The International Credit Channel Of US Monetary Policy And Financial Shocks☆

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Abstract

We provide novel evidence on the existence of an 'international credit channel' for the transmission of US shocks across borders. Using a two-country SVAR for the United States and the United Kingdom, we show that US monetary policy shocks, identified using high frequency surprises around policy announcements as external instruments, can significantly affect credit spreads in both countries, but less so UK economic activity. We then recover a US financial shock, which we identify within the same model using sign restrictions, and show that financial shocks are quickly transmitted internationally, with effects on credit spreads that are similar to the ones of monetary policy shocks. Unlike monetary policy shocks, however, financial shocks have a sizeable impact on economic activity and consumer prices in both countries. Our results are in line with general equilibrium open economy models with credit market imperfections and a high degree of financial integration.

Keywords: SVAR, Credit Channel, International Transmission, External Instruments, Sign Restrictions, Financial Shocks, Monetary Policy.
JEL codes: C32, E44, F44.

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1 Introduction

In a recent influential paper, Rey (2016) pointed to the existence of an 'international credit channel' of US monetary policy shocks. In a world with credit market imperfections, dollar-denominated debt, and highly integrated international financial markets, unexplained changes in the Federal Reserve's monetary policy stance should be quickly transmitted across borders and generate synchronized movements in asset prices, credit spreads, and policy rates across countries.[1]

This paper provides novel evidence on the existence of an international credit channel for the transmission US *financial* shocks across borders, and compares their impact to US monetary policy shocks. Three main considerations motivate us to investigate this topic. First, 'exogenous' monetary policy shocks may not be the only source of fluctuations that are transmitted *via* the international credit channel. Monetary policy shocks are rare and typically explain only a fraction of the variation of macroeconomic and financial variables. Indeed, rather than being the source of the shock, monetary policy often responds to shocks that originate elsewhere in the economy. Second, the global financial crisis has highlighted the importance of shocks originating in the financial sector. Recent research based on the 'financial accelerator' mechanism (Bernanke and Gertler, 1989, Kiyotaki and Moore, 1997, Bernanke et al., 1999) suggests that these shocks can play an important role as a source of macroeconomic fluctuations, accounting for more variation of both real and financial variables than is typically explained by monetary policy shocks.[2] Third, the literature on the international transmission of US monetary policy on monetary and financial conditions abroad is growing fast, but is still at its beginnings: "*many more VARs need to be run*" (Rey, 2016) and methodologies can be improved.[3]

In this paper we focus on the effects of both monetary policy and financial shocks

[1]While Rey (2016) coined the expression 'international credit channel' in her influential Mundell-Fleming lecture, some of the mechanisms underlying it have been extensively analyzed in an earlier body of literature. For example, Gertler et al. (2007) and Cespedes et al. (2004) show how foreign-currency denominated debt can generate fluctuations in the net worth of economic agents (and hence their ability to borrow or lend via collateral effects). Krugman (2003), Dedola and Lombardo (2012) and Devereux and Yetman (2010) show that credit market imperfections and international integrated financial markets can lead to highly synchronized movements in asset prices and credit spreads.

[2]See Gilchrist and Zakrajsek (2012), Jermann and Quadrini (2012), Iacoviello (2015a) and Gertler and Kiyotaki (2015)

[3]See, among others, the seminal contribution by Rey (2013), as well as among many others Passari and Rey (2015), Miranda-Agrippino and Rey (2015), Dedola et al. (2015), and Georgiadis and Mehl (2015).

originating in the United States. We then analyze the international transmission of these shocks to the United Kingdom, a relatively large ‘small open economy’ with a well-established regime of inflation targeting, a freely floating exchange rate and an exceptionally large financial sector. To identify monetary and financial shocks in the United States, we develop a novel approach that combines the external instruments identification procedure (Stock and Watson, 2012, Mertens and Ravn, 2013) and sign restrictions (Faust, 1998, Uhlig, 2005, Rubio-Ramirez et al., 2010, Fry and Pagan, 2011).[4] Specifically, we first identify a US monetary policy shock as using as an external instrument the monetary policy surprises pioneered by Gurkaynak et al. (2005) computed with the high-frequency methods (closely following the approach used by Gertler and Karadi (2015)).[5] We then identify a US financial shock that is orthogonal to the monetary policy shock (and to other structural shocks, such as demand and supply shocks) using sign restrictions. We then embed this identification technique into a 2-country structural VAR that allows us to trace out the international transmission of shocks originating in the United States to the United Kingdom.

Unsurprisingly, recent years have witnessed the development of many theoretical models where shocks that originate in the financial sector are given a key role in explaining business cycle fluctuations.[6] These shocks, which the literature loosely defines as ‘financial’, are, however, hard to identify in the data.[7] The identification of each of these shocks separately represents an empirical challenge that goes beyond the scope of this paper. However, we show how to draw from economic theory to derive a set of sign restrictions that are consistent with a broad class of shocks that originate in the financial sector. Specifically, we exploit a regularity of models with financial frictions (in the form of a costly state verification problem) and nominal rigidities (e.g., Bernanke et al., 1999,

[4]This methodology is general and can be easily applied to a wide variety of different questions.

[5]Recently, a number of authors have turned to high-frequency financial market data to quantify unanticipated changes in monetary policy (see for example Gurkaynak et al., 2005, Nakamura and Steinsson, 2013, Rogers et al., 2014).

[6]See, among others, Gilchrist and Leahy (2002), Nolan and Thoenissen (2009), Gertler and Kiyotaki (2010), Gertler and Karadi (2011), Gilchrist and Zakrajsek (2012), Gilchrist and Zakrajsek (2011), Jermann and Quadrini (2012), Negro et al. (2016), Christiano et al. (2014), Dedola and Lombardo (2012), Iacoviello (2015b).

[7]There are several issues. First, the presence of fast-moving financial variables in VARs poses a serious challenge to the plausibility of contemporaneous zero restrictions that are typically used to identify structural shocks in VARs. Second, financial shocks often behave as other aggregate shocks (such as demand shocks or uncertainty shocks, for example), which complicates any identification scheme based on sign restrictions.

Christiano et al., 2014) to achieve identification.

In this class of models, credit spreads and the policy rate typically move in opposite directions. Consider for example a (generic) contractionary shock: while credit spreads increase (as net worth of borrowers falls), monetary policy accommodates the shock. As a result, the response of the borrowing rate to shocks is ambiguous, and depends on the relative strength of the increase in credit spreads and the fall in the policy rate. Using the estimated model in Christiano et al. (2014), we show that in the face of a broad range of financial shocks, movements in the credit spread dominate movements in the policy rate, so that a contractionary financial shock leads to an increase in the borrowing rate. This is not the case for other shocks, such as other aggregate demand or supply shocks. Thus, we can impose different sign restrictions on the borrowing rate to disentangle between financial shocks and other types of shocks.[8]

Our results are as follows. First, in line with previous evidence, US monetary policy shocks affect credit conditions both domestically and internationally. A contractionary monetary policy shock in the United States reduces demand and increases credit spreads at home *via* a domestic credit channel (Bernanke and Gertler, 1995, Gertler and Karadi, 2015). But an international credit channel is also at work: the shock also tightens credit conditions abroad, leading to an increase in UK corporate credit spreads. In line with theory, a US monetary policy shock also leads to a depreciation of Sterling. However, despite the tightening in UK financial conditions and the contractionary impact of lower US demand for UK goods, the shock has only a small negative impact on economic activity and prices in the United Kingdom. Consistent with that, the response of UK monetary policy is broadly neutral. Our results seem to suggest that the depreciation of Sterling helps cushioning the external shock faced by the UK economy.

Second, an international credit channel also arises in the face of US financial shocks. An adverse financial shocks leads to a contraction in the US economy and a sharp increase in US credit spreads. This tightening in US credit conditions is quickly transmitted

[8]Other approaches for the identification of financial shocks have been considered in the empirical literature.See, for example, Meeks (2012), Hristov et al. (2012), Fornari and Stracca (2012), and Gambetti and Musso (2016). Gilchrist et al. (2014) and Caldara et al. (2016) attempt identify separately financial shocks and uncertainty shocks; Furlanetto et al. (2014) to disentangle different types of financial shocks.

internationally, with effects on UK credit spreads that are similar in magnitude to the ones arising from US monetary policy shocks. Moreover, unlike monetary policy shocks, US financial shocks have significant contractionary effects on the United Kingdom. Both UK industrial production and consumer prices fall by more and more quickly than in the case of monetary policy shocks, and this despite an accommodating response of UK monetary policy. These responses are in line with open economy models with financial frictions and a high degree of international financial integration (e.g., Devereux and Yetman, 2010, Dedola and Lombardo, 2012).

Finally, in an attempt to interpret our empirical findings, we explore the role of credit spreads in driving the international transmission of shocks. In open economy general equilibrium with financial integration —as for example Dedola and Lombardo (2012) and Devereux and Yetman (2010)— movements in credit spreads can amplify the response of the domestic economy to foreign shocks. In particular, by affecting asset prices, these shocks also affect borrower's net worth (and therefore credit spreads), and in turn affect credit demand by households and firms. To accomplish this, we re-estimate the effect of the same US monetary and financial shocks, but keeping credit spreads in the United States and in the United Kingdom constant in the model. For both shocks, our results point to a powerful amplification role played by credit spreads. We interpret this evidence as pointing to the presence of an international credit channel for the transmission of US monetary and financial shocks.

Related literature. Our findings contribute to an established literature on the international transmission mechanism of monetary policy and to a smaller, but burgeoning literature on the international transmission of financial shocks.

The literature on the international transmission mechanism of monetary policy is vast. Some early empirical contributions focused on the real effects of US monetary policy shocks, finding large effects. See for example **?**, Faust and Rogers (2003), Faust et al. (2003), Canova (2005), Neri and Nobili (2010), Mackowiak (2007); and more recently Georgiadis and Mehl (2015) and Dedola et al. (2015). A more recent strand of this literature focused on the spillovers from US monetary policy to international financial markets (see CraineMartin2008; EhrmannFratzscher2009; GurkaynakWright2011;

Fratzscher_etal2013; Moore_etal2013; Rogers et al. (2014)).[9] Papers in this literature typically also find that financial spillovers are large.

In this paper we investigate both the real and financial consequences of monetary policy shocks, with a focus on the international credit channel of monetary policy. As such, Passari and Rey (2015) and Rey (2016) are most closely related to our paper. By focusing on corporate credit spreads, we provide evidence on the international credit channel of US monetary policy that is complementary to the findings in those two studies (which focus instead on mortgage spreads). Moreover, our richer empirical framework allows us to expand and improve on existing estimates of the international spillovers of US monetary policy shocks. We show that simple VAR models that just include foreign monetary policy in the vector of domestic endogenous variables (as in Passari and Rey, 2015, Rey, 2016) can lead to biased *dynamics* in the estimated impulse response functions, relative to a richer VAR specification that also includes the endogenous dynamics of the foreign economy.[10]

We also draw on a smaller, but growing, literature on the international transmission of financial shocks. In a related paper, Eickmeier and Ng (2015) study how US credit supply shocks are transmitted internationally using a Global VAR model and sign restrictions for shock identification. The authors find that negative US credit supply shocks have strong international negative effects. They also find, as we do, that the US dollar appreciates in the face of a US credit supply shock, consistent with a "flight to quality" effect.[11] Helbling et al. (2011) study the transmission of credit shocks (identified with sign restrictions) originating in the U.S. to the global economy using a factor-augmented VAR (FAVAR). Their results suggest that credit shocks play an important role in driving economic activity, especially during global recessions. Chudik and Fratzscher (2011) study two types of finical shocks, a tightening in liquidity conditions and credit markets and a re-pricing of risk and flight of investors into safe asset classes in a Global VAR. Their findings suggest that both types of shocks have played a role in the global transmis-

[9] An even earlier literature focused more narrowly on the impact of US monetary policy on the exchange rate. See Lastrapes (1992), Eichenbaum and Evans (1995), Kim and Roubini (2000), and Clarida and Gali (1994).

[10] For a similar, but more formal and exaustive treatment of this point, is done by Georgiadis (2015).

[11] Abbate et al. (2016) find similar results using a large time-varying FAVAR model, where a financial shock is identified as an innovation to the US financial conditions index developed by Hatzius et al. (2010).

sion process. Relative to these studies, our focus is more narrowly on the international credit channel, and we also provide a comparison between monetary policy and financial shocks.[12]

Finally, our paper also contributes to the literature on the identification of structural shocks in VAR models. Our approach to identification, which combines external instruments and sign restrictions techniques, is simple but powerful. For example, when more than one instrument is available, it allows to reduce the number of sign restrictions needed to identify the remaining shocks in the system. Moreover, if enough instruments and/or unique sign patterns are available, our methodology allows to (set) identify the full matrix of structural parameters of a VAR, recover the underlying structural shocks and compute, for example, full forecast error variance decompositions. This is especially important if, as in our paper, the focus is on more than one shock and their relative importance.

The paper is structured as follows. Section 2 presents the empirical model, our identification strategy, and the data we use. Section 3 shows how we derive from theory a set of sign restrictions that are consistent with a broad class of shocks originating in the financial sector. Section 4 reports the impulse response functions to US monetary and financial shocks and variance decompositions. Section 5 attempts to interpret our empirical findings by means of a simple counterfactual exercise. Section 6 concludes. An Appendix reports additional information on the data, some additional results, and a set of robustness exercises.

2 Empirical Model And Identification Strategy

Our empirical strategy consists in combining the external instruments approach (Stock and Watson, 2012, Mertens and Ravn, 2013) with sign restrictions (Faust, 1998, Uhlig, 2005, Rubio-Ramirez et al., 2010, Fry and Pagan, 2011) to identify structural shocks in a 2-country structural vector autoregressive model (SVAR). In section 2.1 we describe the formal econometric framework and the general methodology underlying our identification

[12] A different (and less directly related to this paper) strand of the literature focuses on the bank-to-bank transmission of financial shocks, without considering the link with the real economy. See Peek and Rosengren (1997), Schnabl (2012), and Ongena et al. (2013).

strategy. In section 2.2 we show how this identification strategy can be embedded within a 2-country VAR for the analysis of the international transmission of shocks. Finally, section 2.3 describes the details of the model specification and the data we use in the empirical application.

2.1 General methodology

Let y_t be an $n \times 1$ vector of observables. We assume that the dynamics of the observables are described by the following structural VAR model:

$$y_t = \Phi(L)\, y_{t-1} + Be_t \tag{1}$$

where $\Phi(\cdot)$ and B are $n \times n$ matrices of coefficients, L is the lag operator, and e is an $n \times 1$ vector of (unobserved) structural shocks with $\mathbb{E}[e_t] = 0$, $\mathbb{E}[e_t, e_t'] = I_n$, $\mathbb{E}[e_t, e_s'] = 0$ for $s \neq t$, where I_n is the identity matrix. The specification in (1) omits deterministic terms and exogenous regressors for notational brevity. Let the $n \times 1$ vector u_t denote the reduced-form residuals, which are related to the unobserved structural shocks by:

$$u_t = Be_t, \tag{2}$$

Since $\mathbb{E}[u_t u_t'] = \Sigma_u = BB'$, an estimate of the covariance matrix of u_t provides $n(n+1)/2$ independent identifying restrictions. However, identification of the elements of at least one of the columns of B requires more identifying restrictions.

The SVAR literature addressed this problem in a variety of ways. Our identification strategy combines the recently developed external instruments approach with a standard sign restriction approach. The external instrument approach has proven a very successful identification strategy when good instruments are available. The sign restriction approach, despite only delivering set identification, allows to intuitively identify shocks that are consistent with economic theory and that affect many variables contemporaneously. This is particularly important in models with financial variables, where standard timing assumptions would be too restrictive for credible identification schemes.

In what follows, for simplicity, we consider the case where we identify only one structural shock (labelled e_t^b) with the external instruments approach. Without loss of generality we choose this shock to be the shock associated with the first equation, so we set $e_t^b \equiv e_{1t}$. We can then identify the remaining $n-1$ shocks, namely $e_t^{\mathcal{B}} \equiv (e'_{2,t}, ..., e'_{n,t})'$, with sign restrictions. In our application below we identify a monetary policy shock with the external instruments approach and a financial shock with sign restrictions, leaving the remaining $n-2$ shocks unconstrained (in the Appendix we show that our results are robust to also identify the remaining shocks with additional sign restrictions). We stress, however, that our approach to identification is general and can be applied to recover the full B matrix, provided that a valid instrument or a set of unique sign restrictions for each shock of interest are available.

We partition the matrix B into a column vector b, which captures the impact of the shock in the first equation, and a matrix $\mathcal{B}$, whose columns capture the impact of the shocks in the remaining $(n-1)$ equations:

$$B = \begin{bmatrix} b & \mathcal{B} \end{bmatrix}. \tag{3}$$

where b is an $n \times 1$ column vector and $\mathcal{B}$ is a $n \times (n-1)$ matrix.

We now show how to identify b and $\mathcal{B}$ using external instruments and sign restrictions, respectively.

External instruments. We assume that there exists an instrument (z_t) that is correlated with the shock of interest (ε_t^b) and uncorrelated with all other shocks $(e_t^{\mathcal{B}})$. It is then possible to isolate the variation in the reduced-form residual (u_t^b) that is due only to shock of interest with a regression of the reduced form residual u_t^b itself on the instrument z_t. By projecting the remaining residuals on the fitted values of the previous regression, it is possible to obtain an estimate of the contributions of the shock of interest to all variables in the system, thus providing an estimate of b (up to a scaling factor).

Since this method is now well understood and widely used in the literature, we refer for the formal details of this methodology to the original papers by Stock and Watson

(2012), Mertens and Ravn (2013). The novel aspect of our approach is that, in our empirical application, we combine the external instruments and sign restrictions identification techniques, which is explained next.

Combining sign restrictions and external instruments. We now show how to combine external instruments identification with a standard sign restriction approach to identify other structural shocks ($e_t^{\mathcal{B}}$) 'conditional' on the shock identified with the external instruments approach (e_t^b).[13]

To identify $\mathcal{B}$ — i.e., the contemporaneous impact of the remaining shocks — we proceed as follows. First, using (3), we re-write the covariance matrix of the reduced-form residuals as:

$$\Sigma_u = BB' = \begin{bmatrix} b & \mathcal{B} \end{bmatrix} \begin{bmatrix} b & \mathcal{B} \end{bmatrix}'. \tag{4}$$

As is well known, this decomposition of the covariance matrix is not unique. Let C be the Cholesky decomposition of the covariance matrix Σ_u, and let Q be an orthonormal matrix such that $QQ' = I$. Then we can write:

$$\Sigma_u = CC' = CQQ'C' = (CQ)\,(CQ)' \tag{5}$$

Our strategy consists precisely in constructing a large number of orthonormal matrices Q that satisfy the following condition:

$$CQ = \begin{bmatrix} b & \mathcal{B} \end{bmatrix}, \tag{6}$$

where $\mathcal{B}$ also satisfies a set of sign restrictions (as derived, for example, from a theoretical model). We do that in three steps.

1. Find a normal vector q of dimension $n \times 1$ that rotates the first column of C, the Cholesky decomposition of Σ_u, into the vector b. That is, we find a $n \times 1$ normal

[13] For the moment we assume that we can rely on theory to derive a unique set of sign restrictions that are consistent with the shocks ($\varepsilon_t^{\mathcal{B}}$) that we want to identify. Below we show how we derive our restrictions for the identification of a financial shock.

vector q such that the following equality holds:

$$Cq = b \tag{7}$$

2. Given q, build the remaining $n-1$ columns of an orthonormal matrix Q following a standard Gram-Schmidt process.[14] That is, find an $(n \times n-1)$ matrix $\mathcal{Q}$ such that the following equality holds:

$$\begin{bmatrix} q & \mathcal{Q} \end{bmatrix} \begin{bmatrix} q & \mathcal{Q} \end{bmatrix}' = QQ' = I. \tag{8}$$

The matrix CQ then represents a candidate identification scheme because:

$$CQ = C \begin{bmatrix} q & \mathcal{Q} \end{bmatrix} = \begin{bmatrix} b & \mathcal{B} \end{bmatrix} = B. \tag{9}$$

3. Check that $\mathcal{B}$ satisfies our set of sign restrictions. If it does, we retain the matrix Q. If does not, we repeat steps (1) and (2) until we obtain a matrix $\mathcal{B}$ that satisfies the restrictions.

Finally we repeat steps (1)-(2)-(3) until we have N matrices B_i (with $i = 1, ..., N$) consistent with our identification restrictions. This completes the (set) identification of B.

2.2 A Two-Country VAR

We now show how the above identification strategy can be embedded within a 2-country VAR model for the analysis of the international transmission of shocks.

Consider a 2-country VAR model for the Home (H) and Foreign (F) economies (where

[14] Let j index the columns of Q. Let Q_{j-1} denote the first $j-1$ columns of Q, such that $Q_{2-1} = Q_1 = q_1$. Let x_j be a draw from a Normal distribution on $\mathbb{R}^N$. Then the $j-$th column of Q can be constructed as:

$$q_j = \frac{\left(I_N - Q_{j-1}Q'_{j-1}\right) x_j}{\left\| \left(I_N - Q_{j-1}Q'_{j-1}\right) x_j \right\|}.$$

we drop deterministic variables, such as a constant or a time trend, for ease of notation):

$$\begin{bmatrix} y_t^F \\ y_t^H \end{bmatrix} = \begin{bmatrix} \Phi_{11}(L) & \Phi_{12}(L) \\ \Phi_{21}(L) & \Phi_{22}(L) \end{bmatrix} \begin{bmatrix} y_{t-1}^F \\ y_{t-1}^H \end{bmatrix} + \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix} \begin{bmatrix} e_t^F \\ e_t^H \end{bmatrix} \tag{10}$$

where $y_t = (y_t^{F\prime}, y_t^{H\prime})'$ is an $(n^F + n^H) \times 1$ vector that collects the $n = n^F + n^H$ endogenous variables stacked by country; $\Phi(L)$ is a matrix polynomial in the lag operator; and $e_t = (e_t^{F\prime}, e_t^{H\prime})'$ is an $(n^F + n^H) \times 1$ vector that collects the structural shocks with covariance matrix $\mathbb{E}[e_t e_t'] = I$.

We treat the Home country as a small open economy by not allowing any feedback from Home variables onto Foreign ones. This is achieved by imposing a block exogeneity restriction on the Φ and B matrices, i.e. we impose $\Phi_{12}(L) = B_{12} = 0$. The block exogeneity assumption has been widely used in the empirical literature in international economics, see for example Cushman and Zha (1997), Mackowiak (2007), Dungey and Pagan (2009), or Kim and Roubini (2000) — and more recently Dedola et al. (2015).

The block exogeneity assumption conveniently decouples the two countries. As a result, we break the estimation process in two steps. First, we estimate a reduced-form model for the Foreign economy and identify a subset of the structural shocks e_t^F with the identification strategy outlined above. We then estimate a reduced-form VAR for the Home country, where we treat lags of Foreign variables as additional exogenous variables.

To quantify the impact of Foreign structural shocks on Home variables (i.e., the matrix B_{21}) we simply regress the Home reduced-form residuals, u_t^H, on the Foreign structural shocks e_t^F. The OLS coefficients of that regression will capture the response of Home variables to Foreign shocks, while the residuals will capture a linear combination of the Home structural shocks e_t^H.[15] The estimates we compute are equivalent to those obtained with the two steps approach of Canova (2005).

[15]It would of course be possible to also recover the Home structural shocks by identifying the remaining block of the identification scheme. This is, however, beyond the scope of this paper.

2.3 Data & Estimation

In our application, the United States are the Foreign economy and the United Kingdom the Home economy. For the estimation of the US VAR we follow as closely as possible Gertler and Karadi (2015), deviating from their baseline specification along two dimensions. First, estimate the model over an larger sample period that covers the period 1979:M7–2015:M3. To do that, we extend their original data set, also including the series for the monetary policy instrument (which, as in their baseline, is the monetary policy surprises based on the 4-months ahead futures on the Fed Funds (FF4). Second, we augment their baseline specification with an additional variable that —as we shall explain in the next section— is crucial for the identification of the financial shock.

In sum, our baseline specification for the US model includes the same variables as Gertler and Karadi (2015) (namely, the log industrial production, the log consumer price index, the one-year government bond rate as the policy indicator, the Gilchrist and Zakrajsek (2012) excess bond premium) and the nominal yield on the 10-year corporate bond.[16] As Gertler and Karadi (2015) the model includes 12 lags of the endogenous variables and a constant.

We then estimate the UK VAR with monthly data over the same sample. In the vector of endogenous variables we include: the nominal yield on 1-year gilts as the policy indicator, in a similar vein to Gertler and Karadi (2015), a (log) index of industrial production, a log index of consumer prices, the nominal exchange rate vis-a-vis the US Dollar and a measure of corporate spreads. A detailed description of the data is provided in the Appendix. We chose 12 lags for the endogenous variables as in the US VAR. Moreover, we include as exogenous regressors 3 lags of US variables and a constant.[17]

3 Set Identification of Financial Shocks

The aim of this section is to derive a set of sign restrictions that are consistent with a broad class of shocks that originate in the financial sector, drawing from theoretical

[16] A detailed description of the data is provided in the Appendix.

[17] We choose the number of lags of US variables according to the Akaike lag length criterion. The result are robust to the inclusion of 12 lags of US variables, although the precision of the estimates is somewhat lower, not surprisingly given the large number of parameters to estimate.

models with financial frictions. Our ultimate goal is to use these restrictions to identify a financial shock within the SVAR framework described above.

The identification of financial shocks within an SVAR framework is a challenging task. Indeed, in the earlier literature, the introduction of 'fast-moving' financial variables posed a serious challenge to the plausibility of any of the contemporaneous zero restrictions that were typically used to identify structural shocks in VARs. The literature has therefore moved to set identification, e.g. by imposing a number of sign restrictions on the impulse response functions from the VAR.[18]

However, even with set identification, the task of achieving an economically plausible identification is not trivial. There are two major challenges. First, different financial shocks (e.g., to net worth, to the external finance premium, etc.) have very similar qualitative effects on the aggregate economy. Indeed, in sticky price models with financial frictions *a la* Bernanke et al. (1999), various types of adverse financial shocks all generate a fall in activity and prices, an increase in credit spreads and a monetary policy loosening by an inflation-targeting monetary authority.[19] Second, since in financial accelerator models credit spreads are typically countercyclical, adverse demand shocks can lead to similar dynamics to those of adverse financial shocks. Indeed, many papers in the literature show that financial shocks tend to behave like aggregate demand shocks (see Curdia and Woodford (2010), Gertler and Karadi (2011), Gilchrist and Zakrajsek (2012) for financial shocks; and Bundick and Basu (2014) and Leduc and Liu (2016) for uncertainty shocks). It is therefore difficult to disentangle these two types of shocks based on the sign of their impact on the economy.

In this paper we show that it is possible to find a minimum set of restrictions that allows us to distinguish a financial shock from a "classical" aggregate demand shock. The identification of *different types* of financial shocks (and disentangling between financial

[18] See, among many others, Meeks (2012), Musso et al. (2011), Hristov et al. (2012), Eickmeier and Ng (2015). Alternatively, some papers in the literature used the penalty function approach (initially proposed by Faust (1998) and Uhlig (2005)) to disentlagnle financial or uncertainty shocks. See Pinter et al. (2013) and Caldara et al. (2016) .

[19] The recent literature has analyzed different types of financial shocks in this class of models. For example, shocks to the external finance premium, i.e. the premium over risk free rate to access external funding (Gilchrist and Zakrajsek, 2012); risk shocks, i.e. exogenous increases in the cross-sectional dispersion of entrepreneurial productivity (Christiano et al., 2014); or equity shocks, i.e. shocks to entrepreneurs' net worth (Christiano et al., 2014).

shocks and uncertainty shocks), however, represents an empirical challenge that goes beyond the scope of this paper.[20] In what follows, we therefore use the term financial shock in a broad sense.

To derive a set of sign restrictions that allows us to disentangle financial shocks from aggregate demand shocks we draw from theoretical models with sticky prices and a financial accelerator mechanism (Bernanke and Gertler, 1995, Bernanke et al., 1999). In these models, the borrowing rate on a loan with m-periods ahead maturity (i_B^m) is typically given by the sum of two components: the rate on a government bond of similar maturity (i^m) plus a spread that arises because of imperfect information in credit markets (x^m). That is:

$$i_B^m = i^m + x^m. \tag{11}$$

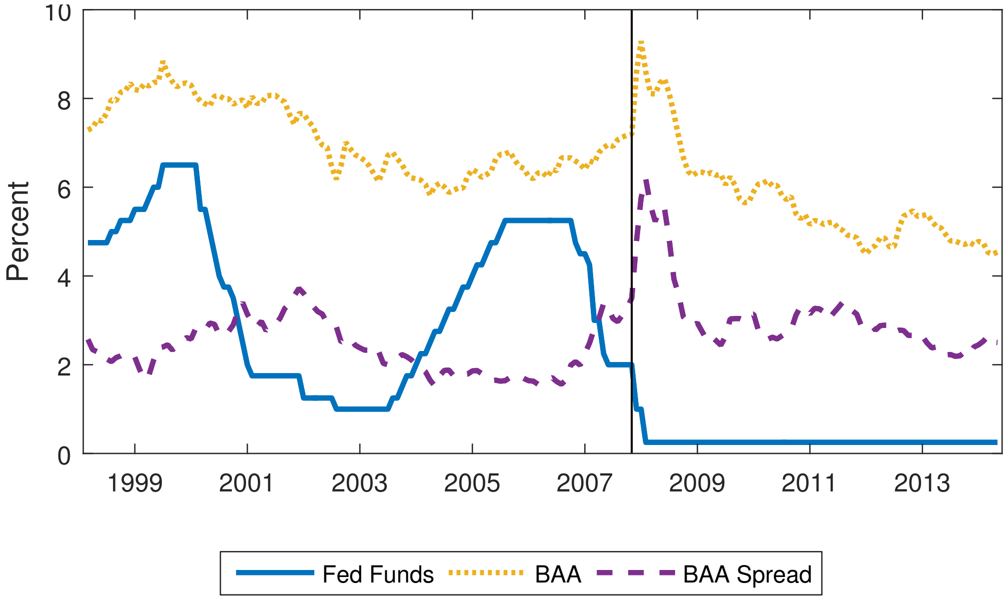
In this class of models, the credit spread (x^m) endogenously respond to shocks in a countercyclical fashion, while the safe interest rate (i^m) is typically controlled by the central bank by means of a Taylor rule. Hence, a key feature of these models is that the equilibrium response of the borrowing rate (i_B^m) to shocks is theoretically ambiguous. To see that, assume that a negative demand or financial shock hits the economy, putting downward pressure on both economic activity and prices. In response to the shock, monetary policy lowers the policy rate ($i^m \downarrow$) while the credit spread increases ($x^m \uparrow$). It is therefore clear that, depending on (i) the monetary policy reaction function and (ii) the 'semi-elasticity' of the credit spread to the shock, the borrowing rate prevailing in the economy might either increase or decrease.

In this paper we exploit the ambiguous response of the borrowing rate (i_B^m) to shocks to achieve identification. Our conjecture is that, in the face of financial shocks, movements in the credit spread dominate movements in the policy rate, so that a negative financial shock leads to an increase in the borrowing rate. On the other hand, in the face of demand shocks, movements in the policy rate dominate over movements in the credit spread, so that a negative demand shock leads to a fall in the borrowing rate. If this is the case, we can impose different sign restrictions on the borrowing rate to disentangle between

[20] Furlanetto et al. (2014) disentangle between different types of financial shocks; Caldara et al. (2016) and Gilchrist et al. (2014) disentangle between uncertainty shocks and financial shocks.

demand and financial shocks.

Figure 1 Fed Funds, BAA Interest Rate, And BAA Spread



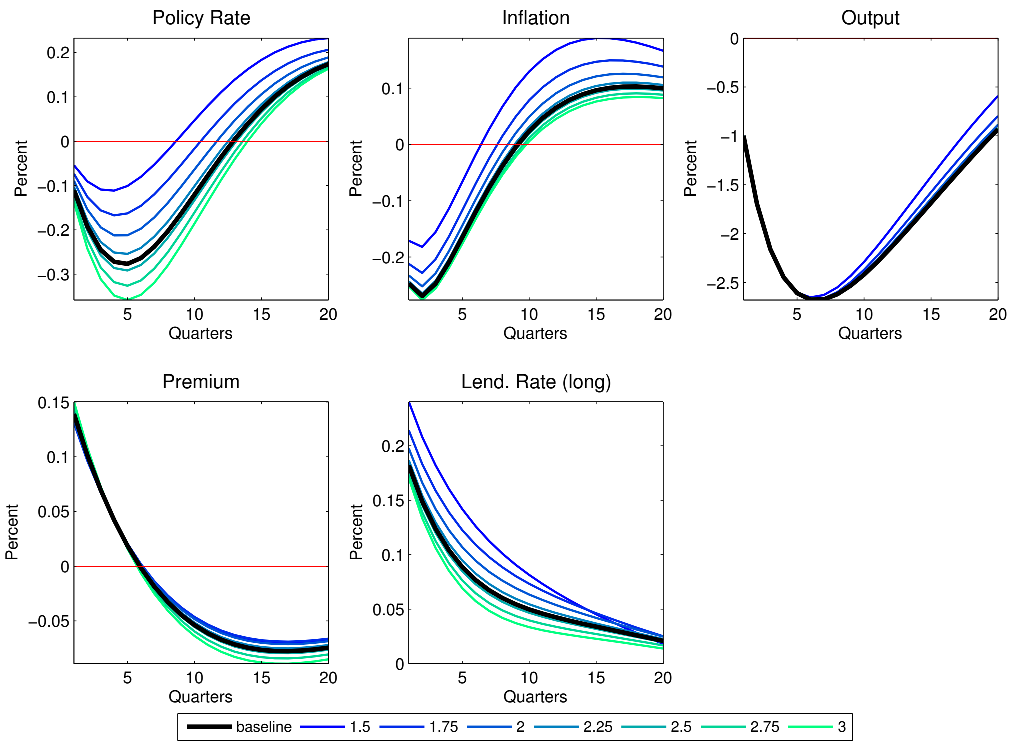
Note. The chart reports the Fed Funds rate (solid line), the yield on BAA-rated corporate debt (dotted line), and its spread over a safe interest rate of the same maturity (a 10-year government bond) over the period 1999:M1 to 2015:M3. The vertical line shows 2008:M9, when Lehman brothers collapsed.

This conjecture originates from (arguably) the most spectacular financial shock in our sample: the global financial crisis. Figure 1 reports the behavior of the Fed funds rate (solid line), the yield on BAA-rated corporate debt (dotted line), and its spread over a safe interest rate of the same maturity over the period 1999:M1 to 2015:M3. A vertical line shows 2008:M9, when Lehman brothers collapsed . Figure 1 clearly shows the mechanisms described above. While the Fed sharply cut the Fed Funds rate, trying to lower borrowing costs, credit spreads quickly spiked, putting upward pressure on borrowing costs. From the chart it is clear that, in the last months of 2008, the spread component dominated over the policy rate component, leading to an overall increase in the borrowing rate.

In what follows, we formalize our conjecture using a standard financial accelerator model —the variant of Bernanke et al. (1999) estimated by Christiano et al. (2014). Specifically we show that the mechanism described above (i.e., that movements in the credit spread dominate movements in the policy rate) is true for a variety of financial shocks. Moreover, we show this is not the case in the face of other aggregate (demand or supply) shocks. We also show that our result does not depend on the monetary policy reaction function.

We start with financial shocks. Figure 2 plots the responses of output, inflation, the policy rate, the credit spread, and the borrowing rate in response to a shock that raises the cost of external finance.[21] The dark thick line displays the responses using the baseline estimated parameters in the original Christiano et al. (2014) paper. The impulse responses clearly show that the policy rate and the credit spread move in different directions, but the latter dominates. As a result, the borrowing rate increases.

Figure 2 Impulse Responses To A Risk Premium Shock



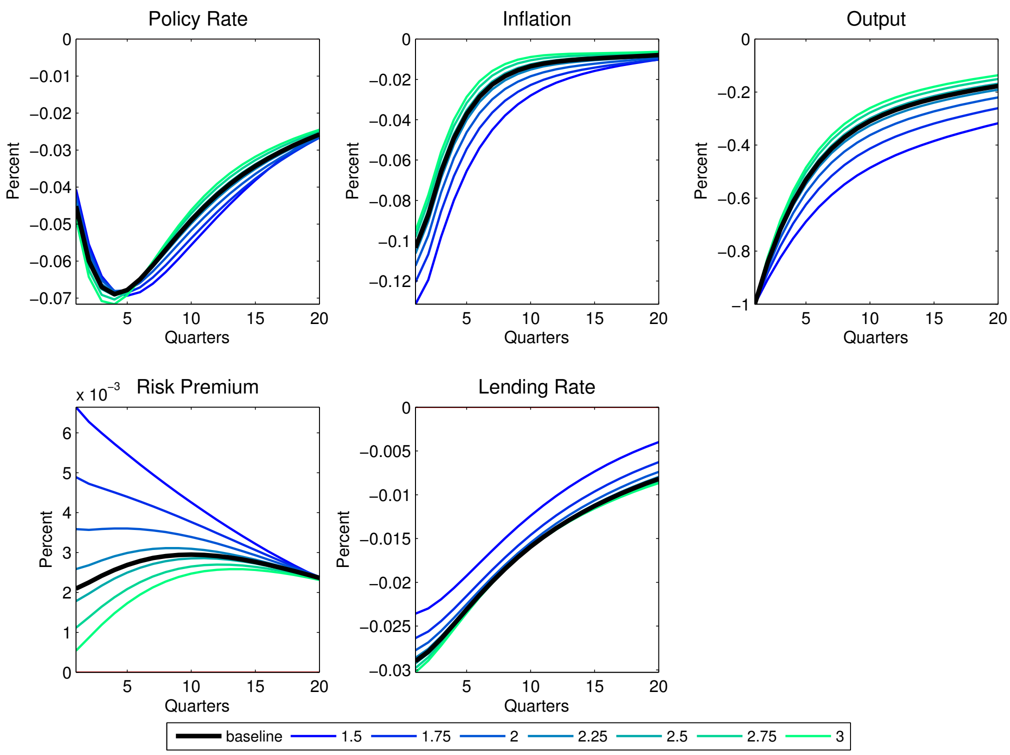
Note. The thick dark line is computed using the parametrization in the baseline estimated model of CMR. The thin colored lines are obtained by varying the coefficient on inflation in the Taylor Rule. We consider values from 1.5 to 3. The size of the shock is normalized so that it generates a fall in output of 1 percent.

A key determinant of the response of the borrowing rate is the reaction function of the central bank. For example, a more 'aggressive' monetary policy rule would generate a larger fall in the policy rate, which would also decrease the lending rate. If this effect is

[21] As in Gilchrist and Zakrajsek (2012), we model this shocks by means of an additive term in the definition of the external finance premium. Results are similar for other financial shocks such as, for example, a risk shock. See the Appendix.

string enough, then the response of the lending rate could turn negative, thus contradicting our identification assumption. To address this issue, we assess the robustness of the theoretical predictions above to different monetary policy reaction functions. The thin lines in Figure 2 display how the impulse responses change when changing the parameter governing the response of the policy rate to inflation in the Taylor rule (ϕ^{π}). We consider a wide set of parameter values, ranging from $\phi^{\pi} = 1.5$ to $\phi^{\pi} = 3$, well within the range topically considered in the literature. The impulse responses under these alternative Taylor rules show that the borrowing rate increases irrespective of the strength of the monetary policy response to inflation.

Figure 3 Impulse Responses To A Government Spending Shock



Note. The thick dark line is computed using the parametrization in the baseline estimated model of CMR. The thin colored lines are obtained by varying the coefficient on inflation in the Taylor Rule. We consider values from 1.5 to 3. The size of the shock is normalized so that it generates a fall in output of 1 percent.

We now turn to aggregate demand shocks. Figure 3 reports the IRFs of the same variables considered above to a negative shock to government consumption.[22] The shocks is contractionary, so that output and inflation fall and the central bank responds by

[22]Results are similar when we consider other type of demand shocks, such as preference shocks or investment specific shocks. See the Appendix.

lowering the policy rate. Since the credit spread is countercyclical, similarly to what we observed for the financial shock, the policy rate and the credit spread move in different directions. However, in the face of an aggregate demand shock, the movement in the policy rate now dominates and, as a result, the borrowing rate falls. Again, we check that our finding is robust to the strength of the response of the central bank to inflation, as shown by the thin lines in Figure 3.

These results therefore suggest that there exists a minimum set of sign restrictions that allow to distinguish between financial and demand shocks based on the response of the borrowing rate. In the next section we thus impose these restrictions in a structural VAR of the type described in section 2 in order to identify a financial shock, its impact on the macroeconomy and its international transmission.

4 Results

In this section we present the main results of the paper. We first discuss the impulse response functions to a monetary policy shock, and then to a financial shock.

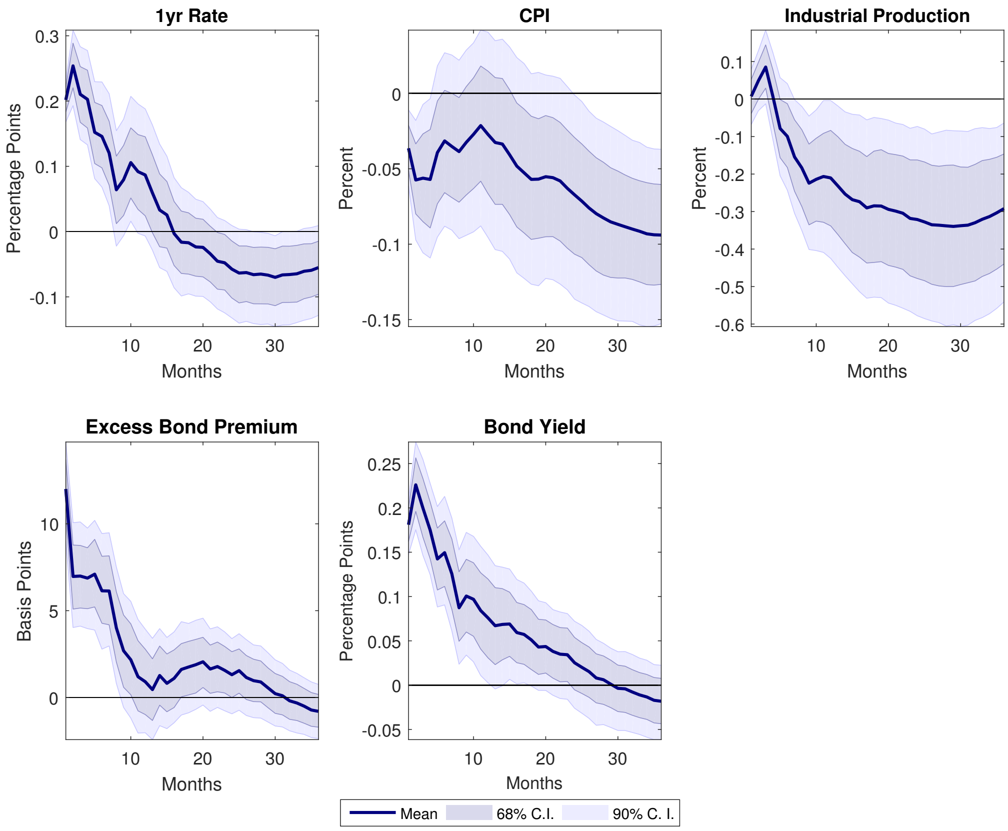
4.1 Monetary policy shock

We start with the responses of the US economy. The impulse responses of US variables to a 1 standard deviation US monetary policy shock are reported in Figure 4.

Despite the longer sample (updated to 2015:M3) and the inclusion of bond yields in the data set, the results remain consistent with Gertler and Karadi (2015). A surprise increase in the 1-year rate (instrumented with exogenous monetary policy surprises) leads to a significant fall in industrial production, a small fall in CPI, and an increase in the excess bond premium, which Gertler and Karadi (2015) interpret as being consistent with a credit channel of monetary policy.

Departing from Gertler and Karadi (2015), our specification also includes a corporate bond yield, which also increases in response to the monetary policy shock. This is not surprising, since monetary policy should affect the corporate bond yield through at least

Figure 4 US Monetary Policy Shock



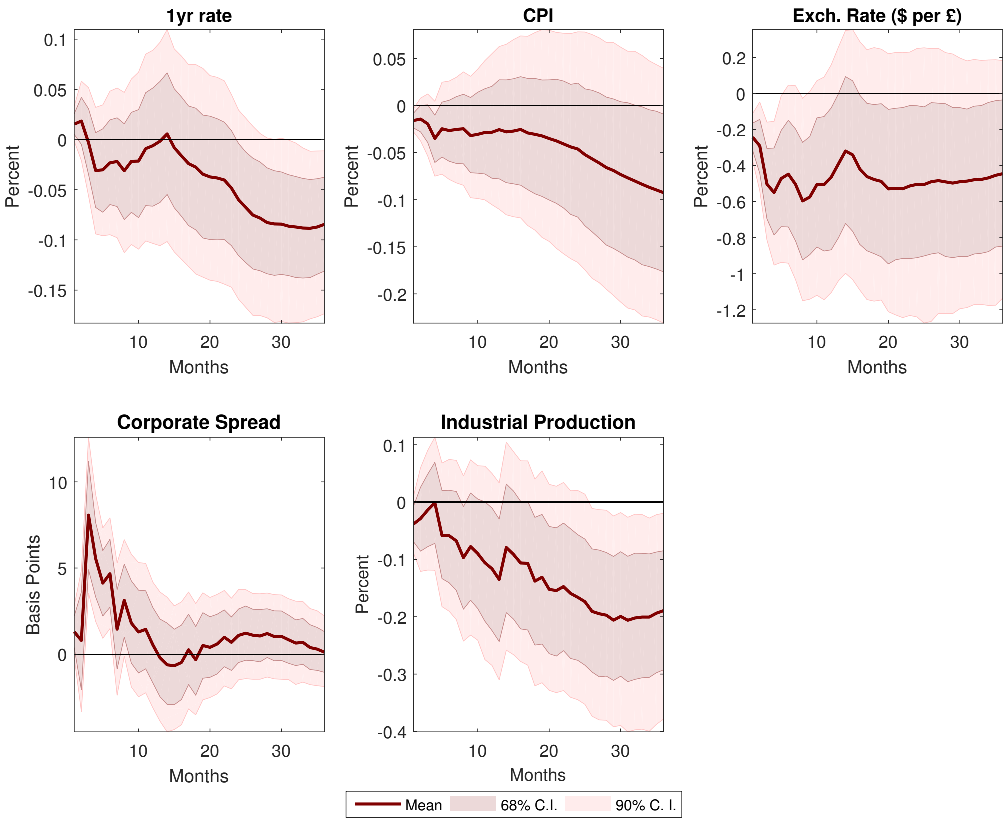
NOTE. US VAR estimated in log levels, with 12 lags, a constant and a linear trend over the 1979:7-2015:3 period. The 1-year Treasury Yield is instrumented using the same instrument as in Gertler and Karadi (2015). The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications.

two channels: the expectations channel, i.e. the path of future expected short rates, and the aforementioned credit channel, which should have an impact on bond premia.

The response of UK variables to a US monetary policy shock is reported in Figure 5. Starting from the exchange rate, the impulse responses show that sterling depreciates vis-à-vis the US dollar, at first by about 25 basis points, and then gradually reaching half a percentage point. This is the response we would expect in partial equilibrium from a tightening in US monetary policy, but it is also consistent, in general equilibrium, with the short-term interest rate differential implied by the US and UK impulse responses, as the UK short-term interest rate only falls further out, dampening the fall in real activity.

The response of output (and prices) in the UK is theoretically ambiguous, as the international transmission of monetary shocks can happen through different channels:

Figure 5 US Monetary Policy Shock – Transmission To The UK



Note. UK VAR estimated in log levels with a constant and time trend, with 12 and 3 lags for UK and US variables, respectively, over the 1979:7-2015:3 period. The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications.

first, the contractionary monetary policy shock can lower US demand for both US and UK goods, thus negatively affecting UK output and prices ('demand channel'); second, an appreciation of the US dollar vis-à-vis sterling can lead to a terms-of-trade improvement for the United States and shift US demand towards UK exports, thus positively affecting UK output and prices ('expenditure-switching effect'), but also push up on prices due to exchange-rate pass-through; finally, with integrated international financial markets, the increase in US credit spreads can lead to a similar increase in credit spreads in the United Kingdom, negatively affecting UK output and prices (an 'international credit channel').[23]

We find that industrial production slightly falls in response to a US contractionary

[23] As discussed in the introduction, the theoretical underpinning of this channel is the presence of a portfolio balance effects among financially interconnected economies, whereby movements in asset prices abroad are quickly transmitted to the H economy affecting the net worth of H agents. See Dedola and Lombardo (2012) and Devereux and Yetman (2010) among others. Ehrmann and Fratzscher (2009) provide empirical evidence on this.

monetary policy shock, suggesting that the foreign demand and credit channels dominate over the expenditure-switching channel. The response of CPI is statistically insignificant, perhaps suggesting that the negative demand effects are countered by the pass-through to domestic prices of a weaker sterling. These results are in line with the mean group estimates of Dedola et al. (2015) for advanced economies. Finally, the UK corporate credit spread increases slightly on impact, and then jumps by about 8 basis points within the third month. Our results therefore also corroborate the existence of an international credit channel of monetary policy.

The results we report are complementary to the ones provided by Rey (2016) and Passari and Rey (2015), in that we provide evidence on the international credit channel using corporate spreads rather than mortgage spreads. The magnitude of the increase in the corporate spread (as well as its persistence) is similar to what these studies find for mortgage spreads, although we find that the peak response is somewhat more delayed. But our results also display some differences relative to Rey (2016): our estimates show that UK industrial production (and, to a less extent, CPI) contracts in a statistically significantly fashion too. Moreover, we find no evidence of 'fear of floating', with a response of the UK policy rate that is basically not statistically different from zero.

In the Appendix we explore one potential explanation for these differences that highlights the benefits of our approach for correctly accounting for the international transmission mechanism of both monetary policy and financial shocks. Specifically, we compare our 2-country VAR with a simpler VAR (that closely resembles the one used in Rey (2016) and Passari and Rey (2015)), where a foreign variable —the US Fed Funds— is included in the vector of domestic endogenous variables.

In this simpler specification there are two main differences relative to our baseline VAR. First, there is no block-exogeneity assumption, i.e. the US policy rate is allowed to load on UK variables. Second, US dynamics are by construction summarized by the dynamic response of the US interest rate, since no other US variable is included in the VAR. If the true model was the one that we estimated in our baseline, then this simpler VAR model would be mis-specified. The results (reported in Figure C.1) indeed show that both the impact response and its propagation are rather different from our baseline. In particular, while in the short-run the corporate spread, CPI and the exchange rate behave in a qualitatively similar way, further out the results appear to be dominated by a sharp fall in spreads and a boom in industrial production, which are difficult to rationalize.

4.2 Financial shock

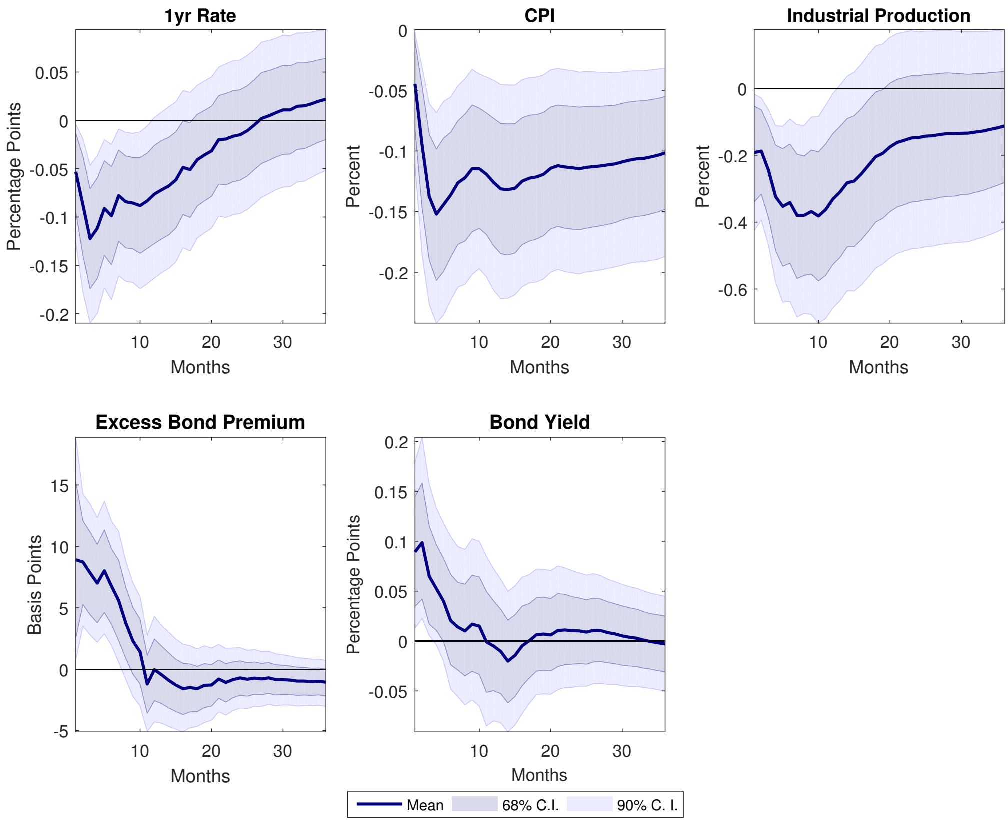
We interpret this shock as an increase in the effective cost of financial intermediation, which therefore raises the cost of external finance. As discussed above, this could be also interpreted as a shock to the idiosyncratic variance of entrepreneurial productivity, as in Christiano et al. (2014), or a shock to the efficiency of the financial intermediation process, as in Gilchrist and Zakrajsek (2012).

We start by analyzing the response of the US economy to a 1 standard deviation financial shock, plotted in Figure 6. Consistent with the sign restrictions derived in section 3, a (negative) financial shock is identified as a shock that increases spreads and bond yields, lowers activity and inflation, and leads to a fall in the policy rate.

The shock has persistent effects on activity and prices. Furthermore, the Excess Bond Premium remains elevated for several periods beyond the three months over which we require the sign restrictions to hold. The bond yield, which initially also increases, gradually falls as the effects of looser monetary policy feed through.

To have a sense of the relative importance of financial shocks and monetary policy shocks we compute a forecast error variance decomposition exercise. The results (reported in the Appendix, see Figures B.3 and B.4) show that both monetary and financial shocks explain a relatively large share of the variance of US real variables. Specifically, our identified US financial shocks are at least as important as monetary policy shocks in driving business cycle fluctuations, explaining more than 20 percent of the forecast error variance of US industrial production. For the financial shock this is in line with the findings of Christiano et al. (2014). The share of forecast error variance explained by the monetary policy shock is instead larger than what is typically found in the literature, and in line with the recent findings of Caldara and Herbst (2016).

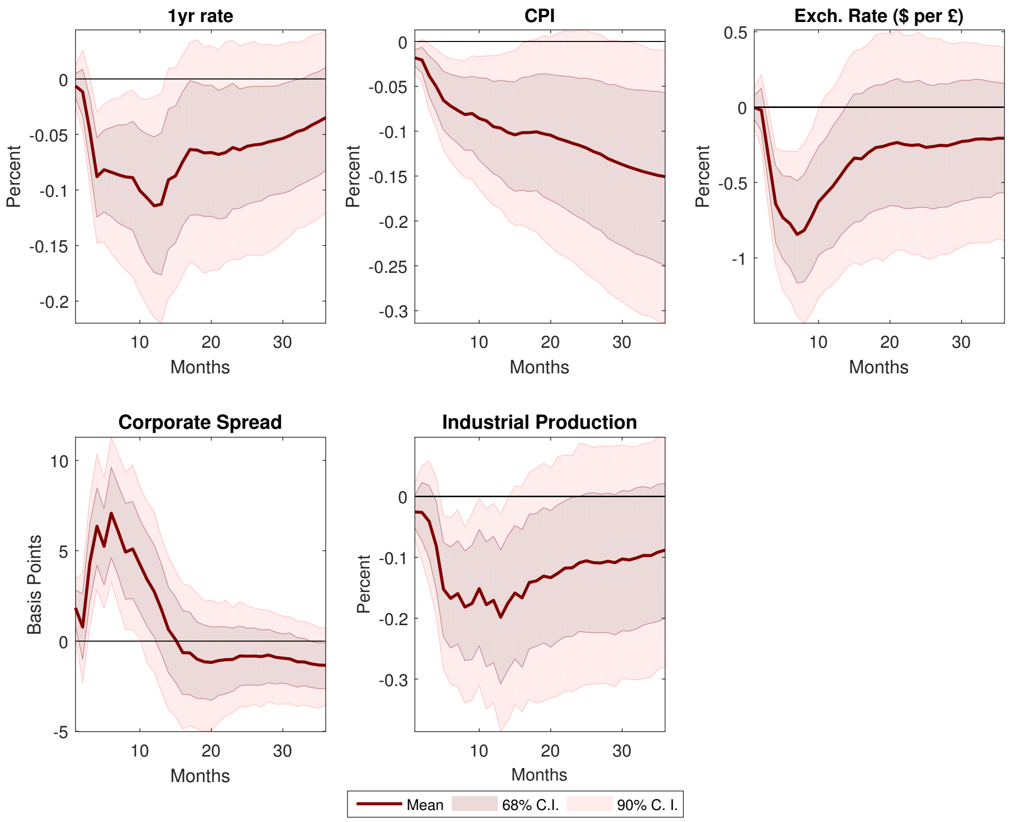
Figure 6 US Financial Shock



Note. US VAR estimated in log levels, with 12 lags, a constant and a linear trend over the 1979:7-2015:3 period. The 1-year Treasury Yield is instrumented using the same instrument as in Gertler and Karadi (2015). The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications and 30 rotations per bootstrap draw.

Figure 7 plots the responses of UK variables to a financial shock originating in the United States. The shock induces strong comovement of US and UK variables, as predicted by theoretical models with financial frictions and integrated financial markets (as in Dedola and Lombardo, 2012, for example). UK consumer prices tend to fall along their US counterparts, and so does UK industrial production. The response of the UK policy rate is muted on impact, but it falls substantially afterwards, consistent with a stabilizing monetary policy response in the face of an adverse shock. The value of sterling is little affected on impact, but it subsequently depreciates vis-à-vis the dollar. This seems broadly consistent with a negative interest rate differential, as the expected path of UK short rates is somewhat lower than that of US ones. Note that our results are similar to those in Eickmeier and Ng (2015), which use a different empirical model to assess the transmission of US financial shocks.

Figure 7 US Financial Shock – Transmission To The UK



Note. UK VAR estimated in log levels with a constant and time trend, with 12 and 3 lags for UK and US variables, respectively, over the 1979:7-2015:3 period. The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications and 30 rotations per bootstrap draw.

Finally, in response to the US financial shock, the UK credit spread also increases. While the initial increase is somewhat small, it then rapidly increases to over 5 basis points. We interpret this response as being consistent with an international credit channel for US financial shocks, as suggested by theoretical models with financial frictions and integrated financial markets (as Dedola and Lombardo, 2012, Ueda, 2012, among others). Moreover, given the quantitative importance of financial shocks in driving US macroeconomic fluctuations, as documented by Christiano et al. (2014), our results also help explaining the high degree of international comovement of macroeconomic variables and policy rates that we observe in the data.

5 Inspecting the International Transmission Mechanism

The evidence we reported in the previous section shows that both monetary and financial shocks originating in the United States significantly affect credit conditions (as summarized by credit spreads), both domestically and internationally. We interpreted this evidence as suggesting that, in line with theoretical models with financial frictions and high degree of financial integration, there is an international credit channel at work.

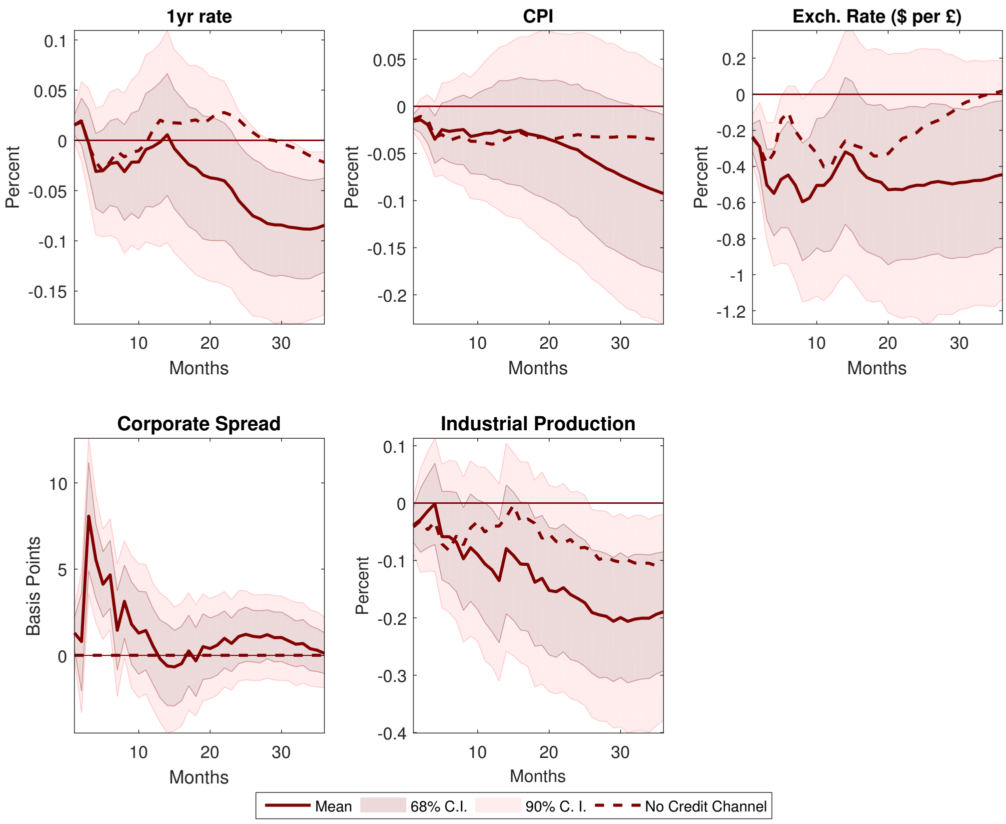
When the standard closed-economy credit channel is at work (Bernanke and Gertler, 1989), an adverse shock lowers the net worth of borrowers, and their borrowing cost increases via an increase of the spread they have to pay over a risk free rate. The increase in borrowing costs depresses agents' demand, which further depresses net worth and, therefore, credit spreads. This is the feedback loop that gives rise to the financial accelerator mechanism.

When agents hold both domestic and foreign assets and liabilities, domestic net worth (and, therefore, the domestic credit spread) is also directly affected by foreign shocks, via movements in the price of foreign assets and/or the exchange rate. The no-arbitrage conditions imposed by international financial integration imply a strong pressure towards the cross-border equalization of asset prices, leverage, and credit premia faced by financially constrained investors, thus creating tight linkages in macroeconomic dynamics across countries (see Krugman (2003), Dedola and Lombardo (2012), Devereux and Yetman (2010)).

If an international credit channel is at work, therefore, credit spreads both abroad and at home should act a source of amplification of foreign shocks. A crude, yet intuitive way to investigate whether our model captures a similar mechanism involves closing the main channel of transmission associated with financial frictions, and then looking at the counterfactual responses to the same shocks that we considered above. In our empirical model, we can compare our baseline impulse responses to US monetary and financial shocks with counterfactual ones in which the credit spread in both countries is kept at its unconditional mean value. The difference between the two sets of responses can provide some evidence on the amplification role of credit spreads via the international credit channel.

Figure 8 plots the UK impulse responses to a US monetary policy shock when we close the credit channel alongside the baseline, and Figure 9 plots the UK impulse responses to a US financial shock when we close the credit channel. We report the US responses in the Appendix.

Figure 8 UK 'S RESPONSE TO US MONETARY POLICY SHOCK: CLOSING THE INTERNATIONAL CREDIT CHANNEL



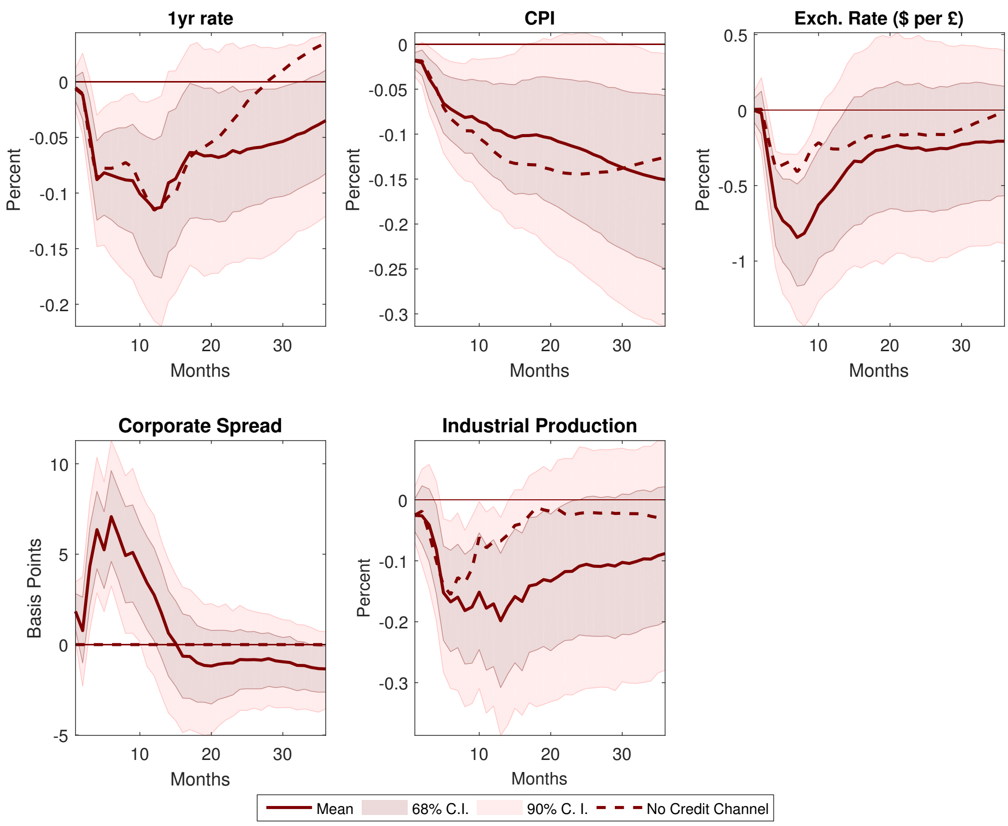
NOTE. UK VAR estimated in log levels with a constant and time trend, with 12 and 3 lags for UK and US variables, respectively, over the 1979:7-2015:3 period. The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications and 30 rotations per bootstrap draw.

Starting from the US monetary policy shock (Figure 8), when we shut down the credit spread in both the UK and the US, we observe a more muted response of UK variables. In particular, the UK experiences a smaller fall in industrial production, which troughs at around 0.1 (relative to a trough of 0.2 in our baseline). Consistent with that, the UK policy rate is even more neutral than in the baseline. Finally, even if the impact response is basically unchanged, Sterling depreciates by less in the months following the shock.

This is consistent with credit spreads amplifying the transmission of the US monetary policy shock.

Turning to the US financial shock, Figure 9 shows that when shutting down the international credit channel, the UK economy is less susceptible to foreign financial shocks. Similar to the monetary policy shock, the UK experiences a smaller fall in industrial production, a slightly tighter monetary policy stance, and les of an exchange rate depreciation.

Figure 9 UK 's Response To US Financial Shock: Closing The International Credit Channel



Note. UK VAR estimated in log levels with a constant and time trend, with 12 and 3 lags for UK and US variables, respectively, over the 1979:7-2015:3 period. The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications and 30 rotations per bootstrap draw.

Overall, the evidence reported in this section suggests that credit spreads can significantly amplify the international transmission of monetary policy shocks. This points to the existence of an international credit channel and is in line with theoretical models with financial frictions and high degree of financial integration, where leveraged investors holding foreign and domestic risky assets can act as a powerful propagation mechanism of shocks across countries, through their exposures to balance sheets interconnected across countries.

6 Conclusion

We provide novel evidence on the existence of an 'international credit channel' for the transmission of US shocks across borders. First, we corroborate the results in the seminal contribution of Rey (2016), showing that US monetary policy shocks lead to a tightening of financial conditions in the UK, and also to small but statistically significant falls in real and nominal variables.

Second, we provide novel evidence on the international transmission of US financial shocks. Like monetary policy shocks, financial shocks are also transmitted through an international credit channel. Different from monetary policy shocks, however, they seem to have larger and more persistent effects on the UK economy.

Our results corroborate some predictions of general equilibrium open economy models with credit market imperfections (Devereux and Yetman, 2010, Dedola and Lombardo, 2012), in which balance sheet effects and bond and asset markets integration are crucial for the transmission of both monetary policy and financial shocks.

In sum, in this paper we provide novel empirical evidence on the existence of an international credit channel for the transmission of both monetary policy shocks and the systematic component of monetary policy, i.e. its response to other shocks hitting the economy. To do so we develop a new identification technique that allows us to recover a US monetary policy and a US financial shock. In line with theory, our results show that financial shocks are quickly transmitted internationally, with effects on credit spreads that are similar (but larger in magnitude) to the ones of monetary policy shocks. Unlike monetary policy shocks, however, financial shocks have a sizeable impact on economic activity and consumer prices in both countries, and lead to a comovement in policy rates.

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A Data

United States

We extend the original data set of Gertler and Karadi (2015) (1-year Treasury Yield, CPI, industrial production, Excess Bond Premium) to 2015:M3, including the series for the monetary policy instrument

The updated Excess Bond Premium series from Gilchrist and Zakrajsek (2012) is available on Simon Gilchrist's webpage http://people.bu.edu/sgilchri/Data/data.htm.

We construct a bond yield series by summing Gilchrist and Zakrajsek (2012)'s credit spreads on the 10-year government bond yield.

United Kingdom

We use the following variables: 1-year Gilt yield, CPI, \$/£ exchange rate, high-yield corporate credit spread, industrial production, LFS unemployment. All variables are from Datastream and seasonally adjusted, apart from the high-yield corporate credit spread that is constructed by the Bank of England.

B Additional Results

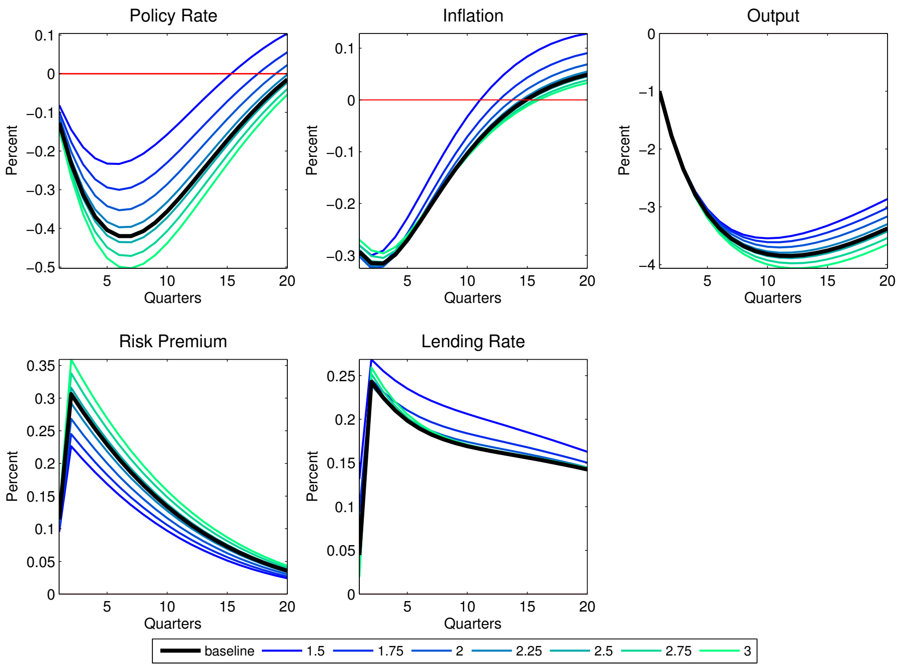
Theoretical impulse responses. The sign restrictions we derived from theory hold for other types of financial and demand shocks. Figure B.1 reports the impulse responses to an unanticipated risk shock as in CMR. The shock leads to a fall in output and inflation, an increase in the credit spread and a loosening of monetary policy. Consistent with our sign restrictions, and with the shock to the risk premium, the increase in the credit spread dominates over the fall in the policy rate, leading to an *increase* in the borrowing interest rate paid by entrepreneurs. As for the risk premium shock, this result is not affected by the strength of the response of monetary policy to the shocks, as the thin colored lines show.

Similarly, our sign restrictions also hold when considering other types of aggregate demand shock. Figure B.2 reports the impulse responses to a shock to consumer preferences. as for the financial shock, the aggregate demand shock leads to a fall in output and inflation, an increase in the credit spread and a loosening of monetary policy. Consistent with our sign restrictions, and different from the financial shocks, the increase in the credit spread is now dominated by the fall in the policy rate, leading to a *fall* in the borrowing interest rate paid by entrepreneurs.

Forecast error variance decompositions. Our methodology also allows us to compute contributions to forecast error variance decompositions from both monetary and financial shocks, which we report in Figures B.3 and B.4, respectively.

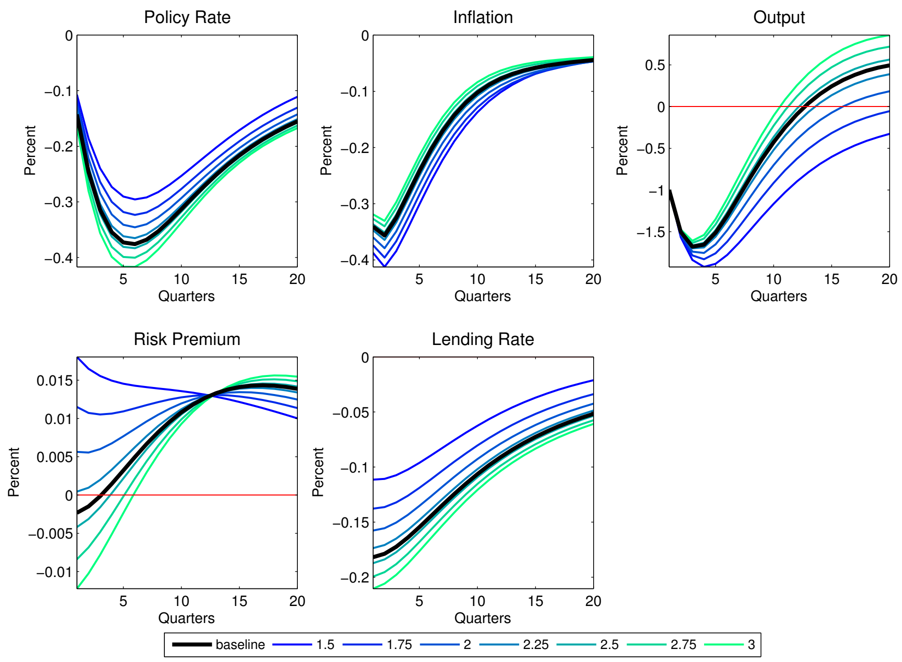
Counterfactual Impulse Responses: Closing the International Credit Channel. We compute the counterfactual impulse responses for both US monetary and financial shocks by setting to zero the coefficients of the credit spreads equations in both the UK and the US. Figure B.5 plots the US impulse responses to a US monetary policy shock when we close the credit channel. Figure B.6 plots the US impulse responses to a US financial shock when we close the credit channel.

Figure B.1 IMPULSE RESPONSES TO A RISK SHOCK



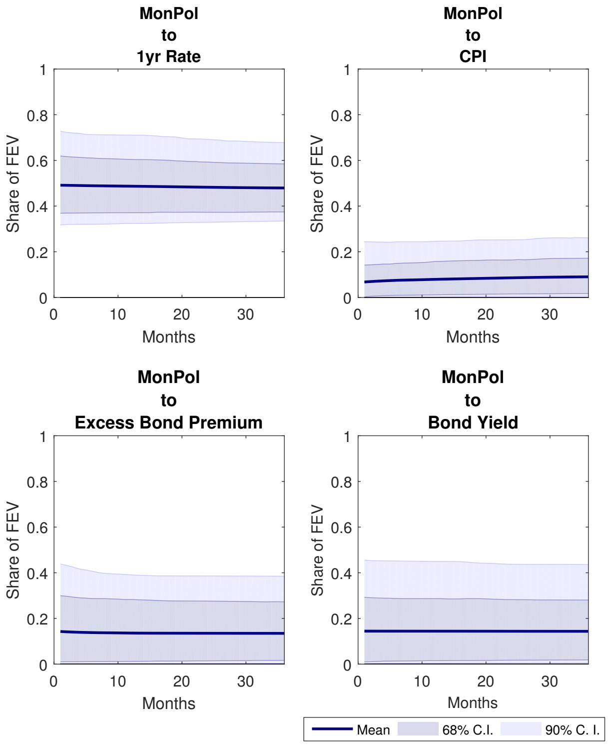
NOTE. The thick dark line is computed using the parametrization in the baseline estimated model of CMR. The thin colored lines are obtained by varying the coefficient on inflation in the Taylor Rule. We consider values from 1.5 to 3. The size of the shock is normalized so that it generates a fall in output of 1 percent.

Figure B.2 Impulse Responses To A Risk Consumers' Preference Shock



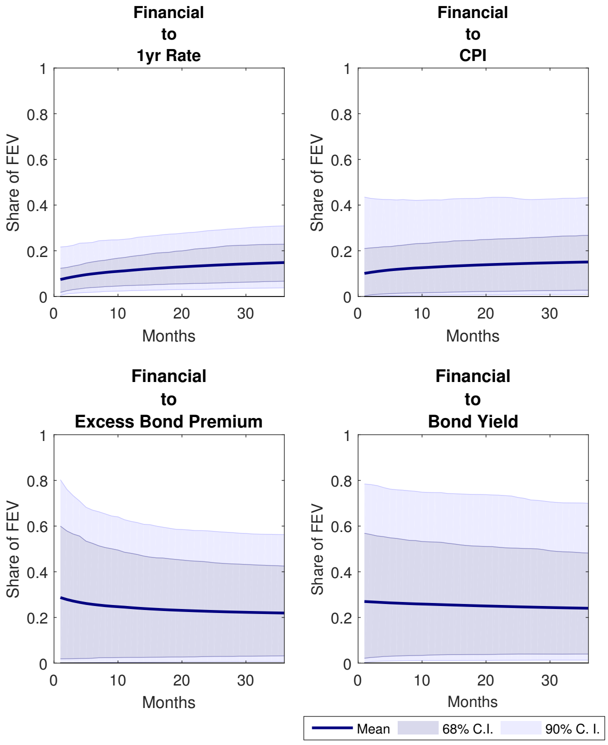
Note. The thick dark line is computed using the parametrization in the baseline estimated model of CMR. The thin colored lines are obtained by varying the coefficient on inflation in the Taylor Rule. We consider values from 1.5 to 3. The size of the shock is normalized so that it generates a fall in output of 1 percent.

Figure B.3 FEVD – US Monetary Policy Shock



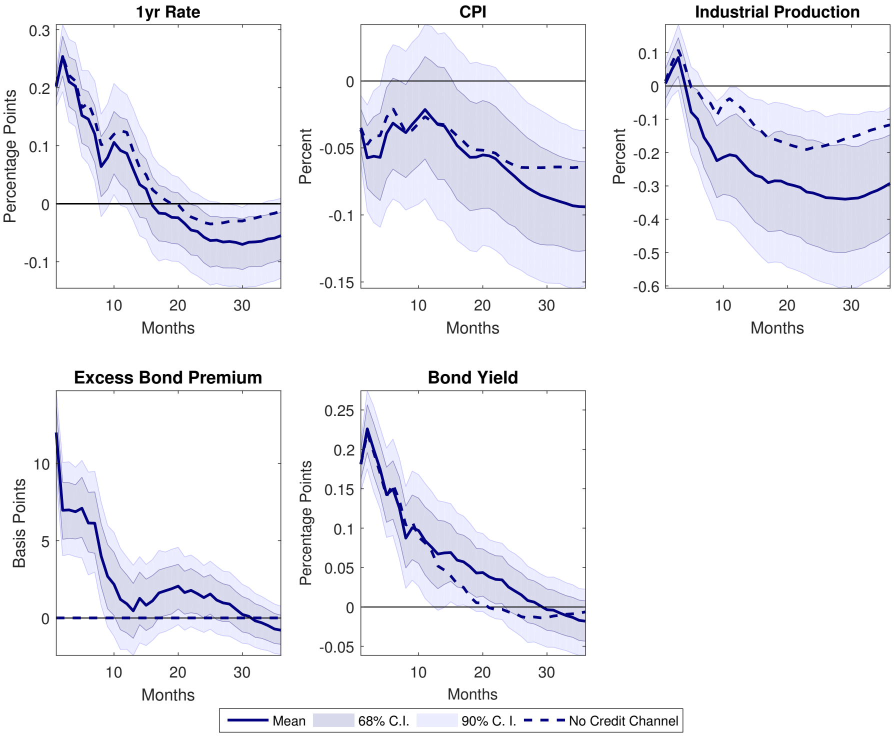
Note. US VAR estimated in log levels, with 12 lags, a constant and a linear trend over the 1979:7-2015:3 period. The 1-year Government Gilt Yield is instrumented using the same instrument as in Gertler and Karadi (2015). The solid line and shaded areas report the mean, 68 and 95% confidence intervals computed using wild bootstrap with 100 replications.

Figure B.4 FEVD — US Financial Shock



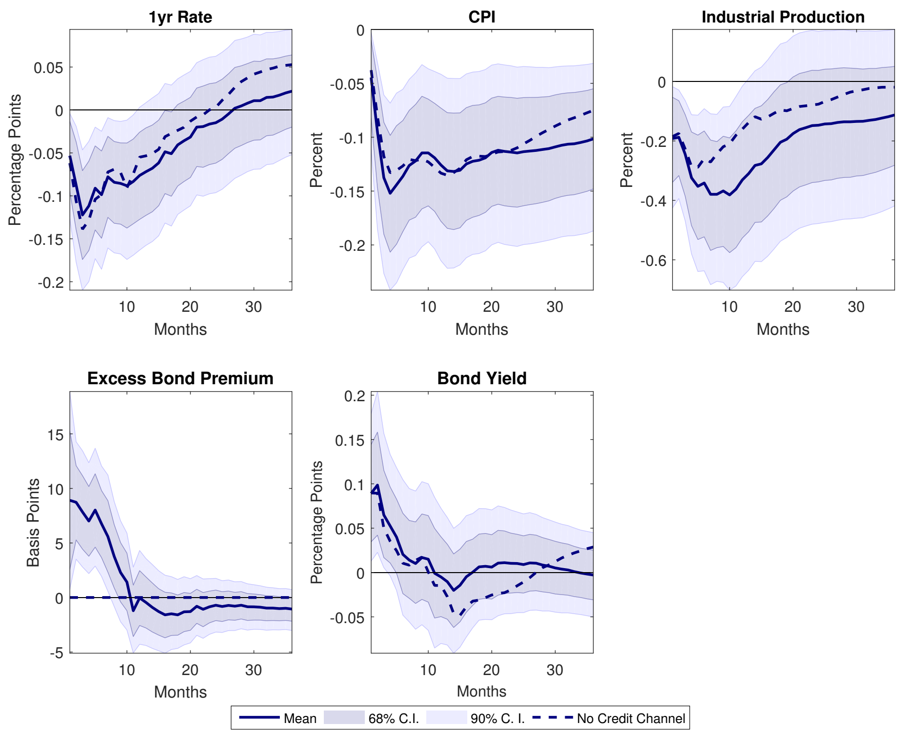
Note. US VAR estimated in log levels, with 12 lags, a constant and a linear trend over the 1979:7-2015:3 period. The 1-year Government Gilt Yield is instrumented using the same instrument as in Gertler and Karadi (2015). The solid line and shaded areas report the mean, 68 and 95% confidence intervals computed using wild bootstrap with 100 replications.

Figure B.5 US 's Response To US Monetary Policy Shock: Closing The International Credit Channel



Note. UK VAR estimated in log levels with a constant and time trend, with 12 and 3 lags for UK and US variables, respectively, over the 1979:7-2015:3 period. The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications and 30 rotations per bootstrap draw.

Figure B.6 US's Response To US Financial Shock: Closing The International Credit Channel



Note. UK VAR estimated in log levels with a constant and time trend, with 12 and 3 lags for UK and US variables, respectively, over the 1979:7-2015:3 period. The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications and 30 rotations per bootstrap draw.

C Explaining Differences with the Literature

In this section we present some evidence that explains the differences between our results and those in the literature. This allows us to highlight the benefits of our approach for correctly accounting for the international transmission mechanism of both monetary policy and financial shocks. Since the benefits are irrespective of the type of shock considered, we focus on monetary policy shocks, which allows us to compare our approach to existing studies in the literature.

Specifically, we compare our 2-country VAR with a simpler VAR where a foreign variable is included in the vector of domestic endogenous variables. That is, we consider a simple specification where the vector of endogenous variables includes the US 1-year interest rate together with the same UK variables that we included in our main results (i.e., a log-index of industrial production, a log-index of consumer prices, the nominal exchange rate vis-a-vis the US dollar and a measure of corporate spreads). This VAR specification closely resembles the one used in Rey (2016) and Passari and Rey (2015) (with the exception of the exchange rate, which is not included in their specification).

There are two main differences relative to our baseline VAR. First, there is no block-exogeneity assumption, i.e. the US policy rate is allowed to load on UK variables. Second, US dynamics are by construction summarized by the dynamic response of the US interest rate, since no other US variable is included in the VAR. If the true model was the one that we estimated in our baseline, then this simpler VAR model would be mis-specified. This is problematic because model mis-specification can affect both the identification of shocks and their transmission.[24] That is, it can lead to both different impact responses and dynamics.

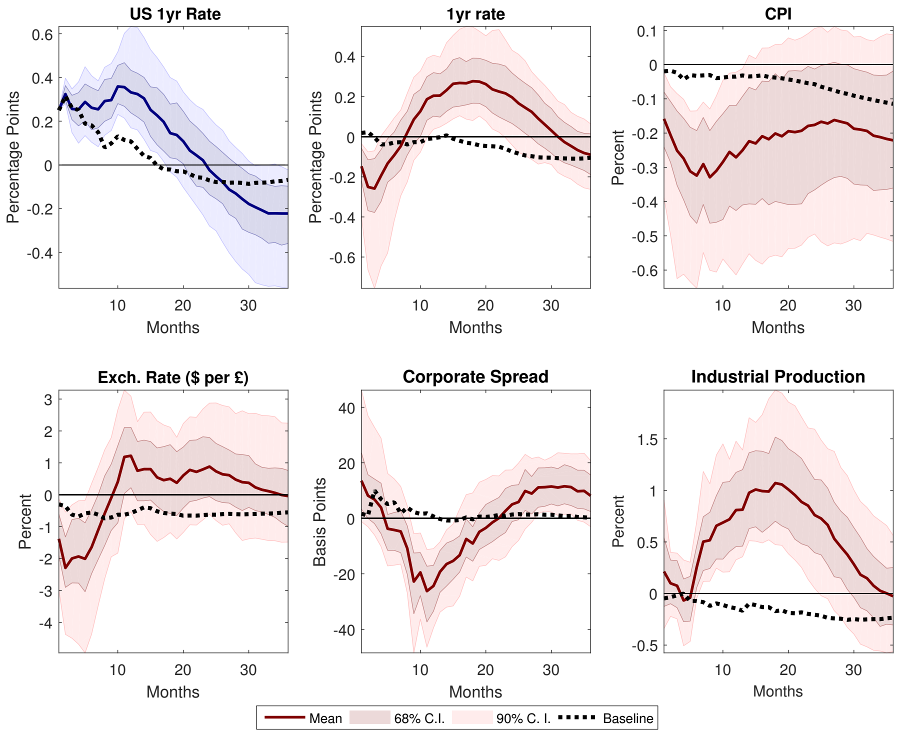
Figure C.1 reports the IRFs to a US monetary policy shock in such a VAR.[25] To make the responses more directly comparable to our baseline, we normalize the shock to yield a 25 basis points increase in the US 1-year rate on impact, which corresponds roughly to the 1 standard deviation shock in Figures 4 and 5. The results show that, indeed, both the impact response and its propagation are rather different from our baseline. In particular, while in the short-run the corporate spread, CPI and the exchange rate behave in a qualitatively similar way, further out the results appear to be dominated by a sharp fall in spreads and a boom in industrial production, which are difficult to rationalize.

These findings are similar to those in Georgiadis (2015), who show that a similar bias arises when using bilateral (rather than multilateral models) for assessing international

[24] Identification would not be affected by the model's mispecifcation only under two conditions: when the instrument for monetary policy (i) does not include any noise and (ii) is not correlated with lagged variables. Both conditons, however, are typically not satisfied in the data.

[25] Results are qualitatively similar, but not identical, to Passari and Rey (2015). The differences arise because of slightly different sample periods, our use of corporate rather than mortgage spreads, a different UK short-term interest series, the omission of the VIX in our specification and of the \$/£ exchange rate in theirs.

Figure C.1 US MONETARY POLICY SHOCK IN A VAR
IN THE SPIRIT OF PASSARI AND REY (2015)



NOTE. VAR estimated in log levels, with 12 lags, a constant and a linear trend over the 1979:7-2015:3 period. The 1-year US Government Treasury Yield is instrumented using the same instrument as in Gertler and Karadi (2015). The solid line plots the mean response.The shaded areas report the the 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications.

spillovers.[26] The intuition is simple: bilateral models might fail to take into account higher-order, indirect spillover channels. In a similar way, in the simple VAR in Figure C.1, US dynamics affect the UK only through the US 1-year interest rate, excluding any other spillover channels (arising, for example, from comovement of real and financial variables).

[26]In our application, the bias arising from using a bilateral model is likely to be mild. This is because, as Georgiadis (2015) show, the United States account for a large share of the United Kingdom's integration with the rest of the world. Accounting for indirect spillovers would likely lead to slightly larger spillover estimates.

D Robustness

In this section we provide a battery of checks suggesting that our estimation results are robust in several respects.

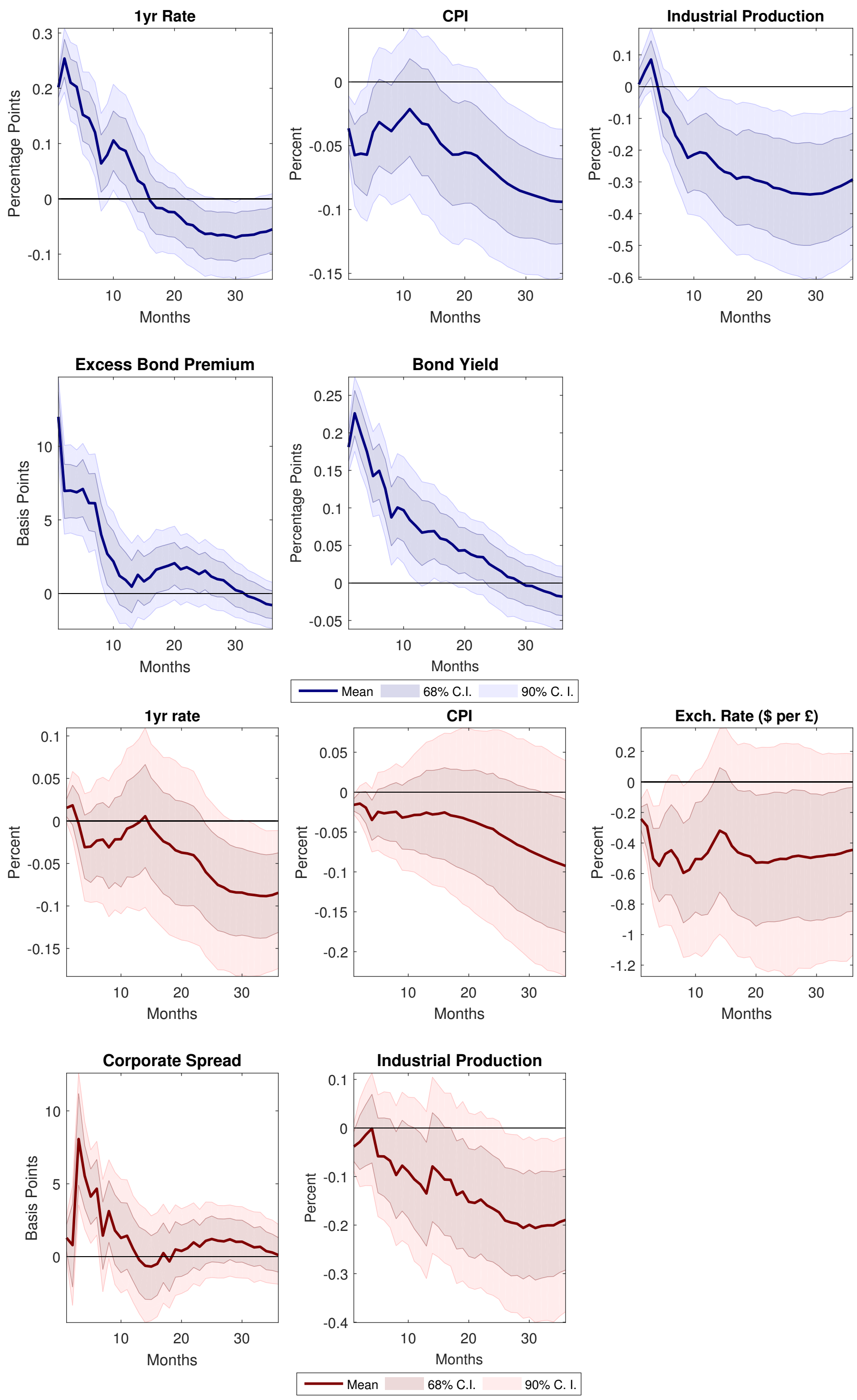
Figures D.1-D.2 the impulse responses that we obtain when we impose additional sign restrictions in order to identify also an aggregate demand and an aggregate supply shock.to our baseline.

Figures D.3-D.4 report the results estimated on a shorter sample for the UK (starting in 1993:M1), when the UK adopted an inflation target as its nominal anchor following its exit from the Exchange Rate Mechanism.for the endogenous variables, which we set to 4 according to the Akaike criterion.

Figures D.5-D.6 report the impulse responses computed over a shorter sample for both the UK and the US that excludes the global financial crisis, i.e. from 1979:M3 to 2008:M8. Not surprisingly, the period of the global financial crisis is important for the identification of financial shocks. However, the impulse responses in Figures D.5-D.6 show that our results —despite begin less precisely estimated— remain qualitatively valid.

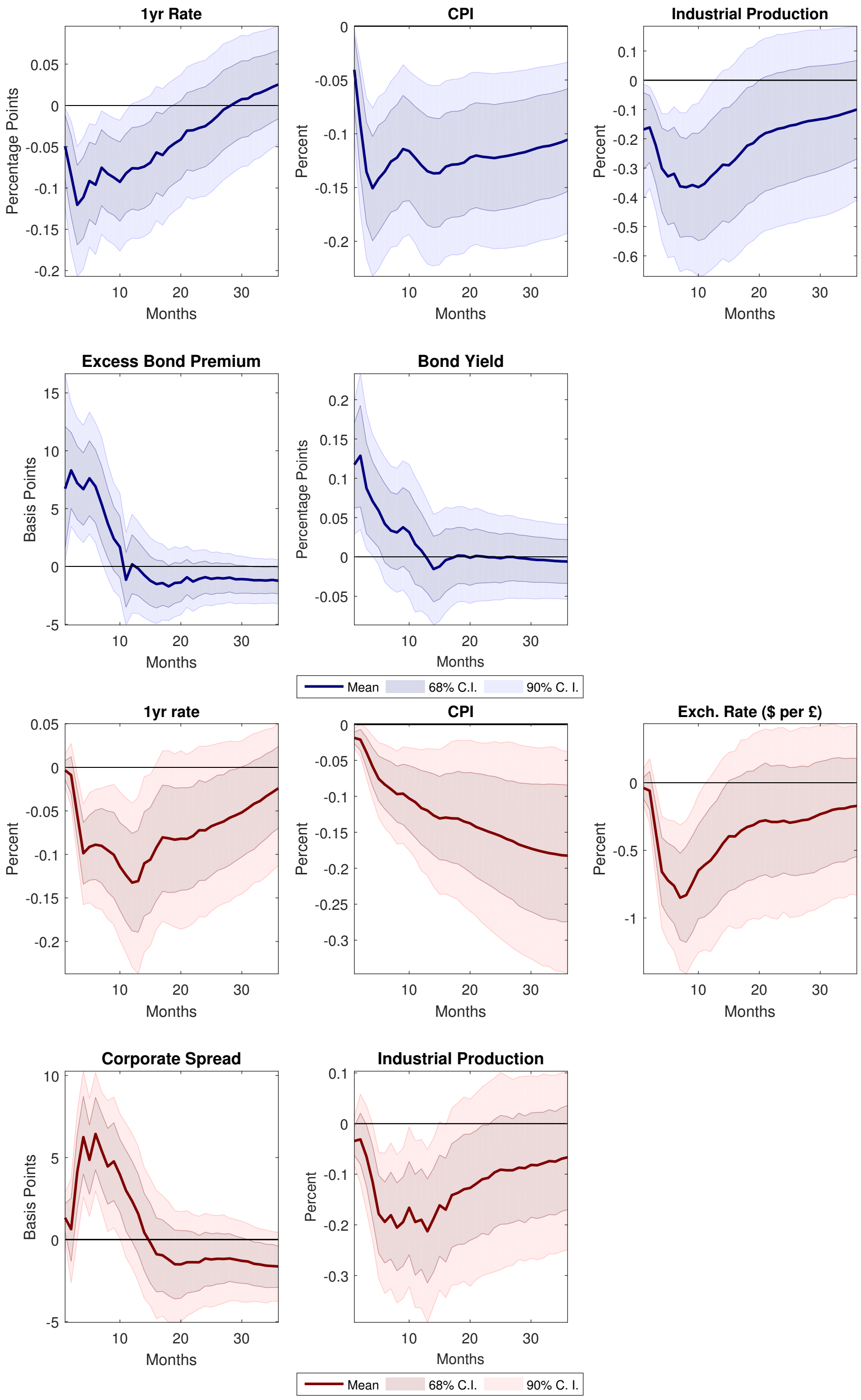
Finally, Figures D.7-D.8 report the results that we obtain using Unemployment as a measure of economic activity in the United Kingdom (instead of industrial production as in our baseline). Again, the impulse responses are very similar to our baseline, with unemployment begin little affected by the monetary policy shock; and slightly more affected by the US financial shock (at lest at the 68% confidence interval), despite a sharp fall in the UK policy rate.

Figure D.1 Monetary Policy Shock – Identifying Four Shocks



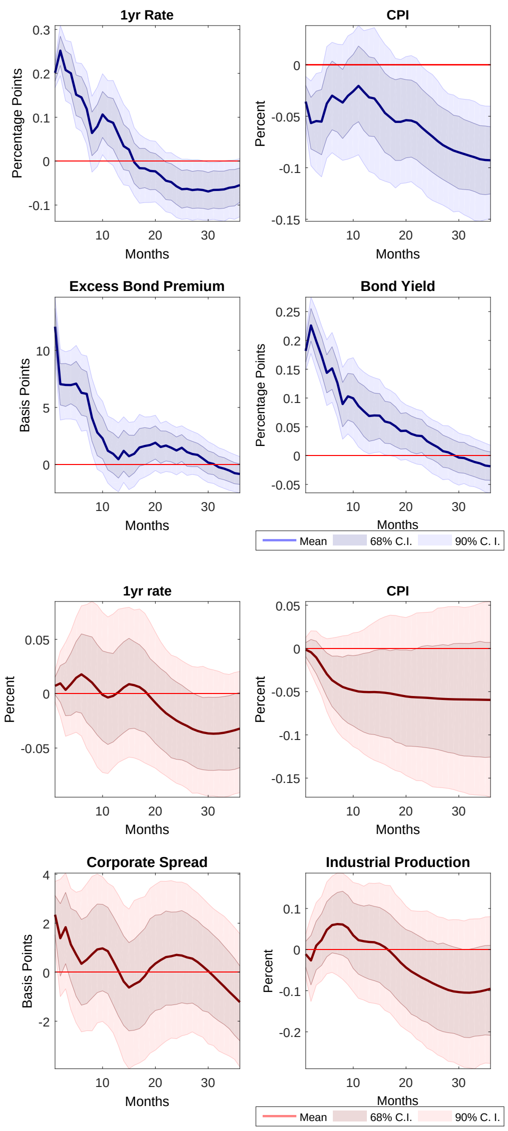
Note. US VAR estimated in log levels, with 12 lags, a constant and a linear trend over the 1979:7-2015:3 period. The 1-year Treasury Yield is instrumented using the same instrument as in Gertler and Karadi (2015). The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications and 30 rotations per bootstrap draw.

Figure D.2 Financial Shock – Identifying Four Shocks



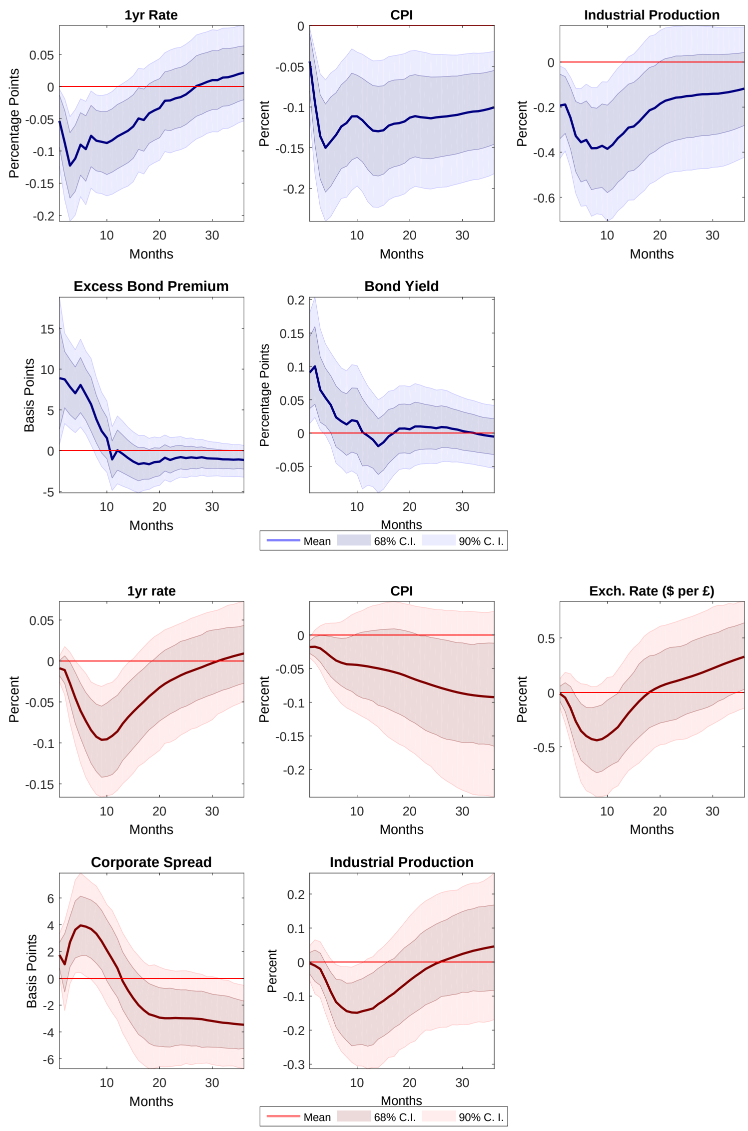
Note. US VAR estimated in log levels, with 12 lags, a constant and a linear trend over the 1979:7-2015:3 period. The 1-year Treasury Yield is instrumented using the same instrument as in Gertler and Karadi (2015). The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications and 30 rotations per bootstrap draw.

Figure D.3 MONETARY POLICY SHOCK – UK SAMPLE POST 1993



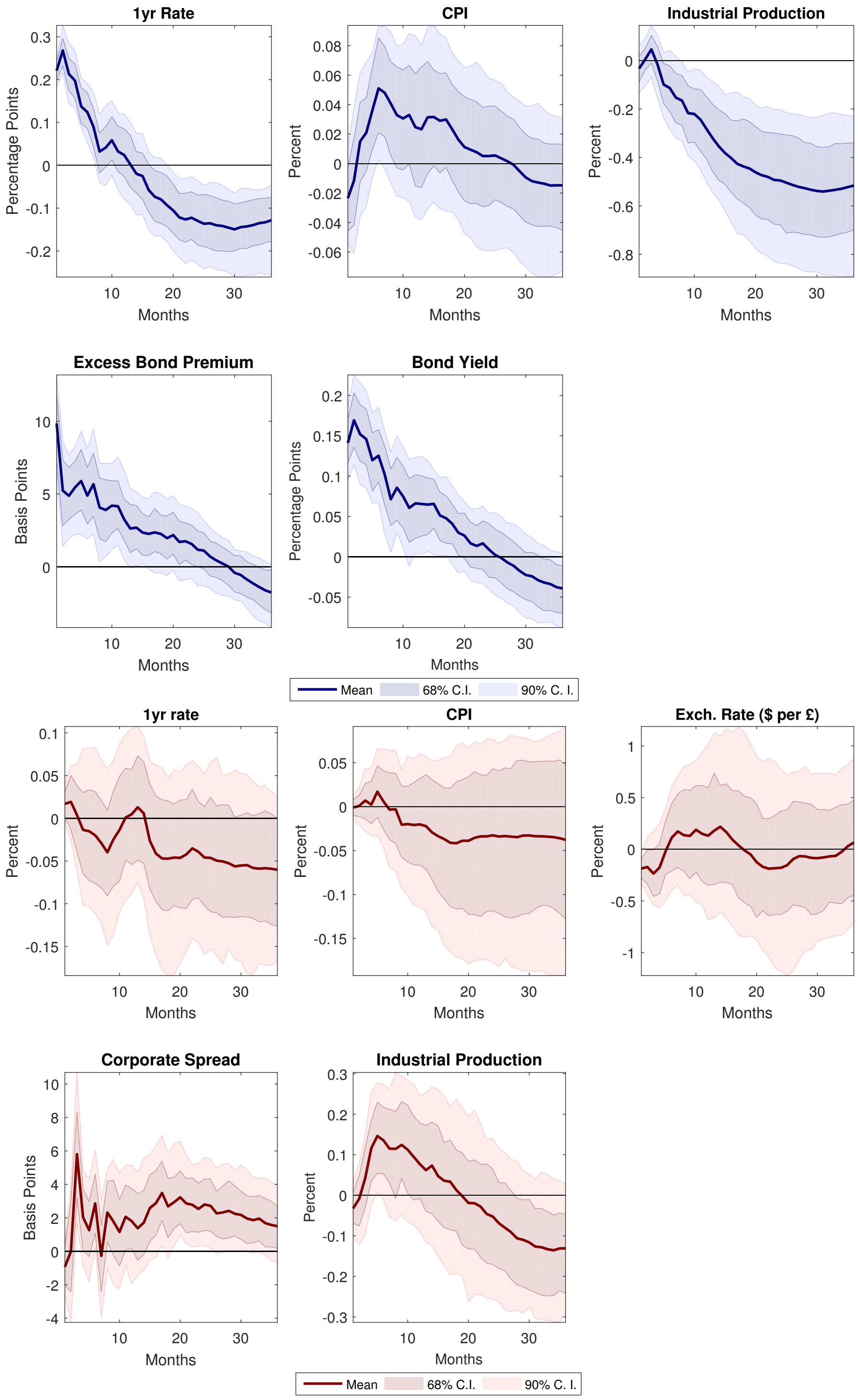
NOTE. US VAR estimated in log levels, with 12 lags, a constant and a linear trend over the 1979:7-2015:3 period. The 1-year Treasury Yield is instrumented using the same instrument as in Gertler and Karadi (2015). The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications and 30 rotations per bootstrap draw.

Figure D.4 Financial Shock – UK Sample Post 1993



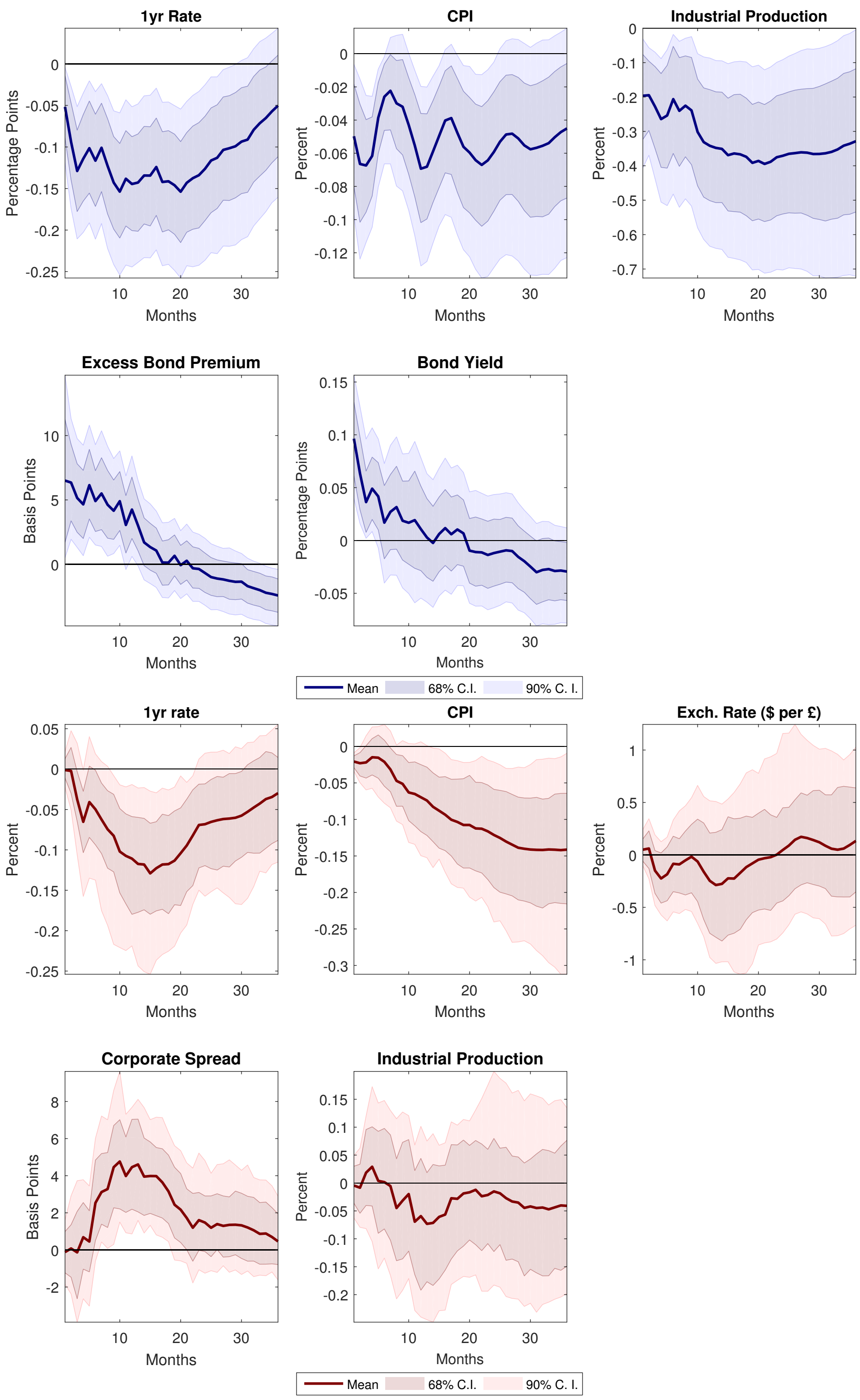
Note. US VAR estimated in log levels, with 12 lags, a constant and a linear trend over the 1979:7-2015:3 period. The 1-year Treasury Yield is instrumented using the same instrument as in Gertler and Karadi (2015). The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications and 30 rotations per bootstrap draw.

Figure D.5 Monetary Policy Shock – Excluding The Global Financial Crisis



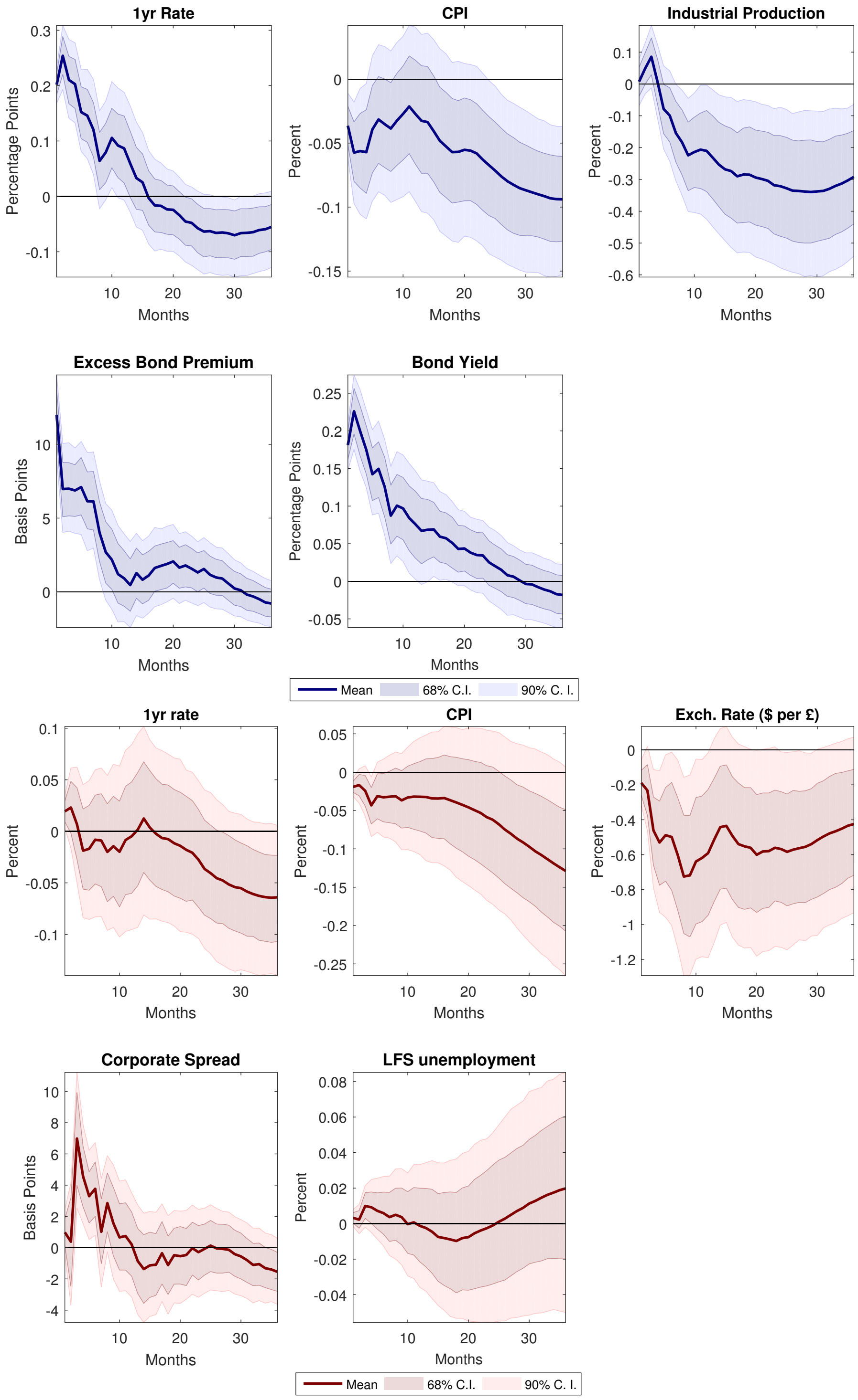
Note. US VAR estimated in log levels, with 12 lags, a constant and a linear trend over the 1979:7-2008:8 period. The 1-year Treasury Yield is instrumented using the same instrument as in Gertler and Karadi (2015). The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications and 30 rotations per bootstrap draw.

Figure D.6 Financial Shock – Excluding The Global Financial Crisis



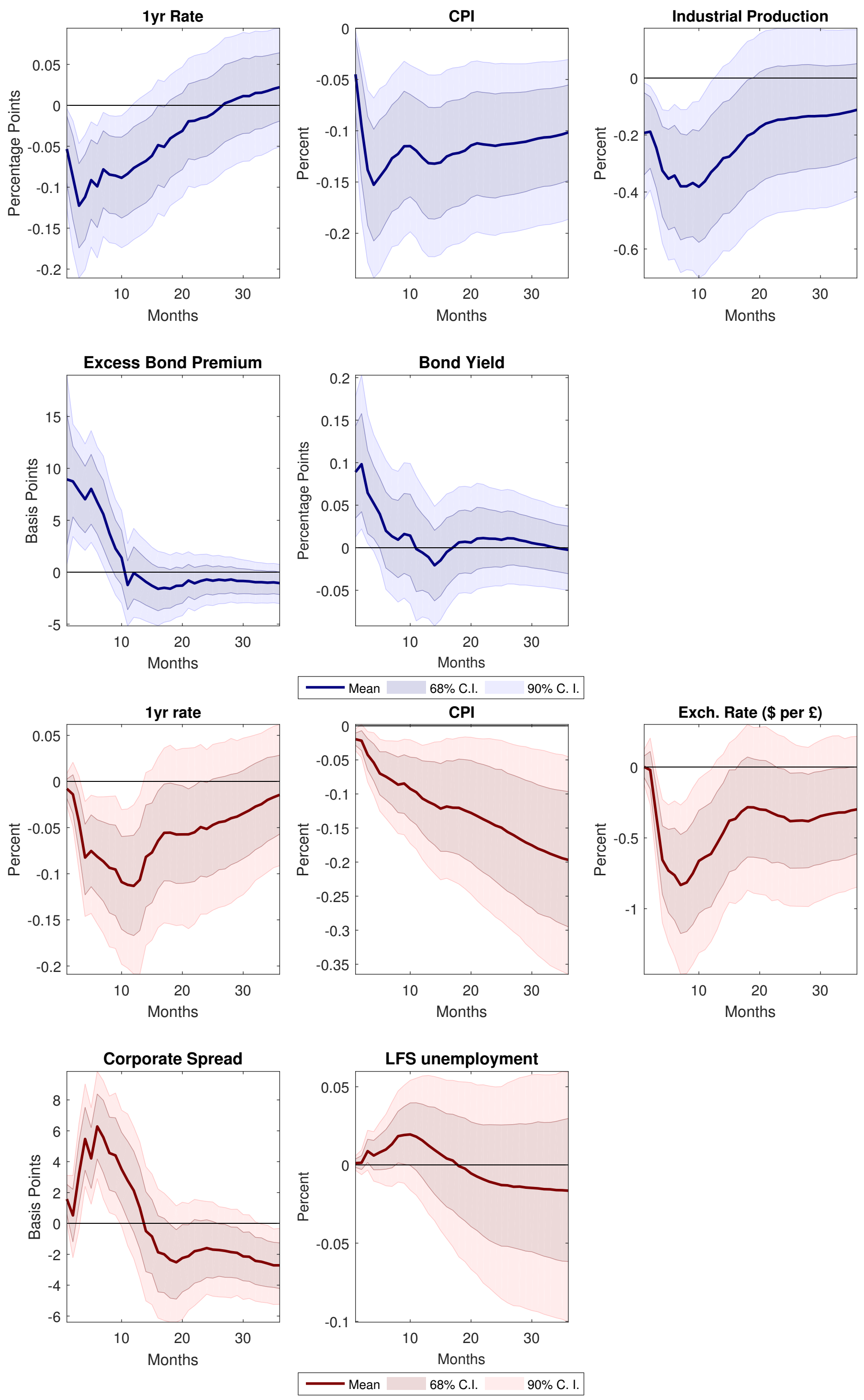
Note. US VAR estimated in log levels, with 12 lags, a constant and a linear trend over the 1979:7-2008:8 period. The 1-year Treasury Yield is instrumented using the same instrument as in Gertler and Karadi (2015). The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications and 30 rotations per bootstrap draw.

Figure D.7 Monetary Policy Shock – Specification With Unemployment



Note. US VAR estimated in log levels, with 12 lags, a constant and a linear trend over the 1979:7-2015:3 period. The 1-year Treasury Yield is instrumented using the same instrument as in Gertler and Karadi (2015). The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications and 30 rotations per bootstrap draw.

Figure D.8 Financial Shock – Specification With Unemployment



Note. US VAR estimated in log levels, with 12 lags, a constant and a linear trend over the 1979:7-2015:3 period. The 1-year Treasury Yield is instrumented using the same instrument as in Gertler and Karadi (2015). The solid line and shaded areas report the mean, 68 and 90% confidence intervals computed using wild bootstrap with 1000 replications and 30 rotations per bootstrap draw.