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Financial shocks and inflation dynamics*

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Abstract

We assess the effects of financial shocks on inflation, and to what extent financial shocks can account for the "missing disinflation" during the Great Recession. We apply a Bayesian vector autoregressive model to US data and identify financial shocks through a combination of narrative and short-run sign restrictions. Our main finding is that contractionary financial shocks temporarily increase inflation. This result withstands a large battery of robustness checks. Negative financial shocks help therefore to explain why inflation did not drop more sharply in the aftermath of the financial crisis. Our analysis suggests that higher borrowing costs after negative financial shocks can account for the modest decrease in inflation after the financial crisis. A policy implication is that financial shocks act as supply-type shocks, moving output and inflation in opposite directions, thereby worsening the trade-off for a central bank with a dual mandate.

JEL classification: E31, E44, E58

Keywords: Financial shocks, inflation dynamics, monetary policy, financial frictions, cost channel, sign restrictions

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1 Introduction

Despite a massive fall in demand during the Global Financial Crisis (GFC), the US economy experienced only a modest disinflation. One prominent explanation for this "missing disinflation puzzle" is that inflation expectations remained well anchored in the aftermath of the crisis (Bernanke 2010, Yellen 2013, Coibon and Gorodnichenko 2015).[1] In this paper, we provide evidence that inflation declined by less than many would have expected because the fall in demand was accompanied by a contractionary financial shock, which created inflationary pressures.

Our finding that a contractionary financial shock results in temporarily higher inflation provides useful empirical evidence to an ongoing theoretical debate about the response of inflation to financial shocks. Macroeconomic models featuring financial frictions are in fact compatible with financial shocks acting both as demand and cost-push shocks. This depends on whether aggregate-demand or aggregate-supply effects dominate in the transmission mechanism. Papers that model financial shocks as demand shocks include Curdia and Woodford (2010), Gertler and Karadi (2011) and Del Negro et al. (2015). In these models, higher borrowing costs following contractionary financial shocks lead to a fall in consumption and investment. Both imply a decline in labour demand, which in turns reduces marginal costs and inflation. By contrast, papers that model financial shocks as cost-push shocks include Gilchrist et al. (2017), De Fiore and Tristani (2013), Christiano et al. (2014) and Meh and Moran (2010). In the first three papers, financial shocks influence the pricing decision of firms, either because firms prefer to hedge against the risk of relying on costly external finance, or because borrowing costs are actually part of firms' marginal costs. An increase in the cost of external finance leads therefore to an increase in inflation, either via higher markups or via higher marginal costs. Table 1 summarizes the implications of these and other models for the behavior of inflation after financial shocks. Overall, financial shocks propagate through the economy through various aggregate supply- and demand-type channels, and their impact on inflation depends on which channel

[1] Another prominent explanation is that short-run unemployment, which increased by less during the GFC and recovered more quickly thereafter, is a more relevant measure of economic slack than long-run unemployment (Gordon 2013, Krueger et al. 2014).

dominates.[2] Hence, whether financial shocks raise or lower aggregate inflation is ultimately an empirical question, which we try to answer in this paper.

To obtain a first idea on the empirical link between inflation and the financial side of the economy, we estimate a reduced-form Phillips curve which closely follows Coibon and Gorodnichenko (2015). After replicating their key findings,[3] we augment the Phillips curve with the excess bond premium (EBP), a widely-used price measure of credit supply which serves as a key variable in the remainder of the paper.[4] We find that the EBP enters significantly with a positive sign (cf. Table 2) indicating that a worsening of credit conditions raises inflation.[5] Moreover, figure 1 shows that the EBP helps predict inflation to some extent, especially after 2009. Appendix A provides more details on this Phillips curve estimation.

In the remainder of the paper, we investigate the impact of financial conditions on inflation through a more structural setup. Specifically, we apply a vector autoregressive model (VAR) estimated with Bayesian methods to a set of US macroeconomic and financial data. We identify financial shocks by imposing short-run sign restrictions on impulse response functions, as well as narrative restrictions reflecting common knowledge about the size and relevance of financial shocks during the GFC. Contractionary financial shocks in our model increase funding costs and decrease credit growth and stock prices, thereby matching the characterization of financial shocks in standard macroeconomic models. Most importantly, our identification strategy is fully agnostic about the response of inflation after financial shocks (and therefore about the contribution of financial shocks for inflation dynamics), while still disentangling financial from other structural shocks such as aggregate supply and demand shocks.

Our first key result is that contractionary financial shocks that decrease output and credit growth tend to increase inflation. The effect arises on impact and is

[2]The models do not allow to associate specific characteristics of financial shocks to a specific inflation response. For example, Gerali et al. (2010), Gertler and Karadi (2011) and Hristov and Huelsewig (2017) consider shocks to bank capital, but inflation responses differ (cf. Table 1). It would be interesting to investigate empirically the effects of different types of financial shocks (such as shocks from the banking versus the non-banking financial sector or shocks to different positions of the balance sheets of banks), but this goes beyond the scope of this paper and is left for future research.

[3]Coibon and Gorodnichenko (2015) find that a backward-looking Phillips curve, estimated over the pre-crisis sample period, substantially underpredicts consumer price inflation between 2009 and 2011 (the "missing disinflation" puzzle). This puzzle is partially solved when households' future inflation expectations are added to the set of explanatory variables.

[4]This series is taken from Simon Gilchrist's website.

[5]This result is in line with De Fiore and Tristani (2013), who find a sizeable positive coefficient on credit spreads in their estimated Phillips curve.

significant over about a year. Based on a historical decomposition, we find that contractionary financial shocks contributed positively to inflation during and after the GFC. Absent financial shocks, the fall in inflation between 2008 and 2009 would have been on average 0.6pp larger. Hence, negative financial shocks compensated to some extent deflationary pressures from other developments. Towards the end of the sample, expansionary financial shocks prevented a more pronounced pick-up in inflation.[6]

We then explore the transmission channels that can account for the inflation response after financial shocks. Contractionary financial shocks raise borrowing costs by increasing credit spreads. This can in turn increase overall marginal costs, which may partly explain the positive inflation response. Our result is therefore consistent with models where aggregate supply effects dominate in the transmission mechanism of financial shocks, such as De Fiore and Tristani (2013) and Gilchrist et al. (2017).

Our main finding is robust against a battery of checks. We show that financial shocks affect banking variables and survey measures of credit supply in the expected way, which supports our identification scheme. Moreover, our key result does not change if we exclude the GFC and post-GFC (zero lower bound) period from the estimation sample. Our key finding is therefore not driven by a special role of the GFC, nor by the limited ability of monetary policy to reduce the policy rate in response to contractionary financial shocks. In a counterfactual experiment, we further show that one could have predicted less of a decline in inflation in the aftermath of the GFC based on pre-GFC parameter estimates and correctly observed financial shocks during the GFC. This result is therefore in line with the Phillips curve findings mentioned earlier. Importantly, we also show that the identified financial shock is not contaminated by other shocks, including shocks to aggregate supply, demand, technology news, monetary policy, uncertainty, oil and housing. Finally, we experiment with alternative measures of interest rates, inflation and credit, but our key finding remains unaffected.

Our approach offers two contributions relative to the existing literature. First, we propose an identification scheme for financial shocks that leaves the inflation response unrestricted. Previous work based on sign restrictions, which focuses on the effects of financial shocks on real economic activity, imposes either a positive comovement between output and inflation, or a positive comovement between output and the policy rate after financial shocks, which also biases the inflation

[6] The recovery after the GFC is characterised by the "missing inflation puzzle", addressed for instance by Bobeica and Jarocinski (2019) and Linde and Trabandt (2019).

response (Busch et al. 2010, Conti et al. 2015, De Santis and Darracq-Paries 2015, Furlanetto et al. 2017, Gambetti and Musso 2017, Hristov et al. 2012). Other papers restrict the impact effect on inflation and output to be zero, but leave the sign of their responses beyond impact unrestricted (Gilchrist and Zakrajšek 2012, Peersman 2011). In these papers contractionary financial shocks decrease inflation, though in Gilchrist and Zakrajšek (2012) the response is not significant.[7] Also, only few papers have applied narrative restrictions so far, and we combine them with sign restrictions.

Our second contribution is to explore various transmission channels of financial shocks, and their implications for inflation in an aggregate time series setup. Previous work by Antoun de Almeida (2015), Balleer et al. (2015) and Gilchrist et al. (2017) relies on data at the product or firm level. These studies focus on the price-setting behavior of financially constrained firms relative to unconstrained ones, and show that borrowing constraints are an important determinant for price-setting behavior. While these studies are well suited to cleanly identify the effect of borrowing constraints on the price-setting behavior of firms, they lack clear cut implications for the behavior of aggregate inflation after financial shocks.[8] Our study fills this gap by showing that contractionary financial shocks might increase aggregate inflation.

The main policy implication from our analysis is that financial shocks which lower output and increase inflation could worsen the trade-off faced by a central bank which seeks to stabilize both output and inflation.

The rest of the paper is structured as follows. In Section 2 we provide details on data, methodology, and the financial shock identification strategy. We present results from the baseline model and investigate the transmission channels of financial shocks in Section 3. In Section 4 we discuss several robustness checks and explore the reaction of banking variables and survey measures to financial shocks. Section 5 concludes.

[7] As a cross check, we have applied a recursive identification scheme similar to the one adopted in Gilchrist and Zakrajšek (2012) and find, consistent with Gilchrist and Zakrajšek (2012), a negative inflation response after contractionary financial shocks (which is however insignificant in Gilchrist and Zakrajšek 2012). Similarly, Del Negro et al. (2020) find demand effects dominating after a recursively identified shock to the EBP. They do not attempt to separate credit supply shocks from other shocks (such as uncertainty or monetary policy shocks), which, they argue, is hard to do. Hence, the identification scheme matters for the inflation response.

[8] Gilchrist et al. (2017) point out representativeness of their data for aggregate fluctuations, but their data are limited to a sample of firms.

2 Data and modeling approach

2.1 Data

Our baseline analysis departs from an n-dimensional vector X_t of seasonally adjusted quarterly series: real GDP, core inflation, a policy interest rate, credit growth, the EBP, and stock prices. These are standard variables in empirical macro-financial studies.

We use the core CPI, excluding energy and food, to measure inflation.[9] We choose core, instead of headline inflation, in order to disentangle financial shocks from commodity price shocks, such as oil shocks. We further investigate this issue in Section 4 by including the oil price in our baseline VAR model. The EBP, which we use also in the Phillips curve analysis, is a risk premium that reflects systematic deviations in the pricing of US corporate bonds relative to the issuers' expected default risk. It thus constitutes a proxy for the effective risk-bearing capacity of the financial sector, and is a direct price measure of credit supply. We measure credit growth using total credit to the private nonfinancial sector, taken from the Financial Accounts of the United States. In the robustness analysis we also consider alternative credit measures. Nominal stock prices are taken from Robert Shiller's website. We deflate the credit and stock price series by the CPI. Finally, we use the federal funds rate as the main policy interest rate. From 2008Q4 onwards, we replace the federal funds rate with the shadow short rate (SSR) from Krippner (2015), which allows to account for unconventional monetary policy. The SSR reflects in fact changes in the term structure of interest rates, which is affected by quantitative easing and forward guidance policies (Gertler and Karadi 2015, Krippner 2015).

GDP and stock prices enter in logarithms, the policy rate and the EBP in levels, the CPI in year-on-year differences of logarithms.[10] We filter outstanding credit using log year-on-year differences. Financial intermediaries' balance sheet variables are subject to secular trends due to changes in the structure of the financial system and regulatory changes. Following Adrian et al. (2016), we deal with this issue by using detrended credit.[11] While the year-on-year change is a conve-

[9]We use CPI inflation rather than PCE deflator inflation to remain consistent with the Phillips curve estimation above, which we set up as in Coibon and Gorodnichenko (2015).

[10]See Ang and Piazzesi (2003), Bjoernland and Leitemo (2009), Canova et al. (2007) and Primiceri (2005) for similar transformations of key variables in VAR models.

[11]Credit growth can also be interpreted as a proxy for new credit, which is a flow variable, as GDP (whereas credit is a stock variable). This makes the change in credit a better fit for the imposed sign restrictions on the response of credit relative to GDP, which we discuss later in

nient way of detrending credit, we show below that our results are not affected when using a one-sided HP filter applied to outstanding credit.[12] If not stated otherwise, we take the series from the FRED database of the Federal Reserve Bank of St. Louis.

The sample period ranges from 1988Q1 to 2019Q2. By choosing 1988Q1 as a starting point we exclude any monetary regime prior to the Greenspan one. Moreover, the period since the mid-1980s until the beginning of the GFC is associated with the Great Moderation. Hence, our sample period excludes the Great Inflation period. We check to what extent parameters have changed with the GFC in Section 4.

2.2 Vector autoregression

We assume that the $n \times 1$ vector of endogenous variables $\mathbf{y}_t$ follows a VAR model of order p:

$$\mathbf{y}_t' = \mathbf{x}_t'\mathbf{B} + \mathbf{w}_t', \quad \mathbb{E}(\mathbf{w}_t') = 0, \, \mathbb{E}(\mathbf{w}_t\mathbf{w}_t') = \mathbf{\Sigma} \tag{1}$$

where the regressors' matrix is defined as $\mathbf{x}_t' = [\mathbf{y}_{t-1}', \ldots, \mathbf{y}_{t-p}', 1]$ and $\mathbf{B}$ is a $(np+1) \times n$ matrix of reduced form coefficients. The $n \times 1$ vector $\mathbf{w}_t$ denotes reduced-form innovations which are assumed to be Gaussian with mean zero and positive definite covariance matrix $\mathbf{\Sigma}$. The lag length p is set to 2, as suggested by the Akaike and Hannan-Quinn information criteria. We estimate the VAR using Bayesian methods. The prior distribution of the reduced form parameters is assumed to be a normal-inverse-Wishart density, with the prior mean and variances centred around OLS estimates.

2.3 Identifying financial shocks

Identifying financial shocks in the data is not trivial. Different structural macroeconomic models with a financial sector have different implications for key features of financial shocks, including their effect on important variables such as inflation (cf. Table 1). One reason is the different transmission channels embedded in the model. Consequently, there is no consensus in the literature on how to best identify financial shocks.

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the text. Moreover, a large share of US credit is long term and therefore largely predetermined. Hence, it is more meaningful to assume that new credit reacts rapidly to the shocks.

[12]See Edge and Meisenzahl (2011), for a discussion on the consequences of different detrending methods for credit gap measures.

To identify financial shocks, we propose an identification strategy that combines short-run sign restrictions on impulse response functions, and narrative restrictions on the shock size and the historical decomposition. These identifying restrictions are summarized in Table 3. Our identifying assumptions are economically reasonable and consistent with a large body of theoretical and empirical work on the dynamic propagation of financial shocks. At the same time, we remain fully agnostic about the effects of financial shocks on inflation dynamics. We discuss sign and narrative restrictions in turn.

Sign restrictions Throughout the paper, we focus on contractionary financial shocks which lead to a decrease in GDP. Furthermore, we restrict the EBP to increase and credit growth and stock prices to fall.[13] These three restrictions are standard, and match key features of financial shocks in structural macroeconomic models.

We disentangle financial shocks from aggregate supply and aggregate demand shocks by assuming that contractionary financial shocks decrease credit growth by more than GDP. This relative restriction on credit growth and GDP is intuitively plausible. After contractionary aggregate supply and demand shocks, investors might increase risk premia and reduce credit in response to the economic downturn. However, it is reasonable to assume that investors adjust their lending and investment strategies only gradually in response to the shock. Hence, we should first observe a deterioration in economic activity, while credit growth should respond initially only mildly. Financial shocks, by contrast, originate in the financial sector (as seen in the GFC) and exogenously decrease credit supply. Lower credit supply, however, should transmit to the overall economy initially only weakly: entrepreneurs and households need some to time to fully adjust their production processes and demand decisions in response to the lower supply of credit. Hence, we should observe a fall in credit growth that exceeds the fall in output growth for some time. Note that this is similar to the intuition underlying the use of a zero contemporaneous restriction on output. However, our relative restriction is more agnostic than such a recursiveness assumption, which other empirical studies employ.

The relative restriction on credit growth and GDP is consistent with DSGE models featuring an active financial sector and shocks that directly affect banks'

[13] By restricting the stock price to decrease, we follow Furlanetto et al. (2017). They argue that investment-specific demand shocks lead to a negative co-movement between stock prices and output, while financial shocks imply a positive co-movement between the two.

balance sheets. Examples of these models include Covas and Driscoll (2013), Curdia and Woodford (2010), Gelain et al. (2017), Gerali et al. (2010), Gertler and Karadi (2011), Hristov and Huelsewig (2017), Iacoviello (2015) and Meh and Moran (2010).[14] Key to this credit-to-GDP response is a realistic banking sector that is subject to endogenous bank balance-sheet constraints due to financial frictions. By contrast, standard financial accelerator models along the lines of Bernanke et al. (1999) do not necessarily imply that credit relative to GDP decreases after a contractionary financial shock (see e.g. De Fiore and Tristani 2013, Christiano et al. 2010).[15] The reason is that, in these models, firms effectively borrow directly from households while financial intermediaries are simply a veil. Given that we are interested in shocks and dynamics similar to those observed during the GFC - when the financial sector has been at the center stage - we choose to focus on restrictions consistent with models featuring a more complex financial sector.

Within the set of empirical studies, Eickmeier and Ng (2015) impose the same restriction on the credit-to-GDP ratio as we do. Furthermore, our credit-to-GDP restriction is also consistent with empirical findings by Fornari and Stracca (2012) and De Santis and Darracq-Paries (2015), who have credit and GDP included in their model and identify financial shocks with sign restrictions, but leave the credit-to-GDP response unrestricted.

While we need the credit-to-GDP restriction to *ex ante* disentangle financial shocks from other shocks (especially when we re-estimate the model over the pre-GFC sample), this restriction is not crucial for our key findings. When the restriction is dropped, credit relative to GDP still declines after contractionary financial shocks, and our key results remains unchanged.[16]

Finally, we disentangle financial shocks from monetary policy shocks by using a conditional sign restriction approach.[17] Specifically, we impose the restrictions described above, and then check the inflation response for each model which yields financial shocks satisfying the restrictions. If inflation falls on impact, the response

[14]While the credit-to-GDP restriction can be unambiguously derived from DSGE models with a banking sector with frictions, these models do not imply a clear-cut inflation response (see Table 1).

[15]Carlstrom et al. (2014) and Carlstrom et al. (2016) extend the standard financial accelerator framework to include an optimal lending contract between lenders and borrowers. In this enhanced framework credit relative to GDP declines after a contractionary financial shock.

[16]Results not shown but available upon request.

[17]This approach is similar in spirit to Arias et al. (2019) who restrict the systematic component of monetary policy.

of a central bank following a Taylor rule is unambiguously negative. In this case, we restrict the policy rate to decrease on impact. If inflation increases, we do not restrict the policy rate. In this way, we disentangle financial from monetary policy shocks. In standard New Keynesian and structural VAR models, monetary policy shocks move the interest rate in one direction, and the price level and output in the other direction (e.g. Peersman 2005). Given that we use the shadow short rate, which translates (at least parts of) unconventional monetary policy measures into short-term interest rate movements, we apply the identification scheme to the full sample estimate of the model without distinguishing between non-ZLB and ZLB periods. In Section 4, we check whether this is valid by re-estimating the model over the pre-GFC period, by more explicitly accounting for monetary policy shocks, and by discussing the relationship between financial and monetary policy shocks.[18]

We note that similar restrictions have been used in previous empirical work, which focuses on the real effect of financial shocks. However, this literature either restricts inflation to be positive or not to react on impact, or it restricts the policy rate to increase after expansionary financial shocks, which might also bias the inflation response.[19] The novelty of our identification scheme is that it disentangles financial shocks from other structural shocks, while being fully agnostic on the response of inflation and of the policy rate.

Paustian (2007) shows that one can sharpen the shock identification by identifying additional shocks. Hence, in addition to financial shocks, we also explicitly identify two key standard macroeconomic shocks which are typically found to be important drivers of the economy: aggregate supply and demand shocks. Contractionary aggregate demand shocks lead to a decline in real GDP, credit, inflation and the policy rate, and raise the credit-to-GDP ratio. This last restriction disentangles financial and aggregate demand shocks, and is for instance consistent with the effects of a preference shock in Iacoviello (2015), Hristov and Huelsewig (2017) and Gelain et al. (2017), or with the effects of a fiscal shock in Hristov and Huelsewig (2017). Contractionary aggregate supply shocks lead to a decline

[18]Relaxing the conditional restriction on the policy rate produces the same qualitative results, but increases the model uncertainty associated with the sign restrictions. This might be because the financial shock is not appropriately separated from a monetary policy shock without the restriction on the interest rate.

[19]See e.g., Busch et al. (2010), De Santis and Darracq-Paries (2015), Eickmeier and Ng (2015), Furlanetto et al. (2017), Gambetti and Musso (2017), Helbling et al. (2011), Hristov et al. (2012), Meeks (2012), Peersman (2010)

in GDP and stock prices, raise the credit-to-GDP ratio, and lead to a higher inflation.

Finally, we restrict the remaining $n-3=3$ shocks not to have the same characteristics as the identified shocks. Hence, the identified financial, aggregate demand and aggregate supply shocks are the only shocks that satisfy the restrictions. We impose all sign restrictions only on impact, and hence remain relatively agnostic.

Narrative restrictions Beside sign restrictions, we employ two narrative restrictions in our identification scheme. These are based on the assumption, now widely accepted, that financial shocks were extremely important during the GFC.[20] The first narrative restriction is imposed on the financial shock series: we impose that the largest contractionary financial shock over our sample period occurs in 2008Q3. The second narrative restriction is imposed on the historical decomposition: the absolute value of the contribution of the financial shock to the dynamics of the EBP in 2008Q3 is larger than the sum of the absolute value of the contributions of all other structural shocks. These restrictions deserve some discussion.

Our approach closely follows Ludvigson et al. (2020a) and Ludvigson et al. (2020b) who impose restrictions on shocks, as well as Antolín-Díaz and Rubio-Ramírez (2018) who restrain the historical decomposition. We impose one restriction on the shock and one on the historical decomposition, and hence exploit knowledge about realizations of financial shocks over time, and in comparison with realizations of other shocks in 2008Q3.

We choose 2008Q3 because it includes the month (September) when Lehman Brothers filed for bankruptcy, which is commonly associated as the major trigger of the Great Recession (see also Ludvigson et al. 2020b). While there had been financial turmoil before that date, with the burst of the subprime mortgage bubble in 2007, it is widely agreed that the largest shock hit the US economy (and probably also the rest of the world) in 2008Q3, with the collapse of Lehman Brothers in September 2008. The government had previously bailed out other major financial institutions (Bear Sterns, Fannie Mae, and Freddie Mac), and it came as a surprise that it decided not to rescue Lehman Brothers as well. This triggered financial market panic: stock prices tanked, and investors fled money market mutual funds. The shock spread through 2008Q4 and subsequent quarters. By 2008Q4, policy

[20] See for instance Yellen (2015) or Bernanke (2018), who argue that the unusual severity of the GFC was mainly due to panic in funding and securitization markets, which lead to a negative credit supply shock.

had already reacted: the US Congress passed a bailout bill in October 2008 and central banks tried to restore liquidity, e.g. by directly issuing short-term loans for businesses, lowering interest rates to basically zero, and coordinating actions of central banks throughout the globe. Our timing choice is in line with Ludvigson et al. (2020b) who focus on uncertainty shocks and find evidence of a large positive financial uncertainty shock in September 2008. It is also not inconsistent with Ludvigson et al. (2020a) who, in one of their applications, restrict the EBP credit spread shock to be particularly large either in September 2008 or in October 2008 or in both. In our view 2008Q4 was mostly characterized by the reaction to the Lehman shock, rather than by another financial shock, which is why we focus on 2008Q3 here. We have also checked whether any other shock (demand or supply shocks as well as the three other rotated orthogonalized residuals) has its extremum in 2008Q3 and found this not to be the case. Hence, financial shocks are the only shocks that have their extremum in 2008Q3.

Beside imposing that a particularly large contractionary financial shock occurred in 2008Q3, we also impose that the contribution of this shock to the EBP is very large. Given that the EBP is constructed as systematic deviations in the pricing of US corporate bonds relative to the issuers' expected default risk, it should be relatively exogenous with respect to the rest of the economy, and it is plausible to assume an "overwhelming" contribution of financial shocks (as Antolín-Díaz and Rubio-Ramírez 2018 put it) to the EBP in 2008Q3. To what extent the EBP is really largely exogenous to the rest of the economy is somewhat controversial in the literature. On the one hand, Furlanetto et al. (2017) find that credit shocks identified with sign restrictions explain 44% of the EBP's forecast error variance at the 1-quarter horizon, and only 16% at the 20 quarter horizon. Gertler and Karadi (2015) find moreover a significant reaction of the EBP to monetary policy shocks. On the other hand, Gilchrist and Zakrajšek (2012) recursively identify financial shocks and find that they explain a very large share of the EBP (median estimate: over 80%). Moreover, Caldara et al. (2016) impose that financial shocks maximize the response of the EBP over a predefined horizon. We are more agnostic than Caldara et al. (2016) and impose that financial shocks explain a large fraction of the EBP only in 2008Q3. We will show that there is room left for other shocks to explain EBP dynamics during the Great Recession.

In Section 4, we explore the robustness of our key results against alternative identification schemes. Importantly, while our baseline model and identification scheme allows us to disentangle financial from standard (macro and conventional monetary policy) shocks, we modify the model to explicitly separate financial shocks from other shocks such as technology news shocks or oil shocks. We also illustrate the effects of imposing the narrative restrictions in addition to the sign restrictions.

To implement the restrictions, we follow the algorithm in Antolín-Díaz and Rubio-Ramírez (2018), described in Appendix B. We obtain 1000 draws from the posterior of the reduced form coefficients that satisfy the baseline restrictions. We approximate their weights in the importance step by using 1000 draws.

3 Results

3.1 Results from the baseline model

Impulse response analysis In Figure 2, we present impulse responses of selected variables to a contractionary financial shock. The solid red lines are median impulse responses, while the shaded areas are 68% credible sets. As imposed by the restrictions, the EBP increases and credit growth decreases. The negative effects on credit growth and GDP are very persistent, with the peak effects occurring after 1-2 years following the shock.

Most importantly, inflation increases on impact by 0.1 percentage points and remains positive for around one year after the shock. We re-emphasize here that we are agnostic about the response of inflation after the financial shock, leaving its sign unrestricted. Hence, our result suggests that aggregate supply effects dominate demand effects in the transmission of financial shocks.[21]

Variance and historical decomposition Table 4 shows the forecast error variance decomposition at the four-year horizon. The financial shock accounts for more than half of the forecast error variance of credit growth, and for 45% of that of the EBP. Moreover, financial shocks explain 44% of GDP fluctuations, and 15%

[21] To save space we do not show results for all variables included in our VAR model. Stock prices also decrease persistently. The policy rate does not change significantly on impact, but decreases thereafter, following the GDP response.

of inflation fluctuations.[22] Hence, on average over the sample period, financial shocks made notable, although not very large contributions to inflation dynamics.

Figure 3 shows the historical decomposition of the EBP, credit growth, inflation and GDP over the period 1999-2019. Expansionary financial shocks contributed to the pre-crisis credit and output boom by holding the EBP down over most of this period and pushing credit growth and GDP up. Contractionary financial shocks over the GFC accounted for large parts of the drop in credit growth and, as imposed, the rise in the EBP. Consistent with Furlanetto et al. (2017) and Mumtaz et al. (2018), the financial shock does not, however, fully explain the increase in the EBP, suggesting that the EBP is also affected by other shocks. Most importantly, contractionary financial shocks made positive contributions to inflation around and after the GFC. Between 2008 and 2009, contractionary financial shocks increased core inflation by around 0.6 percentage points. Put differently, core CPI inflation fell from 2.5% to 1.5% in 2008-09, and our results suggest that the fall in inflation would have been 0.6pp larger in the absence of financial shocks. Financial shocks also explain a substantial fraction of the GDP decline after the 2007-09 recession. Our results for the GFC corroborate the results in Del Negro et al. (2015). They show that a DSGE model needs to be augmented with financial frictions and a credit spread to successfully predict the moderate decline in inflation and the strong decline in output during the GFC.

Lastly, we note that contractionary financial shocks also accounted for the financial headwinds in the late-1980s/early-1990s, and kept inflation somewhat up over much of that period as well (not shown). Moreover, expansionary financial shocks held down inflation since late 2016, and can therefore partly explain the "missing inflation" at the end of the sample.

Transmission channels of financial shocks relevant for inflation Why does inflation increase after contractionary financial shocks? In Figure 4 we present impulse responses to the financial shock of variables that capture key transmission channels. We include these variables one by one in the baseline VAR. We treat the endogenous variables from our baseline model as block exogenous for the added variable, and restrict the residual covariance matrix so that shocks to the

[22]The share for GDP is larger than what is reported in the empirical VAR literature which finds contributions of credit supply or financial shocks to the forecast error variance of GDP between 10% and 30%. See for example Bean et al. (2010), Busch et al. (2010), De Nicolò and Lucchetta (2011), Eickmeier and Ng (2015), Furlanetto et al. (2017), Helbling et al. (2011), Hristov et al. (2012), Meeks (2012) and Peersman (2011). We work here with a relatively small VAR compared to these other studies, which might be an explanation.

additional variables do not affect the endogenous variables nor the financial shock estimates.

The first row of Figure 4 shows that contractionary financial shocks lead to a strong and hump-shaped fall in real private investment, consumption and employment. The fall in consumption is potentially the result of wealth effects following the decline in asset prices after the financial shock. Investment decreases by more than consumption, consistent with the restriction imposed by Furlanetto et al. (2017) to identify financial shocks. The gradual decrease in demand is likely to be the reason behind the return of inflation to baseline after its initial increase.

The key determinant of firms' pricing decisions are current and expected future marginal costs. We therefore explore their behavior by looking at the response of the labor income share, a proxy for marginal costs used for instance in Nekarda and Ramey (2013). Figure 4 shows that the labor share does not move significantly in the first few quarters after the shock, and decreases afterwards as both real wages and employment decrease. Hence, the movement in the labor share cannot explain the early increase in inflation. However, it potentially contributes to the decline in inflation one year after the shock.

Models where firms have to borrow in advance to finance production, i.e. featuring a cost, credit or working-capital channel such as De Fiore and Tristani (2013) and Christiano et al. (2014), imply that financing costs are part of firms' marginal costs and therefore matter for price-setting decisions.[23] Accordingly, we assess the responses of different borrowing spreads after the financial shock, capturing different segments of financial markets. The spreads are defined as the Baa corporate bond yield over the 10-year government bond yield; the 3-month commercial paper rate over the 3-month T-bill rate; the C&I loan rate over the 2-year government bond yield; the 30-year mortgage rate over the 10-year government bond yield.[24] All spreads increase significantly over the first few quarters, and the shapes of the responses roughly match the inflation response.

[23] Barth and Ramey (2001) argue that the cost channel is potentially an important feature of the transmission mechanism of shocks to funding conditions. They show that the share of working capital in the non-financial corporate sector, defined as private inventories plus trade receivables, is large relative to total sales. Following their definition of (gross) working capital, we calculate that it amounts to more than 5 quarters of final sales over our sample period. This number is similar to the one computed by Barth and Ramey (2001).

[24] The US has non-negligible mortgage pre-payment activity. The conventional estimate for the duration of mortgages in the US is 7-8 years. Hence, rather than computing the mortgage spread relative to the 30-year government bond rate, we calculate the spread relative to the 10-year government bond rate. See also Walentin (2014) for a similar discussion.

To summarize, results suggest that a mechanism related to the credit or working-capital channel might in part be able to explain the increase in inflation after contractionary financial shocks. These raise borrowing costs on a broad scale, causing an overall increase in firms' marginal costs, which may contribute to the increase in inflation. Nevertheless, other supply-type mechanisms, such as the one emphasized in Gilchrist et al. (2017), may have played a role as well.

4 Validation and robustness

4.1 Responses of credit supply and banking variables to the financial shock

To better understand the characteristics of our financial shock, and to validate that we are indeed identifying a financial shock, we explore the behavior of credit supply measures and banking variables. The series are again added one by one to the VAR, treating the endogenous variables from our baseline model as block exogenous for the added variable. We present the results in Figure 5.

First, we add survey measures of credit supply in order to verify whether our identified shock is consistent with the answers of banking sector survey participants. We use data from the Senior Loan Officer Opinion Survey on Bank Lending Practices: the net percentage of domestic respondents tightening standards for C&I loans ("tightening standards") and the net percentage of domestic respondents reporting increased willingness to make consumer installment loans ("willingness to lend to consumers").[25] The willingness to lend to consumers decreases on impact after the contractionary financial shock, and remains negative for one year. Similarly, banks tighten their credit standards markedly on impact, and keep them above baseline for more than one year. Hence, both survey measures move in the expected direction.

Second, we include data on the return on assets of commercial banks, the ratio of non-performing loans to total loans, the ratio of bank capital to total assets and the volatility of bank stock prices. Bank return on assets, a measure of bank profitability, decreases significantly and remains negative for about 2 years. This decrease is reflected in the response of the bank capital ratio, which also

[25] We construct the "tightening standards" series as the arithmetic mean of the series for large, medium and small firms. Since the individual "tightening standards" series start in 1990Q2, we estimate the model over 1990Q2-2019Q2. The "willingness to lend to consumers" series is instead available over the entire sample period.

drops significantly on impact and remains negative for almost a year. The lower profitability translates into lower net worth, e.g. bank capital, thus generating a weaker capital position. The ratio of non-performing loans to total loans also rises significantly. The response is hump shaped, reaching its maximum after more than a year. The behavior of the non-performing loans ratio follows closely the movement of GDP. The fall in economic activity after the financial shock worsens the balance sheets of entrepreneurs and households, which in turn delays scheduled loan payments (higher nonperforming loans). In addition, the volatility of bank stock prices increases significantly after the financial shock.

Overall, the response of these credit supply and banking variables are consistent with a financial shock.

4.2 Is the Great Recession period different?

One potentially critical point is that the Great Recession period might be different from more "normal" times; for example because financial frictions are larger in crisis times or because the policy rate was constrained at its zero lower bound. To address this point, we re-estimate the model over the pre-GFC period, i.e. over the period 1988Q1 to 2007Q2. Figure 6 (left panel) shows that the positive inflation response after a contractionary financial shock is slightly weaker in the pre-GFC subsample, but the credible sets overlap suggesting that differences are probably not significant.[26]

We also conduct a counterfactual experiment, as follows.[27] We combine the structural shocks from the full model and the reduced-form parameters from the pre-GFC model in order to assess whether one could have predicted positive contributions of financial shocks (assuming they had been observed) to inflation dynamics after the GFC. The answer is yes, even though the counterfactual contributions of financial shocks are slightly smaller compared to those resulting from the baseline model (blue dotted line in Figure 6, right panel). In particular, using the parameter estimates from the pre-GFC subsample, we find that the fall in inflation between 2008 and 2009 would have been 0.4 percentage points larger absent the negative financial shocks.

[26]Note that the credible sets from the pre-GFC model are wider. This is not surprising given that, in the model estimated over the full sample, we impose narrative restrictions, which we show in the next subsection to sharpen inference.

[27]We thank an anonymous referee for suggesting this experiment.

Overall, we can conclude that our main finding that contractionary financial shocks increase inflation also holds for less turbulent times. It is interesting to note that this key finding cannot be explained by the zero lower bound and monetary policy not being able to response to negative financial shocks by lowering the interest rate. Also, based on pre-crisis parameters and assuming that financial shocks had been observed, one could have predicted that inflation would not fall as much as implied by a simple Phillips curve relationship. This corroborates the extended Phillips curve estimation results presented in the introduction.

4.3 Understanding the role of the narrative restrictions

We assess next the importance of narrative restrictions by removing them from the set of identifying restrictions. Figure 7 compares the baseline impulse responses with those obtained from a specification without the two narrative restrictions (blue lines). When narrative restrictions are dropped, our key result remains the same: inflation increases temporarily after contractionary financial shocks. However, the response of the EBP, GDP and credit growth to financial shocks is slightly weaker. Moreover, inference for EBP and inflation dynamics after the financial shock worsens. Figure 8 shows the corresponding historical decomposition. When the narrative restrictions are dropped, the contribution of financial shocks to the EBP, credit growth and GDP during the GFC is much smaller. In addition, the contribution to inflation is also smaller, both during and after the GFC.

Figures C1-C3 in the Appendix further show the effects of removing the narrative restrictions on either the impulse response functions or the historical decomposition. The figures reveal that the restriction on the shock size improves inference for inflation, while the restriction on the historical decomposition leads to more plausible contributions of the financial shock during the GFC.[28]

[28] Removing the restriction on the shock size yields a slightly weaker inflation response than in the baseline identification scheme, and inference of inflation worsens notably. Removing the restriction on the historical decomposition does not alter much impulse responses. The historical decomposition is changed as follows. The contribution of financial shocks to the EBP is larger (and more plausible) with the restriction on the historical decomposition. The contribution of financial shocks to inflation dynamics is smaller without the restriction on the shock size. Moreover, the pre-GFC credit and GDP boom is explained less by financial shocks when the restriction on the shock size is removed.

4.4 (Unconventional) monetary policy shocks

In Section 2.3 we have argued that our identification scheme disentangles financial shocks from monetary policy shocks typically identified in the literature. Recall that monetary policy shocks move interest rates in one direction, and prices and output in the opposite direction. By contrast, our financial shocks either move output, inflation and the policy rate in the same direction or move output and inflation in opposite directions.

However, the aggregate supply channels that may influence the transmission of financial shocks could also play a role in the transmission of monetary policy shocks. The cost channel of monetary policy is one specific example of a transmission channel that could cause inflation to fall after expansionary monetary policy shocks. The cost channel of monetary policy has been in fact brought forward as one explanation of the "price puzzle", for instance by Castelnuovo (2012) and Gaiotti and Secchi (2006). If the cost channel is a relevant transmission mechanism, our financial shocks may not be disentangled from monetary policy shocks. Put differently, a monetary policy shock that affects funding costs is a specific type of financial shocks.

This concern should be even more relevant for unconventional monetary policy, which is at least in part designed to explicitly stimulate credit supply and lower funding costs and, through that, to stimulate economic activity and inflation.[29] Existing work already emphasizes the link between unconventional monetary policy and credit supply or financial shocks. De Santis and Darracq-Paries (2015) explicitly identify unconventional monetary policy shocks in the euro area in a VAR model as shocks that increase credit supply. Moreover, in a time-varying parameter VAR for the US, Prieto et al. (2016) find that credit spread shocks have contributed positively to GDP growth from 2010 onwards. They argue that those credit spread shocks probably capture unconventional monetary policy actions.

We investigate here to what extent monetary policy actions lie behind our financial shocks. Figure 9 plots our financial shock estimates (solid line) against the monetary "policy news shock" measure taken from Nakamura and Steinsson (2018) (dashed line) in the last two decades of the sample.[30] This "policy news shock" is based on high-frequency responses of current and expected future interest rates in a 30-minute window surrounding scheduled Federal Reserve announcements, and

[29]See Bernanke (2009).

[30]The Nakamura and Steinsson (2018) measure is available until early-2014.

captures the effects of forward guidance.[31] We normalize the shock series in figure 9 so that negative values represent a monetary policy easing (which can be expected to raise credit growth and lower funding costs) and expansionary financial conditions and that the standard deviation is one over the period over which we plot the shocks.

Figure 9 reveals that the two shocks are basically uncorrelated over the sample (correlation coefficient: -0.03). Financial shocks seem, however, somewhat correlated with monetary policy shocks around the 2001 recession and the GFC. In both episodes, the Federal Reserve strongly lowered the federal funds rate and provided liquidity to financial institutions in order to stabilize the financial system.[32] In addition, in the course of the GFC the Federal Reserve lent directly to borrowers and investors in credit markets, and purchased longer-term securities.[33] This finding is consistent with Eickmeier et al. (2016) who find a price puzzle after an expansionary monetary policy shock in high-volatility periods. Similarly, Fry-McKibbin and Zheng (2016) find that prices decline after expansionary monetary policy shocks in financial stress periods, but not in low stress periods. They argue that this is consistent with cost channel effects during financial stress periods.

We conduct two further checks. First, we include the Nakamura and Steinsson (2018) monetary policy shock as an explanatory variable in the VAR, and re-run the estimation and shock identification.[34] The idea is that the monetary policy shock should capture all remaining uncontrolled effects of monetary policy shocks. Second, we identify a monetary policy shock in addition to the baseline shocks, by imposing that the policy rate increases and inflation, output and credit growth decrease on impact after a contractionary monetary policy shock. Figure C5 in the Appendix shows that, even after explicitly accounting for monetary policy shocks, the contractionary financial shock continues to have inflationary effects.

To sum up, results suggest that our financial shock is barely contaminated by monetary policy shocks, and that contractionary financial shocks cleaned from monetary policy shocks still produce positive effects on inflation.

[31] For further details we refer to Nakamura and Steinsson (2018).

[32] The Federal Reserve acted as a liquidity provider to counter the disruption of normal channels of borrowing and payments after September 11, 2001 (Meyer 2001).

[33] See Bernanke (2009) and Kohn (2010) for details on the liquidity provision to financial institutions during the GFC by the Federal Reserve.

[34] For that purpose we extend the Nakamura and Steinsson (2018) shocks, which are available from 1995 onwards, with the monetary policy shocks constructed by Romer and Romer (2004).

4.5 Further robustness checks: other shocks and alternative measures of interest rates, inflation and credit

We carry out a large battery of further robustness checks. We test whether we disentangle financial from other shocks, including housing shocks, technology news shocks, oil shocks and uncertainty shocks. This is achieved by adding additional variables one by one to the baseline model, and imposing additional restrictions to identify one additional shock at a time, as discussed in Appendix C. We note that, for computational reasons, it is not feasible to identify all shocks simultaneously. Moreover, we replace our measures of interest rates, inflation and credit with alternative measures and add inflation expectations to the model. None of these alterations changes our results, and we refer to Appendix C for details.

5 Conclusion

While there exists a large literature on the relationship between financial shocks and the real economy, the literature on the link between financial shocks and inflation dynamics is still in its infancy. However, understanding the link between financial and price stability is of key importance to monetary policy makers.

In this paper, we use a Bayesian VAR analysis and propose a novel identification scheme for financial shocks based on sign and narrative restrictions, which remains fully agnostic about the effects of financial shocks on inflation. Our main finding is that contractionary financial shocks tend to have temporary inflationary effects. We also show that this inflationary effect prevented a much stronger fall in inflation during the financial crisis. Hence, our results suggest that financial shocks might be an additional explanation for the "missing disinflation puzzle" during the financial crisis, as well as for the "missing inflation puzzle" over the subsequent recovery phase. A key implication of our finding is that financial shocks which simultaneously lower output and rise inflation might worsen the policy trade-off for a central bank which seeks to stabilize both.

We also explore different transmission channels of financial shocks and their implications for inflation dynamics. Our findings suggest that higher borrowing costs could explain the observed short-term inflationary effects of financial shocks.

Our key result that contractionary financial shocks have inflationary effects is robust against a battery of robustness checks, such as the use of alternative or additional variables, alternative shock identification schemes and variations of the sample period. Moreover, the identified financial shocks affect banking variables and survey measures of credit supply in the expected way.

We note that we focus here on a broad financial (credit supply) shock. One promising future avenue could be to assess the effects of specific types of financial shocks, such as those emphasized in Table 1.

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Tables

Table 1: **Theoretical responses of inflation to contractionary financial shocks implied by different models**: An increase (decrease) is denoted with a + (-) sign. FT refers to De Fiore and Tristani (2013); MM refers to Meh and Moran (2010); GNSS refers to Gerali et al. (2010); GSSZ refers to Gilchrist et al. (2017); GK refers to Gertler and Karadi (2011); CW refers to Curdia and Woodford (2010); HH refers to Hristov and Huelsewig (2017); GLN refers to Gelain et al. (2017); CMR refers to Christiano et al. (2010).

MODEL	SHOCK	π
FT	FIRM NET WORTH DECREASE	+
MM	BANK CAPITAL DECREASE	+
GNSS	BANK CAPITAL DECREASE	+
GSSZ	INCREASE IN EXTERNAL FINANCE COST	+
GK	NEGATIVE CAPITAL QUALITY SHOCK	−
CW	HIGHER FRACTION OF NONPERFORMING LOANS	−
HH	BANK CAPITAL DECREASE	very brief −, then +
GLN	TIGHTER LENDING STANDARDS	−
CMR	HIGHER DEMAND FOR BANK RESERVES	+
CMR	LOWER EFFICIENCY IN BANK FUNDING ACTIVITY	−

Table 2: **Phillips curve estimation results**: IV-estimation results for different Phillips curve specifications, with backward-looking inflation expectations (BACK) or household inflation expectations (HH), with or without the excess bond premium and oil price inflation. Slack is measured by the unemployment gap. Robust standard errors in parentheses. See Appendix A for further details.

			SPECIFICATION		
VARIABLES	BACK	HH	HH, EBP	HH, OIL	HH, OIL, EBP
ugap	-0.091	-0.112	-0.002	-0.082	0.046
	(0.168)	(0.138)	(0.107)	(0.120)	(0.096)
ebp			0.349*		0.503**
			(0.185)		(0.227)
oil				4.022***	4.201***
				(0.856)	(0.766)
constant	-0.047	0.026	0.042	-0.041	-0.081
	(0.162)	(0.159)	(0.128)	(0.142)	(0.125)
Observations	77	77	77	77	77
R-squared	0.007	-0.004	0.022	0.231	0.274

Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 3: **Restrictions to identify financial, aggregate demand and aggregate supply shocks**: This table shows the restrictions imposed on the impulse response functions of the endogenous variables in the baseline VAR to identify financial, aggregate demand and aggregate supply shocks. All restrictions are imposed on impact and are implemented as ≥ 0 ($\uparrow$) or ≤ 0 ($\downarrow$). See text for details.

SIGN RESTRICTIONS							
	gdp	inflation	credit growth	interest rate	ebp	stock prices	credit growth to gdp
financial shock	$\downarrow$		$\downarrow$	$\downarrow$ iff inflation $\downarrow$	$\uparrow$	$\downarrow$	$\downarrow$
demand shock	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$			$\uparrow$
supply shock	$\downarrow$	$\uparrow$				$\downarrow$	$\uparrow$
NARRATIVE RESTRICTIONS TO IDENTIFY FINANCIAL SHOCKS							
Largest contractionary shock in 2008Q3							
Contribution to EBP dynamics in 2008Q3 larger than the sum of all other shocks in absolute terms							

Table 4: **Forecast error variance decomposition**: This table shows the median forecast error variance shares explained by financial shocks, for each of the variables in the baseline VAR, at a four-year horizon.

gdp	inflation	credit growth	ebp
0.44	0.15	0.57	0.45

Figures

Figure 1: **Inflation and Phillips curve predictions**: Plot shows actual headline inflation (thick solid line), and predictions from different Phillips curve specifications, based on backward-looking inflation expectations (red dashed line), household inflation expectations (solid black line), household inflation expectations and oil price inflation (green dashed line), household inflation expectations, oil price inflation and the excess bond premium (black dotted line). See Appendix A for further details.

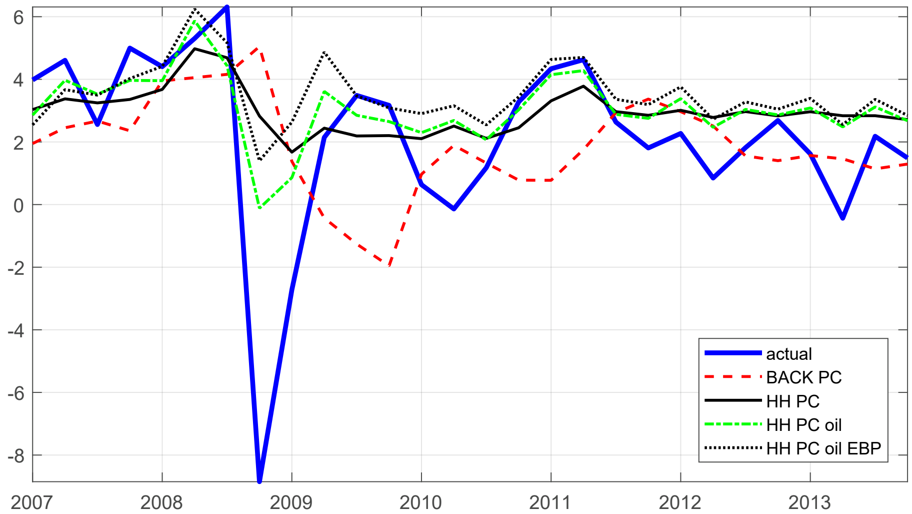


Figure 2: **Impulse responses to a one-standard deviation contractionary financial shock**: Plot shows median impulse responses (solid lines) and 68% credible sets (shaded areas). The response of gdp is in percent, those of the other variables are in percentage points.

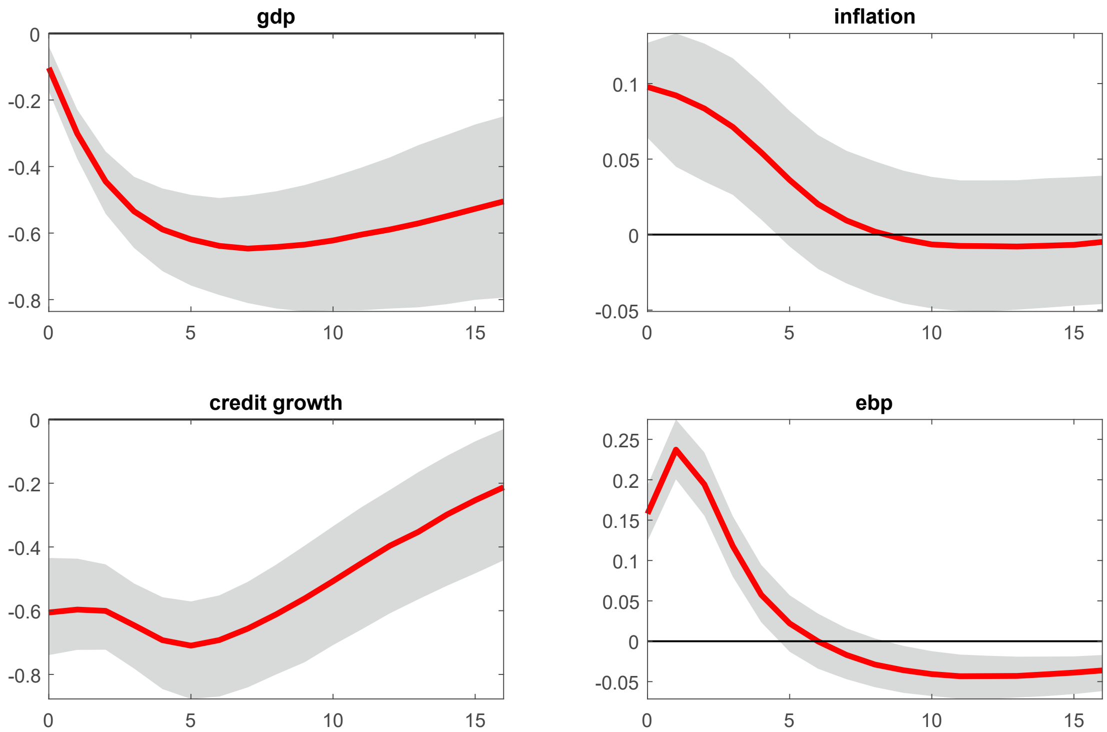


Figure 3: **Historical decomposition of key variables**: Plot shows the contribution of all shocks to explaining the deviation of key variables from their deterministic component (solid lines), and the contribution of the financial shocks (bars). Contributions to gdp are in percent; those to the other variables are in percentage points.

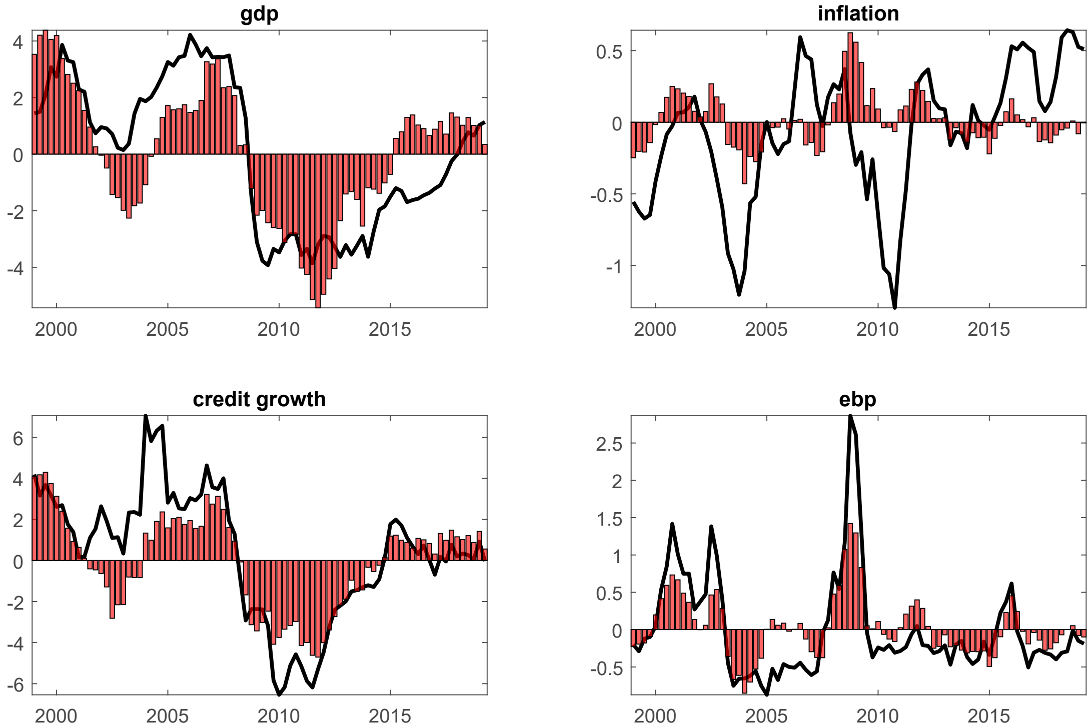


Figure 4: **Transmission channels of financial shocks relevant for inflation**: Plot shows median impulse responses (solid lines) and 68% credible sets (shaded areas). Responses of investment, consumption, employment and the real wage are in percent; those of the remaining variables are in percentage points. See text for a description of the variables.

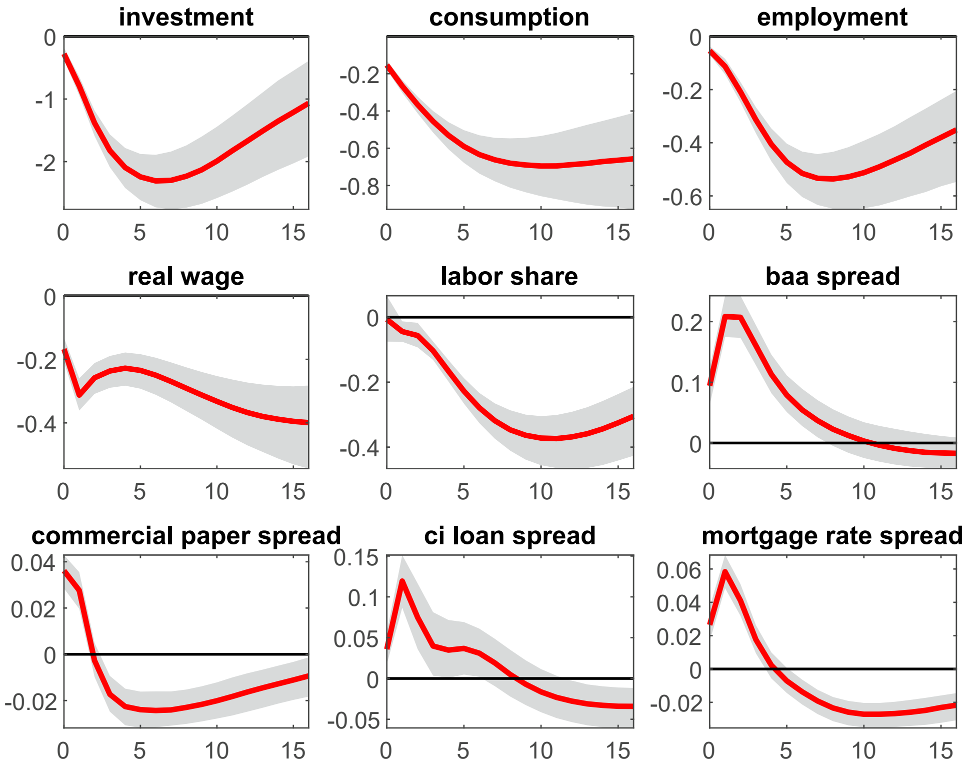


Figure 5: **Response of credit supply and banking variables to a one-standard deviation contractionary financial shock**: Plot shows median impulse responses (solid lines) and 68% credible sets (shaded areas). Responses of the willingness to lend to consumers, lending standards, the bank return on assets, the non-performing loans ratio and the bank capital ratio in percentage points. See text for a description of the variables.

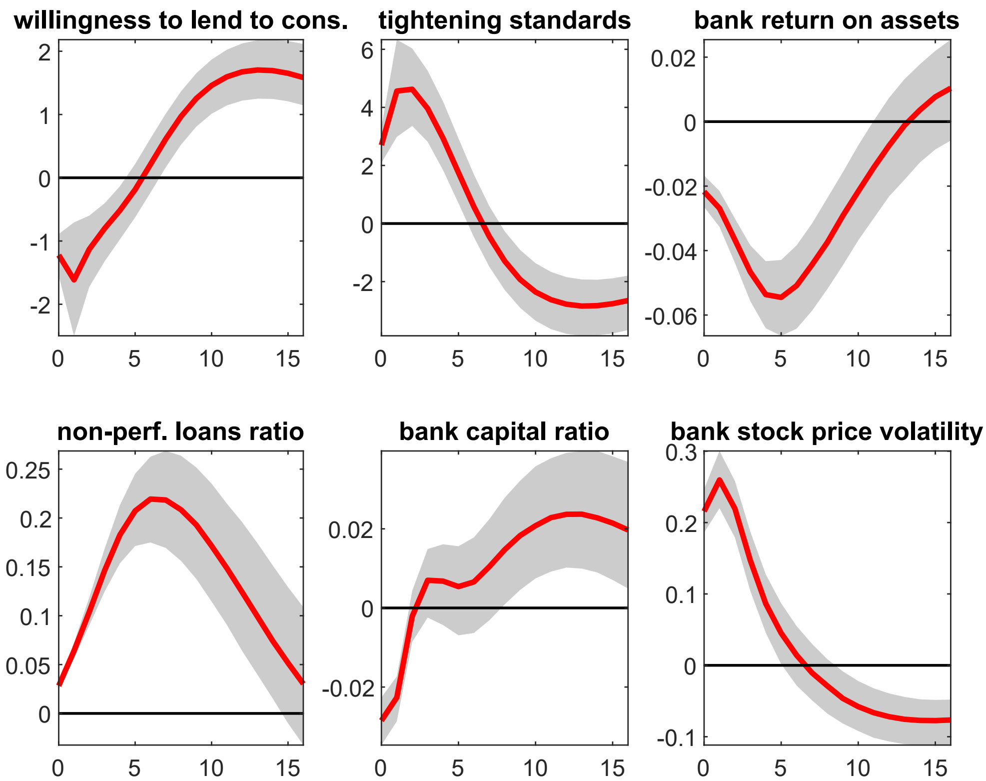


Figure 6: **Does the GFC make a difference?** Left graph: Impulse response functions of inflation to contractionary financial shocks, median baseline estimate (red solid line), and 68% credible sets (shaded areas), and pre-GFC median estimate (blue dotted line). Right graph: Historical decomposition of inflation, baseline model (all shocks: black solid lines, financial shocks: red bars) and counterfactual contributions of financial shocks (based on structural shocks estimated over the full sample and reduced-form parameters estimated over the pre-GFC sample: blue dotted lines). See text for details.

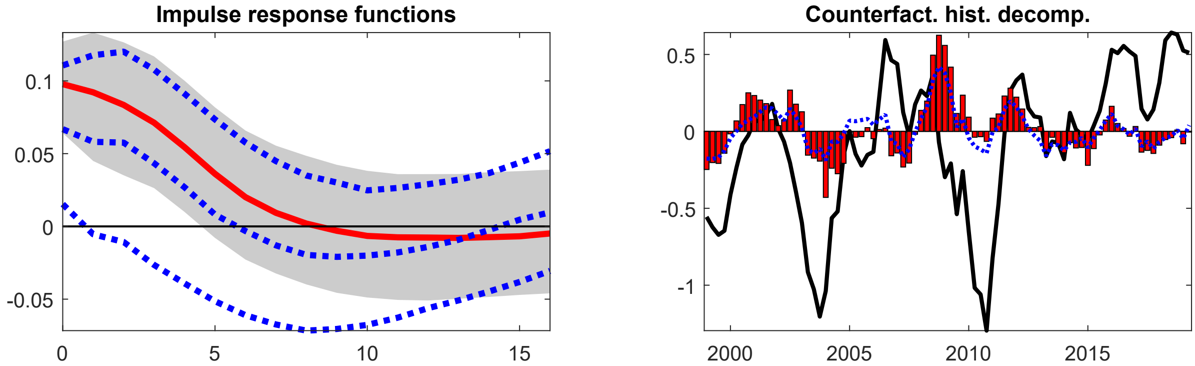


Figure 7: **Impulse responses to a one-standard deviation contractionary financial shock - role of the narrative restrictions**: Plot shows median impulse responses and 68% credible sets in the baseline model (solid red lines and shaded areas), and in the model without narrative restrictions (solid and dotted blue lines). The response of gdp is in percent; those of the other variables are in percentage points.

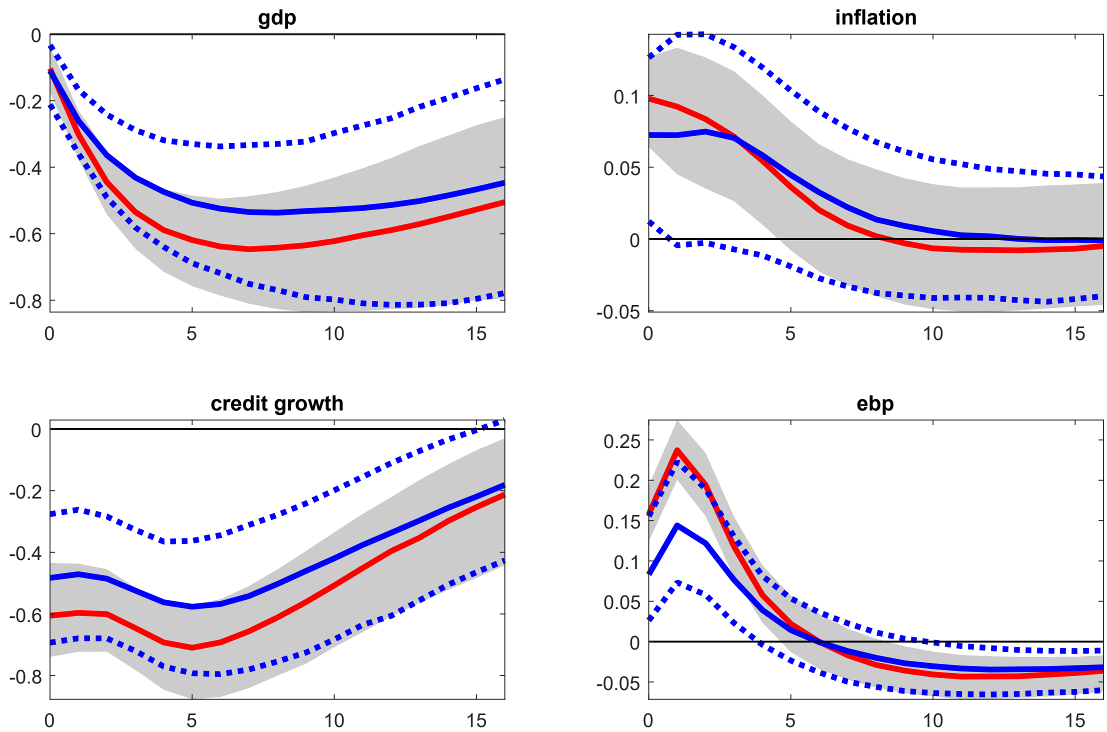


Figure 8: **Historical decomposition of key variables - effects of the narrative restrictions**: Plot shows contribution of all shocks to explaining the deviation of key variables from their deterministic component in the baseline model (solid black lines), contribution of financial shocks in the baseline (red bars) and in the model without narrative restrictions (blue dotted lines). Contributions to gdp are in percent; those to the other variables are in percentage points.

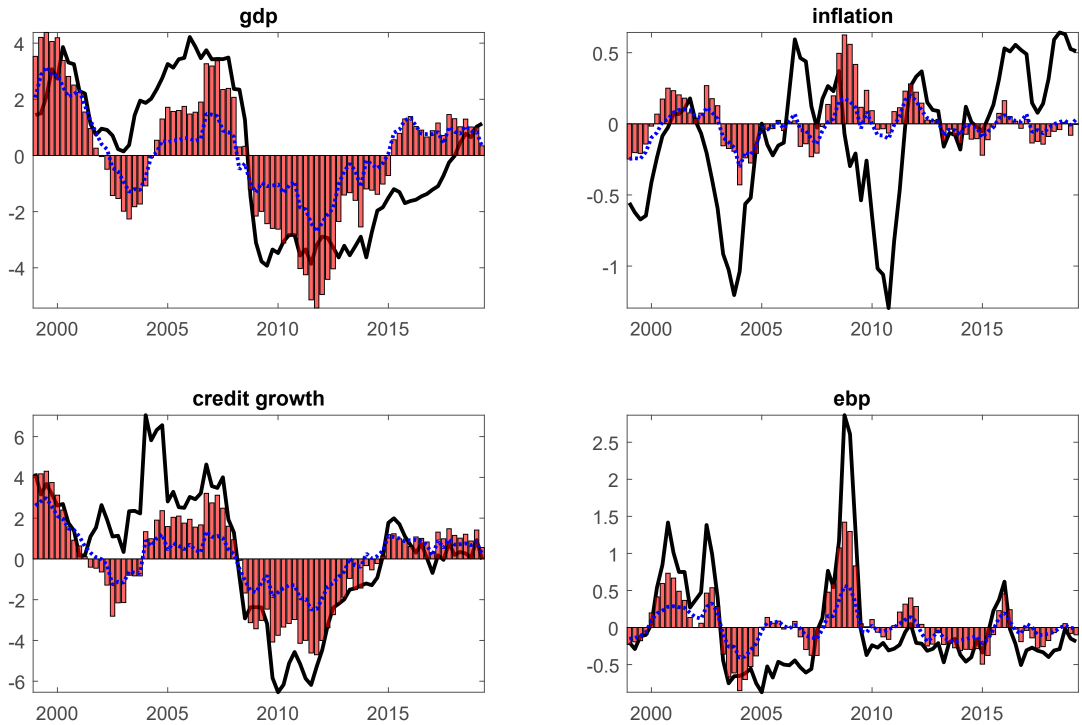
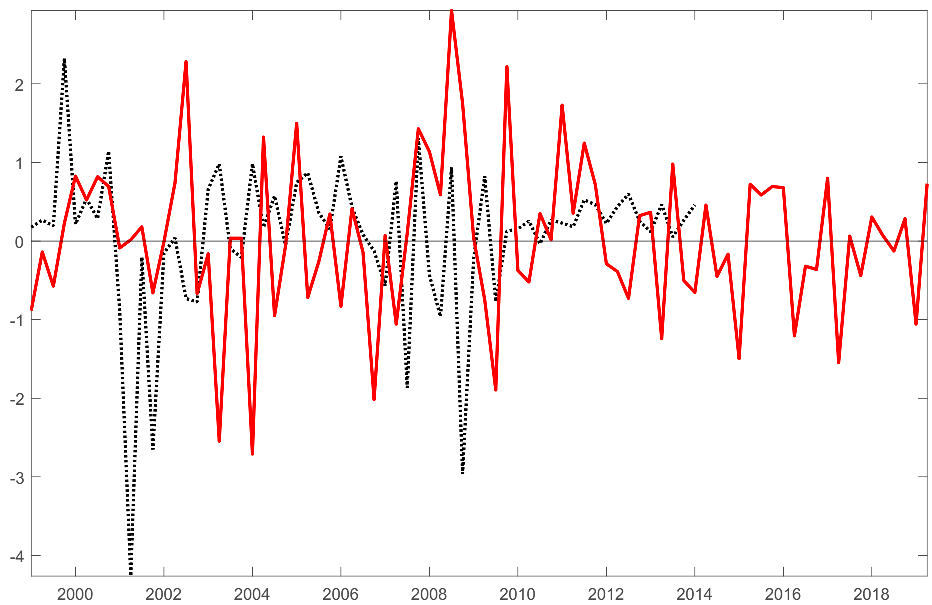


Figure 9: **Financial and monetary policy shocks**: Identified financial shocks (solid line) and Nakamura and Steinsson (2018) monetary policy shocks (dashed-dotted line). The shocks are standardized so that negative values represent expansionary monetary policy and financial shocks. Both series have standard deviation of 1 over the considered sample. See text for details.



38

A Phillips curve estimation

We explore the role of financial conditions in explaining inflation dynamics by estimating a series of simple Phillips curves. We estimate the Phillips curves based on a pre-GFC sample from 1988Q1 to 2007Q4 and use the estimated coefficients to generate predicted inflation rates for the GFC and the subsequent period. As a simple baseline against which to compare alternative specifications, we consider the following expectation-augmented Phillips curve:

$$\pi_t = c + \kappa x_t + \beta \pi^e_{t+1} + v_t$$

where π_t is headline inflation, π^e_{t+1} inflation expectations, x_t a measure of economic activity, and v_t a shock. We measure economic activity through the difference between the unemployment rate and the natural rate of unemployment, estimated by the Congressional Budget Office but assumed here to be observable. We consider two measures of inflation expectations: backward-looking, whereby expected inflation can be approximated by the average of the previous four quarters' inflation rates as in Mazumder and Ball (2011), and forward-looking, whereby expected inflation is measured by one-year ahead inflation expectations taken from the University of Michigan consumer survey. Following Coibon and Gorodnichenko (2015), we estimate the Phillips curves by IV, instrumenting the current unemployment gap through a constant and its lag.

Figure 1 shows actual inflation (thick solid line) along with the two Phillips-curve predictions, respectively based on backward-looking and household inflation expectations (red dashed and solid black lines). We confirm here the findings of Coibon and Gorodnichenko (2015): A backward-looking Phillips curve, estimated over the pre-crisis sample period, substantially underpredicts consumer price inflation between 2009 and 2011 (the "missing disinflation" puzzle). This puzzle is partially solved when households' forward-looking inflation expectations are added to the set of explanatory variables.

Oil prices have also been mentioned as a possible explanation for why inflation did not fall more after the GFC. To examine whether oil prices improve the fit of the Phillips curve, we augment the model based on household inflation expectations with oil price inflation. The resulting counterfactual inflation rate (green dashed line in Figure 1) indicates that oil prices improve the fit of the Phillips curve model, especially in the 2009-2010 period.

To gauge if financial conditions can improve the predictive ability of the Phillips Curve we augment the above specification with the excess bond premium (EBP), and estimate the following equation:

$$\pi_t = c + \kappa x_t + \beta E_t \pi^e_{t+1} + \delta \pi^{oil}_t + \gamma ebp_t + v_t$$

Where π^e_{t+1} are households inflation expectations. For consistency, we instrument the EBP with a constant and its lag. Table 2 (last column) presents the estimation results and shows that the coefficient of the EBP γ is positive and significant. This indicates that a worsening of credit conditions raises inflation. This result is in line with De Fiore and Tristani (2013), who find a sizeable positive coefficient on credit spreads in their estimated Phillips curve. The black dotted line in Figure 1 shows the counterfactual inflation rate produced by this Phillips curve specification augmented with financial conditions. During and after the GFC, the implied inflation rates are consistently above those from the model without the excess bond premium. Hence, contractionary financial conditions do indeed help explain why inflation was not much lower during this period. Augmenting the Phillips curve with the EBP helps especially in 2009, where the predicted inflation rate is up to one percentage point higher compared to the model with only household expectations.

Overall, while the EBP's contribution in predicting inflation may be modest, these results support the notion that tighter financial conditions might be associated with higher inflation rates.

B Bayesian estimation

This Section describes the algorithm used to identify sign and narrative sign restrictions, and relies heavily on Antolín-Díaz and Rubio-Ramírez (2018).

We start with the orthogonal reduced-form parametrization of the reduced-form VAR in equation (1), as in Arias et al. (2018). This parametrization is characterized by the reduced-form parameters $\mathbf{B}$ and $\mathbf{\Sigma}$, together with an orthogonal $n \times n$ matrix $\mathbf{Q} \in O(n)$.

We have chosen priors of $(\mathbf{B}, \mathbf{\Sigma}, \mathbf{Q})$ that are uniform-normal-inverse-Wishart. The following algorithm makes independent draws from the uniform-normal-inverse-Wishart posterior of $(\mathbf{B}, \mathbf{\Sigma}, \mathbf{Q})$ conditional on the traditional sign and narrative sign restrictions:

(i) Independently draw $(\mathbf{B}, \mathbf{\Sigma})$ from the normal-inverse Wishart posterior of the reduced form parameters and $\mathbf{Q}$ from the uniform distribution over $O(n)$

(ii) Check whether traditional sign restrictions and narrative sign restrictions are satisfied

(iii) If not, discard the draw. If yes, compute the importance weight of $(\mathbf{B}, \mathbf{\Sigma}, \mathbf{Q})$ as follows:

  (a) Simulate M independent draws of shocks ε^{ν} from the standard normal distribution, where ν is the number of shocks constrained by the narrative sign restrictions (1 in this application)

  (b) Approximate $\omega(\mathbf{B}, \mathbf{\Sigma}, \mathbf{Q})$ by the proportion of M draws (1000 in this application) the satisfy the narrative sign restrictions and set the importance weight to $1/\omega(\mathbf{B}, \mathbf{\Sigma}, \mathbf{Q})$

(iv) Return to step (i) until the required number of draws has been obtained (1000 in this application)

(v) Draw with replacement from the set of $(\mathbf{B}, \mathbf{\Sigma}, \mathbf{Q})$ using the importance weights

C Additional results and robustness

C.1 Effect of each of the narrative restrictions

Figure C1: **Impulse responses to a one-standard deviation contractionary financial shock - effects of the narrative restriction on the shock size: Robustness checks Ia**: Plot shows median impulse responses and 68% credible sets in the baseline model (solid red lines and shaded areas), and in the model without narrative restriction (solid and dotted blue lines). The response of gdp is in percent; those of the other variables are in percentage points.

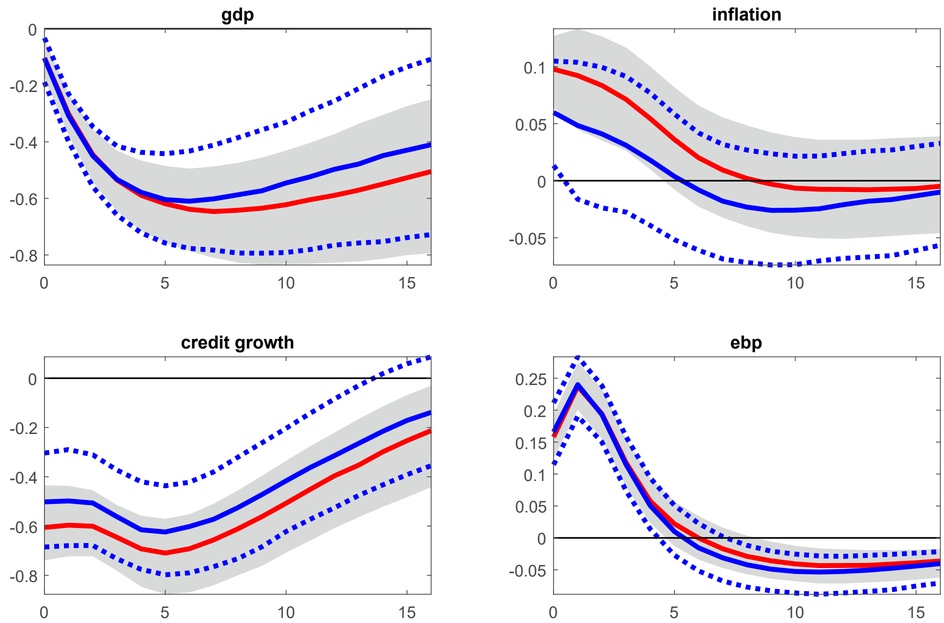


Figure C2: **Impulse responses to a one-standard deviation contractionary financial shock - effects of the narrative restriction on the historical decomposition: Robustness checks Ib**: Plot shows median impulse responses and 68% credible sets in the baseline model (solid red lines and shaded areas), and in the model without narrative restrictions (solid and dotted blue lines). The response of gdp is in percent; those of the other variables are in percentage points.

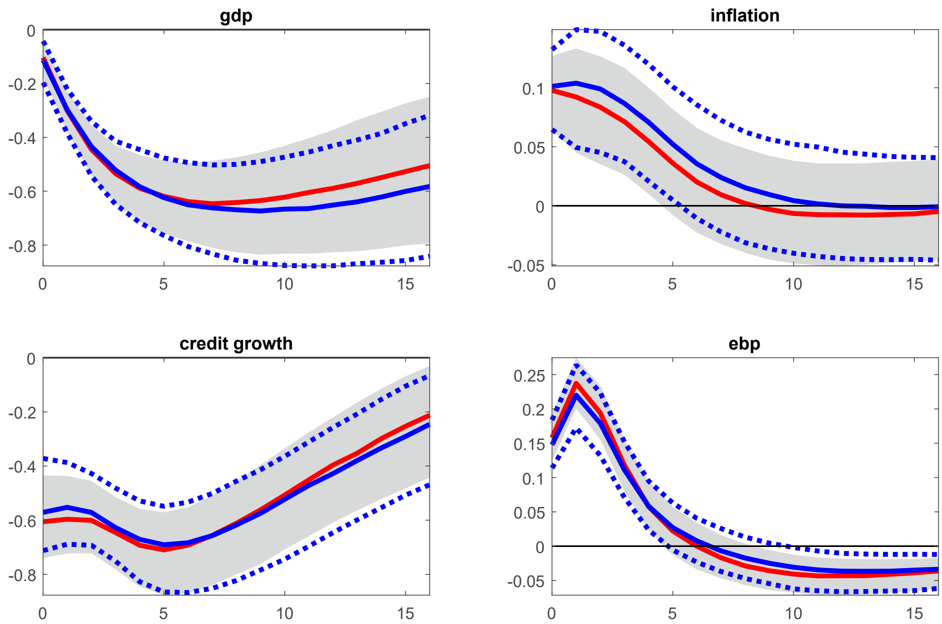
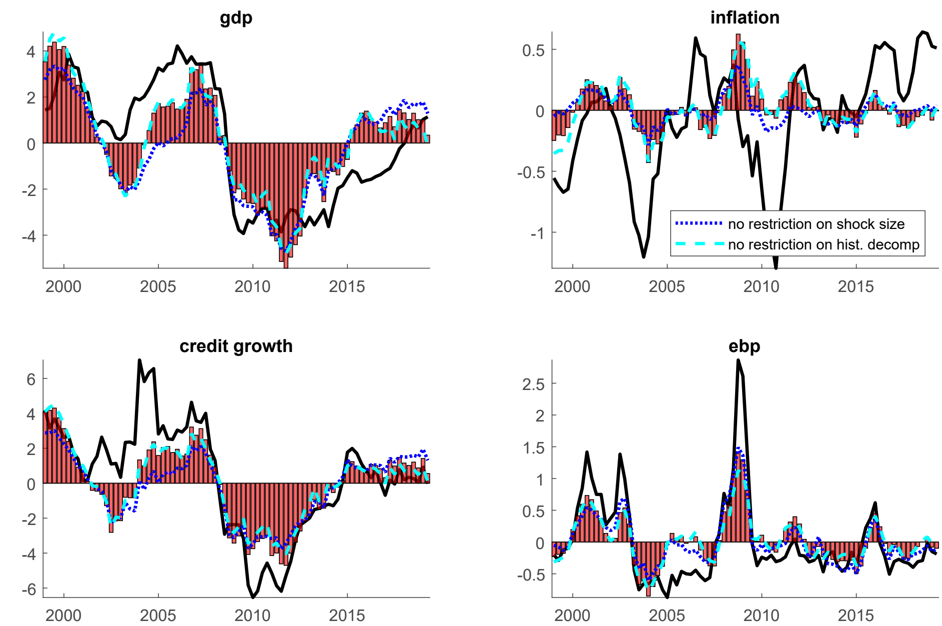


Figure C3: **Historical decomposition of key variables - effects of each narrative restrictions: Robustness checks Ic**: Plot shows contribution of all shocks to explaining the deviation of key variables from their deterministic component (solid black lines), contribution of financial shocks in the baseline model (red bars), in the model without shock size restriction (blue dotted lines), and in the model without restriction on historical decomposition (cyan dashed lines). Contributions to gdp are in percent; those to the other variables are in percentage points.



C.2 Financial shocks versus other shocks not explicitly accounted for in the baseline model

Our baseline specification is a relatively small VAR model, which still allows us to separate financial shocks from standard shocks, such as aggregate demand and supply shocks. Here, we modify the baseline model and discuss to what extent our financial shocks are disentangled from other shocks not explicitly accounted for in our baseline model. It is computationally not feasible to account for all shocks simultaneously and, hence, add additional variables and identify additional shocks one by one. Figures C4 and C5 show impulse responses of inflation to financial shocks. We plot median impulse responses from the alternative models with median impulse responses and credible sets from the baseline model.

Technology and technology news shocks We add total factor productivity (TFP) to our model, which now contains $\tilde{n} = n + 1$ endogenous variables. The TFP series is the one suggested by Fernald (2012), adjusted for unobserved factor utilization, and it enters in logarithmic form. In addition to financial and aggregate demand shocks, we simultaneously identify technology shocks (instead of aggregate supply shocks) and technology news shocks.

We proceed as in Barsky and Sims (2011). First, we identify the technology shock as the only one affecting TFP contemporaneously, i.e. via zero restrictions. Among the remaining $(\tilde{n}-1)$ shocks, the technology news shock explains the maximum of the forecast error variance of the TFP series, but has no contemporaneous impact on TFP. Among the remaining $(\tilde{n}-2)$ shocks, we identify financial and aggregate demand shocks as in the baseline model. As imposed by the identification strategy, TFP does not react on impact and does not move very significantly thereafter after financial shocks. This finding is not at odds with theory, which is ambiguous on the effects of financial shocks on productivity.[35] Figure C4 shows that the response of inflation to financial shocks is slightly weaker than in the baseline model, but the difference is probably not significant.

Housing shocks Next, we consider a narrower financial (credit supply) shock, which we disentangle explicitly from a housing shock. Following Furlanetto et al. (2017), we add real estate value to credit (taken from the Financial Accounts) and restrict this ratio to rise on impact, i.e. credit declines by more

[35] See for instance Khan and Thomas (2013) and Petrosky-Nadeau (2013) who consider the effects of financial shocks on productivity.

than the real estate value, after contractionary financial shocks. Inflation rises by slightly more after financial shocks than in the baseline model (Figure C4).

Oil shocks Oil price inflation is defined as the log year-on-year change in the West Texas Intermediate (WTI) price of crude oil.[36] In order to disentangle financial from oil shocks, we restrict the oil price not to move on impact after financial shocks. The zero restriction on the oil price implies that oil supply and oil demand, which should move the oil price on impact, react only with a delay to financial shocks. The inflation response is basically identical (Figure C4).

Uncertainty shocks To disentangle financial shocks from uncertainty shocks, we add the uncertainty measure constructed by Jurado et al. (2015) (macroeconomic uncertainty, forecast horizon of 1) and restrict the EBP to rise by more than uncertainty on impact (see Furlanetto et al. 2017). The resulting inflation reaction after the financial shock is very similar to the baseline response (Figure C5). Furthermore, macroeconomic uncertainty rises temporarily after the financial shock. It is theoretically unclear how uncertainty affects inflation, and it is hence unclear whether uncertainty represents an additional channel through which financial shocks affect inflation. On the one hand, a rise in uncertainty can lower inflation through standard aggregate demand effects associated with nominal rigidities (Leduc and Liu 2016). On the other hand, a rise in uncertainty can increase inflation in models with concave profit functions and price adjustment costs (Fernández-Villaverde et al. 2015 and Mumtaz and Theodoridis 2016).

[36] Alquist et al. (2013) argue that while the WTI oil price has been regulated before the mid-1980s, it is a reasonable oil price measure since the mid-1980s, which overlaps with our sample period.

Figure C4: **Effect of contractionary financial shocks on inflation: Robustness checks II**: Plot shows median impulse responses (red solid line) and 68% credible sets (shaded areas) from the baseline model. Remaining lines show median impulse responses of inflation based on alternative models. *Disentangle from housing shock:* adding real estate value to credit to the baseline VAR and restricting it to rise on impact after contractionary financial shocks. *Disentangle from tech and tech news shock:* simultaneous identification of technology shocks, technology news shocks, financial shocks and aggregate demand shocks. *Disentangle from oil shock:* adding oil prices to the baseline VAR and restricting the oil price not move on impact after baseline shocks.

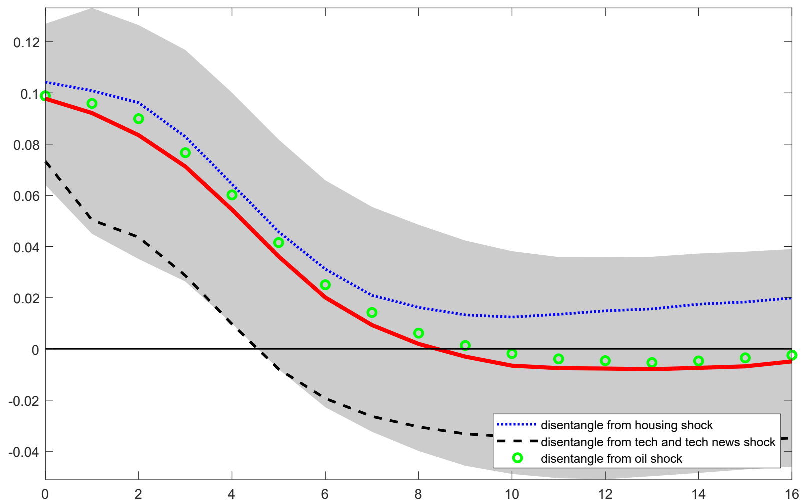
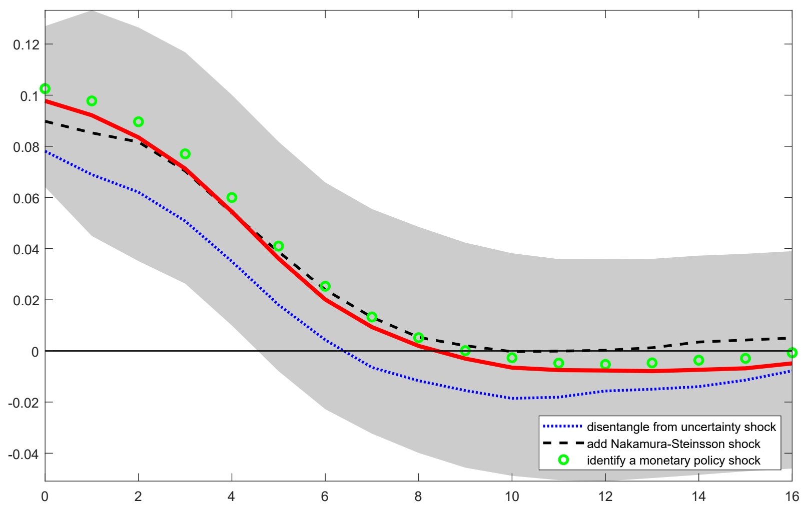


Figure C5: **Effect of contractionary financial shocks on inflation: Robustness checks III**: Plot shows median impulse responses (red solid line) and 68% credible sets (shaded areas) from the baseline model. Remaining lines show median impulse responses of inflation based on alternative models. *Disentangle from uncertainty shock:* adding uncertainty measure to the baseline VAR and restricting the EBP to rise by more than uncertainty after financial shocks. Following Furlanetto et al. (2017) we normalize uncertainty to have the same standard deviation as the EBP. *Add Nakamura-Steinsson shock:* adding the monetary policy shocks series of Nakamura and Steinsson (2018) to the baseline VAR. *Identify a monetary policy shock:* simultaneous identification of monetary policy, financial and aggregate demand and supply shocks.



C.3 Alternative inflation rates, interest rates and credit measures

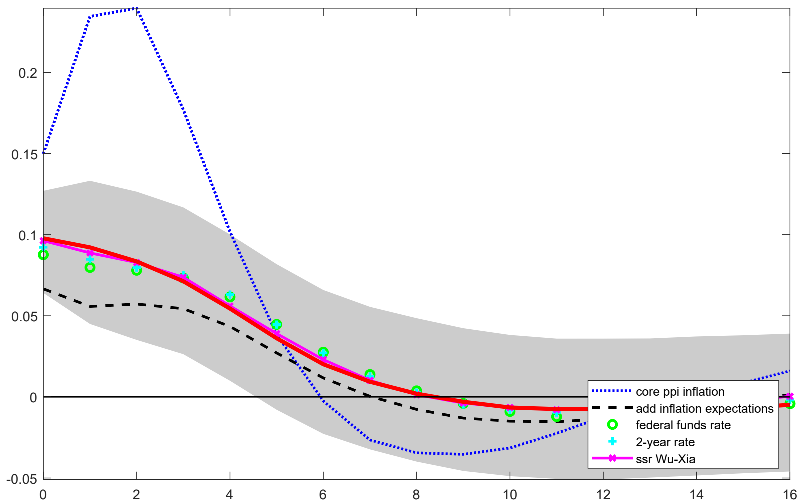
Control for an alternative measure of inflation and for inflation expectations As a set of alternative checks, we replace core CPI inflation with core PPI inflation (Figure C6). Core PPI inflation increases by much more than core CPI inflation. A possible reason could be that PPI inflation is a more direct measure of the price-setting behavior of producers, and that the emphasized supply channels are especially relevant for producers.

We also control for inflation expectations as an omitted variable. Inflation expectations are measured as 1-year ahead forecasts of (year-on-year) inflation from the Surveys of Consumers conducted by the University of Michigan. This follows Castelnuovo and Surico (2010), who argue that inflation expectations should be included in monetary VARs as they help to identify structural shocks. Although the authors focus on monetary policy shocks, this problem might affect other shocks in the system as well.[37] Moreover, we would like to understand whether we are able to replicate previous Phillips curve findings, i.e. that financial conditions have an impact on inflation even when we control for inflation expectations. We do not impose any restriction on inflation expectations. The financial shock still produces an inflationary effect (Figure C6). Inflation expectations also rise temporarily after financial shocks (not shown).

Alternative measures of the short-term interest rate We also check the sensitivity of our main results to changes in the short-term interest rate. First, we replace the linked federal funds rate-SSR variable with the original federal funds rate. Second, following Gertler and Karadi (2015) we use the 2-year T-bill rate as the monetary policy indicator. Third, we link the federal funds rate with the SSR proposed by Wu and Xia (2016). Inflation rises after the financial shock regardless of the exact measure of the short-term interest rate (Figure C6).

[37] They use 1-quarter ahead inflation expectations. In line with the year-on-year inflation variable in our model, we use 1-year ahead inflation expectations.

Figure C6: **Effect of contractionary financial shocks on inflation: Robustness checks IV**: Plot shows median impulse responses (red solid line) and 68% credible sets (shaded areas) from the baseline model. Remaining lines show median impulse responses of inflation based on alternative models. *Core ppi inflation:* replacing core cpi inflation with core ppi inflation. *Add inflation expectations:* adding 1-year ahead inflation expectations to the baseline VAR. *Federal funds rate:* replacing linked federal funds rate-SSR variable with the original federal funds rate series. *2-year rate:* replacing linked federal funds rate-SSR variable with the 2-year T-Bill rate. *Ssr Wu-Xia:* replacing SSR of Krippner (2015) with SSR of Wu and Xia (2016)



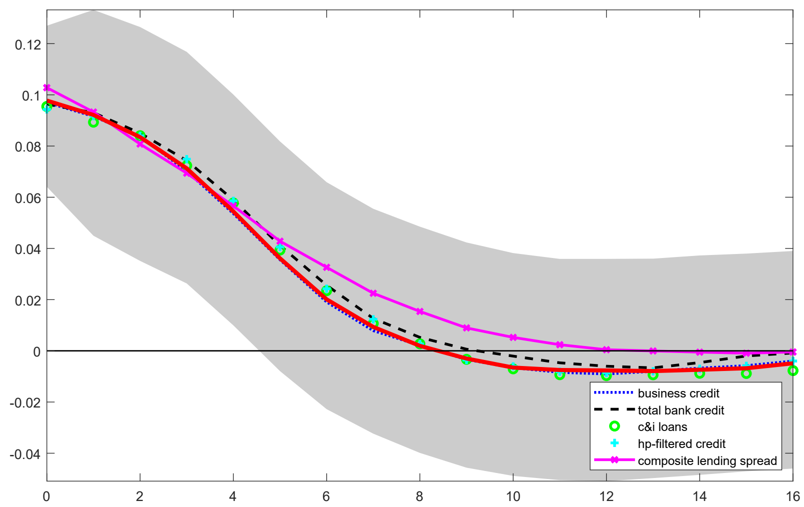
Alternative credit and spread measures We experiment with alternative measures of credit growth and credit spreads to check whether our findings are driven by the baseline credit measure and the EBP. We first replace our measure of total credit with either business credit, total bank credit, or commercial and industrial bank loans. Moreover, we use a different detrending method for credit. Rather than using year-on-year changes we employ a one-sided HP filter applied to the log of outstanding credit.

Furthermore, we replace the EBP with a composite business lending spread, computed as the weighted average of the commercial paper spread, the Baa spread and the C&I loan spread.[38] As for the EBP, we restrict the composite lending spread to decrease after the financial shock.

All identified contractionary financial shocks from these modified models turn out to be inflationary and very similar to those from the baseline model (Figure C7).

[38]The weights are one half of the share of credit market instruments in total business credit, for the commercial paper rate and the Baa spread, respectively, and the share of commercial and industrial loans in total business credit for the C&I loan spread.

Figure C7: **Effect of contractionary financial shocks on inflation: Robustness checks V**: Plot shows median impulse responses (red solid line) and 68% credible sets (shaded areas) from the baseline model. Remaining lines show median impulse responses of inflation based on alternative models. *Business credit*: replacing total credit growth with business credit growth. *Total bank credit:* replacing total credit growth with total bank credit growth. *C&i loans:* replacing total credit growth with commercial and industrial bank loan growth. *HP-filtered credit:* replacing total credit growth with hp-filtered credit. *Composite lending spread:* replacing EBP with a composite lending spread.



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