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Financial shocks and inflation dynamics

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JEL Classification

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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 vector autoregressive model to US data and identify financial shocks through sign restrictions. Our main finding is that expansionary financial shocks temporarily lower inflation. This result withstands a large battery of robustness checks. Moreover, negative financial shocks helped preventing a deflation during the crisis. We then explore the transmission channels of financial shocks relevant for inflation, and find that the cost channel explains the inflation response. A policy implication is that financial shocks that move output and inflation in opposite directions may worsen the trade-off for a central bank with a dual mandate.

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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. Two prominent explanations for this ”missing disinflation puzzle” have been proposed. First, inflation expectations were well anchored (Bernanke 2010, Yellen 2013), while the rise in energy prices prevented a fall in long-run inflation expectations (Coibon and Gorodnichenko 2015). Second, the short-term unemployment rate is a more relevant measure of economic slack, and it increased by less and recovered more quickly than long-run unemployment (Gordon 2013, Krueger et al. 2014). Recently, financial market frictions have been suggested as an alternative explanation for the missing disinflation. For instance, Gilchrist et al. (2015) show that during the GFC financially constrained firms increased prices, while financially unconstrained firms lowered them.[1] To explain this empirical finding, they build a theoretical model where firms price goods above marginal costs in order to hedge against the risk of relying on costly external finance. Financial shocks that increase the cost of external finance may prevent inflation from falling even if output drops considerably.[2]

In general, theoretical models featuring financial frictions are compatible with both an increase and a decrease of inflation after financial shocks. Expansionary financial shocks can lead to an increase in inflation if aggregate demand effects dominate in the transmission mechanism. In general, financial shocks raise asset prices, generating wealth effects that lead to an increase in consumption and, through that, to an increase in inflation. In Curdia and Woodford (2010), a sudden drop in the fraction of non-performing loans reduces the credit spread. Cheaper borrowing induces borrowers to increase consumption, which in turn increases demand and inflation. Another example is Gertler and Karadi (2011), where financial shocks relax banking constraints and allow firms to rent more capital and hire more workers. The higher labor demand increases wages, thereby putting an upward pressure on prices. On the other hand, expansionary financial shocks can have disinflationary effects if aggregate supply channels dominate. Besides the mechanism in Gilchrist et al. (2015) described above, this is the case in models with a cost channel, where firms borrow in advance to finance the wage bill, such as in De Fiore and Tris-

[1]See Antoun de Almeida (2015) for evidence on the euro area, and Balleer et al. (2015) on Germany.

[2]See also Christiano et al. (2015) and Del Negro et al. (2015) for alternative theories in which financial frictions play a key role.

tani (2013).[3] Another mechanism through which financial shocks can lead to a decline in inflation is described in Meh and Moran (2010). In this model banks can charge a lower deposit rate after a financial shock. This prompts a decline in consumption and an increase in labor supply, which in turn causes a fall in real wages, marginal costs and inflation. Table 1 summarizes the implications of these 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 channels dominate.[4] Hence, whether financial shocks raise or lower aggregate inflation is ultimately an empirical question.

We apply a vector autoregressive model (VAR) to a set of US macroeconomic and financial data. We identify financial shocks by combining contemporaneous zero and short-run sign restrictions on impulse response functions. Financial shocks in our model increase credit growth, lower funding costs and raise stock prices, thereby matching the characterization of financial shocks in standard macroeconomic models (see Table 1). Most importantly, our identification strategy is fully agnostic about the response of inflation after financial shocks, while still disentangling financial from other structural shocks.

Our first key result is that financial shocks that increase economic activity and credit growth lead to a reduction in inflation. The effect arises on impact and is significant over about two quarters. Based on a historical decomposition we show that financial shocks contributed to the pre-crisis credit boom, characterized by low risk premia and high credit growth. Moreover, negative financial shocks contributed positively to inflation during the GFC and the subsequent bust, thereby compensating deflationary pressures from other developments.

We then explore the transmission channels that can account for the response of inflation after financial shocks. We find that expansionary financial shocks lower borrowing costs. If the latter are an important component of firms' marginal costs, then the drop in borrowing costs leads to a decline in overall marginal costs that can account for the negative inflation response. The cost channel appears therefore to be the mechanism generating the disinflationary effects of the identified expansionary financial shocks.

[3]A cost channel is also present in Gilchrist et al. (2015), though the authors argue that is not quantitatively significant for the transmission mechanism of financial shocks.

[4]The models discussed here do not allow to associate specific characteristics of financial shocks to a specific inflation response. For example, both Gerali et al. (2010) and Gertler and Karadi (2011) consider shocks to bank capital, but inflation responses differ (see Table 1).

Our main results are robust against a battery of robustness checks, such as using alternative measures of interest rates, inflation and credit, controlling for additional variables, using different shock identification schemes and changing the sample period. We also show that the financial shocks affect banking variables and survey measures of credit supply in the expected way.

We make two contributions to the literature.

First, we suggest an identification scheme for financial shocks which leaves the inflation response unrestricted. Existing 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 (Busch et al. 2010, Conti et al. 2015, De Santis and Darracq-Paries 2015, Furlanetto et al. 2014, Gambetti and Musso 2012, Hristov et al. 2012). Other work restricts the impact effects on inflation and output to zero, but leaves the signs of their impulse responses beyond impact unrestricted (Gilchrist and Zakrajsek 2012, Peersman 2012). The evidence on the effects of financial shocks on inflation dynamics from these papers is mixed: in Peersman (2012), expansionary financial shocks increase inflation, while in Gilchrist and Zakrajsek (2012) inflation does not react significantly to financial shocks.

Second, we 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. (2015) relies on data at the product or firm level. These studies focus on the price setting behavior of financially constrained relative to unconstrained firms, and show that borrowing constraints are an important determinant for the price setting behavior of firms. 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. Our study fills this gap.

The results from our analysis have two policy implications. First, financial shocks which raise output and lower inflation may worsen the trade-off faced by a central bank which seeks to stabilize both output and inflation. Second, a monetary policy designed to strengthen credit supply may have unintended disinflationary effects (e.g. through the cost channel). Clearly, this would not be desirable in an already low inflation environment.

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

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 excess bond premium (EBP), a house price, and a stock price. These are standard variables in empirical macro-financial studies.

We use the core PCE deflator, excluding energy and food, to measure inflation. 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 is a risk premium that reflects systematic deviations in the pricing of US corporate bonds relative to the issuers' expected default risk.[5] 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. The credit series is taken from the Financial Accounts of the United States. In the robustness analysis we also consider alternative credit measures. Nominal house and stock prices are taken from Robert Shiller's website. We deflate the credit and asset price series by the PCE deflator. 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). Using the SSR allows to account for unconventional monetary policy: quantitative easing and forward guidance may primarily affect interest rates at longer maturities (Gertler and Karadi 2015, Krippner 2015). As the SSR reflects changes in the term structure of interest rates, it captures the effects of unconventional monetary policy.

GDP and asset prices enter in logarithms, the policy rate and the EBP in levels, the PCE deflator in year-on-year differences of logarithms. We filter outstanding credit using log year-on-year differences. Financial variables are subject to secular trends due to changes in the structure of the financial system and regulatory changes. Following Adrian et al. (2013), we deal with this issue by using detrended

[5]Retrieved from Simon Gilchrist's website: *http : //people.bu.edu/sgilchri/Data/data.htm*

credit. The year-on-year change is a convenient way of detrending credit.[6] 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 2015Q2. 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.

Figure 1 shows the series, as they enter the VAR model.

2.2 Vector autoregression

We assume that the dynamics of X_t follow a VAR model of order p:

$$X_t = c + B_1 X_{t-1} + \ldots + B_p X_{t-p} + w_t, \quad E(w_t) = 0, \; E(w_t w_t') = W. \tag{1}$$

B_j are $n \times n$ coefficient matrices for $j = 1 \ldots p$, where p is the lag length and set to 2. The AIC suggests 4 lags, the BIC suggests 1 lag when we allow for a maximum lag length of 4. $p = 2$ seems a reasonable compromise and corresponds to what most quarterly VAR studies use. We include a constant represented by the $n \times 1$ vector c. The $n \times 1$ vector w_t represents the reduced-form innovations which are assumed to be Gaussian with mean zero and positive definite covariance matrix $W = E(w_t w_t')$.

2.3 Identifying financial shocks

We identify financial shocks by combining contemporaneous zero restrictions and short-run sign restrictions on impulse response functions. We restrict GDP not to move on impact after expansionary financial shocks. Thereafter, we restrict GDP to rise. The zero restriction on GDP disentangles financial from macroeconomic (i.e. aggregate demand and supply) shocks, which would change GDP instantaneously.

Moreover, we require the EBP not to rise, and credit growth and the stock price not to fall. The restriction on the stock price ensures that we disentangle financial

[6]We show below that our results are not affected when using a one-sided HP filter applied to outstanding credit. See Edge and Meisenzahl (2011), for a discussion on the consequences of different detrending methods for credit gap measures.

shocks from investment-specific demand shocks, which would lead to a decline in the stock price, see Furlanetto et al. (2014).[7]

Previous empirical work - which focuses on the real effect of financial shocks - restricts either inflation to be positive, not to react on impact, or it restricts the policy rate to increase after expansionary financial shocks, which might also bias the inflation response (Conti et al. 2015, De Santis and Darracq-Paries 2015, Fornari and Stracca 2012, Furlanetto et al. 2014, Gambetti and Musso 2012, Gilchrist and Zakrajsek 2012, Hristov et al. 2012, Peersmann 2010). Given our focus on inflation, and that theory is ambiguous on the effects of financial shocks on inflation and the policy interest rate (see Table 1), we instead adopt an identification scheme that leaves the responses of both inflation and the policy rate unrestricted.

Specifically, we impose the restrictions described above on credit growth, the stock price, the EBP and GDP. The house price is left unrestricted. We then check the inflation response for each model which yields financial shocks satisfying the restrictions. If inflation rises on impact, the response of a central bank following a Taylor rule is unambiguously positive. In this case, we restrict the policy rate to increase on impact. If inflation falls, 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 2004). A more detailed discussion on the relationship between financial and monetary policy shocks is provided in Section 4.[8] Finally, we restrict the remaining $n - 1 = 6$ shocks not to have the same characteristics as the financial shocks. Hence, the identified financial shocks are the only shocks that satisfy the restrictions.

We impose all sign restrictions (except for the one on the policy rate) on impact and over the first four quarters following the shocks. This allows us to focus on relatively persistent shocks similar to those we have observed around the GFC. In Table 2 we summarize the sign restrictions, which are all implemented as $\geq / \leq 0$.

[7] Furlanetto et al. (2014) argue as follows. "Investment shocks are shocks to the supply of capital and, therefore, imply a negative co-movement between the stock of capital (together with investment and output) and the price of capital. The price of capital is seen as a proxy of the stock market value for the firm and as a main driver of the firm's net worth. Financial shocks, instead, are shocks to the demand for capital and imply a positive co-movement between output and the price of capital (together with the stock market)."

[8] 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.

Note that our sign restrictions are consistent with a range of structural models with a financial sector (see Table 1). Similar restrictions have been used in previous empirical work.[9] However, as noted above, most of the existing empirical work also restricts the reaction of inflation or of the interest rate. The novelty of our identification scheme is that it disentangles financial shocks from other structural shocks, while being agnostic on the response of inflation and of the policy rate. We explore below the robustness of our key results against alternative identification schemes.

To implement the sign restrictions, we follow the approach suggested by Rubio-Ramirez et al. (2010). Let $W = PP'$ be the Cholesky decomposition of the reduced form variance-covariance matrix of the VAR. Further, let Ω be a $(n-1) \times (n-1)$ random matrix drawn from an independent standard normal distribution. The QR decomposition of Ω delivers $\Omega = QR$. The impact matrix of the structural shocks $\tilde{A}_0$ is then computed by multiplying the second to last element of P (i.e. the orthogonalized residuals not corresponding to the GDP equation) with Q'. If the impulse responses generated by the impact matrix $\tilde{A}_0$ satisfy the sign restrictions, we keep the matrix, otherwise we discard it. We keep drawing from Ω until we obtain 250 impact matrices which satisfy all restrictions simultaneously. The financial shocks are given by the corresponding elements of $\eta_t = (P \times Q')w_t^{2\ldots n}$.[10]

Sign restrictions do not achieve unique identification of shocks (Fry and Pagan 2011 refer to this issue as the "multiple models problem"). Following Fry and Pagan (2007)'s "Median Target" approach, we select among the 250 qualifying models the one whose impulse responses are closest to the median responses across models and horizons. This single model reflects the "central tendency" across all models. Once we have picked a single rotation matrix, we construct confidence bands with 500 bootstrap replications. To correct for a possible small sample bias, we apply the bootstrap-after-bootstrap methodology proposed by Kilian (1998).

We conduct inference on the structural impulse response functions using a wild bootstrap. That is, we generate bootstrap residuals as $w_t^b = w_t \omega_t$, where ω_t is a scalar drawn from the Rademacher two-point distribution: $P(\omega_t = 1) = P(\omega_t = -1) = 1/2$. Based on the point estimates of the VAR parameters and w_t^b we simulate the endogenous variables and re-estimate the VAR model. We then identify the

[9] Busch et al. (2010), Conti et al. (2015), De Santis and Darracq-Paries (2015), Eickmeier and Ng (2015), Furlanetto et al. (2014), Gambetti and Musso (2012), Helbling et al. (2011), Hristov et al. (2012), Meeks (2012), Peersmann (2010)

[10] We also employ the approach suggested by Arias et al. (2014) to impose sign and zero restrictions. That approach is computationally somewhat more cumbersome, as it involves rotating all n rather than rotating $n-1$ residuals (as in our baseline). Results are unaffected.

financial shocks as described above. The confidence bands are then constructed as the percentile intervals of the resulting bootstrap distribution of the impulse response functions.

3 Results

3.1 Results from the baseline model

In Figure 2, we present impulse responses to a one standard deviation financial shock. The solid red lines are median impulse responses, while the shaded areas are the 90% confidence bands. As imposed by the sign restrictions, the EBP declines, and credit growth and the stock price increase. The positive effects on credit growth, the stock price and also on GDP are very persistent, with the peak effect occurring after around one year following the shock. The policy rate declines on impact, but then overshoots after about two quarters. House prices also rise persistently following the shock.

Most importantly, inflation falls on impact by 0.07 percentage points and remains negative for around two quarters 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 results suggest that after financial shocks aggregate supply effects dominate demand effects.[11]

In Table 3, we provide results from the forecast error variance decomposition at the four-year horizon. The financial shock accounts for roughly half of the forecast error variance of credit growth and the EBP. Moreover, financial shocks explain 27% of the fluctuation in GDP and 14% of the fluctuation in inflation.[12] Hence, on average over the sample period, financial shocks made notable, although not very large contributions to inflation dynamics.

In Figure 3, we present the historical decomposition of the EBP, credit growth, inflation and GDP over the period 1999-2015. The financial shock contributed to the pre-crisis credit boom by holding the EBP down and pushing credit growth up. Negative financial shocks over the GFC accounted for large parts of the drop in

[11]As discussed above, we focus on the "Median Target" model, but neglect model uncertainty. Model uncertainty is, however, limited. 98.8% of the models suggest a negative inflation response on impact after expansionary financial shocks.

[12]This share for GDP is roughly in line with 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), Helbling et al. (2011), Hristov et al. (2012), Meeks (2012) and Peersman (2012).

credit growth and the rise in the EBP. Most importantly, around the GFC financial shocks made positive contributions to inflation. Between 2008 and 2009 negative financial shocks increased core inflation by around 0.25 percentage points. Put differently, core inflation, as deviation from its deterministic component, would have been more than 50% lower in the absence of financial shocks. The financial shock also explains a substantial fraction of the GDP decline after the 2000-01 and 2007-09 recessions. 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. We finally note that the financial shock also accounts for the financial headwinds in the late 1980s/early-1990s, and kept inflation up over that period as well (not shown).

3.2 Transmission channels of financial shocks relevant for inflation

Why does inflation decline after expansionary financial shocks? In Figure 4 we present impulse responses to the financial shock of variables that capture the key transmission channels implied by the models summarized in Table 1, as well as other relevant variables. We include these variables one by one in the baseline VAR, but we restrict them not to affect the endogenous variables in the VAR nor the financial shock estimates.[13]

The first row of Figure 4 shows that the financial shock leads to a strong and hump-shaped increase in real private investment, consumption and employment. The increase in consumption is potentially the result of wealth effects due to the increase in asset prices after the financial shock. Investment increases by more than consumption, which is consistent with the restriction imposed by Furlanetto et al. (2014) to identify financial shocks. The gradual increase in demand is likely to be the reason behind the recovery of inflation over the first year after the shock. Real wages increase in a marginally significant way on impact, but turn insignificant already after one quarter. The responses of investment, consumption, employment and wages after the financial shock are in line with the mechanism in Gertler and Karadi (2011). In their model, a financial shock leads to an investment boom because firms can rent more capital. Because of the complementarity between capital and labor, firms increase labor demand putting an upward pressure on real

[13]More specifically, the impulse responses for each of the added variables are computed from an estimated AR(2) model, which includes the endogenous variables of the baseline VAR and the identified financial shocks as additional regressors.

wages and, through that, on firms' marginal costs and inflation. Our baseline result, by contrast, suggests that financial shocks lead to a short-run reduction in inflation. The mechanism in place in models such as in Gertler and Karadi (2011) is therefore not able to explain the disinflationary effects of financial shocks in the data.

The key determinant of the pricing decision of firms are current and expected future marginal costs. We therefore explore their behavior after financial shocks, by looking at the response of the labor income share, a proxy for marginal costs proposed by Nekarda and Ramey (2013). Figure 4 shows that the labor share does not move significantly for more than one year after the shock. Hence, marginal production costs, measured in terms of wages, do not increase significantly after expansionary financial shocks. This rationalizes why inflation fails to increase, but not why it declines.

In calculating their measure of marginal costs, Nekarda and Ramey (2013) assume that marginal costs are solely determined by wages, as well as by the marginal product of labor. However, if firms have to borrow in advance to finance part of the wage bill, then the relevant marginal costs are also determined by borrowing rates. Models featuring a cost channel, such as Christiano et al. (2010) and De Fiore and Tristani (2013), stress the importance of taking into account financing costs for the pricing decision of firms. Accordingly, we assess the responses of different borrowing rates after the financial shock. We show impulse responses of the Baa yield, the commercial paper rate, the interest rates on newly granted commercial and industrial (C&I) loans, and the mortgage lending rate. The Baa yield drops significantly on impact by about 10 basis points and remains negative for more than one year. The interest rates on short-term borrowing also drop significantly on impact but turn insignifincant already after two quarters and then overshoot significantly. Hence, if a cost channel is active, then the reduction in borrowing costs should decrease overall marginal costs, given the absence of a significant movement in the labor income share.[14]

We also look at, but do not show in Figure 4, impulse responses of variables capturing two additional transmission channels of financial shocks which can affect inflation, but are not captured in the models reviewed in Table 1: productivity and uncertainty. First, we find that utilization-adjusted total factor productivity (TFP) (Fernald 2012) does not react significantly to financial shocks. This finding is not at odds with theory, which is ambiguous on the effects of financial shocks on

[14]For the derivation of price markups with a cost channel we refer to Ravenna and Walsh (2006), and Lewis and Poilly (2012).

productivity (Khan and Thomas 2013, Petrosky-Nadeau 2013).[15] Second, we find that macroeconomic uncertainty declines modestly on impact and has a humped-shaped behavior after the financial shock.[16] How a reduction in uncertainty affects inflation is theoretically unclear. On the one hand, it can increase inflation through standard aggregate demand effects associated with nominal rigidities (Leduc and Liu 2016). On the other hand, a decline in uncertainty can reduce inflation in models with concave profit functions and price adjustment costs Fernandez-Villaverde et al. 2015 and Mumtaz and Theodoridis (2016). We do not make a formal attempt to disentangle financial from uncertainty shocks, for which there is not yet a consensus in the literature.[17] We only note here that an improvement in financial conditions goes along with a decline in uncertainty. The fact that the impact effect is not large and the effect builds up very gradually, suggests that the financial shocks are not contaminated by uncertainty shocks, which should have more frontloaded effects on uncertainty (Caggiano et al. 2014, Ludvigson et al. 2016).

To summarize, the results from our analysis suggest that a mechanism related to the cost channel might be able to explain the reduction in inflation after the expansionary financial shock. Expansionary financial shocks reduce borrowing costs significantly on impact. This causes an overall decline in firms' marginal costs which leads to a drop in inflation.

It is also interesting to note that our financial shock can account for key facts observed during and after the GFC, which constitutes a large negative financial shock: a strong decline in asset prices, persistent real effects, an increase in uncertainty, no drop in utilization-adjusted TFP.

4 Additional results and robustness analysis

4.1 Additional results

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 inserted one by one into the

[15]These papers consider the effects of financial shocks on productivity in real models and can therefore not derive implications for inflation.

[16]We use the uncertainty measure constructed by Jurado et al. (2015).

[17]Uncertainty and financial price measures such as stock market volatility are highly correlated, and the VIX is frequently used to proxy uncertainty (e.g. Bloom 2009). Hence, it is hard to disentangle financial from uncertainty shocks, see Caldara et al. (2016) and Furlanetto et al. (2014) for recent attempts.

VAR, and we restrict them not to affect the baseline model's variables nor its shock estimates. We present the results in Figure 5.

First, we add survey measures of credit supply in order to verify whether our identified shocks are consistent with the answers of survey participants from the banking sector. 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").[18] Bank's willingness to lend to consumers increases on impact and remains positive for one year. Similarly, banks loosen their credit standards strongly on impact, and keep them below baseline for more than one year after the financial shock. 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 the profitability of banks - increases significantly and remains positive for one year. This increase is reflected in the response of the bank capital ratio, which also rises significantly on impact and remains positive for about a year (although only marginally significantly). The higher profitability allows banks to increase retained earnings, which in turn increases net worth, e.g. bank capital, thus generating a stronger capital position. Finally, the share of problem loans on the balance sheet of banks - represented by the ratio of non-performing loans in total loans - drops significantly. The response is hump shaped, reaching its minimum after around one year. The behavior of the non-performing loans ratio follows closely the movement of GDP. The increase in economic activity after the financial shock improves the balance sheets of entrepreneurs and households, which in turn decreases the frequency of default. In addition, the volatility of bank stock prices drops significantly.

Finally, we explore the behavior of various credit spreads, namely the Baa spread, the commercial paper spread, the C&I loan spread and the mortgage spread. 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

[18]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 1990Q2-2015Q4. The "willingness to lend to consumers" series is instead available over the entire sample period.

rate over the 10-year government bond yield.[19] In line with what we expect after a financial shock, all spreads decrease significantly. Hence, the identified financial shock decreases risk premia across all maturity buckets and categories of lenders.

All in all, this exercise confirms that our assumptions on the behavior of the endogenous variables in the baseline VAR do indeed identify a financial shock with the expected characteristics.

4.2 Robustness analysis

We conduct several robustness checks with respect to the specification of the baseline VAR. We replace variables from the baseline model with alternative measures; insert additional variables; change our shock identification scheme and assess robustness with respect to the Great Recession. Below we discuss the response of inflation to the financial shocks obtained from the robustness checks, as well as some additional interesting findings. We present the inflation responses in the Appendix.

Alternative measures of inflation and interest rates As a first set of alternative checks, we replace core PCE deflator inflation with either core CPI inflation or core PPI inflation. As a second check we replace the linked federal funds rate-SSR variable with either the original federal funds rate, the 2-year Treasury constant maturity rate (Gertler and Karadi 2015) or, the federal funds rate linked to the SSR proposed by Wu and Xia (2016). In all alternative models financial shocks produce a disinflationary effect. It is worth mentioning that core PPI inflation declines by much more than core CPI inflation or core PCE deflator inflation. A possible reason could be that PPI inflation is a more direct measure of the price-setting behavior of producers, and that the cost channel is especially relevant for the manufacturing industry. However, it might also reflect the fact that PPI inflation is much more volatile that CPI or PCE inflation.

Omitted variables We control for four possibly relevant omitted variables: inflation expectations, oil price inflation, productivity, and the relative share price of financial firms. Financial shocks yield disinflationary effects in all four extended models. We discuss each model in turn.

[19] 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.

Inflation expectations are measured as 1-year ahead forecasts of (year-on-year) GDP deflator inflation from the Survey of Professional Forecasters (SPF).[20] This follows Castelnuovo and Surico (2010), who argue that inflation expectations should be included in monetary VARs as they help to identify structural shocks. Though the authors focus on monetary policy shocks, this problem might affect other shocks in the system as well.[21] We do not impose any restriction on inflation expectations, and find them to drop after financial shocks.

Oil price inflation is defined as the log year-on-year change in the West Texas Intermediate (WTI) price of crude oil.[22] 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. This restriction is moreover consistent with the zero contemporaneous restriction on US GDP.

Productivity, measured as real output per hour in the non-farm business sector, is also restricted not to move on impact after financial shocks. This assumption enables us to to disentangle financial shocks from shocks to future expected activity (Helbling et al. 2011).[23]

Finally, we augment the baseline model with the stock price of non-financial firms relative to that of financial firms (from Datastream), without restricting it. We find that the relative share price increases after financial shocks, in line with the restriction imposed in Fornari and Stracca (2012) to identify financial shocks.

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

[20]Recently, the SPF also publishes PCE deflator inflation expectations. However, those data are not available over most of our sample period. Hence, we rely on GDP deflator inflation expectations.

[21]They use 1-quarter ahead GDP deflator inflation expectations from the SPF. In line with the year-on-year inflation variable in our model, we make use of the 1-year ahead inflation expectations.

[22]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.

[23]Helbling et al. (2011) include productivity as well as the default rate in their otherwise standard VAR model (see also Meeks 2012). They argue that, "[g]iven the forward looking nature of credit markets, the restrictions on productivity and default rates ensure that we identify a credit supply shock rather than an endogenous credit response to expected fluctuations in future activity". Given that we use the EBP from which the expected default of non-financial firms is already filtered out, we confine ourselves to include productivity as a forward looking variable.

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.[24] As for the EBP, we restrict the composite lending spread to decrease after the financial shock. This helps us to separate more formally credit supply from credit demand shocks, which would instead trigger an increase in both credit growth and the credit spread.

All identified financial shocks from the modified models turn out to be disinflationary.

Changes to the shock identification scheme First, we remove the contemporaneous zero restriction on GDP in order to allow GDP to immediately react to the financial shock. In this setup we might give inflation a better chance to increase on impact. Without the zero restriction on GDP, however, financial shocks might not be disentangled from other aggregate macroeconomic shocks. We therefore impose the assumption that credit growth increases by more than GDP over the first year after the shock. Macroeconomic (i.e. aggregate demand and supply) shocks would change GDP by more than credit growth. The impact effect on GDP is small, with an increase of only 0.06%. We still find that financial shocks are disinflationary.

Second, we employ the identification scheme for financial shocks suggested by Caldara et al. (2016). We require financial shocks to maximize the response of the EBP after two quarters following the shock. We do not impose any of the previous restrictions. We obtain a very similar negative inflation response as in our baseline model.

Third, Paustian (2007) shows that one can sharpen the shock identification by identifying additional shocks. We therefore identify, as a further robustness check, a monetary policy shock simultaneously alongside the financial shock. We leave the identifying restrictions for the financial shock unchanged and identify a monetary policy shock with the usual properties: we restrict the policy rate and the EBP to decline and inflation to increase on impact and over the coming year, and output to increase over the first year after the monetary policy shock. To treat financial

[24]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.

and monetary policy shocks alike we restrict output not to move on impact. The financial shock continues to have disinflationary effects.

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. We estimate the model excluding the period that starts with the GFC, i.e. over the period 1988Q1 to 2007Q2. Our key result remains unaffected. As a further check, we allow for a break in the residual covariance matrix with the crisis. Previous studies show that changes in the covariance matrix of VAR residuals can be large, while time variation in the autoregressive parameters is modest (e.g. Prieto et al. 2016). We proceed as follows: after estimating a VAR model with constant parameters over the entire sample period, we orthogonalize the residuals and identify the shocks based on two covariance matrices: one computed based on the residuals prior to 2007Q3, and one based on the residuals starting in 2007Q3. The impulse responses constructed for the two periods overlap. Hence, the contemporaneous effects do not seem to have changed notably over time. The historical decomposition based on the two shock series (pre-GFC and GFC+post-GFC) and the two sets of impulse responses look also very similar.

Overall, our key result that financial shocks have disinflationary effects is robust against those robustness checks.

4.3 Financial shocks and monetary policy

In Section 2.3 we have argued that we disentangle financial shocks from monetary policy shocks as usually 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, prices and the policy rate in the same direction or move output and prices in opposite directions. However, the aggregate supply-type transmission channels discussed above may not only be effective after financial, but also after monetary policy shocks. The cost channel of monetary policy is one specific example for a transmission channel which can lead to a drop in inflation after monetary policy shocks and which has been brought forward as one explanation of the ”price puzzle” (e.g. Castelnuovo 2012, Gaiotti and Secchi 2006, Ravenna and Walsh 2006 and discussions therein). If the cost channel of monetary policy is a relevant transmission mechanism, it is not fully clear whether our financial shock is disentangled from monetary policy shocks. Put differently, a monetary policy shock affects funding costs and is, hence, a specific type of financial shock. This concern should be even more valid for unconventional monetary policy, which is - in part - designed to explicitly stimulate credit supply and lower funding costs and, through these channels, stimulate economic activity and inflation.[25]

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 no evidence for federal funds rate shocks to have affected GDP growth from 2010 onwards. Instead, credit spread shocks have positively contributed to growth. They argue that those credit spread shocks probably capture unconventional monetary policy actions.

We investigate in this section to what extent monetary policy actions lie behind our financial shocks. For that purpose we plot in Figure 6 the financial shock estimates (solid line) against the monetary policy shock measure taken from Nakamura and Steinsson (2015) (dashed line) over 1999-2015. This ”policy news shock” is constructed based on high-frequency responses of current and expected future interest rates in a 30-minute window surrounding scheduled Federal Reserve announcements, and captures the effects of forward guidance.[26] For comparability with our financial shock estimate, we normalize the Nakamura and Steinsson (2015) shock in the figure such that positive values represent a monetary policy easing (which can be expected to raise credit growth and lower funding costs), and that the standard deviation is 1 over the period over which we plot the shocks.

Figure 6 reveals that the correlation between the two shocks is very low over the entire sample (correlation coefficient: 0.03). Financial shocks seem, however, more highly correlated with the 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 with the intention to stabilize the financial system. 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.[27] This finding is consistent with Eickmeier et al. (2016) who find a price puzzle after an expansionary monetary policy shock in high, but not in low financial

[25]See Bernanke (2009), http://www.federalreserve.gov/monetarypolicy/bst_crisisresponse.htm

[26]For further details we refer to Nakamura and Steinsson (2015).

[27]The Federal Reserve acted as a provider of liquidity to encounter the disruption of normal channels of borrowing and payments after the terrorist attacks of September 11, 2011 (Meyer

volatility periods. Similarly, Fry-McKibbin and Zhen (2016) find that prices rise 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.

As a further check, we also include the Nakamura and Steinsson (2015) monetary policy shock measure as an explanatory variable in the VAR, and re-run the estimation and shock identification.[28] The idea is that the monetary policy shock should capture all remaining uncontrolled confounding effects of monetary policy shocks. The identified financial shocks remain disinflationary and the magnitude of the inflation response is also similar to the baseline model as shown in the Appendix.

To sum up, this discussion suggests that our financial shock is barely contaminated by monetary policy shocks with unintended effects on inflation, and that financial shocks cleaned from monetary policy shocks still produce negative effects on inflation. We find, if anything, some correlation between financial and monetary policy shocks in financial stress periods. One implication is that a monetary policy which targets credit supply and borrowing costs may exert downward pressure on inflation through the mechanisms discussed above. This would not be desirable in an environment of already low inflation. However, we would like to emphasize that our results do not imply that the overall effects of monetary policy actions on inflation are negative. Although monetary policy might put a downward pressure on inflation through credit supply effects, other channels might predominate which increase inflation through demand effects. Analyzing those would go beyond the scope of this paper.

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 VAR analysis and propose a novel identification scheme for financial shocks which remains fully agnostic about the effects of financial shocks on inflation. Our main finding is that expansionary financial shocks have disinfla-

2001). See Bernanke (2009) and Kohn (2010) for details on the liquidity provision to financial institutions during the GFC by the Federal Reserve.

[28]For that purpose we lengthen the Nakamura and Steinsson (2015) shocks, which are available from 1995 onwards, with the monetary policy shocks constructed by Romer and Romer (2004). We order the Nakamura and Steinsson (2015) shocks first in the VAR.

tionary effects. We also show that the inflationary effect of negative financial shocks prevented a stronger disinflation during the financial crisis. Hence, our results suggest that financial shocks might be an additional explanation for the ”missing deflation puzzle” during the financial crisis. A key implication of our findings is that financial shocks which raise output and, at the same time, lower inflation might worsen the policy trade-off for a central bank which stabilizes output and prices.

We also explore different transmission channels of financial shocks embedded in standard macroeconomic models, and their implications for inflation dynamics after financial shocks. We find that a mechanism related to the cost channel might be a promising explanation for the disinflationary effects of financial shocks.

Our key result that financial shocks have disinflationary 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.

Finally, although our identified financial shock series is basically uncorrelated with the Nakamura and Steinsson (2015) monetary policy shock measure over the entire sample period, we detect some mild correlation between our financial shocks and monetary policy shocks in times of financial stress. One implication is that a monetary policy which aims at stimulating credit supply and lowering funding costs risks pushing inflation down, something that should be avoided in a low inflation environment.

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6 Tables

Table 1: **Theoretical responses implied by different models**

		variables							
model	financial shock	y	c	w	N	R	*spread*	Q	π
gk	bank capital increase	+	+	+	+	+	−	+	+
cw	drop in npl	+	+			+	−		+
gnss	bank capital increase	+	+	−	−	−	−	+	−
ft	firm net worth increase	+	+	+	+	−	−		−
gssz	drop in ext. fin. cost	+	+	+		−			−
mm	bank capital increase	+	−	−	+	−		−	−

Notes: The variables are output (y), real wages (w), employment (N), the risk-free rate (R), the relative price of capital or financial claim (Q), and inflation π; NPL stands for non-performing loans. An increase (decrease) is denoted with a + (-) sign. A space is left if the transmission mechanism does not involve a certain variable. gk refers to Gertler and Karadi (2011); cw refers to Curdia and Woodford (2010); gnss refers to Gerali et al. (2010); ft refers to De Fiore and Tristani (2013); gssz refers to Gilchrist et al. (2015); mm refers to Meh and Moran (2010).

Table 2: **Sign restrictions to identify financial shocks**

	gdp	inflation	credit growth	interest rate	ebp	stock price	house price
impact	0		↑	↑ iff inflation ↑	↓	↑	
horizons 1 to 4	↑		↑		↓	↑	

Notes: This table shows the restrictions imposed on the signs of the impulse responses of the endogenous variables in the baseline VAR to identify financial shocks. All sign restrictions are implemented as $\geq$ / $\leq$ 0.

Table 3: **Forecast error variance decomposition**

gdp	inflation	credit growth	interest rate	ebp	stock price	house price
0.28	0.14	0.44	0.25	0.50	0.29	0.20

Notes: This table shows the variance shares explained by financial shocks of the endogenous variables in the baseline VAR at the four-year horizon.

7 Figures

Figure 1: **Time series as they enter the VAR**

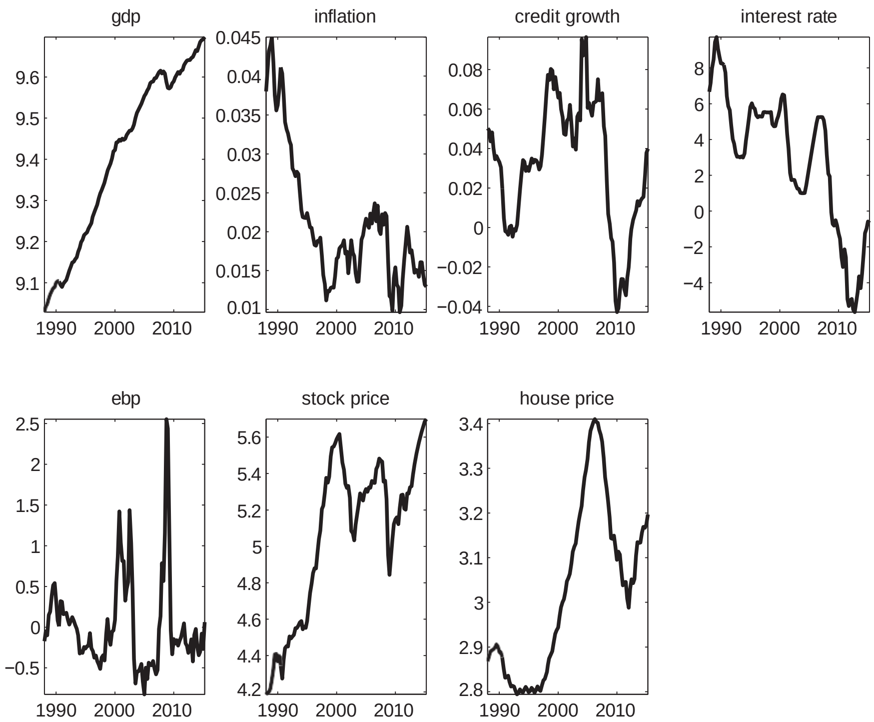
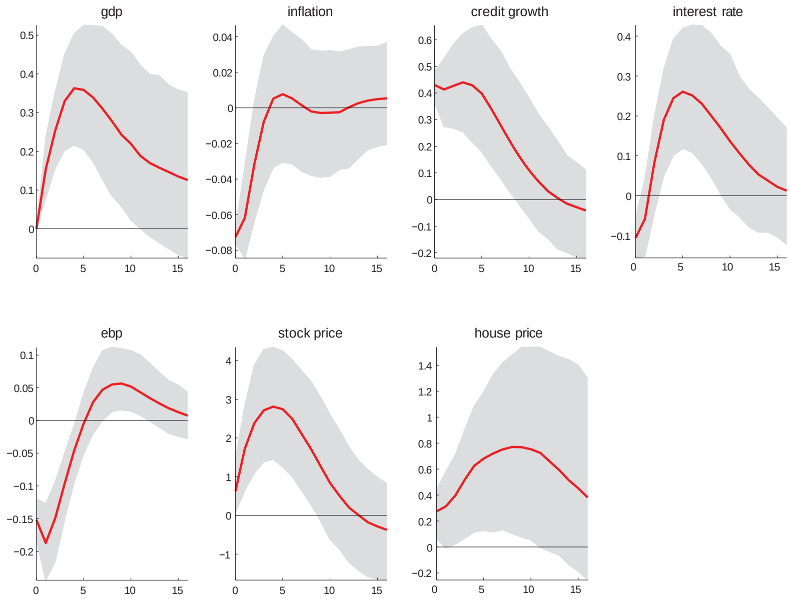
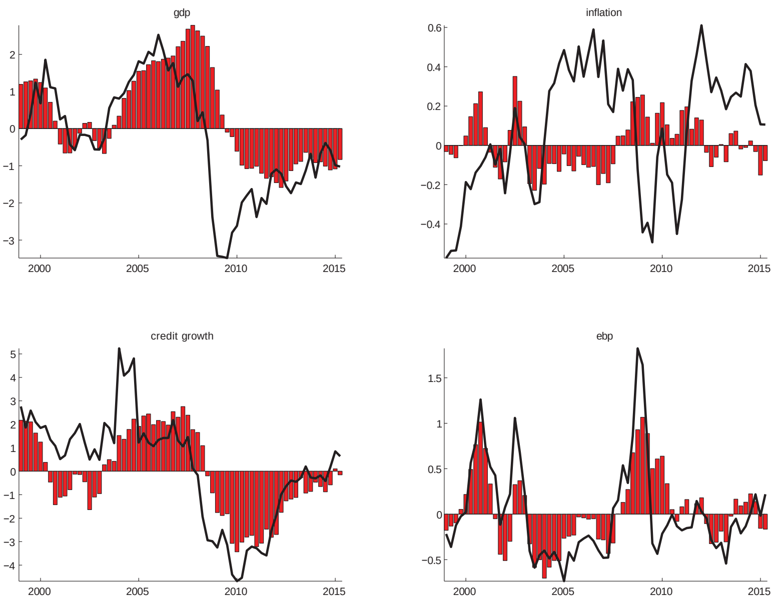


Figure 2: **Impulse responses to a one standard deviation expansionary financial shock**



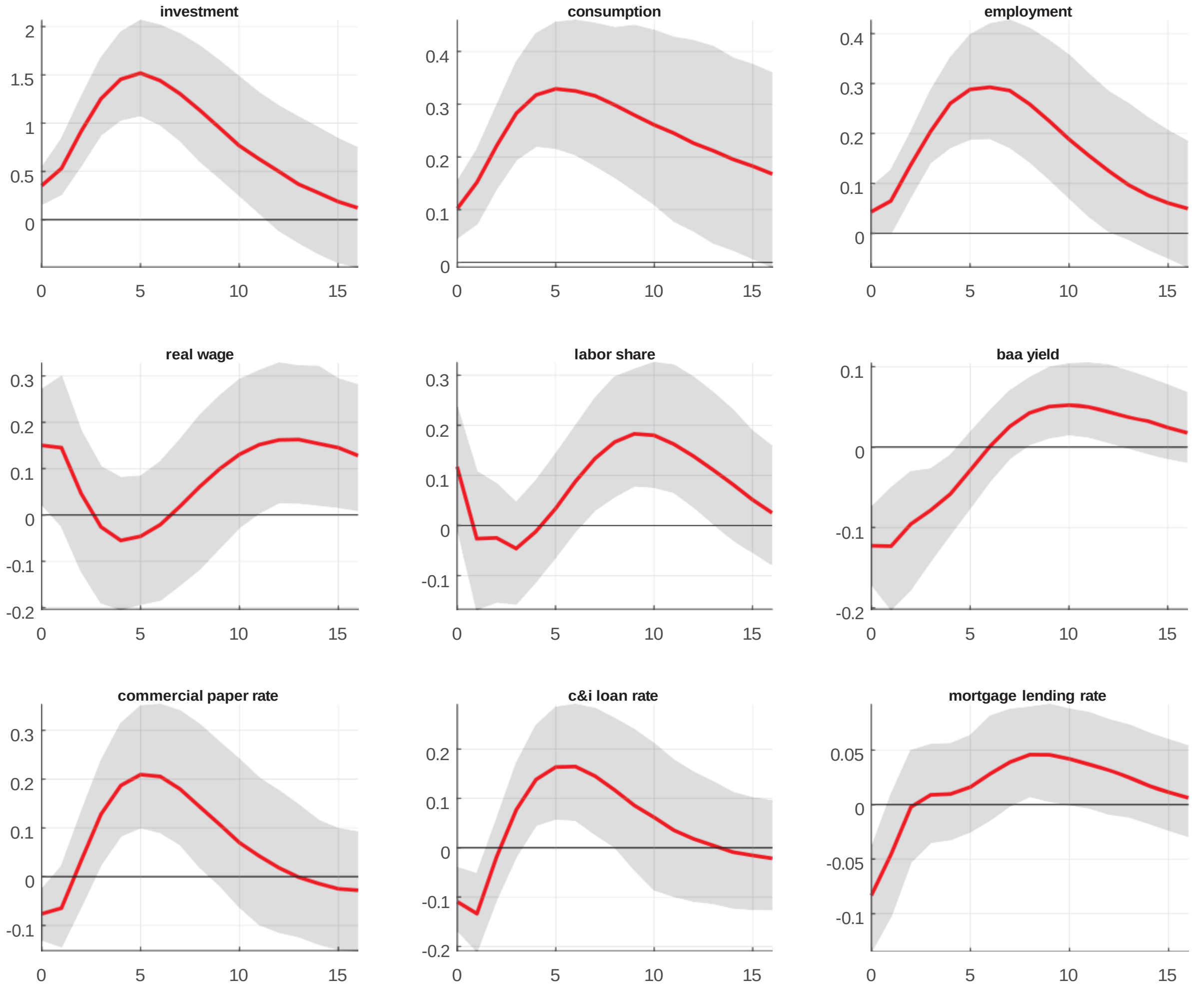
Notes: Plot shows median impulse responses (solid lines) and 90% confidence bands (shaded areas). Responses of GDP, stock and house prices are expressed in %, while those of the remaining variables are in percentage points.

Figure 3: **Historical decomposition of key variables**



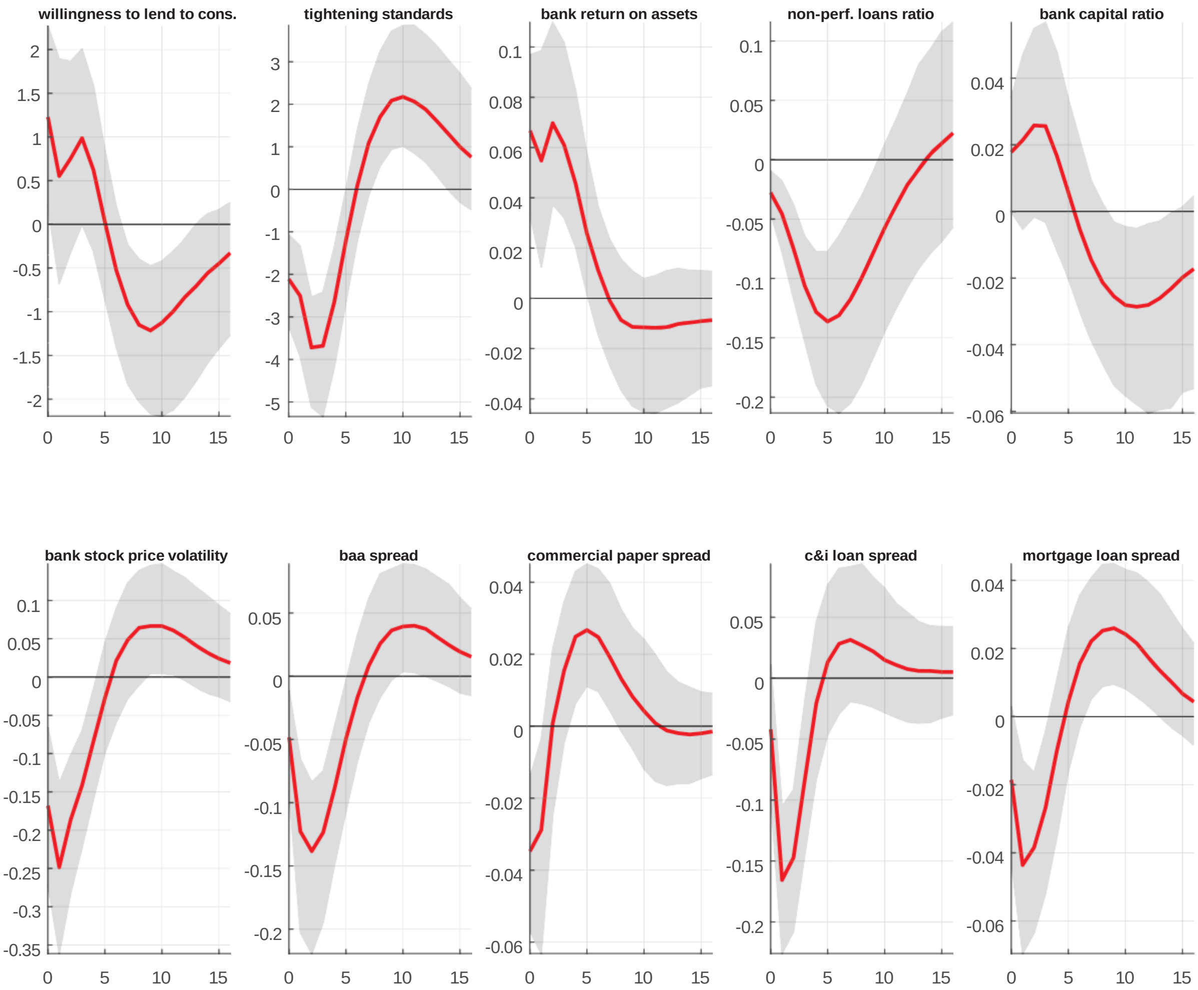
Notes: Plot shows the contribution of all shocks to explaining the deviation of key variables from their deterministic component (solid lines), and the contribution of the financial shocks (bars). Historical contributions are computed for period 0 as the shock estimate at period 0 times the contemporaneous impulse response functions, for period 1 as the shock estimate at period 0 times the impulse response function at horizon 1 plus the shock estimate at period 1 times the contemporaneous impulse response function, etc. Thus, the forecast horizon is 0 for the first observation, 1 for the second, . . . and $T - p$ for the last observation.

Figure 4: **Transmission channels of financial shocks relevant for inflation**



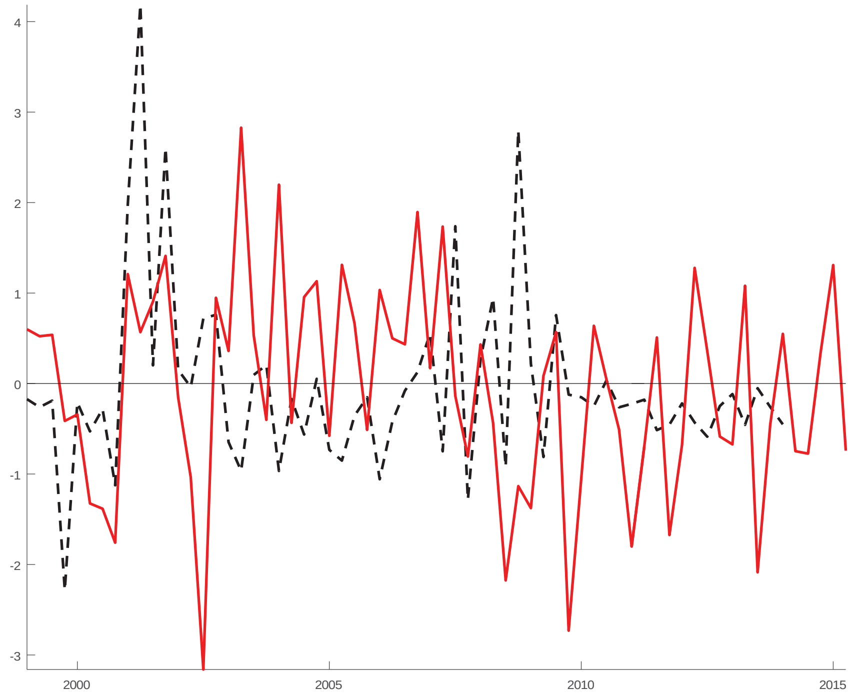
Notes: Plot shows impulse responses of variables capturing main transmission channels to a one standard deviation financial shock: median impulse responses (solid lines) and 90% confidence bands (shaded areas). Responses of investment, consumption, employment and real wages are expressed in %. The remaining impulse responses are expressed 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 expansionary financial shock**



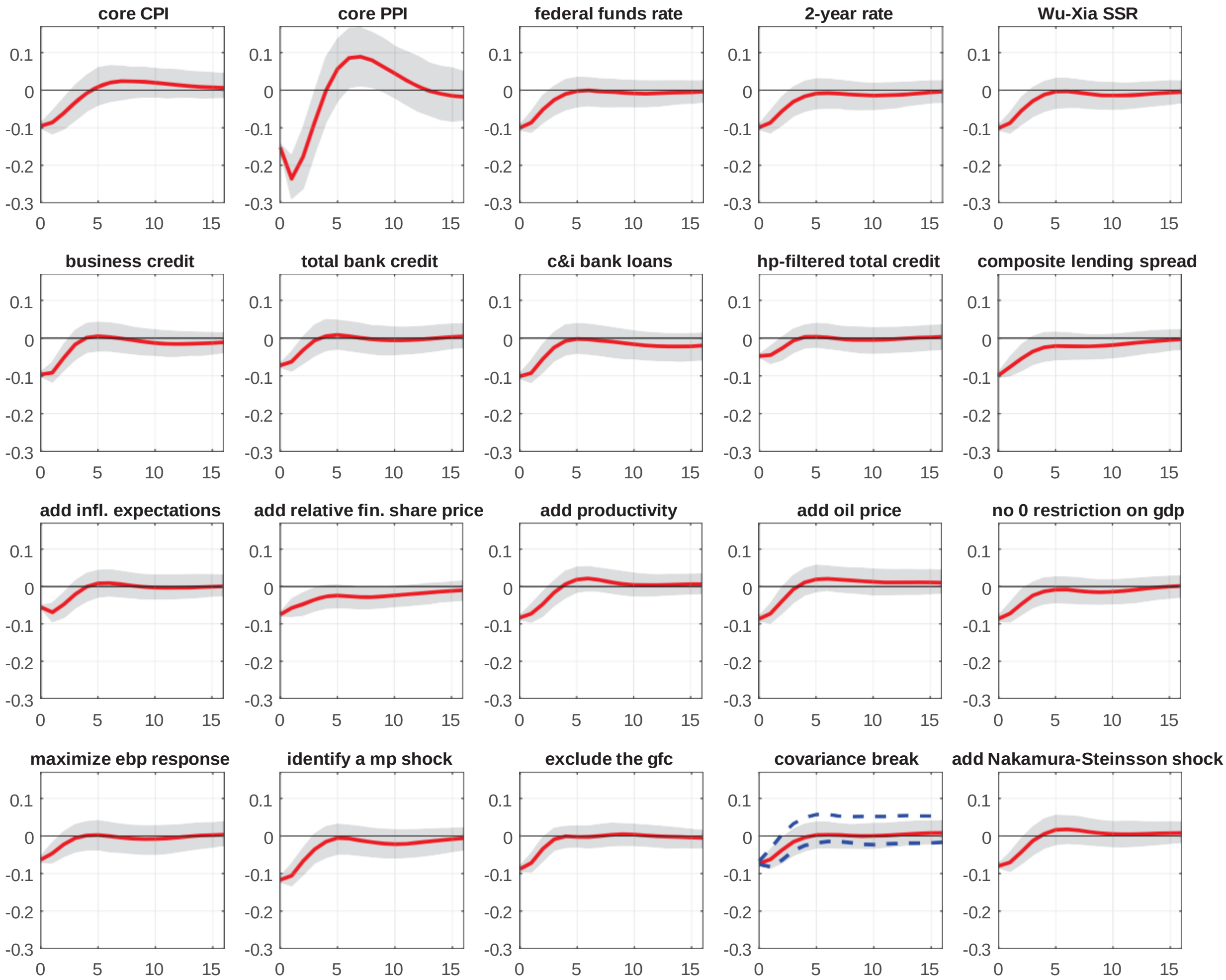
Notes: Plot shows median impulse responses (solid lines) and 90% confidence bands (shaded areas). Responses are expressed in percentage points. See text for a description of the variables.

Figure 6: **Financial and monetary policy shocks**



Notes: Plot shows the identified financial shock (solid line) and the Nakamura and Steinsson (2015) monetary policy shock series (dashed line). The latter is available only until 2014q1 and, to make it comparable with the identified financial shocks, we normalize it such that positive values represent a monetary policy easing and such that the standard deviation is 1 over the plotted period.

A Appendix: Response of inflation in robustness checks



Notes: Plots show the median target responses (solid lines) and 90% confidence bands (shaded areas) of inflation (in percentage points) to one standard deviation financial shocks obtained from alternative model specifications. In the first row, core PCE inflation is replaced with an alternative inflation measure (core CPI inflation or core PPI inflation), or the federal funds rate linked to the SSR of Krippner (2015) is replaced with an alternative interest rate measure (federal funds rate, 2-year rate, federal funds rate linked to the SSR developed by Wu and Xia 2016). In the second row, we experiment with different credit measures, with an alternative filter (hp-filtered total credit), or we replace the EBP with a composite lending spread. In the third and forth rows we add variables to the baseline model, change the identification scheme and assess the parameter time variation during the GFC. In the plot with title ”covariance break” we allow for a break in the residuals' covariance matrix in 2007q3: dashed lines denote 90% confidence bands for the response of inflation over the post-2007q2 period while the shaded areas and solid line refer to the pre-2007q3 period. In the bottom right plot we control for monetary policy shocks by adding the monetary policy news shock measure proposed by Nakamura and Steinsson (2015) (and linked to the shocks of Romer and Romer 2004 in the pre-1995 period). See text for further details.