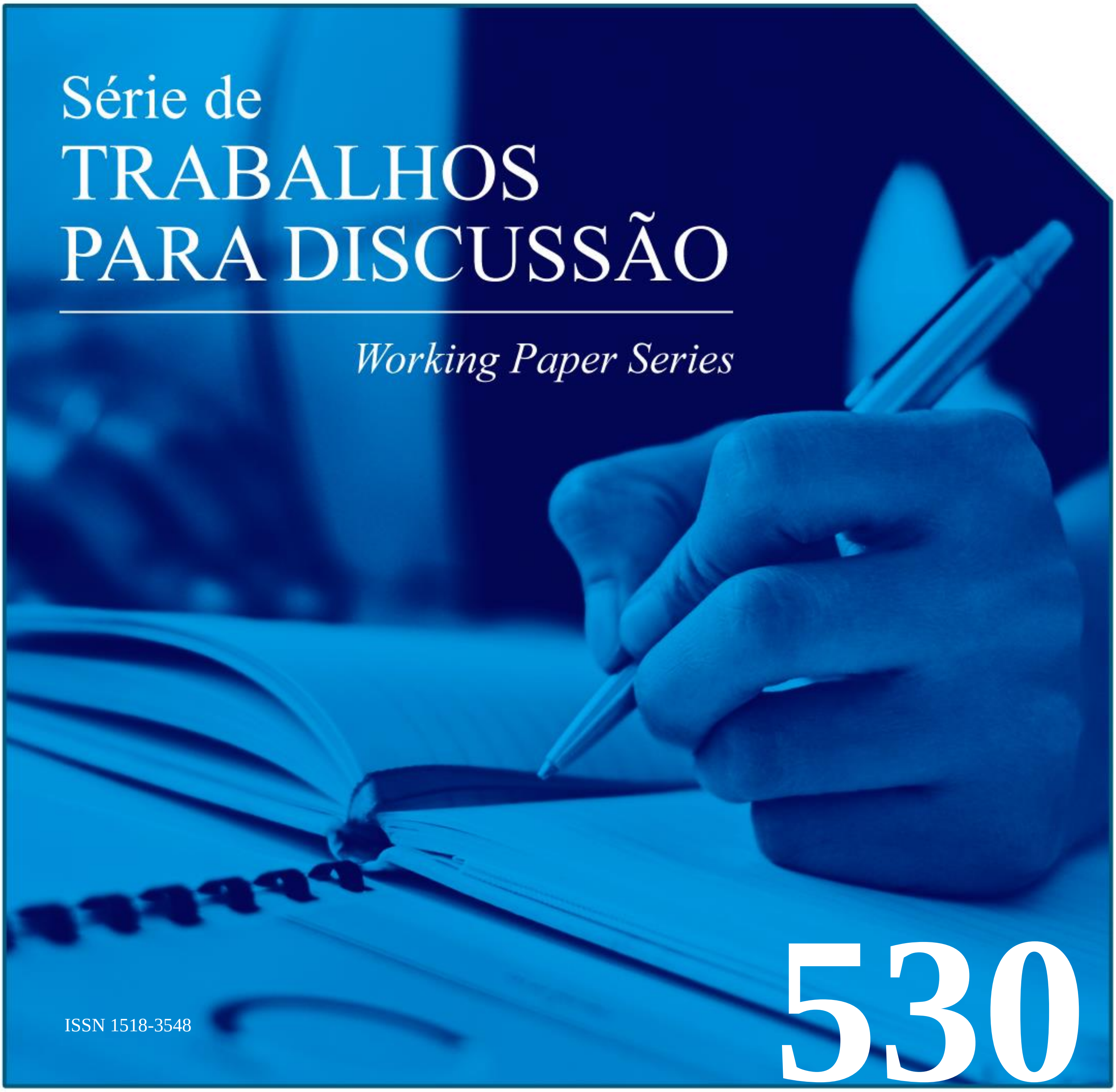

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Forward Guidance Matters: disentangling monetary policy shocks

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Non-technical Summary

In recent years, a new policy tool has been increasingly used by central banks: the communication about the likely future course of monetary policy, known as forward guidance. This new instrument can affect the term structure of interest rates and, potentially, the overall economy.

The central objective of this paper is to assess the dynamic responses of macroeconomic and financial variables to forward guidance shocks. In fact, this is not the first attempt to disentangle forward guidance and conventional monetary policy, and past efforts differ mainly in the way they measure forward guidance and separate it from conventional monetary policy. This paper tackles these issues and the identification challenges deriving from them using a different approach.

In contrast with traditional vector autoregressive (VAR) models that rely on internal information to identify shocks, it relies on external data not commonly included among the VAR model variables. There have usually been two alternatives: to rely on high-frequency futures prices to capture surprises or to rely on the narrative evidence. But why choosing?

Hence the novelty in terms of identification: to combine two sources of extraneous information - high-frequency surprises around Federal Open Market Committee (FOMC) announcements and narrative evidence - with sign restrictions in a structural VAR to fully disentangle the effects of forward guidance shocks from the effects of conventional monetary policy shocks. The surprises are useful to measure forward guidance and in the decomposition of the shocks, and the narrative account of some particular episodes helps enhance the identification. This is particularly convenient since forward guidance is itself a narrative policy instrument.

As a consequence of the use of all the available information, a conventional monetary policy shock has the expected responses even in a recent US sample as opposed to previous literature. Furthermore, forward guidance shocks are also better isolated from other shocks affecting expectations, so results are more refined. It is shown that forward guidance is an effective instrument. Indeed, it is as strong as monetary policy, being therefore an important addition to central banks' toolkit.

Sumário Não Técnico

Recentemente, uma nova ferramenta de política tem sido cada vez mais utilizada por bancos centrais: a comunicação sobre o provável curso futuro da política monetária, conhecida como "forward guidance". Esse novo instrumento pode afetar a estrutura a termo das taxas de juros e, potencialmente, a economia em geral.

O objetivo central deste artigo é avaliar as respostas dinâmicas de variaveis macroeconômicas e financeiras a choques de "forward guidance". De fato, essa não é a primeira tentativa de separar "forward guidance" e política monetária convencional, e estudos diferem principalmente na maneira como medem "forward guidance" e como a separam da política monetária convencional. Este artigo trata desses problemas e dos desafios de identificação deles decorrentes usando uma abordagem diferente.

Diferentemente dos modelos tradicionais de vetores autorregressivos (VAR) que usam informações internas ao modelo para identificar choques, o presente estudo se baseia em dados externos que normalmente não são incluídos entre as variáveis do modelo VAR. Geralmente, existem duas alternativas: usar preços de contratos futuros em alta frequência para capturar surpresas ou utilizar a evidência narrativa. Mas por que escolher?

Logo, a novidade em termos de identificação é a seguinte: combinar duas fontes de informações externas - surpresas nos preços de contratos futuros em torno dos anúncios do Comitê de Política Monetária dos Estados Unidos e evidências narrativas - com restrições de sinais em um VAR estrutural para separar os efeitos de choques de "forward guidance" dos efeitos dos choques da política monetária convencional. As surpresas são úteis para medir "forward guidance" e para a decomposição dos choques, e a evidência narrativa acerca de alguns episódios específicos ajuda a aprimorar a identificação. Isso é particularmente conveniente, pois "forward guidance" é um instrumento narrativo.

Como consequência do uso de todas as informações disponíveis, um choque convencional de política monetária tem as respostas esperadas, mesmo em uma amostra recente dos EUA, em contraste com a literatura anterior. Além disso, os choques de "forward guidance" também são melhor isolados de outros choques que afetam as expectativas, e os resultados são mais refinados. Mostra-se que "forward guidance" é um instrumento efetivo. De fato, é tão potente quanto a política monetária, sendo, portanto, uma adição importante ao ferramental dos bancos centrais.

Forward Guidance Matters: disentangling monetary policy shocks

Leonardo N. Ferreira*†

Abstract

Central banks have usually employed short-term rates as the main instrument of monetary policy. In the last decades, however, forward guidance has also become a central tool for monetary policy. In an innovative way this paper combines two sources of extraneous information – high frequency surprises and narrative evidence – with sign restrictions in a structural vector autoregressive (VAR) model to fully disentangle the effects of forward guidance shocks from the effects of conventional monetary policy shocks. Results show that conventional monetary policy has the expected effects even in a recent US sample, in contrast with the evidence reported by Barakchian and Crowe (2013) and Ramey (2016), and that forward guidance is an effective policy tool. In fact, it is at least as strong as conventional monetary policy.

Keywords: Forward Guidance, Monetary Policy, Narrative Sign Restrictions, High-frequency identification

JEL Classification: E30, E32, E43, E52, E58, C11, C50

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1 Introduction

Central banks have usually employed short-term interest rates as the main instrument of monetary policy. The extent to which such instrument is effective depends upon its ability to affect the path of expected future short-term real interest rates since, according to standard macroeconomic theory, such as Woodford (2003) and Galí (2015), consumption and output are driven by the sum of all future short-term real rates: the long-term real rate.[1]

In recent years, a prominent alternative way to affect long-term interest rates has been intensively used: the communication about the likely future course of monetary policy, known as forward guidance. In this framework, if central banks can commit to a future path of interest rates, their communication may affect the economy even in the absence of changes in the short-term policy rate. Hence, forward guidance (or more broadly, communication) also becomes a policy tool.

These two policy instruments (short-term interest rates and forward guidance) are obviously intrinsically connected. First, forward guidance matters for the identification of the conventional monetary policy shocks in that such shocks cannot be properly recovered unless anticipated changes in the policy rates are taken into account. Second, forward guidance is one reason why, as pointed out by Ramey (2016), estimating the causal effects of conventional monetary policy has become a challenge. With anticipation effects and monetary policy conducted more systematically, finding truly exogenous monetary policy shocks in recent samples has become increasingly difficult.

On the other hand, forward guidance shocks can be a valuable source of not so systematic policy. This tool became prevalent during the zero lower bound (ZLB) period when the use of the conventional policy rate was constrained and episodes of truly exogenous forward guidance shocks can be found. Campbell et al. (2012) and Campbell et al. (2017) show their effectiveness in moving long-term government bond rates. But what about the dynamic responses of macroeconomic and financial variables to these shocks?

This paper tackles this question by disentangling forward guidance and conventional monetary policy shocks in an innovative way: combining two sources

[1] To see the monetary transmission mechanism in the New Keynesian model clearly, it is useful to remember that, iterating forward, the Euler equation becomes:

$$\hat{y_t} = -\frac{1}{\sigma} E_t \sum_{i=0}^{\infty} (\hat{i}_{t+i} - \pi_{t+i+1})$$

where $\hat{x}$ denotes the percentage deviation of a variable X_t around its steady state, y is the output, i is the nominal interest rate, π is the inflation rate, and $\frac{1}{\sigma}$ governs the intertemporal elasticity of substitution.

of extraneous information with sign restrictions in a structural vector autoregressive (VAR) model estimated using data since the 90s, which is when the Federal Open Market Committee (FOMC) started to issue statements immediately after each meeting.

The first source of extraneous information is based on high-frequency futures prices and it builds on Kuttner (2001) and Gürkaynak et al. (2005). The use of high-frequency surprises around FOMC announcements is important to address endogeneity concerns as well as to help in the decomposition of the shocks. Specifically, the vector of variables of the VAR incorporates Gürkaynak et al. (2005)'s target and path factors, which capture surprises in the current and future rates respectively. Their inclusion together with the other variables in the spirit of Jarociński and Karadi (2020) is an alternative to their use as external instruments in Proxy SVARs.

The second source is the narrative account of some particular episodes that are used to enhance and refine the identification. The idea was formalised by Antolín-Díaz and Rubio-Ramírez (2018) as narrative sign restrictions. First, sign restrictions consistent with economic theory are placed not only on the standard variables but also on the factors in order to properly isolate the shocks of interest. Then, uncontroversial episodes of forward guidance and conventional monetary policy shocks are used to refine the credible set. This is particularly convenient since forward guidance is itself a narrative policy instrument.

Most importantly, following Uhlig (2005), the sign restrictions are agnostic. Therefore, the VAR model does not place any restriction on the responses of the industrial production and lets the data and the adjacent restrictions "decide" them, avoiding the circularity pointed out by Cochrane (1994). As in Uhlig (2005), the idea is to leave the question of interest open, but using prior information about the behaviour of the other variables through the sign and the narrative sign restrictions.

This agnostic approach is especially important because, notwithstanding the relevance of the topic, there is still a lack of consensus among researchers and policy-makers about the effects of forward guidance. For example, McKay et al. (2016) find that the effect on GDP in models with incomplete markets is much lower than in models with complete markets.[2] Nonetheless, a few quarters of forward guidance is still powerful enough to effectively prevent recessions. In contrast, after adding several features to McKay et al. (2016)'s model to bring it closer to the data, Hagedorn et al. (2019) find that the effects of forward guidance

[2]McKay et al. (2016) combine elements from standard New Keynesian models, such as nominal rigidities, with elements from standard incomplete models, such as uninsurable risks and borrowing constraints. See also Del Negro et al. (2012) for a discussion of the forward guidance puzzle.

are, in fact, negligible.

VAR models can then help shed some light on New Keynesian models, providing them with some reference and bringing them even closer to the data. Being Bayesian, it also allows for a formal comparison between the effects of forward guidance and the effects of conventional monetary policy in a high posterior density interval (HPDI) sense.

Therefore, the contribution of this paper is twofold. In terms of identification, the novelty is to employ in the same agnostic set-up all the available extraneous information, namely futures surprises and narrative evidence, which is useful for the identification of the structural shocks. The economic contribution is to show that, using this identification strategy, forward guidance is an effective policy tool.

Specifically, results show that the direction of the effect of conventional monetary policy is the expected even in a recent US sample, in contrast with the evidence reported by Barakchian and Crowe (2013) and Ramey (2016). In terms of magnitude, the response of industrial production following a conventional monetary policy shock is larger than suggested by a range of empirical estimates. Results also show that the effect of forward guidance can be at least as strong as the effect of conventional monetary policy.

Related Literature

The papers most closely related to this one can be divided into two groups. In the first group, forward guidance is mixed with conventional monetary policy. By using futures contracts whose horizon comprises at least the next FOMC meeting, the shocks coined as monetary policy shocks in the next two papers incorporate the impact of forward guidance. Andrade and Ferroni (2018) employ market-based measures of inflation expectations and future interest rates together with sign restrictions to identify Delphic and Odyssean monetary shocks. In a similar endeavour, Jarociński and Karadi (2020) explore the co-movements of interest rates and stock prices around the announcements combined with sign restrictions to identify monetary policy shocks and central bank information shocks. Debortoli et al. (2019) estimate a time-varying VAR that uses the 10-year government bond rate as a policy indicator and find that the responses to different shocks do not present material differences in the ZLB. The corollary is that unconventional monetary policy (including forward guidance) acted as a substitute for conventional monetary policy.[3]

In the second group, forward guidance is isolated from conventional monetary

[3]In a similar vein, Swanson (2018) shows the Federal Reserve was not very constrained in its ability to influence medium- and longer-term interest rates and the economy due to effective forward guidance and the large-scale asset purchases.

policy. Similar to this paper, D'Amico and King (2015) combine measures of expectations with sign restrictions. Differently, however, they use survey-based measures of macroeconomic variables, which may respond with some delay as pointed out by Coibion and Gorodnichenko (2012, 2015) and may not fully isolate forward guidance shocks from other shocks affecting expectations. In fact, D'Amico and King (2015) acknowledge that any information, not only the shocks generated by forward guidance, which causes agents to change beliefs about the future course of monetary policy, should be captured in their identification. They see it as an advantage as they seem to be interested in overall anticipated monetary policy. Nevertheless, for the purpose of this paper, disentangling forward guidance shocks from conventional monetary shocks or any other kind, this would be a weakness.

Lakdawala (2019) uses market-based measures of expectations, specifically the Gürkaynak et al. (2005)'s target and path factors. Unlike this paper, however, he employs such measures as external instruments in the VAR, what raises concerns in the presence of anticipation effects. Since the path factor captures news about future changes in the policy rate, it is considered safer to incorporate it into the vector of variables in the VAR (Ramey, 2016). Moreover, Lakdawala (2019)'s sample period starts long before the use of forward guidance by the FOMC.

Bundick and Smith (2019) also use surprises in futures contracts to examine the macroeconomic effects of forward guidance. They compute the daily surprises in the 12-month ahead federal funds futures contract, which, in theory, would also encompass the conventional monetary policy shock. In that case, however, this is not a concern since they focus on the ZLB. This measure of forward guidance shocks is then ordered last in a recursive VAR. A caveat is that by restricting their sample to the ZLB, their estimation disregard numerous episodes of forward guidance that took place in the periods pre or post-ZLB. Hansen and McMahon (2016) follow a different path. They use tools from computational linguistics to extract and measure the information released by the FOMC on the state of economic conditions and on forward guidance, which is inputted in a factor-augmented VAR model identified recursively.

This paper complements this recent literature by combining the advantages of high-frequency identification with the appeal of narrative sign restrictions to identify the dynamic responses of important macroeconomic and financial variables to conventional monetary policy and forward guidance shocks. The rest of the paper is organised as follows. Section 2 describes the econometric approach. Section 3 presents the results. Section 4 concludes.

2 Econometric Framework

The point of departure for the analysis is a VAR model of the form:

$$\begin{pmatrix} m_t \\ y_t \end{pmatrix} = c + \sum_{p=1}^{P} \beta^p \begin{pmatrix} m_{t-p} \\ y_{t-p} \end{pmatrix} + A_0 \varepsilon_t, \tag{1}$$

where m_t is a vector of N_m surprises. The monthly series are built by adding up the intra-day surprises occurring in month t on the days of FOMC meetings and letting the series take a value of zero in months without FOMC announcements. y_t is a vector of N_y monthly macroeconomic and financial variables. p denotes the lags, with $p = 1, ..., P$. The structural shocks ε_t are related to the reduced-form innovations u_t via $u_t = A_0 \varepsilon_t$ where A_0 is a decomposition of the the covariance matrix Σ such that $Var(u_t) = A_0 A_0' = \Sigma$.

The baseline Bayesian VAR is estimated for the US using a flat prior and 5 lags[4] on 7 macroeconomic and financial variables (2 high-frequency variables (m_t) and 5 low-frequency variables (y_t)) spanning the period from 1993M01 to 2017M12. m_t includes the target and path factors. y_t consists of the consumer price index (CPI), the industrial production index (IP), the fed funds rate (FF), the 2-year government bond rate (GS2), and the excess bond premium (EBP) computed by Gilchrist and Zakrajšek (2012). The first two variables of y_t are in log levels.

The target and path factors are constructed based on the methodology of Gürkaynak et al. (2005). Surprises in the prices of fed funds futures and Eurodollar futures are computed for a 30-minute window around 220 scheduled and unscheduled FOMC meetings to estimate these two factors.[5] By construction, the target factor accounts for most of the surprise in the futures rates for the current month (FF1) and the path factor influences only expected future rates.[6]

Gürkaynak et al. (2005) show the path factor is closely related with FOMC statements.[7] Such forward-looking statements provide agents with news on future information about changes in short-term interest rates. Furthermore, as a

[4]This choice was based on the Akaike information criterion (AIC), which is considered the most accurate criterion for monthly VARs by Ivanov and Kilian (2005).

[5]Such surprises also capture the effects of the large-scale asset purchases. This is not an issue since there is evidence that the main effect of the Federal Reserve bond purchases was via "signaling effects that lower expected future short-term interest rates", namely forward guidance (Bauer and Rudebusch, 2013). Following Campbell et al. (2012), however, the outlier meetings in September 2001 (9/11) and March 2009 (QE1) were dropped.

[6]See Gürkaynak et al. (2005) for the constructions of the factors.

[7]Gürkaynak et al. (2018) provide further evidence in this regard. They show there is a close correspondence between the path factor and a latent factor that captures non-headline news.

market-based measure of expectations, the path factor is robust to concerns usually associated with survey-based measures of expectations, such as staleness and insufficient skin in the game (Coibion and Gorodnichenko, 2012, 2015).

Due to its characteristics, in order to address the effects of anticipation in monetary policy, the path factor is incorporated into the vector of the variables in the VAR and not used as an external instrument.[8] In a model with news shocks, the inclusion of variables that reflect views on the future path of the economy is even more relevant since their omission can potentially lead to misspecification (D'Amico and King, 2015).

The excess bond premium, introduced by Gilchrist and Zakrajšek (2012), is a corporate bond credit spread purged from the default risk, with a high informational content about the economy. As pointed out by Caldara and Herbst (2019), the inclusion of credit spreads is of paramount importance and can result in large differences in the effects found in VAR models. This happens because an increase in credit spreads generates a persistent decrease in real activity and a failure to account for this endogenous reaction induces an attenuation in the response of all variables to monetary shocks.[9]

The use of two policy indicators (the fed funds rate and the 2-year government bond rate) is crucial to the decomposition of monetary policy shocks into conventional and forward guidance shocks. Moreover, the sample does not stop in 2007 or 2008, as it is typical in VAR models of monetary policy due to the turbulence caused by the financial crisis and the following ZLB period, because this would jeopardise the objective of this paper since forward guidance was intensively used during the ZLB period. The 2-year government bond rate was chosen because it is consistent with the horizon of forward guidance. The other variables are standard: CPI and IP.[10]

2.1 Identification

This subsection explains how high-frequency data are combined with sign restrictions and narrative information within this econometric framework to identify the two shocks of interest: forward guidance and conventional monetary policy shocks.

[8] Section 2.2 further elaborates on this issue.

[9] See also Section 9 of Miranda-Agrippino and Ricco (2019).

[10] Results are similar when the sample period ends in 2012 as shown in the Appendix. While this span reduces the influence of the zero lower bound in the estimation, it still includes an important episode of forward guidance used in the identification.

2.1.1 Sign restrictions and high-frequency identification

Following Rubio-Ramirez et al. (2010), a candidate A_0 is found by calculating $\tilde{A}_0$, an arbitrary matrix square root of Σ, using Cholesky and multiplying it with a rotation matrix Q. The impulse responses using this candidate structural impact matrix are then checked and kept if the restrictions are satisfied.

Sign restrictions are placed on high- and low-frequency variables. Nevertheless, similar to Uhlig (2005)'s proposal, the procedure is agnostic about the response of the industrial production after both shocks. This is robust to the mixed evidence for the importance of monetary shocks found by Ramey (2016) and compatible with the absence of effects of monetary policy on real activity in regressions run for the Great Moderation period. Following Uhlig (2005), however, to compensate for that agnostic approach, restrictions are applied to a longer period.

It is postulated that a monetary policy shock increases the fed funds rate and the EBP and reduces the CPI for periods 0 to 5 months. In order to disentangle monetary policy shocks and prevent them from being a combination of other underlying shocks that satisfy the restrictions placed on the low-frequency variables, it is further assumed the target path moves up on impact.[11]

A forward guidance shock is defined as a shock that increases the 2-year government bond rate and the EBP and decreases the CPI for period 0 to 5 months. Because forward guidance shocks are assumed to have no contemporaneous effect on the fed funds rate, the response of the fed funds rate is zero on impact. Furthermore, the path factor rises on impact. Once more, the inclusion of the factor is important to isolate the shock of interest from other shocks that might affect similarly the 2-year government bond rate, the CPI, and the EBP. Table 1 summarises the restrictions.[12]

Table 1: Zero and sign restrictions on responses

	MP shock	FG shock
target factor	+	
path factor		+
IP		
CPI	-	-
EBP	+	+
fed funds	+	0
2-year rate		+

[11] Uhlig (2005) restricted the response of the nonborrowed reserves with the same objective.

[12] No zero restrictions were placed on the factors as this would increase the burden on the importance sampling.

The restrictions on the lower-frequency variables are standard and motivated by the New Keynesian set-up. Several sources (e.g. Smets and Wouters (2007), Gertler and Karadi (2011), McKay et al. (2016), Hagedorn et al. (2019)) show that Table 1 describes the expected responses to monetary and forward guidance shocks.[13] The restrictions on the high-frequency variables are such that the shock of interest is isolated. Because the window around the release is very narrow, it is assumed the surprises are not affected by macroeconomic news other than the announcement.

Moreover, since, as aforementioned, the path factor is closely related to FOMC statements, which telegraph not only forward guidance but also central bank private information, the sign restrictions on the EBP and the CPI are important to cleanse, by construction, the forward guidance shock from any informational advantage the central bank may have. As shown in Jarociński and Karadi (2020), information shocks are expected to have the opposite effect on the EBP and the CPI. The combination of sign restrictions and high-frequency data then lends itself to an ideal way to properly disentangle pure monetary and forward guidance shocks.

However, the set of admissible structural parameters implied by sign restrictions can sometimes be too large with very different or implausible implications for the results. Arias et al. (2019) pointed out this is the case in Uhlig (2005), for instance, in which the posterior probability bands of the impulse responses are very wide and structural parameters incompatible with the systematic response of monetary policy to output are retained.

2.1.2 Narrative information

In order the to refine the set of admissible structural parameters, the narrative account of a small number of key and uncontroversial events will be used to motivate further restrictions when estimating sign-identified VAR models as in Antolín-Díaz and Rubio-Ramírez (2018). This approach brings some flavour of the historical case studies pioneered by Friedman and Schwartz (1963), which are seen by Ramey (2016) as the best sources of evidence regarding the effects of monetary policy shocks.

In practice, to check if the narrative sign restrictions are satisfied, evaluate the following inequalities:

$$\varepsilon_{j,t}(\Theta) > 0 \tag{2}$$

$$|H_{i,j,t}(\Theta, \varepsilon_t(\Theta))| > \sum_{j' \neq j} |H_{i,j',t}(\Theta, \varepsilon_t(\Theta))| \tag{3}$$

where Θ collects the values of all structural parameters, the first inequality implies

[13] Despite the conflicting quantitative results for forward guidance shocks, the different models agree on the direction of the responses.

jth shocks must be positive at time t and the second inequality implies the contribution of the jth shock to variable i at time t must be greater than the sum of the contribution of all the other shocks to variable i at time t. The full algorithm is described in the Appendix.

For the monetary policy shocks, the main source is Antolín-Díaz and Rubio-Ramírez (2018), who examined in detail episodes that are good candidates to have been conventional monetary policy. The dates that are comprised in the shorter sample period here considered are: February 1994, October 1998, April 2001 and November 2002. Antolín-Díaz and Rubio-Ramírez (2018) also point out it is possible to obtain qualitatively similar results imposing narrative restrictions only for February 1994 or April 2001 on their own.[14]

Particularly, February 1994 was the month the FOMC began a series of tightening moves and caught the market by surprise. In April 2001, the FOMC decreased the fed funds rate unexpectedly in between scheduled meetings (Antolín-Díaz and Rubio-Ramírez, 2018).

For the forward guidance shocks, the main references are Gürkaynak et al. (2005) and Campbell et al. (2012), who scrutinised the FOMC statements and highlighted some important episodes of forward guidance. Some examples are:

August 2011, when the FOMC specified the intended time length of the stimulus and replaced "extended period" with "mid-2013": "The Committee currently anticipates that economic conditions ... are likely to warrant exceptionally low levels for the federal funds rate at least through mid-2013."

January 2012, when the FOMC replaced "mid-2013" with "late 2014": "the Committee ... currently anticipates that economic conditions ... are likely to warrant exceptionally low levels for the federal funds rate at least through late 2014."

September 2012, when "late 2014" was replaced with "mid-2015": "the Committee ... currently anticipates that exceptionally low levels for the federal funds rate are likely to be warranted at least through mid-2015."

December 2012, when forward guidance became based on the state of the economy: "the Committee ... currently anticipates that this exceptionally low range for the federal funds rate will be appropriate at least as long as the unemployment rate remains above 6-1/2 percent, inflation between one and two years ahead is projected to be no more than a half percentage point above the Committee's 2 percent longer-run goal, and longer-term inflation expectations

[14]It is worth noting, however, that when their sample is shortened to 1993-2007, such restrictions are no longer sufficient to imply that contractionary monetary policy shocks cause output to fall (not even using a Minnesota prior).

continue to be well anchored."

March 2015, when the FOMC announced the intention to patiently begin the normalisation: "The Committee anticipates that it will be appropriate to raise the target range for the federal funds rate when it has seen further improvement in the labor market and is reasonably confident that inflation will move back to its 2 percent objective over the medium term."

Because restrictions are placed on both shocks, parsimony is required. After cross-checking market responses, news and the literature to select only the crucial dates, the surviving restrictions are:

Narrative Sign Restriction 1. The monetary policy shock must be positive for the observation corresponding to February 1994.

Narrative Sign Restriction 2. For the period specified by Restriction 1, the monetary policy shock is the overwhelming contributor to the observed unexpected movements in the federal funds rate. In other words, the absolute value of the contribution of monetary policy shocks is larger than the sum of the absolute value of the contribution of all other structural shocks.

Narrative Sign Restriction 3. The forward guidance shock must be negative for the observation corresponding to January 2012.

It should be noted that, because the literature about forward guidance is still infant, the restrictions placed on this shock are much weaker. One has only to be confident that a forward guidance shock occurred regardless of what happened to the other shocks. January 2012 is chosen because it is considered one of the strongest episodes of forward guidance, being even the benchmark for the simulation in Campbell et al. (2012). Checking the high-frequency data around the announcement in that month, it is possible to confirm that the surprises show the expected behaviour: the change in the path factor is negative and the change in the SP500 is positive. Furthermore, it is possible to get qualitatively similar results using different restrictions.

2.2 Potential Advantages over Proxy SVARs

Proxy SVARs rely on external instruments correlated with the shock of interest, and uncorrelated with other structural shocks. Moreover, to address the issue of whether the high-frequency surprises are truly exogenous or just reflect the Fed's private information, the measures or surprises are regressed on measures of the Fed's private information. The results, however, are dependent on the way this measure is built and can be puzzling (Miranda-Agrippino and Ricco, 2019; Ramey, 2016).

The narrative approach, however, does not rely on an exogeneity assumption and has a more straightforward implementation. Even when other shocks take place on the selected episodes, one has only to be confident i) that a specific shock occurred regardless of what happened to the other shocks when restrictions are imposed only on the sign of the shocks; and/or ii) that this shock was more relevant than other ones when the restrictions are imposed on the historical decomposition (Antolín-Díaz and Rubio-Ramírez, 2018).

This is particularly pertinent for forward guidance shocks since they are very often accompanied by information shocks. Even in that case, there is no need to purge the path factor from central bank private information when the narrative sign restrictions are implemented. This is achieved by construction through the sign restrictions as already pointed out.

Another potential advantage is associated with the invertibility assumption. Plagborg-Møller and Wolf (2019), Miranda-Agrippino and Ricco (2019) and Paul (2019) show that, under some conditions, the impulse responses obtained with Proxy VARs are equivalent to the ones obtained with a recursive scheme that includes the instrument as an endogenous variable and orders it first. Nonetheless, with news shocks, or more specifically forward guidance shocks, invertibility concerns become even more serious (Plagborg-Møller and Wolf, 2018; Ramey, 2016). Incorporating the path factor into the vector of variables of the VAR makes the inference valid even if the VAR without it is not fully or partially invertible.

This is in line with and exemplified in D'Amico and King (2015). They show that, for the specific case of forward guidance, measures of expectations should be included in the VAR to avoid misspecification even when there is no special interest in these variables. Including the path factor in the VAR as a variable tackles this issue.

3 Results

3.1 Impulse Responses

Figure 1 shows the impulse responses to a one-standard-deviation conventional monetary policy shock. Grey and blue represent the results with only sign restrictions, and pink and red represent the narrative sign restrictions. Unless otherwise stated, the estimates discussed in this section refer to the red line (narrative sign restrictions).

Narrative Sign Restrictions 1, 2 and 3 are jointly imposed on top of the sign restrictions displayed in Table 1 and the impulse responses are normalised so that the initial impact on the fed funds (FF) is the same across the identification schemes, approximately 5 basis points. As in Nakamura and Steinsson (2018) and Jarociński and Karadi (2020), monetary shocks are quite small.[15]

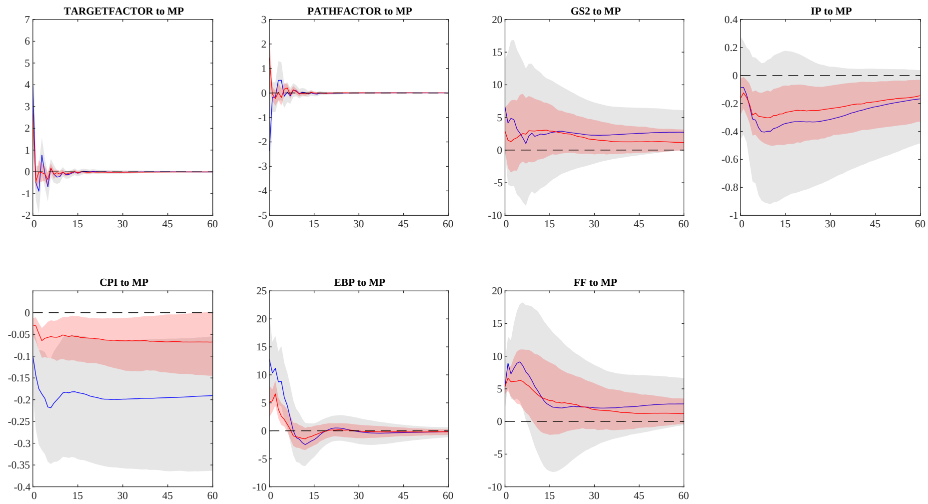

Figure 1: Impulse Responses to a Conventional Monetary Policy Shock

Notes: The grey shaded area represents the 68 percent (point-wise) HPD credible sets for the IRFs and the blue lines are the median IRFs using sign restrictions. The pink shaded areas and the red lines display the equivalent quantities for the models that additionally satisfy narrative sign restrictions.

The narrative restrictions narrow down the high posterior density interval substantially and industrial production falls on impact and this effect is persistent. This result is stronger than Antolín-Díaz and Rubio-Ramírez (2018) re-estimated for a post-90 sample and subject to Narrative Sign Restriction 1 and 2 as their VAR would not have found any effect of monetary policy on industrial production for this new specification.

The "significant" decrease of industrial production also contrasts with the evidence reported by Barakchian and Crowe (2013) and Ramey (2016), who show that several specifications and identification schemes do not lead to the expected responses when estimated for recent periods. On the other hand, the behaviour of industrial production is similar to Caldara and Herbst (2019), who find a persistent decline in real activity for a recent sample after incorporating credit spreads. Coupled with the imposition of restrictions for 6 periods, this leads to rather persistent effects.

The posterior median falls almost 0.2%, an order of magnitude somewhat larger than Gertler and Karadi (2015)'s benchmark result and much larger than suggested by a range of empirical estimates according to which, in response to a 1 percentage

[15] Their monetary shocks, however, comprise conventional monetary policy shocks and forward guidance shocks.

point contractionary monetary policy innovation, output and prices fall around 0.5 to 1 percent at the peak (Cloyne and Hürtgen, 2016). The fall, however, is in line with Romer and Romer (2004) before the adjustments proposed by Coibion (2012) as well as similar to the response found by Gertler and Karadi (2015) after they clean their measure of policy surprises of the Fed's private information.[16] Furthermore, it should be noted that, although the median response of industrial production is outside the "expected" range (-0.025 – -0.05%), this "expected" range is within the credible set.

CPI decreases on impact and around 0.05% in the long run. The magnitude is in line with the values found in previous studies. The excess bond premium goes up 5 basis points and GS2 increases in approximately 12 months by half of the magnitude of the initial impact on FF, but 0 is within the interval. Also, it is worth noting that the narrative restrictions reduce the magnitude of the responses of the EBP and the CPI.[17]

Figure 2 shows the impulse responses to a one-standard-deviation forward guidance shock. The impulse responses are normalised so that the initial impact on GS2 is the same across the identification schemes, approximately 8 basis points. The industrial production index falls more than 0.2% after 1 year and for some time with no effects on impact, contradicting the New Keynesian model.

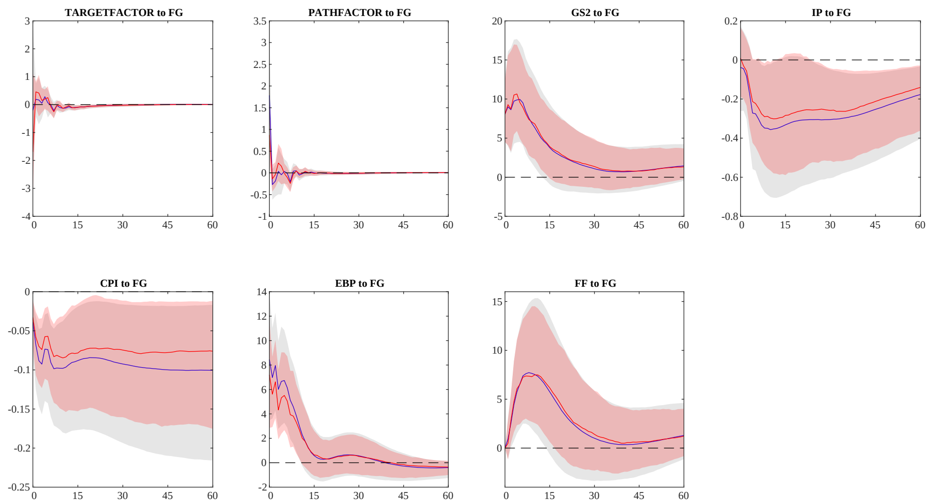

Figure 2: Impulse Responses to a Forward Guidance Shock

Notes: The grey shaded area represents the 68 percent (point-wise) HPD credible sets for the IRFs and the blue lines are the median IRFs using sign restrictions. The pink shaded areas and the red lines display the equivalent quantities for the models that additionally satisfy narrative sign restrictions.

[16] More recently, Holm et al. (2020) also found new evidence of strong effects on industrial production at a monthly frequency for Norway.

[17] Even though factors are built to be unconditionally uncorrelated, their correlation conditional on the other variables in the system differs from zero.

Even though both MP and FG shocks affect the economy due to their effect on the path of expected future short-term real interest rates, it seems that forward guidance takes more time to influence output. CPI goes down around 0.08% and the excess bond premium increases 7 basis points. The fed funds rate goes up in 12 months by a magnitude slightly lower than the initial impact on GS2.

Overall, the responses do not change much when the narrative restrictions are applied, especially of GS2, FF and EBP. This happens because the restriction is weaker and the posterior distribution of the forward guidance shock for January 2012 using only sign restrictions is already concentrated below zero. Still, the narrative restrictions help reduce the HPDI for CPI and industrial production. Lastly, it should be noted that the response of the industrial production to a forward guidance shock is at least as strong as its response to a conventional monetary policy shock in a HPDI sense as displayed in Figure 3.

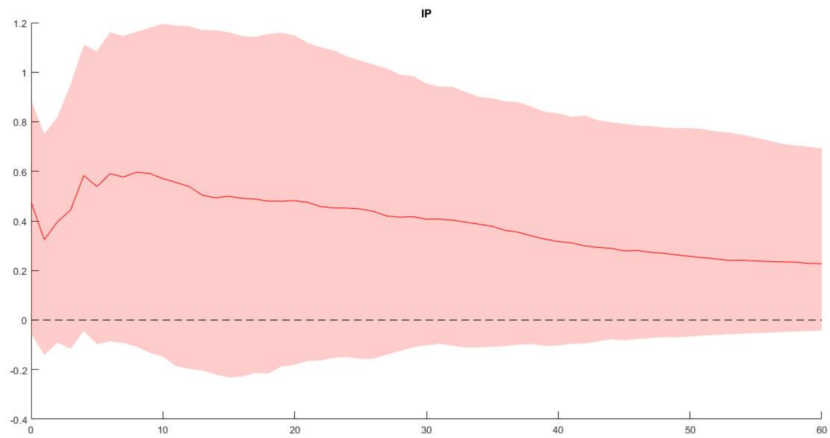

Figure 3: Difference in Impulse Responses of IP

Notes: The pink shaded area represents the 68 percent (point-wise) HPD credible sets for the difference between the IRFs of IP after a FG shock and after a MP shock. In order to make the original impulse responses comparable, they are normalised so that the initial impact on GS2 is the same after both shocks: 8 basis points.

Benchmarks for the effect of forward guidance shock in VARs are more scarce. In Lakdawala (2019)'s main results, CPI and industrial production rise. After cleansing the path factor of Fed private information, the price puzzle remains and there is a small but insignificant decline in output. D'Amico and King (2015) find a significant reduction on impact for both CPI and output. They find responses to the policy-expectations shock stronger than the responses to the unanticipated shock. Bundick and Smith (2019) find that expansionary forward guidance shocks lead to moderate increases in output and the price level. Despite not being able to formally compare the results with the effects of conventional monetary policy shocks due to their focus on the ZLB, they find, as in here, that forward guidance shocks share many empirical features with conventional monetary policy shocks.

To sum up, the results show forward guidance matters for macroeconomic outcomes, including industrial production, being an effective policy tool. In fact, it may be an important part of shocks labelled as monetary policy shocks. Nakamura and Steinsson (2018) and Jarociński and Karadi (2020), for instance, acknowledge that their monetary policy indicator/surprises capture the effects of "forward guidance" whereas here the monetary policy shock captures only the conventional monetary policy shock.

3.2 Variance Decomposition

Figure 4 presents the forecast error variance decomposition of the VAR along 10 years, measuring the reduction in the forecast variance resulting from knowing future realisations of each shock. As aforementioned, the estimated shocks are quite small. This is a by-product of the high-frequency identification and has consequences for both the variance decomposition and the historical decomposition.

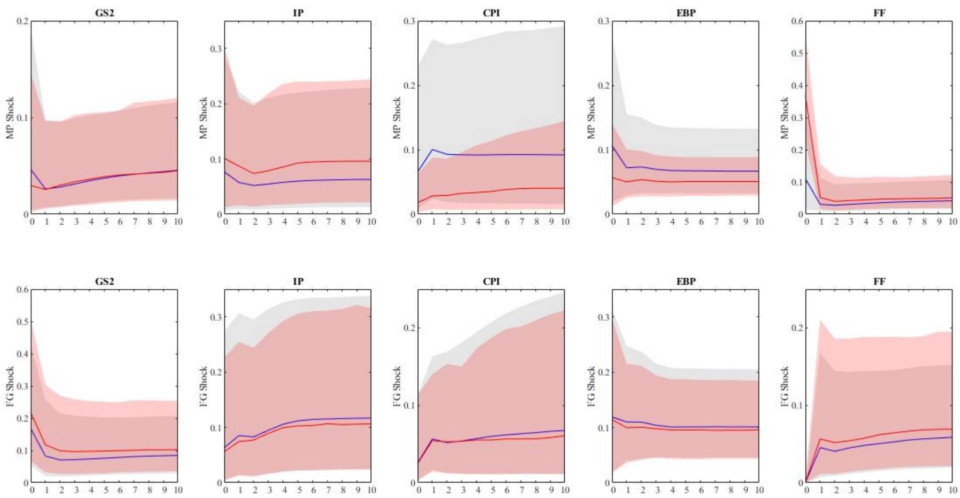

Figure 4: Forecast Error Variance Decomposition

The narrative restrictions reduce the credible set of most of the variables. The conventional monetary policy shock explains a negligible fraction of short-run movements in CPI and IP in line with previous literature even though the number for the contribution to the CPI is lower than usual. The conventional monetary policy shock explains very little of the forecast error variance of the excess bond premium and of the 2-year government bond rate. The contribution to the fed funds changes heavily after the imposition of the narrative restrictions and the percentage on impact as well as its decay over time are in line with a trivariate VAR identified with standard sign restrictions.

Forward guidance shocks also explain a negligible fraction of short-run movements in CPI and IP, albeit slightly larger than the contribution of MP shocks to CPI. On the other hand, forward guidance shocks explain a reasonable percentage of the forecast error variance of GS2, especially on impact and with some degree of persistence if compared to the behaviour of the other variables. The reverse happens to the fed funds, to whose variance there is no contribution on impact, but some contribution arises over time. For the excess bond premium, the percentage doubles when compared to the MP shock. When comparing, however, one should bear in mind that posterior uncertainty is large.

3.3 Historical Decomposition

This subsection investigates the cumulative role played by the estimated shocks in driving the variables of the model. In order to do so, the historical decomposition of selected variables are displayed. Although the shocks are small, it is still possible to match the historical decomposition of some variables with historical episodes.

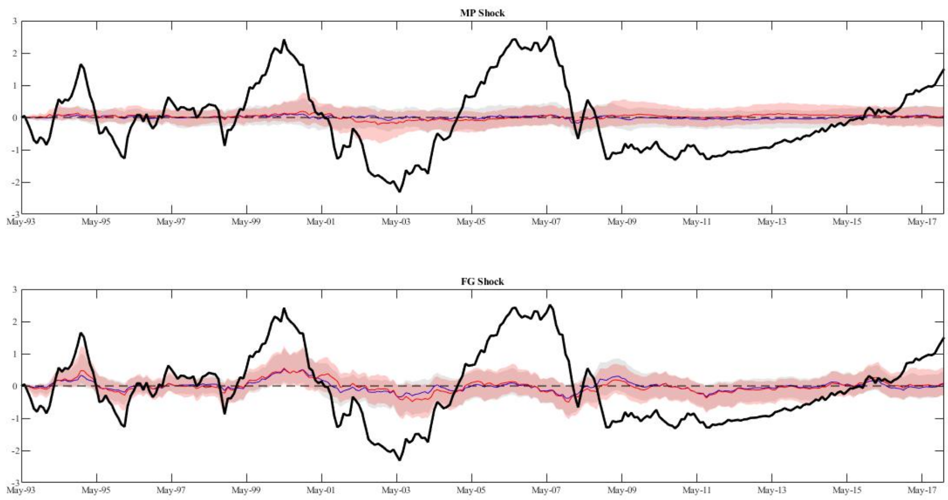

Figure 5: Historical Decomposition of the 2-year government bond rate

Figure 5 shows the historical decomposition of the 2-year government bond rate. According to the top graph, the conventional monetary policy shock did not contribute to GS2. Regarding the bottom graph, the identification approach interprets the peak in December 1994 as a response to a forward guidance shock deriving probably from the expectation that the series of tightening initiated in 1994 would continue in 1995. In December 1994, as a consequence of this fear of more tightening moves, the magnitude of the adjustment in the 2-year rate was much higher than the change in the fed funds rate. Likewise, the spike in GS2 in late 1999 following a statement that announced a change in policy bias going forward from neutral to tightening was interpreted as the endogenous response to the forward guidance shock.

Later, in 2003, the downturn in GS2 is also interpreted as responses to forward guidance shocks, following the statements announcing that balance of risks is dominated by risk of “an unwelcome substantial fall in inflation” (May) and maintaining the expression “considerable period” (October), pushing back expectations of future tightening moves. This started to be reversed after the expression “considerable period” was dropped in January 2004. In late 2011 and early 2012, the episodes of forward guidance already analysed had a slightly negative but “not significant” contribution to GS2.

Figure 6 shows the historical decomposition of the fed funds rate. In addition to February 1994, the conventional monetary policy shock contributed to the peak in the fed funds in the end of 2000. During that year, successive increases took place in the policy rate as part of a process of monetary tightening that had begun in early 1999. Particularly, in May 2000 the committee stated the belief that “the risks continue to be weighed mainly toward conditions that may generate heightened inflation pressures in the foreseeable future” and approved a 50 basis points increase in the policy rate.

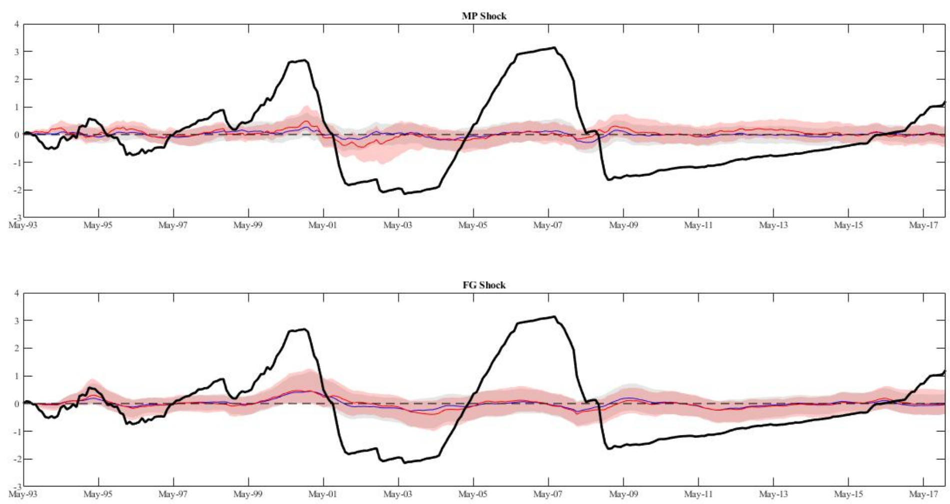

Figure 6: Historical Decomposition of the Fed Funds

According to the bottom graph, only some of the forward guidance shocks that contributed to GS2 also play an important role in the fed funds rate. Moreover, as expected, the impact on the fed funds rate takes place with some delay. First, the forward guidance shock also contributed to the spike in the fed funds rate in late 2000. Second, the decrease in the fed funds rate in the end of 2003 and in the beginning of 2004 is also interpreted as an endogenous response to the forward guidance shock.

Figure 7 shows the historical decomposition of industrial production. Neither shock contributed materially to the industrial production, showing that, despite their effects in the impulse responses, monetary policy and forward guidance shocks were not so important in driving the industrial production during the period analysed. Finally, it should be noted that, for all the variables, if the results described were the ones based on the sign restrictions only, most of the episodes would not have been relevant in the probabilistic sense.

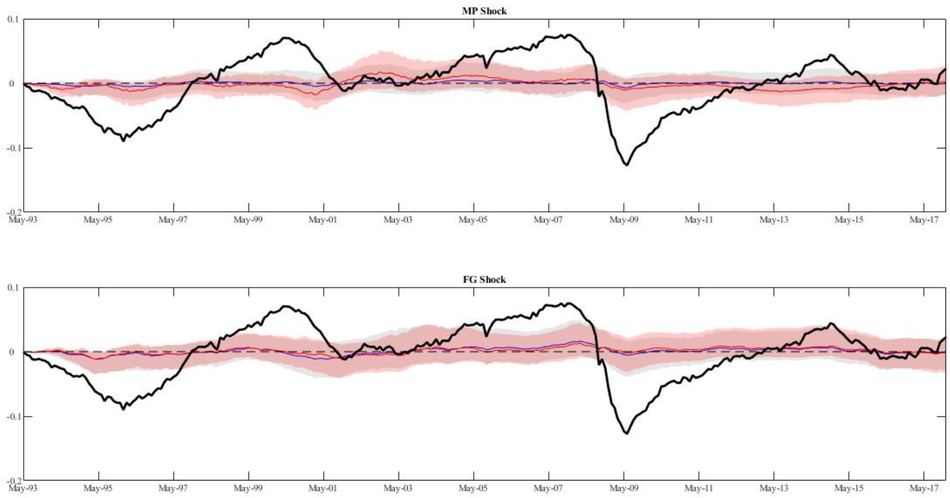

Figure 7: Historical Decomposition of the Industrial Production

3.4 Informational Sufficiency

A common concern about VARs is whether the structural shocks are fundamental. In a model with shocks that may be anticipated by economic agents, such concern is even more important. To check this, the orthogonality F-test proposed by Forni and Gambetti (2014) is conducted. It consists of a regression of the shocks on a large dataset capturing agents' information set and an F-test for the significance of the regression. In practice, the agents' information set is summarised by the past values of principal components of the FRED-MD database (McCracken and Ng, 2016).

The idea is that if the shocks are predicted by past available information, the structural MA representation of the variables included in the VAR is non-fundamental and the VAR is misspecified, in the sense that there is not sufficient information to recover the structural shocks. Such an approach is appealing in that it does not require a well-defined theoretical model of reference.

Table 2 presents the results of the test for different combinations of the number of lags and principal components. The hypothesis that the shocks are not predicted by past available information is not rejected for either of shocks or number of lags, when the choice of principal components is based on the Bai and Ng (2002)'s criteria (PC=7). Such result is robust to different numbers of PCs. This orthogonality to the past of the "state variables" associated with a correct identification scheme implies both shocks are indeed the desired object of interest: conventional monetary shocks and forward guidance shocks.

Table 2: p-Values of the orthogonality F-test proposed by Forni and Gambetti (2014)

	2 lags			4 lags		
	PC=4	PC=7	PC=10	PC=4	PC=7	PC=10
MP shock	0.98	0.91	0.48	0.99	0.88	0.19
FG shock	0.81	0.19	0.22	0.93	0.43	0.10

3.5 Using other events

The benchmark results rely on episodes that took place in February 1994 and January 2012. Nevertheless, as listed previously, there are other informative episodes that can be used. First, March 2015, when the FOMC announced the intention to patiently begin the normalisation, is explored as an episode of contractionary forward guidance. Although there is less information about this event in the literature, it received abundant media coverage.

Despite the fact that the responses are qualitatively similar to the benchmark, the response of IP to the forward guidance shock was stronger as reported in Figure 8. Most importantly, IP responds almost on impact as suggested by New Keynesian models. The impulse responses for the monetary policy shock are unchanged and presented in the Appendix.

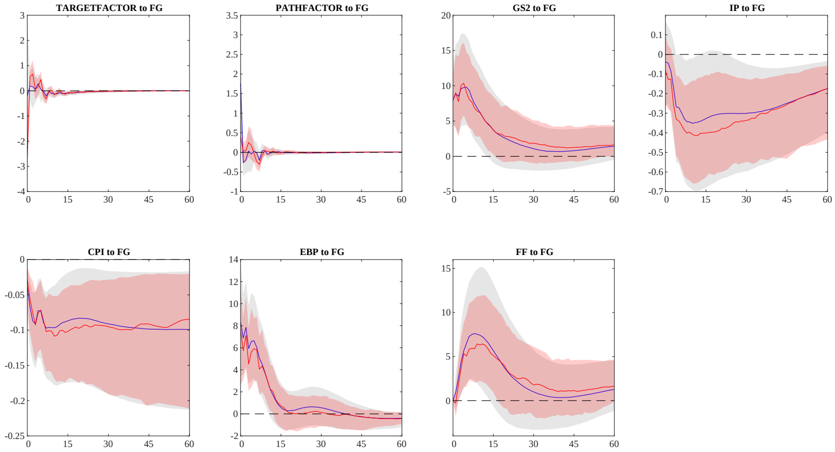

Figure 8: Impulse Responses to a Forward Guidance Shock Using March 2015

Notes: The grey shaded area represents the 68 percent (point-wise) HPD credible sets for the IRFs and the blue lines are the median IRFs using sign restrictions. The pink shaded areas and the red lines display the equivalent quantities for the models that additionally satisfy narrative sign restrictions.

Second, the sign of the shocks of Antolín-Díaz and Rubio-Ramírez (2018)'s episodes comprised in 1993-2017 are restricted: February 1994 (+), October 1998 (-), April 2001 (-) and November 2002 (-). The restriction on the FG shock is kept unchanged.

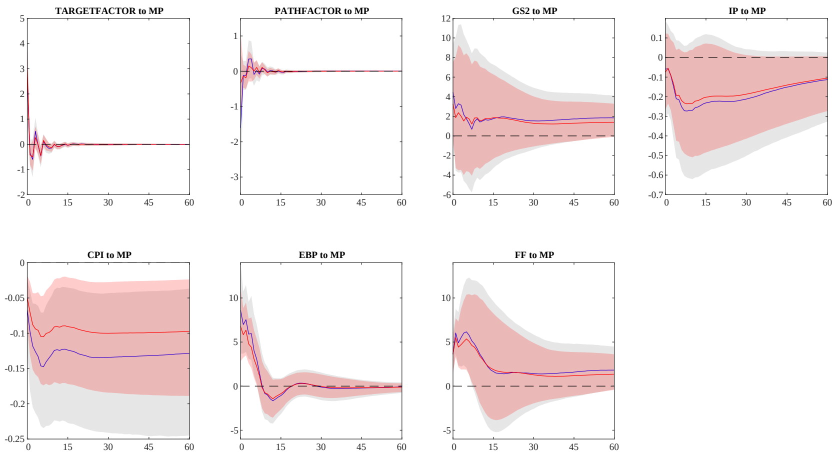

Figure 9: Impulse Responses to a Conventional Monetary Shock Using Restrictions on the Sign of the Shocks

Notes: The grey shaded area represents the 68 percent (point-wise) HPD credible sets for the IRFs and the blue lines are the median IRFs using sign restrictions. The pink shaded areas and red lines display the equivalent quantities for the models that additionally satisfy narrative sign restrictions.

Figure 9 shows that the impulse responses following a monetary policy shock have wider credible sets, implying that these four restrictions on the sign of the shocks are weaker than the benchmark restriction. The interval for the impulse response of industrial production following a conventional monetary policy shock now includes zero.

Overall, however, posterior medians are virtually unaltered. The same is true for the forward guidance shock in Figure 10, with the only significant difference being that 0 is outside the credible set for IP even sooner. Additional robustness exercises are presented in the Appendix.

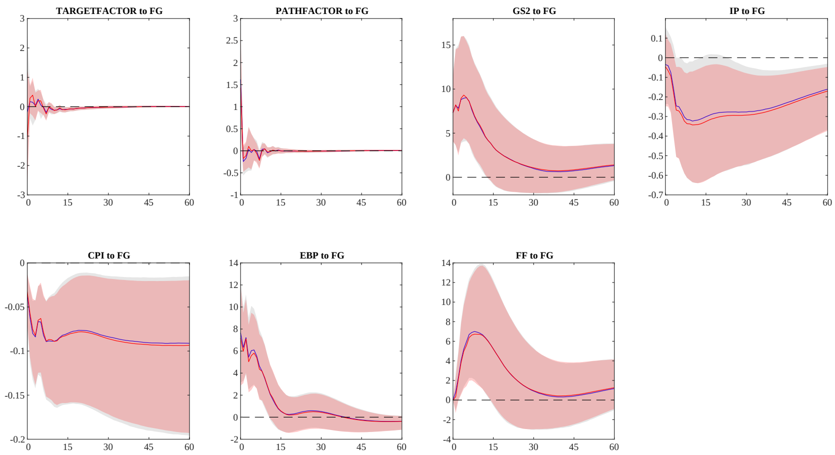

Figure 10: Impulse Responses to a Forward Guidance Shock Using Restrictions on the Sign of the Shocks

Notes: The grey shaded area represents the 68 percent (point-wise) HPD credible sets for the IRFs and the blue lines are the median IRFs using sign restrictions. The pink shaded areas and red lines display the equivalent quantities for the models that additionally satisfy narrative sign restrictions.

4 Conclusion

This paper has addressed the identification of conventional monetary policy and forward guidance shocks. In order to do that, two sources of extraneous information – high-frequency surprises and narrative evidence – were combined with sign restriction in a structural VAR. The factors allow for a proper isolation of conventional monetary and forward guidance shocks from other shocks (or a combination of shocks) that satisfy the sign restrictions placed on the low-frequency variables. The narrative restrictions help further refine the credible set.

Results show that, in contrast with the evidence reported by Barakchian and Crowe (2013) and Ramey (2016), the identification scheme leads to the expected responses for output following a conventional monetary policy shock even when the model is estimated for a recent sample: 1993-2017. In fact, a quite large effect emerges from the refinements in the identification.

Results also show that forward guidance has been an effective policy tool. Therefore, forward guidance matters not only to the proper identification of conventional monetary policy shocks but also due to its effect on output and other macroeconomic variables. Specifically, its effects on industrial production are at least as strong as the effects of conventional monetary policy.

Several robustness exercises show that the results hold under alternative specifications. An important implication of such results is that they provide additional support for the view that the Federal Reserve may not be so constrained even during ZLB periods.

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Appendix

A. Conjugate Priors and Posteriors

Given a multivariate normal inverse Wishart (NIW) distribution (conjugate prior) of the form NIW$(v_0, \Psi_0, \beta_0, S_0)$:

$$\begin{aligned} \Sigma &\sim IW(S_0, v_0) \\ \beta|\Sigma &\sim \mathcal{N}(\beta_0, \Sigma \otimes \Psi_0) \end{aligned}$$

where S_0 is the prior scale matrix, v_0 the degrees of freedom and Ψ_0 is a diagonal matrix with common elements to all equations.

The posterior distribution over the reduced-form parameters is NIW$(v_1, \Psi_1, \beta_1, S_1)$:

$$\begin{aligned} \Sigma|y &\sim IW(S_1, v_1) \\ \beta|y, \Sigma &\sim \mathcal{N}(\beta_1, \Sigma \otimes \Psi_1) \end{aligned}$$

where, for the general case:

$$\begin{aligned} v_1 &= v_0 + T \\ \Psi_1 &= (X'X + \Psi_0^{-1})^{-1} \\ \beta_1 &= \Psi_1(X'Y + {\Psi_0}^{-1}\beta_0) \\ S_1 &= Y'Y + S_0 + \beta_0'\Psi_0^{-1}\beta_0 - \beta_1'\Psi_1^{-1}\beta_1 \end{aligned}$$

and, for the flat (Jeffreys) prior, simply:

$$\begin{aligned} v_1 &= T \\ \Psi_1 &= (X'X)^{-1} \\ \beta_1 &= \Psi_1(X'Y) = \hat{\beta}^{OLS} \\ S_1 &= \hat{S}^{OLS} \end{aligned}$$

B. Algorithm

The algorithm follows very closely Arias et al. (2018) and Antolín-Díaz and Rubio-Ramírez (2018). As customary, the starting point in identification by sign restrictions is to characterise the set admissible models by drawing Q, where Q $\in O(n)$, the set of all orthogonal $n \times n$ matrices.

Arias et al. (2018) use an alternative parametrisation to emphasise the role of the orthogonal matrix Q, which they call orthogonal reduced-form parametrisation. This parametrisation is characterised by the reduced-form parameters β and Σ together with Q. The NIW(v, Ψ, β, S) then becomes UNIW(v, Ψ, β, S), the uniform-normal-inverse-Wishart distribution over the orthogonal reduced-form parametrisation. They show that independent draws of β, Σ and Q from UNIW(v, Ψ, β, S) are independent draws from a normal-generalised-normal distribution over the structural parametrisation, denoted by NGN(v, Ψ, β, S)[18].[19]

Nevertheless, when zero restrictions are also imposed, additional sub-steps are necessary to properly achieve the objective of drawing from the correct distribution. Arias et al. (2018) argue that the distribution over the structural parametrisation conditional on the zero restrictions is no longer equal to the NGN(v, Ψ, β, S). They then suggest the computation of its density and its use as a proposal distribution for an importance sampler to draw from the NGN(v, Ψ, β, S) distribution over the structural parametrisation conditional on the zero restrictions.

Similarly, Antolín-Díaz and Rubio-Ramírez (2018) show that it is not correct to simply discard the draws that do not satisfy the narrative sign restrictions. Such a procedure would give high posterior probability to draws that are more likely to satisfy the narrative restrictions and would deviate from drawing from the UNIW(v, Ψ, β, S) distribution. Therefore, importance weights inversely proportional to the probability of satisfying the narrative restrictions are computed and the draws are re-sampled accordingly. As before, this implies making independent draws from the NGN(v, Ψ, β, S). The following algorithm describes the whole procedure. In practice, the algorithm starts with an educated guess of the number of iterations necessary to achieve the required number of independent draws.[20]

ALGORITHM: This algorithm makes independent draws from the NGN(v, Ψ, β, S) distribution over the structural parametrisation conditional on the zero, traditional and narrative sign restrictions.

1. Independently draw (β, Σ) from the NIW(v, Ψ, β, S) distribution.

[18] See Arias et al. (2018) for a detailed description.

[19] There has been increasing concern about the informativeness of priors. Giacomini and Kitagawa (2018), for instance, propose imposing posterior bounds on the impulse response functions. However, as the implementation of this procedure would imply additional computational burden, Arias et al. (2018)'s method, which is agnostic with respect to the identification, is preferred.

[20] This number is calibrated in order for the algorithm to generate the desired number of draws that satisfy the zero, traditional and narrative sign restrictions.

2. For $1 \leq j \leq N$, draw $\mathbf{x}_j \in \mathbb{R}^{N+1-j-z_j}$ independently from a standard normal distribution and set $\mathbf{w}_j = \mathbf{x}_j / \|\mathbf{x}_j\|$, where z_j is the number of zero restrictions associated with the jth structural shock.

3. Define Q = $[q_1 \ ... \ q_N]$ recursively by $q_j = K_j w_j$ for any matrix K_j whose columns form an orthonormal basis for the null space of the (j – 1 + z_j) × N matrix

$$M_j = [q_1 \ ... \ q_{j-1} \ (Z_j F(f_h^{-1}(\beta, \Sigma, I_n)))]$$

where Z_j defines the zero restrictions on the jth structural shock for $1 \leq j \leq N$, f_h^{-1} is the function that transforms draws over the orthogonal reduced-form parametrisation into draws from the structural parametrisation, and F is a function of the structural parameters defined as a matrix that vertically stacks the impulse responses over which the restrictions will be imposed.[21]

4. Check if the sign restrictions are satisfied. If they are, compute the importance weights. Otherwise, discard the draw.

5. Return to Step 1 until the required number of draws satisfying the zero and sign restrictions has been obtained.

6. Re-sample with replacement using the importance weights.

7. Check if the narrative sign restrictions are satisfied:

$$\varepsilon_{j,t}(\Theta) > 0 \tag{1}$$

$$|H_{i,j,t}(\Theta, \varepsilon_t(\Theta))| > \sum_{j' \neq j} |H_{i,j',t}(\Theta, \varepsilon_t(\Theta))| \tag{2}$$

where Θ collects the values of all structural parameters, equation (1) implies that jth shocks must be positive at time t and equation (2) implies that the contribution of the jth shock to variable i at time t must be greater than the sum of the contribution of all the other shocks to variable i at time t.[22] If the restrictions for the particular case are satisfied, approximate the new importance weights as the inverse of the probability of satisfying the narrative restrictions as

[21] For instance, make L_0=chol($\hat{\Sigma}$) an initial guess of the structural impact matrix multiplier. That implies $L_1 = \beta L_0$ and $F = [L_0; \ L_1]$. For a numerical example in more detail, see Arias et al. (2014) – working paper version – or Kilian and Lütkepohl (2017), pages 475-482.

[22] To have negative narrative sign restrictions, just impose equation (1) with a negative sign on the left-hand side.

in Antolín-Díaz and Rubio-Ramírez (2018). Otherwise, discard the draw.

8. Re-sample with replacement using the new importance weights.

C. Computational Aspects

The importance samplers are the most onerous part of the algorithm. For the latter, however, it is necessary to compute the weights only for the draws that satisfy the zero, traditional and narrative sign restrictions, which usually are hundreds of draws. On the other hand, the first importance sampler is computationally much more demanding because it involves computing the weights for all the candidate draws that satisfy the zero and sign restrictions. This number of draws can reach hundreds of thousands depending on the number of narrative sign restrictions imposed and how restrictive they are.

For the benchmark case, the number of draws satisfying the zero and sign restrictions was 250,000 and the effective sample size from Step 5 is 121,040. The number of draws satisfying the narrative sign restrictions was 3,295 (1.31%) and the effective sample size from Step 8 calculated based on 100,000 weights is 1,900.[23] Because two importance samplers are used, it is also useful to keep track of the number of unique draws which survive until the end. So it is possible to be sure that the second importance sampler is not dominated by only a few surviving draws from the first one. The number of unique draws that satisfy the narrative sign restrictions is 1,119.

[23]The increase in the effective sample size from Step 8 with 1,000,000 weights is very marginal: from 1,900 to 1,902.

D. Robustness

First, the impulse responses following a monetary policy shock using March 2015 as an episode of contractionary forward guidance is displayed. Second, it is possible to see that imposing weaker narrative sign restrictions in February 1994 leads to similar results. In this weaker restriction, the sum operator is replaced with the 'max':

$$|H_{i,j,t}(\Theta, \varepsilon_t(\Theta))| > \max_{j' \neq j} |H_{i,j',t}(\Theta, \varepsilon_t(\Theta))| \tag{3}$$

Third, to account for the fact that even the 2-year government bond rate may have been affected by the ZLB, the sample period is also ended in 2012. The results are qualitatively the same. Finally, the sign restrictions on the excess bond premium are removed. Effects become weaker: zero is outside the credible set for the industrial production only after some years.

i. Narrative Sign Restriction: FG shock was positive in March 2015

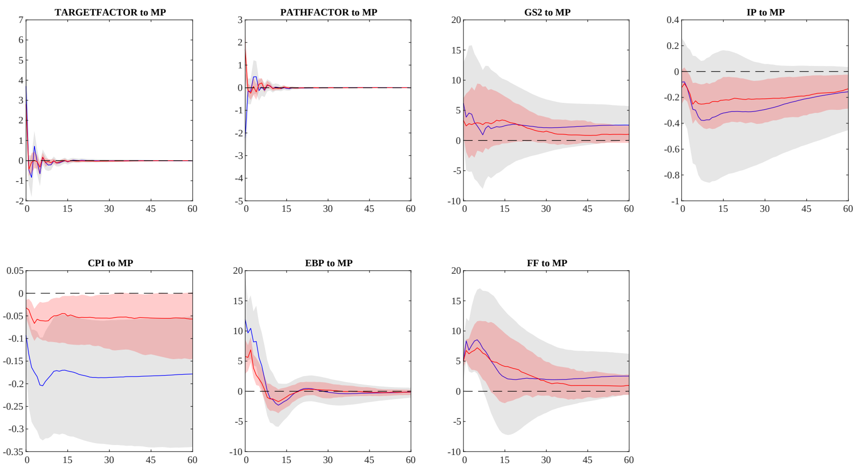

Figure 1: Impulse Responses to a Conventional Monetary Policy Shock Using March 2015

Notes: The grey shaded area represents the 68 percent (point-wise) HPD credible sets for the IRFs and the blue lines are the median IRFs using sign restrictions. The pink shaded areas and the red lines display the equivalent quantities for the models that additionally satisfy narrative sign restrictions.

ii. Narrative Sign Restriction: Weak restriction in February 1994

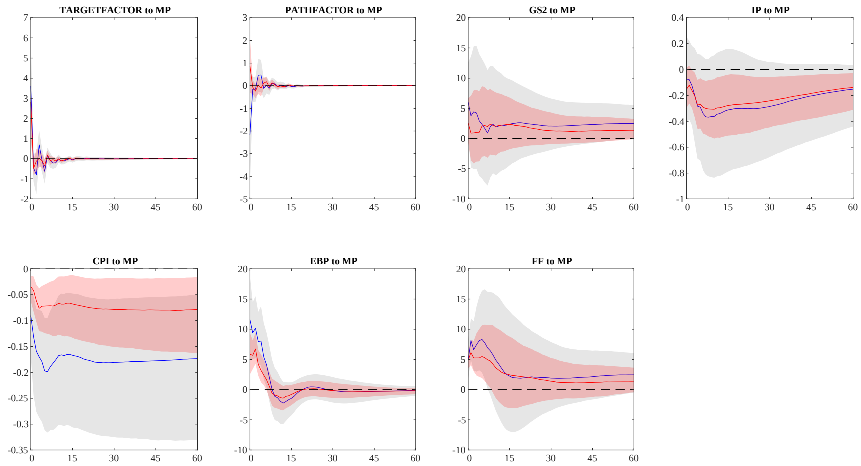

Figure 2: Impulse Responses to a Conventional Monetary Policy Shock Using Weak 1994

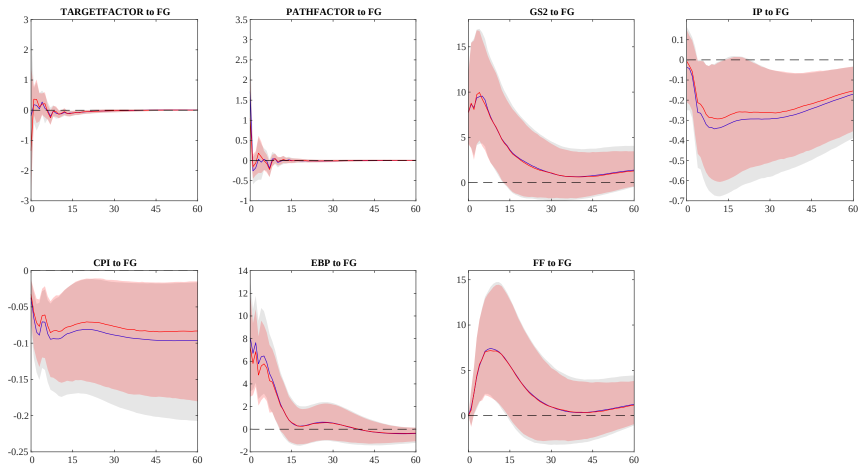

Figure 3: Impulse Responses to a Forward Guidance Shock Using Weak 1994

Notes: The grey shaded area represents the 68 percent (point-wise) HPD credible sets for the IRFs and the blue lines are the median IRFs using sign restrictions. The pink shaded areas and the red lines display the equivalent quantities for the models that additionally satisfy narrative sign restrictions.

iii. Sample period: 1993-2012

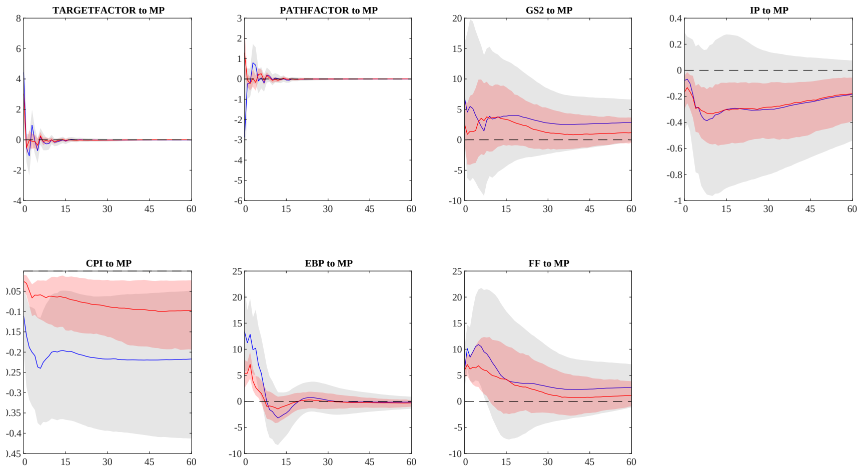

Figure 4: Impulse Responses to a Conventional Monetary Policy Shock

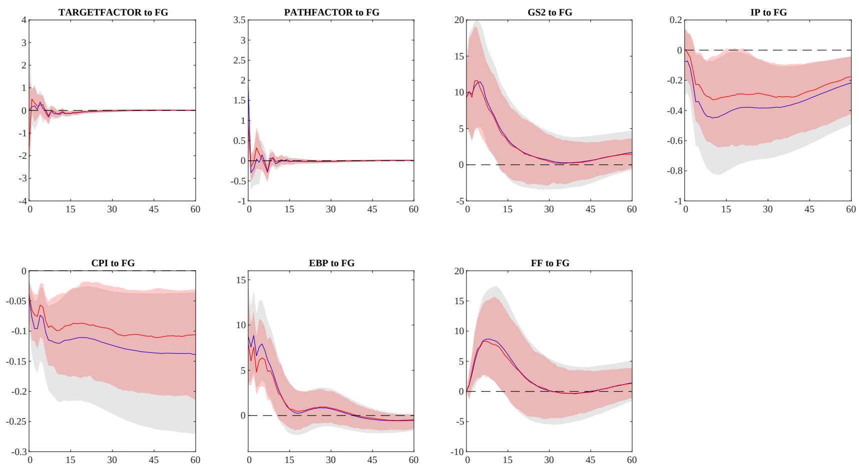

Figure 5: Impulse Responses to a Forward Guidance Shock

Notes: The grey shaded area represents the 68 percent (point-wise) HPD credible sets for the IRFs and the blue lines are the median IRFs using sign restrictions. The pink shaded areas and the red lines display the equivalent quantities for the models that additionally satisfy narrative sign restrictions.

iv. No Sign Restrictions on EBP

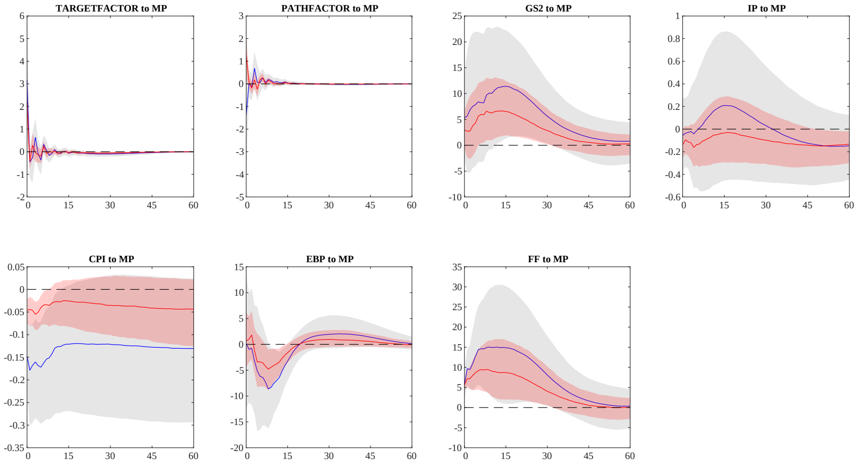

Figure 6: Impulse Responses to a Conventional Monetary Policy Shock

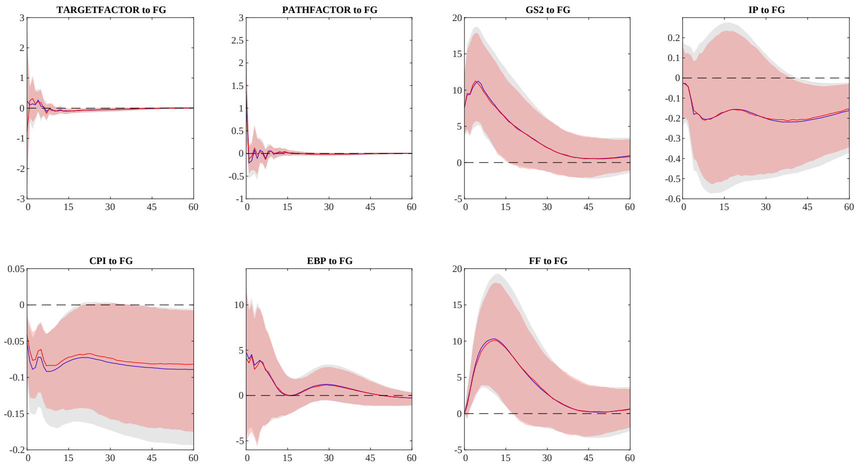

Figure 7: Impulse Responses to a Forward Guidance Shock

Notes: The grey shaded area represents the 68 percent (point-wise) HPD credible sets for the IRFs and the blue lines are the median IRFs using sign restrictions. The pink shaded areas and the red lines display the equivalent quantities for the models that additionally satisfy narrative sign restrictions.