BANK OF ENGLAND

Staff Working Paper No. 693

Financial shocks, credit spreads and the international credit channel

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November 2017

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Abstract

Recent empirical evidence on the cross-country synchronization of credit spreads in response to US monetary policy shocks has led to the notion of an 'international credit channel' of US monetary policy. This paper provides novel evidence on the existence of an international credit channel for the transmission of US *financial* shocks across borders, and compares their impact to US monetary policy shocks. We identify monetary policy and financial shocks by combining the external instruments approach with sign restrictions in a two-country SVAR for the United States and the United Kingdom. Adverse US financial shocks trigger a sharp and persistent contraction in the US economy, and an increase in US credit spreads. Crucially, this tightening in US credit conditions is quickly transmitted internationally, leading to an increase in credit spreads and a slowdown in economic activity in the United Kingdom. Unlike financial shocks, monetary policy shocks do not seem to induce as much international co-movement. Our results are in line with general equilibrium open economy models with credit market imperfections and a high degree of financial integration.

Key words: SVAR, credit channel, international transmission, external instruments, sign restrictions, financial shocks, monetary policy.

JEL classification: C32, E44, F44.

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The views expressed in this paper are those of the authors, and not necessarily those of the Bank of England or its committees. We would like to thank Luca Dedola for many insightful discussions and comments on earlier drafts of this paper, as well as Saleem Bahaj, Dario Caldara, Giancarlo Corsetti, Andrea Ferrero, Paolo Gelain, Jorgo Georgiadis, Francesco Furlanetto, Paul Hubert, Graciela Kaminsky, Roland Meeks, Evgenia Passari, Michele Piffer, Alessandro Rebucci and Ricardo Reis. We have also benefited from comments by participants at the the 2017 MMF Conference, 2017 SED Annual Meeting, ECB-BoE-IMF workshop on 'Spillovers from Macroeconomic Policies, 2nd BoE-BdF International Macro Workshop', and at seminars at the Bank of England and ECB. The online Supplement to this paper can be downloaded at the following web page: https://sites.google.com/site/ambropo/CS_IntlCredChannel_OnlineAppendix.pdf.

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ISSN 1749-9135 (on-line)

1 Introduction

Unexpected changes in the Federal Reserve's monetary policy stance are quickly transmitted across borders and lead to synchronized movements in asset prices, credit spreads, and policy rates across countries.[1] As traditional open economy models—which emphasize demand, expenditure switching, and risk sharing channels—are silent on most of these facts, Rey (2016) conjectured the existence of an 'international credit channel' of monetary policy to rationalize this growing body of empirical evidence. This channel rests on the interaction between three main ingredients: a domestic credit channel of monetary policy (Bernanke and Gertler, 1995), high levels of international financial market integration, and the predominance of the US dollar as an international currency. With agency costs between borrowers and lenders and dollar-denominated balance sheets, US monetary policy affects the net worth of economic agents worldwide, and, in turn, generates strong co-movement of financial conditions across the globe.[2]

This paper studies US *financial* shocks and tests whether they are also transmitted across borders through an international credit channel. Two main considerations motivate us to investigate this topic. First, unexpected changes in monetary policy need not be the only shock that is transmitted via the international credit channel, and focusing on a different shock can provide further empirical evidence on its existence. Second, the comparison between US monetary and financial shocks can help us to better understand this channel of transmission, as well as to test the predictions of general equilibrium open economy models with credit market imperfections.

In our empirical analysis, we focus on the international transmission of US monetary and financial shocks to the United Kingdom, a relatively large 'small open economy'

[1] Rey (2016) provides extensive empirical evidence on these facts. Other papers have recently focused on this angle of the international transmission of monetary policy shocks. See among others, Rey (2013), Passari and Rey (2015), Bruno and Shin (2015), Rogers et al. (2014), Miranda-Agrippino and Rey (2015), Georgiadis and Mehl (2015), Dedola et al. (2017), and Gerko and Rey (2017).

[2] While Rey (2016) coined the expression 'international credit channel' in her influential Mundell-Fleming lecture, some of the mechanisms underlying it have been analyzed in an earlier body of literature. For example, Cespedes et al. (2004) and Gertler et al. (2007) 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), Devereux and Yetman (2010), Dedola and Lombardo (2012), and Ueda (2012) show that credit market imperfections and international integrated financial markets can lead to highly synchronized movements in asset prices and credit spreads.

with a well-established regime of inflation targeting, a freely floating exchange rate, and a well-developed financial sector—which, therefore, makes it a good laboratory to explore our main question. To identify monetary and financial shocks in the United States, we develop a new approach that combines the external instruments identification procedure (Stock and Watson, 2012, Mertens and Ravn, 2013) with sign restrictions (Faust, 1998, Uhlig, 2005, Rubio-Ramirez et al., 2010, Fry and Pagan, 2011).[3] Specifically, we first identify a US monetary policy shock using the 'high frequency' monetary policy surprises constructed by Gurkaynak et al. (2005), closely following the approach proposed by Gertler and Karadi (2015) (and used by many others in the recent literature).[4] We then identify a US financial shock that is orthogonal to the US monetary policy shock (and to other structural shocks, such as demand and supply shocks) using sign restrictions. Finally, we embed this identification approach in a 2-country structural VAR that allows us to investigate the international transmission of US shocks to the United Kingdom.

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.[5] These shocks, which the literature loosely labels 'financial', are however hard to identify in the data, for two main reasons. First, the presence of fast-moving financial variables poses a challenge to the plausibility of the contemporaneous zero restrictions that are typically used to identify structural shocks in VAR models. Second, financial shocks often behave as other aggregate shocks, which complicates any identification scheme based on sign restrictions. In this paper we show that is possible to derive from economic theory a minimum set of sign restrictions that are consistent with a broad class of shocks that originate in the financial sector, but different from other aggregate shocks.[6]

[3]Our new methodology is general and can be easily applied to a wide variety of different questions.

[4]Recently, a number of authors have turned to high-frequency financial market data to quantify unanticipated changes in monetary policy. See, among many others, Nakamura and Steinsson (2013) and Rogers et al. (2014) for the US, and Cesa-Bianchi et al. (2016) and Miranda-Agrippino (2016) for the UK.

[5]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 (2015).

[6]Other approaches for the identification of financial shocks have been considered in the empirical literature. See, for example, Musso et al. (2011), Meeks (2012), Hristov et al. (2012), Fornari and Stracca (2012), Gambetti and Musso (2016), and Abbate et al. (2016). Gilchrist et al. (2014) and Caldara et al. (2016) attempt to separately identify financial shocks and uncertainty shocks; Furlanetto

Specifically, we exploit a regularity present in models with financial frictions and nominal rigidities (e.g., Bernanke et al., 1999, Christiano et al., 2014) to achieve identification. In this class of models, financial shocks tend to behave like aggregate demand shocks.[7] As such, credit spreads and the policy rate typically move in opposite directions. Consider for example a contractionary demand or financial shock: while credit spreads increase (as net worth of borrowers falls), monetary policy accommodates the shock by lowering the short-term interest rate. As a result, the response of the *level* of the borrowing rate to the shock 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 wide variety of financial shocks—movements in the credit spread dominate over movements in the policy rate, so that a contractionary financial shock unambiguously leads to an increase in the borrowing rate.[8] Crucially, this is not the case for other demand shocks, such as government spending or consumers' preference shocks. Thus, we can impose different sign restrictions on the level of the borrowing rate to disentangle between financial shocks and other types of demand shocks. In sum, our identification scheme is simple, does not require implausible zero contemporaneous restrictions, and is consistent with a wide variety of financial shocks.

The paper has three main results. First, our empirical evidence provides strong empirical support for the existence of an international credit channel of US financial shocks. Adverse financial shocks trigger a sharp and persistent contraction in the US economy, and an increase in US credit spreads. Crucially, this tightening in US credit conditions is quickly transmitted internationally, leading to an increase in credit spreads in the United Kingdom, as well as a fall in prices and economic activity. Interestingly, the increase in UK spreads happens despite an accommodating response of domestic monetary policy, which should act to reduce spreads via a domestic credit channel. Our impulse responses are comparable with those obtained from open economy models with financial frictions and a high degree of international financial integration (e.g.,

et al. (2014) to identify different types of financial shocks. The identification of each of these shocks separately represents an empirical challenge that goes beyond the scope of this paper.

[7]While in the vast majority of theoretical models financial shocks tend to behave as aggregate demand shocks, there are examples in the literature where financial shocks imply dynamics typical of supply shocks (e.g., most notably, Gilchrist et al., 2017). As we discuss in section 3, our identification strategy is flexible and can be modified to take this into account.

[8]As we show below, this result does not depend on the aggressiveness of monetary policy reaction function.

Devereux and Yetman, 2010, Dedola and Lombardo, 2012). As in those models, US financial shocks induce a strong co-movement of economic activity, consumer prices, credit spreads, and policy rates across countries, in line with the unconditional properties of the data.

Second, our empirical evidence corroborates previous results on the international credit channel of US monetary policy, but also sheds new light on some of the existing (and somewhat puzzling) results. As in Gertler and Karadi (2015), a contractionary monetary policy shock in the United States reduces demand and increases credit spreads. But an international credit channel is also at work: the US shock tightens credit conditions internationally, leading to an increase in corporate credit spreads in the United Kingdom. These results are qualitatively similar to Passari and Rey (2015) and Rey (2016), who focus on mortgage spreads, but differ from those in Gerko and Rey (2017), who find that corporate bond spreads fall in response to a US monetary policy tightening. Our corporate bond spreads data (which overcome some of the limitations in the data used by Gerko and Rey (2017)) in conjunction with a richer empirical specification allow us to provide direct and novel evidence of the existence of an international credit channel of monetary policy working through corporate bond markets. Finally, we also find that, unlike financial shocks, monetary policy shocks do not seem to induce as much international co-movement: despite the tightening in UK financial conditions and the contractionary impact of lower US demand for UK goods, the US monetary policy shock has only a small (and statistically insignificant) negative impact on economic activity and prices in the United Kingdom in the short run. Consistent with that, the response of UK monetary policy is broadly neutral.

Third, in an attempt to further interpret our empirical findings, we explore the role of credit spreads in driving the international transmission of shocks. We focus on credit spreads because (in open economy general equilibrium models with financial frictions) movements in credit spreads can substantially amplify the response of the domestic economy to foreign shocks. The mechanism is simple: when agents have cross-country asset holdings, a foreign shock, by affecting foreign asset prices, also affects foreign *and* domestic borrowers' net worth, leading to synchronized movements in credit spreads across countries. To check whether this mechanism is at work in the data, we recompute the effects of US monetary policy and financial shocks, while keeping US and UK credit spreads constant in the model. For both shocks, our results point to a powerful amplification role played by credit spreads. We interpret this evidence as suggestive of the relevance of the international credit channel for the transmission of US 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 Kim (2001), 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. (2017). A more recent strand of this literature focused on the spillovers from US monetary policy to international financial markets (see Craine and Martin (2008), Ehrmann and Fratzscher (2009), Fratzscher et al. (2016), 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, but we focus more squarely 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 these studies (which focus instead on mortgage spreads). In a contemporaneous paper to ours, Gerko and Rey (2017) find that UK corporate credit spreads fall in response to a US monetary policy tightening, and conjecture that this response—which is in contrast to what the international credit channel would imply—is due to the way the corporate bond spreads they use is constructed. Our different results are driven by the different data we use (that possibly overcome some of the limitations in their data) and the richer dynamics in our empirical model.[10]

We also draw on a smaller, but growing, literature on the international transmission

[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]Simple VAR models that just include an indicator of foreign monetary policy in the vector of domestic endogenous variables (as in Passari and Rey, 2015, Rey, 2016, Gerko and Rey, 2017) might 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. For a similar, but more formal and exhaustive treatment of this point, see Georgiadis (2015).

of financial shocks. Helbling et al. (2011) study the international transmission of credit supply shocks originating in the US a factor-augmented VAR (FAVAR), with a combination of zero and sign restrictions. Despite the different identification restrictions, they find that credit shocks play an important role in driving economic activity, especially during global recessions. Eickmeier and Ng (2015) also use sign restrictions to study how US credit supply shocks are transmitted internationally using a Global VAR model, and find that US credit supply shocks have strong international spillovers. Relative to these studies, we not only provide an alternative approach for the identification of financial shocks, but we also more narrowly focus on the international credit channel and on the comparison between financial shocks and monetary policy shocks. Note, moreover, that our results are also similar to Baskaya et al. (2017), despite their use of a different empirical approach—that exploits granular bank-level data—and focus on a different country (Turkey).[11]

Finally, our paper also provides a methodological contribution to the literature on identification of structural shocks in VAR models. Our approach to identification, which combines external instruments and sign restrictions techniques, is simple but powerful and can be applied to a wide range of questions.

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. 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 and some additional results. An online Supplement reports an extensive set of robustness checks on our results.

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,

[11] 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. (2015).

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 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, in section 2.3 we describe 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:

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

where $\Phi(\cdot)$ and B are $n \times n$ matrices of coefficients, L is the lag operator, and e_t 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:

$$u_t = B e_t. \tag{2}$$

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.

Our identification strategy combines the recently developed external instruments approach with a standard sign restriction approach. The external instrument approach has proven to be a very successful identification strategy when good instruments are available. The sign restriction approach, despite only delivering set identification, allows us to 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 (or sometimes implausible) for credible identification schemes.

For simplicity, and without loss of generality, 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.[12]

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

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

where b is an $n \times 1$ 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 the 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) and 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 the external instruments identification approach with a standard sign re-

[12] In our baseline specification (described 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. We show in the Appendix that our results are robust when, in addition to monetary policy and financial shocks, we also also identify the remaining shocks with additional sign restrictions.

striction approach to identify the remaining structural shocks ($e_t^{\mathcal{B}}$) 'conditional' on the shock identified with the external instrument (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:

$$\Sigma_u = BB' = \left[\begin{array}{cc} b & \mathcal{B} \end{array}\right]\left[\begin{array}{cc} b & \mathcal{B} \end{array}\right]'. \tag{4}$$

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:

$$CQ = \left[\begin{array}{cc} b & \mathcal{B} \end{array}\right], \tag{6}$$

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 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

[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.

[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:

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

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 M matrices B_i (with $i = 1, 2, ..., M$) consistent with our identification restrictions. This completes the (set) identification of structural matrix 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 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), Kim and Roubini (2000), and, more recently, Dedola et al. (2017).

The block exogeneity assumption conveniently de-couples 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).

2.3 Data and Estimation

In our application, the United States is 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, we estimate the model over a larger sample period, namely from 1979:M7 to 2015:M3. To do that, we extend their original data set, including the series of monetary policy surprises following the method described in Gurkaynak et al. (2005). Specifically, as in Gertler and Karadi (2015)'s baseline, we use as an external instrument the monetary policy surprises based on the 4-months ahead futures on the Fed Funds rate (FF4). Second, we augment their baseline specification with an additional variable (the level of the borrowing rate) 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 of industrial production, the log of the consumer price index, the one-year government bond rate as the policy indicator, and

[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.

the Gilchrist and Zakrajsek (2012) excess bond premium), and the nominal yield on the 10-year corporate bond.[16] As in Gertler and Karadi (2015), our 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 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. First and foremost, the presence of 'fast-moving' financial variables poses a serious challenge to the plausibility of any of the contemporaneous zero restrictions that are 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 sign restrictions, the task of achieving an economically plausible identification is not trivial. There are two major challenges. First, in the vast majority

[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.

[18]The following papers, among many others, identify financial shocks with zero contemporaneous restrictions, sign restrictions or a combination of both: Musso et al. (2011), Meeks (2012), Hristov et al. (2012), Fornari and Stracca (2012), Gilchrist et al. (2014), Furlanetto et al. (2014), Gambetti and Musso (2016), and Abbate et al. (2016). Alternatively, some papers in the literature use the penalty function approach (initially proposed by Faust (1998) and Uhlig (2005)) to disentangle between financial or uncertainty shocks. See Pinter et al. (2013) and Caldara et al. (2016) .

of theoretical models, financial shocks typically lead to dynamics of output, consumer prices, and policy rates that are similar to those of aggregate demand shocks, such as consumers' preference shocks, government spending shocks, etc (see, among many others, Curdia and Woodford (2010), Gertler and Karadi (2011), and Gilchrist and Zakrajsek (2012)).[19] Second, while the literature has analyzed different types of financial shocks (e.g., to net worth, to the external finance premium, etc.), these tend to have very similar qualitative effects on the aggregate economy. For example, 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.[20] To separately identify these different financial shocks one would need to increase the dimensionality of the VAR model which would quickly lead to a curse of dimensionality problem.

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, however, represents an empirical challenge that goes beyond the scope of this paper.[21] 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 et al., 1999, Christiano et al., 2014). 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

[19] While in the vast majority of theoretical models financial shocks tend to behave as aggregate demand shocks, there are examples in the literature where financial shocks imply dynamics typical of supply shocks (e.g., most notably, Gilchrist et al., 2017). As we discuss below, our identification strategy can be modified to take this into account.

[20] 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).

[21] Furlanetto et al. (2014) disentangle between different types of financial shocks; Pinter et al. (2013), Caldara et al. (2016), and Gilchrist et al. (2014) disentangle between uncertainty shocks and financial shocks.

of imperfect information in credit markets (x^m). That is:

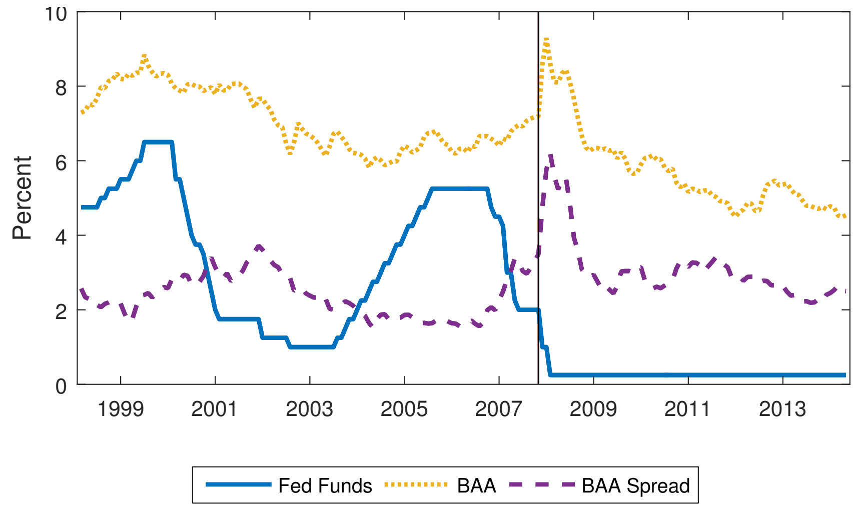
$$i_B^m = i^m + x^m. \tag{11}$$

In this class of models, the credit spread (x^m) endogenously responds 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 demand and financial 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 over 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 demand and financial shocks.

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 (dashed line) over the period 1999:M1 to 2015:M3. A vertical line shows 2008:M9, when Lehman Brothers collapsed. The figure shows that, during the 2007-08 period, a mechanism as the one described above might have been at work. This is particularly evident in the last months of 2008: while the Fed sharply cut the Fed Funds rate, trying to accommodate the shock, credit spreads quickly spiked, putting upward pressure on borrowing costs. From the chart it is clear that the spread component dominated over the policy rate component, leading to an overall increase in the borrowing rate.

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.

In what follows, we formalize this conjecture using a well-known and widely used financial accelerator model, the 'modern' variant of Bernanke et al. (1999) developed (and 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 wide variety of financial shocks. Moreover, we show that this is not the case in the face of other aggregate demand shocks. We also show that our result does not depend on the monetary policy reaction function.

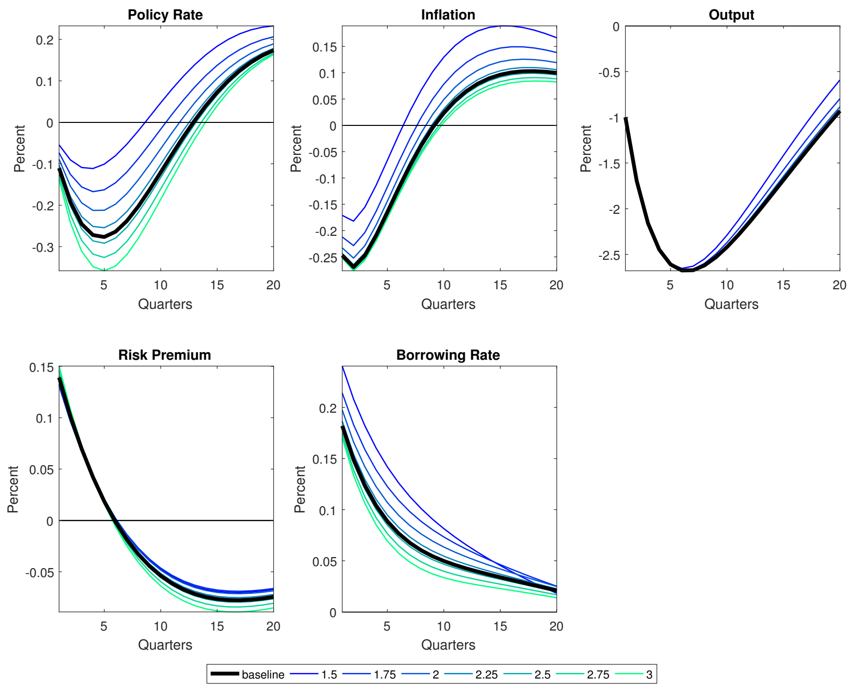
We start with financial shocks. Figure 2 plots the responses of output, inflation, the policy rate, the credit spread, and the borrowing rate in response to a shock that raises the cost of external finance.[22,23] The dark thick line displays the impulse responses we obtain using the baseline estimated parameters in Christiano et al. (2014). The impulse responses clearly show that the policy rate and the credit spread move in

[22] Specifically, and with reference to Christiano et al. (2014) original code, we plot the following variables: output is `gdp_obs`; inflation is `inflation_obs`; the policy rate is `Re`; the risk premium is `premium_obs`; the borrowing rate is defined as the long term rate `RL` plus the risk premium.

[23] As in Gilchrist and Zakrajsek (2012), we model this shock by means of an additive term in the definition of the external finance premium. Results are similar for other financial shocks. See the online supplement.

different directions, but the latter dominates. As a result, the borrowing rate increases.

Figure 2 Impulse Responses to a Risk Premium Shock

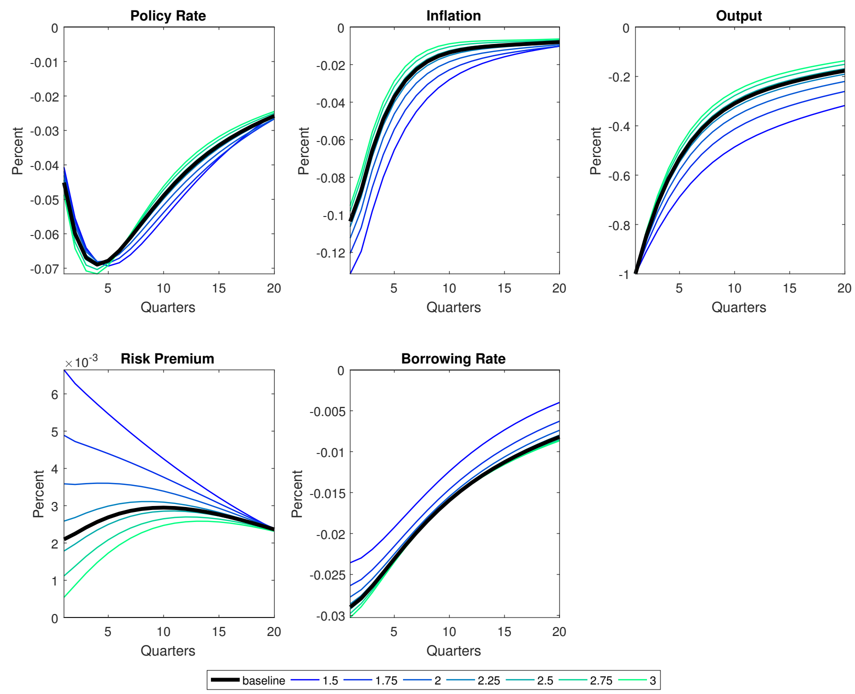


Note. The thick dark line is computed using the parametrization in the baseline estimated model of Christiano et al. (2014). The thin colored lines are obtained by varying the coefficient on inflation in the Taylor Rule. We consider values from 1.5 to 3. The size of the shock is normalized so that it generates a fall in output of 1 percent.

As already discussed, 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 (i.e., a Taylor rule with a higher coefficient on deviations of inflation from target) would generate a larger fall in the policy rate, which would also decrease the lending rate. If this effect is strong enough, the response of the lending rate could turn negative, thus invalidating our identification assumption. To address this issue, we assess the robustness of the above theoretical predictions 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 deviations of inflation from target in the Taylor rule (ϕ^{π}). We consider a wide set of parameter values that covers the range typically considered in the literature, i.e. we consider values from

$\phi^{\pi} = 1.5$ to $\phi^{\pi} = 3$. 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. In the Supplement we also show that this result holds true for other financial shocks.

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 Christiano et al. (2014). 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 in Figure 2 to a negative shock to government consumption.[24] The shock is contractionary, so that output and inflation fall and the central bank responds by 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 over the credit spread. As a result, the borrowing

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

rate falls. Again, we check that our finding is robust to the strength of the central bank response to deviations of inflation from target, as shown by the thin lines in Figure 3; and to other types of demand shocks, such as consumers' preference shocks (reported in the Supplement).

These results therefore suggest that there exists a minimum set of sign restrictions that allows us to distinguish between financial and demand shocks based on the response of the borrowing rate. Specifically, a (contractionary) financial shock is defined as a shock that decreases output, prices and the policy rate, and increases the credit spread and 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. Finally, to account for the fact that some financial shocks might behave like supply shocks, we will also consider an additional identification scheme where we do not restrict the response of inflation to fall (results reported in the online Supplement).

4 Empirical Results

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

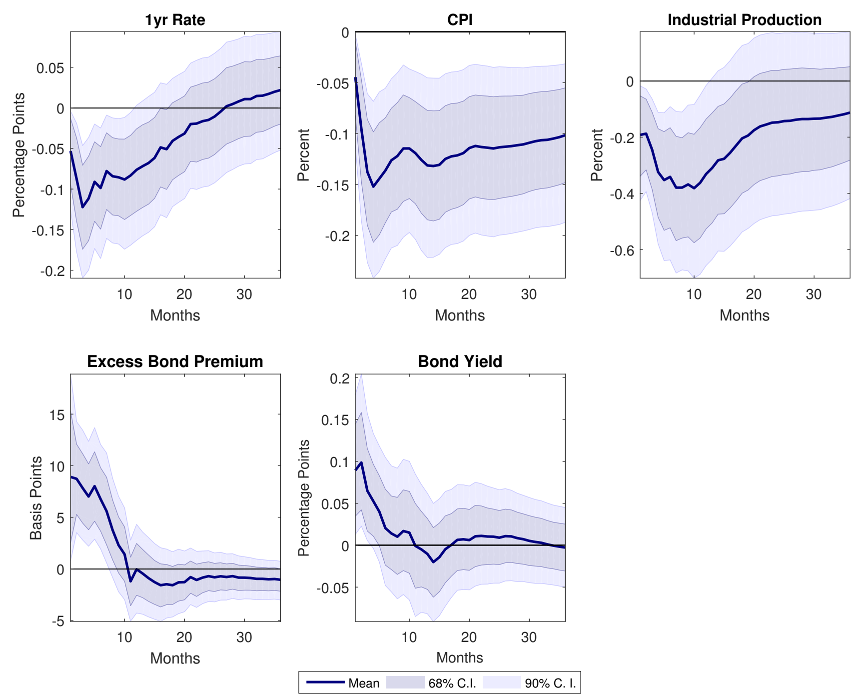
4.1 A US Financial Shock

We interpret this shock as an increase in the effective cost of financial intermediation, which therefore raises the cost of external finance.[25] We start by analyzing the response of the US economy to a 1 standard deviation US financial shock, plotted in Figure 4. Consistent with the sign restrictions derived in section 3, the (contractionary) financial shock 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, as well as on the Excess Bond Premium, which peaks at slightly less than 10 basis points and

[25] As discussed above, this could be driven, for example, by a shock to the efficiency of the financial intermediation process, a shock that reduces equity (net worth) and therefore agents' borrowing capacity, or a shock to the idiosyncratic variance of entrepreneurial productivity. See for example as in Gilchrist and Zakrajsek (2012) and Christiano et al. (2014).

remains elevated for several months before revering to its long-run value. The bond yield, which initially also increases, gradually falls as the effect of looser monetary policy feeds through.

Figure 4 US Financial Shock: Transmission Within the US Economy

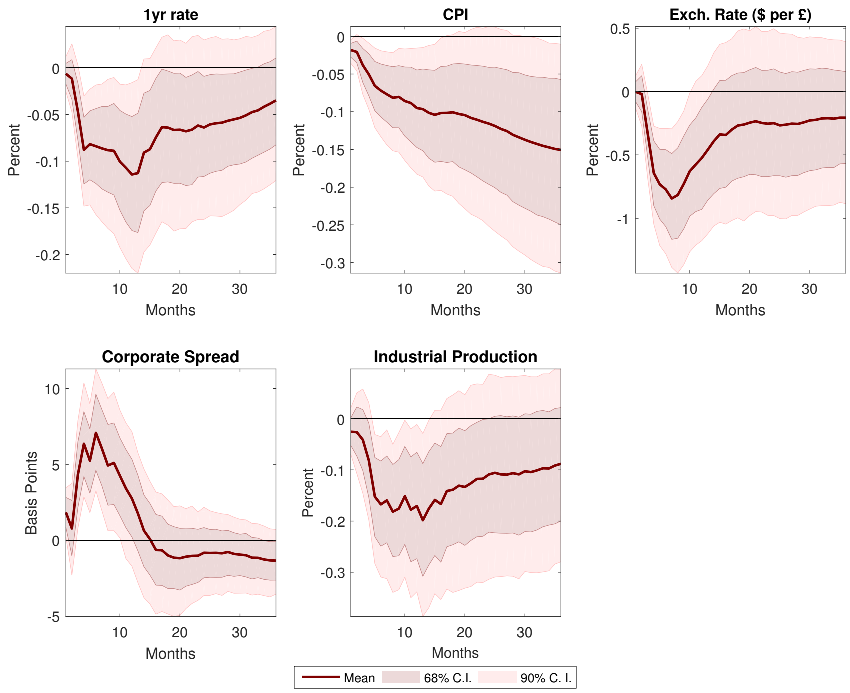


Note. The solid line and shaded areas report the mean, 68% and 90% confidence intervals computed using wild bootstrap with with 1000 replications and 100 rotations per bootstrap draw.

Figure 5 plots the responses of UK variables to a financial shock originating in the United States. An implication of the international credit channel is that the increase in US credit spreads should be quickly transmitted internationally, leading to an increase in UK credit spreads. Figure 5 shows that this is indeed the case. While the initial increase is somewhat small, credit spreads rapidly increases to about 7 basis points, a magnitude that is similar to the one observed in the US.

The US financial shock also leads to a contraction in the UK economy: UK consumer prices tend to fall along with their US counterpart, and so does UK industrial production. The value of sterling is little affected on impact, but it subsequently depre-

Figure 5 US Financial Shock: Transmission to the UK Economy



Note. The solid line and shaded areas report the mean, 68% and 90% confidence intervals computed using wild bootstrap with with 1000 replications and 100 rotations per bootstrap draw.

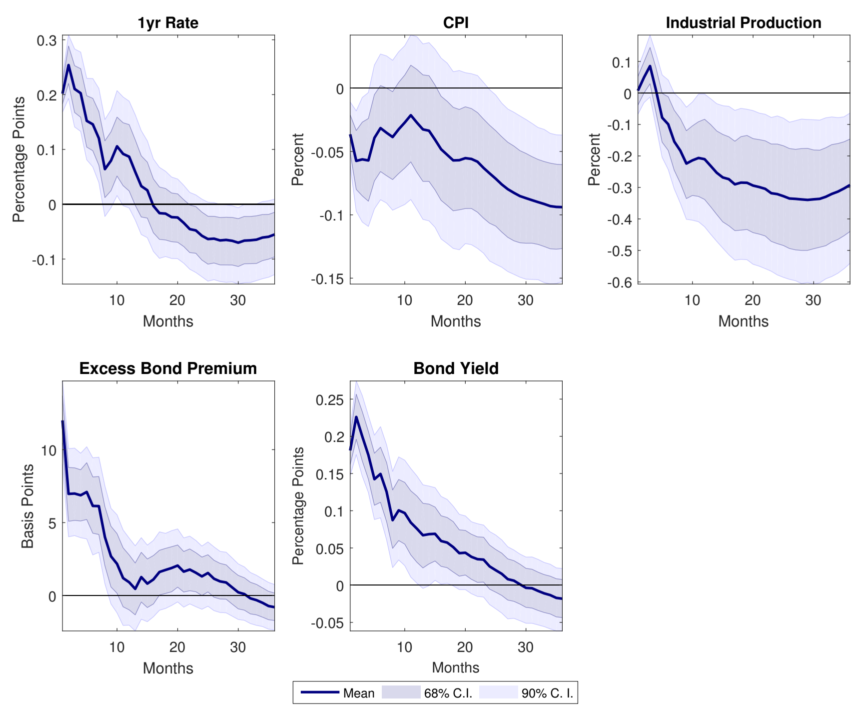
ciates vis-à-vis the dollar. This result is similar to Eickmeier and Ng (2015)'s—which use a different empirical model to assess the transmission of US financial shocks—and can be interpreted as a flight to the 'safe haven' US dollar. The response of the UK policy rate is muted on impact, but substantial afterwards, consistent with a stabilizing monetary policy response in the face of an adverse shock. Note that, interestingly, UK credit spreads increase despite an accommodating response of UK monetary policy, which acts to reduce spreads *via* a domestic credit channel. Overall, we interpret this response as being consistent with an international credit channel for US financial shocks, as implied by theoretical models with financial frictions and integrated financial markets (as Krugman, 2003, Devereux and Yetman, 2010, Dedola and Lombardo, 2012, Ueda, 2012, among others).

Finally note that financial shocks induce strong international co-movement of economic activity, consumer prices, and policy rates across countries. As we shall show in the next subsection, this degree of co-movement is higher than the one generated by monetary policy shocks, especially for what concerns policy rates. Financial shocks could therefore help in explaining the high degree of international co-movement of macroeconomic variables and policy rates that we observe in the data.

4.2 A US Monetary Policy Shock

We now turn to US monetary policy shocks, starting again 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 6.

Figure 6 US MONETARY POLICY SHOCK: TRANSMISSION WITHIN THE US ECONOMY



NOTE. The solid line and shaded areas report the mean, 68% and 90% confidence intervals computed using wild bootstrap with with 1000 replications and 100 rotations per bootstrap draw.

Despite the longer sample (updated to 2015:M3) and the inclusion of bond yields in the vector of endogenous variables, the results remain very similar to those in 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 (domestic) credit channel of monetary policy.[26] The corporate bond yield also increases in response to the monetary policy shock. This is not surprising, since monetary policy should affect the corporate bond yield through two different 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.

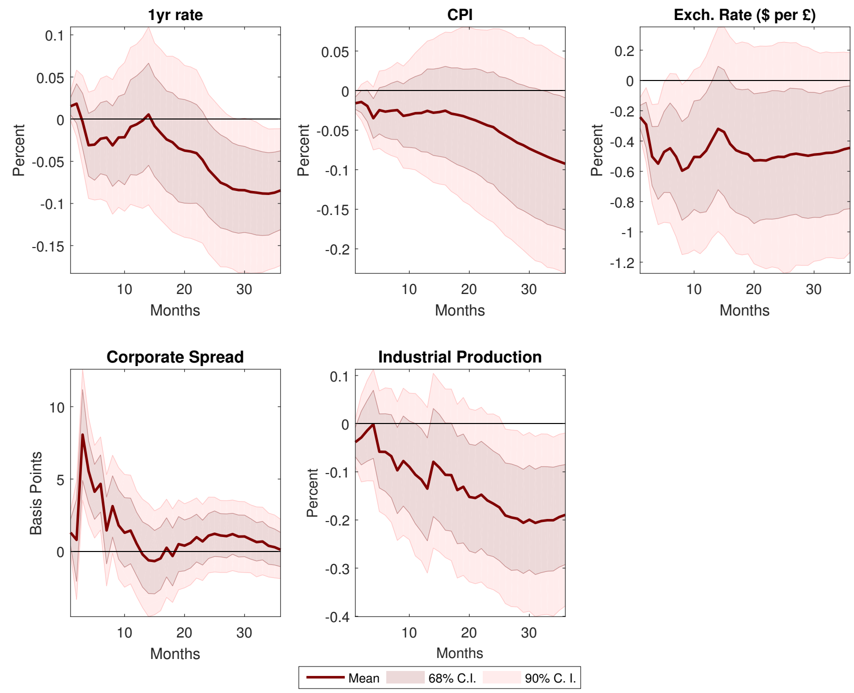
The response of UK variables to a US monetary policy shock is reported in Figure 7. As for financial shocks, our results corroborate the existence of an international credit channel of monetary policy. The UK corporate credit spread increases slightly on impact, and then jumps by about 8 basis points within the third month. The results we report are complementary to the ones provided by Rey (2016) and Passari and Rey (2015), as 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. Moreover the response of corporate credit spreads sheds some lights on the somewhat puzzling result in Gerko and Rey (2017), who find that corporate bond spreads fall in response to a US monetary policy tightening. As discussed above, a combination of different data and a richer model specification allows us to extend the results on the international credit channel to corporate bond markets.

Finally, the impulse responses also 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. Industrial production slightly falls in response to a US contractionary monetary policy shock, suggesting that the foreign demand and credit channels dominate over the expenditure-switching channel. The impact, however, is not statistically significant in the first year, and only becomes statistically significant in the second year at the 68 percent confidence level. The response of CPI is also statistically insignificant, suggesting that the negative demand effects are countered by the pass-through to domestic prices of a weaker sterling.[27]

[26] Following the literature, we check that the value of the F-statistic from the first stage is above 10. In our baseline specification the F-statistic is 23.46.

[27] These results are in line with the mean group estimates of Dedola et al. (2017) for advanced

Figure 7 US Monetary Policy Shock: Transmission to the UK Economy



Note. The solid line and shaded areas report the mean, 68% and 90% confidence intervals computed using wild bootstrap with with 1000 replications and 100 rotations per bootstrap draw.

The statistically insignificant initial response of UK activity, prices and short-term interest rates also seem to suggest that the depreciation of Sterling helps cushioning the impact of this external shock faced by the UK economy. Eventually, at longer horizons, the shock gradually leads to a slowdown in UK economic activity and prices, and with it, to a lower short-term interest rate. But importantly, the overall degree of co-movement with US variables—and especially with the US policy rate—appears to be smaller than for financial shocks originating in the US.

economies.

5 Inspecting the International Transmission Mechanism

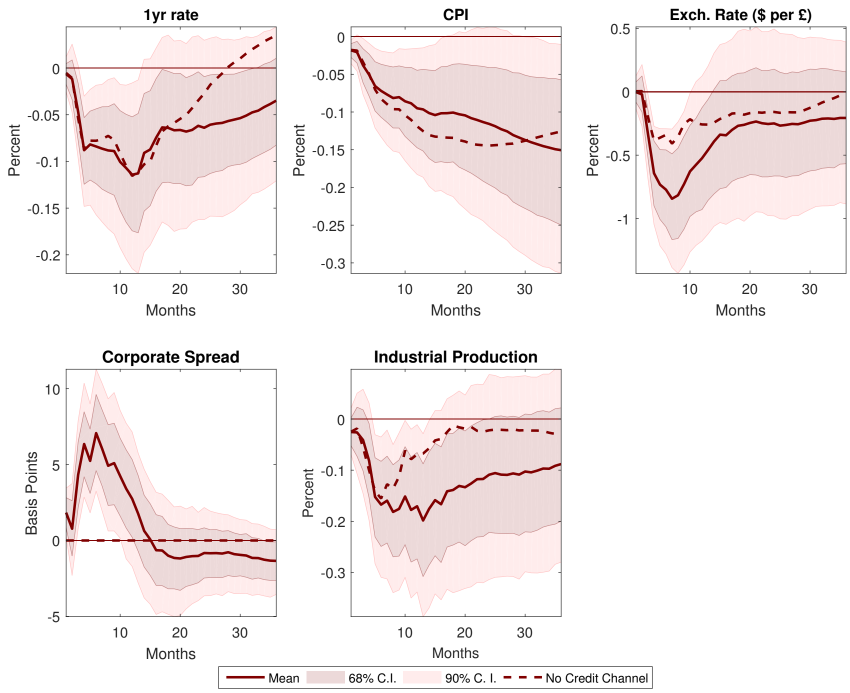
The evidence we reported in the previous section shows that both monetary and financial shocks originating in the United States significantly affect credit conditions (as summarized by credit spreads), both domestically and internationally. We interpreted this evidence as suggesting that, in line with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

According to the closed-economy credit channel mechanism (Bernanke and Gertler, 1989), adverse shocks lower borrowers' net worth and lead to an increase in their borrowing costs through an increase in the spreads they pay over the risk-free rate. The increase in borrowing costs depresses agents' demand, which in turn depresses net worth and raises credit spreads further. This is the feedback loop that gives rise to the financial accelerator mechanism.

When agents' balance sheets are denominated in both domestic and foreign currency, their net worth (and, therefore, the credit spreads they face) is also directly affected by foreign shocks through movements in the price of foreign assets and liabilities and/or the exchange rate. The no-arbitrage conditions imposed by international financial integration imply a strong pressure towards 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)).

Thus, if an international credit channel is at work, domestic and foreign credit spreads should not only co-move, but also amplify 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 financial and monetary policy shocks with counterfactual ones, in which the credit spread in both countries is held fixed at its steady state value. The difference between the two sets of responses can then provide some evidence on the amplification role of credit spreads via the international credit channel.

Figure 8 UK's Response to US Financial Shock: Closing the International Credit Channel



Note. The solid line and shaded areas report the mean, 68% and 90% confidence intervals computed using wild bootstrap with with 1000 replications and 100 rotations per bootstrap draw as in our baseline (see Figure 5). The dashed line reports the counterfactual impulse response computed keeping credit spreads at their unconditional mean values.

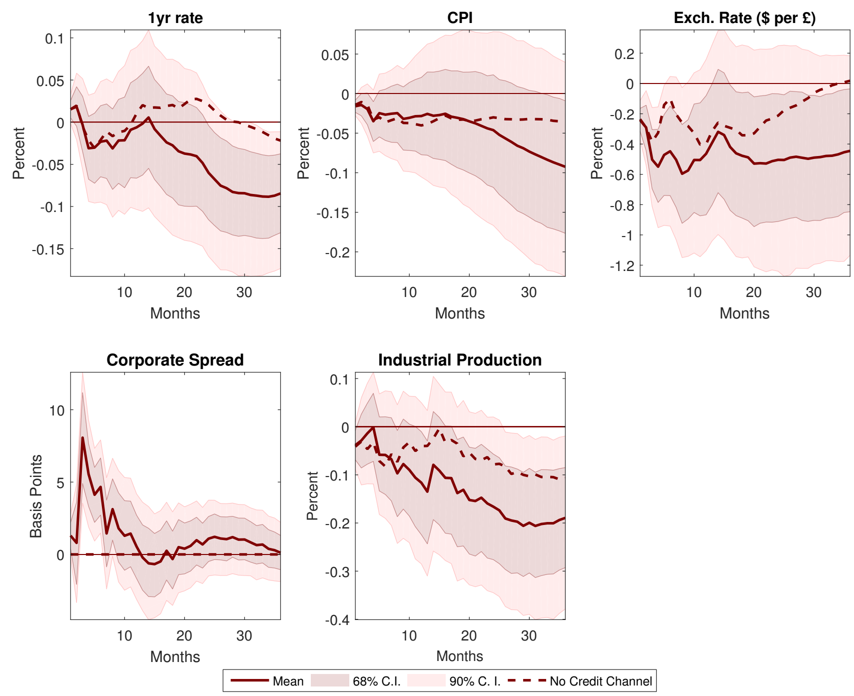
Figure 8 plots the UK impulse responses to a US financial shock when we close the credit channel alongside the baseline, and Figure 9 does the same for a US monetary policy shock. We report the responses of US variables in the Appendix.

Starting with the US financial shock, Figure 8 shows that when shutting down the international credit channel, the UK economy is less susceptible to foreign financial shocks. In this counterfactual impulse responses, the UK experiences a substantially smaller and less persistent fall in industrial production; a still accommodative, but slightly tighter monetary policy stance, and a smaller exchange rate depreciation.

Turning to the US monetary policy shock (Figure 9), when we shut down the credit spread in both the UK and the US, we also observe a more muted response of UK variables. In particular, the UK experiences a smaller fall in industrial production, and 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 and reverts more quickly to steady state.

Figure 9 UK's Response to US Monetary Policy Shock: Closing the International Credit Channel



Note. The solid line and shaded areas report the mean, 68% and 90% confidence intervals computed using wild bootstrap with with 1000 replications and 100 rotations per bootstrap draw as in our baseline (see Figure 7). The dashed line reports the counterfactual impulse response computed keeping credit spreads at their unconditional mean values.

Overall, the evidence reported in this section therefore 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 empirical evidence on the existence of an international credit channel for the transmission of US shocks across borders. To do so, we combine two widely used identification techniques in a novel fashion, which allows us to recover a US financial shock alongside a US monetary policy shock. We then embed this identification technique in a two-country structural VAR for the analysis of the international transmission of US shocks to the UK economy.

Our results provide strong evidence in support of an international credit channel for the transmission of US shocks across borders. Like monetary policy shocks, US financial shocks lead to synchronized movements in credit spreads across countries. Unlike monetary policy shocks, however, US financial shocks lead to a sharp contraction in the UK economy and to stronger co-movement of economic activity, consumer prices, and policy rates across countries. Our results also support the notion that frictions in domestic and international financial contracting can act as a powerful spillover amplifier. The findings in this paper corroborate the predictions of general equilibrium open economy models with credit market imperfections, in which balance sheet effects and bond and asset markets integration are crucial for the transmission of both monetary policy and financial shocks.

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A Appendix: 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. All variables are from Datastream and seasonally adjusted. We also updated the series of monetary policy surprises of Gurkaynak et al. (2005). Specifically we use surprises over a 30-minute window in the three-month ahead fed funds futures (FF4). An update of the Excess Bond Premium series (originally from Gilchrist and Zakrajsek (2012)) is available on Simon Gilchrist's web page http://people.bu.edu/sgilchri/Data/data.htm. Finally, for consistency with the credit spread data, we construct a bond yield series by summing Gilchrist and Zakrajsek (2012)'s credit spreads (also available Simon Gilchrist's web page, labelled GZ in the original spreadsheet) to the yield on the 10-year US government bond.

United Kingdom. We use the following variables: 1-year Gilt yield as policy indicator (Bank of England), the CPI (OECD Main Economic Indicators), the nominal $/£ exchange rate (Bank of England), an index of industrial production (ONS), and the LFS unemployment (ONS). All variables are and seasonally adjusted. The corporate credit spread is taken from "*The UK recession in context—what do three centuries of data tell us?*", Data Annex - Version 2.2 (July 2015). Specifically, we use the series labelled '*Spliced interpolated series 1854-2015*' minus the series labelled '*10 year zero coupon gilt yields*' from the tab '*33. Mthly corp bond yields*' of the excel file available online.

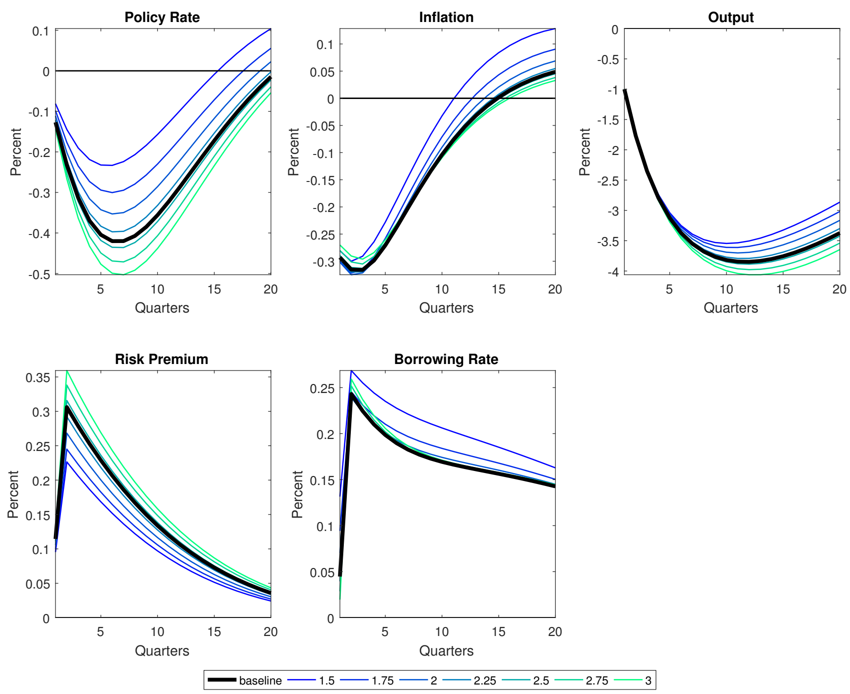
B Appendix: Additional Results

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 Christiano et al. (2014). 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.

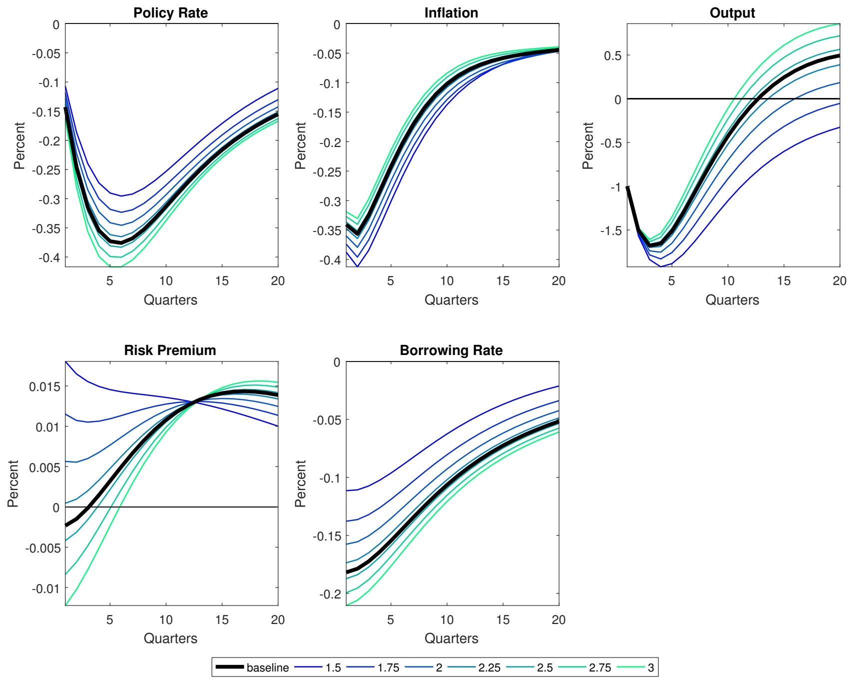
Counterfactual Impulse Responses: Closing the International Credit Channel. We compute the counterfactual impulse responses for both US monetary and financial shocks by setting to zero the coefficients of the credit spreads equations in both the UK and the US. Figure B.3 plots the US impulse responses to a US monetary policy shock when we close the credit channel. Figure B.4 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



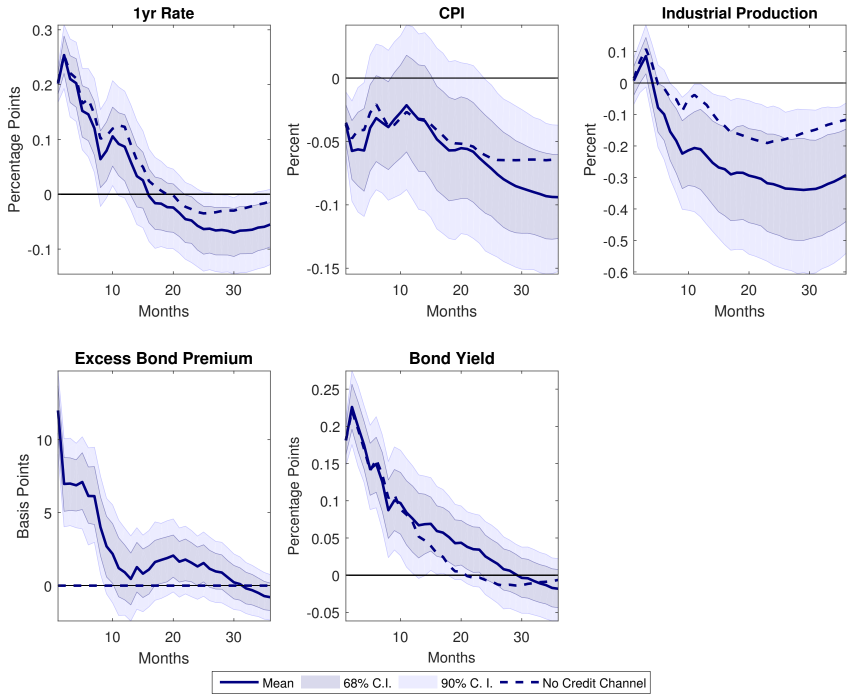
Note. The thick dark line is computed using the parametrization in the baseline estimated model of Christiano et al. (2014). The thin colored lines are obtained by varying the coefficient on inflation in the Taylor Rule. We consider values from 1.5 to 3. The size of the shock is normalized so that it generates a fall in output of 1 percent.

Figure B.2 Impulse Responses to a Risk Consumers' Preference Shock



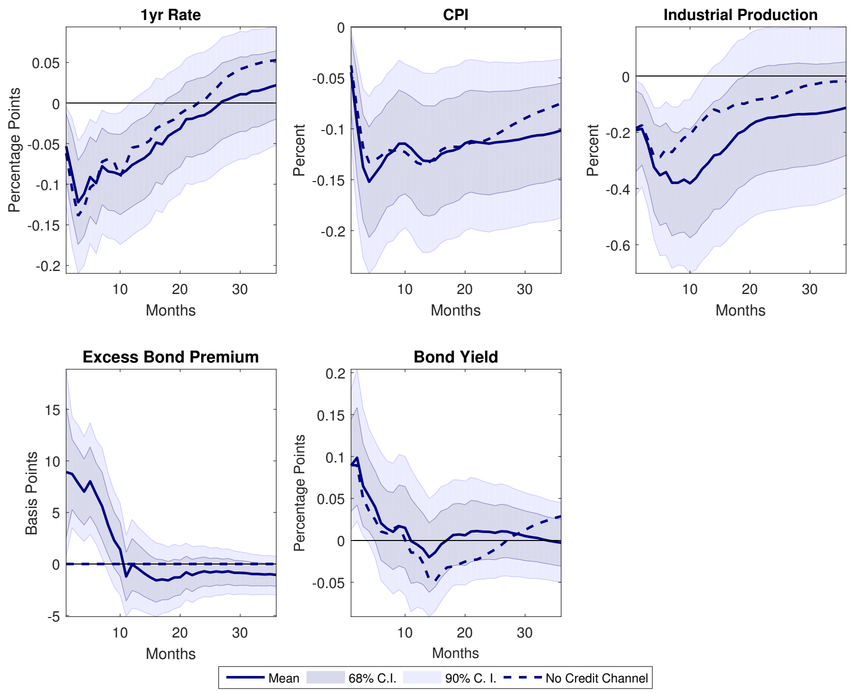
Note. The thick dark line is computed using the parametrization in the baseline estimated model of Christiano et al. (2014). The thin colored lines are obtained by varying the coefficient on inflation in the Taylor Rule. We consider values from 1.5 to 3. The size of the shock is normalized so that it generates a fall in output of 1 percent.

Figure B.3 US's Response to US Monetary Policy Shock: Closing the International Credit Channel



Note. The solid line and shaded areas report the mean, 68% and 90% confidence intervals computed using wild bootstrap with with 1000 replications and 100 rotations per bootstrap draw. The dashed line reports the counterfactual impulse response computed keeping credit spreads at their unconditional mean values.

Figure B.4 US's Response to US Financial Shock: Closing the International Credit Channel



Note. The solid line and shaded areas report the mean, 68% and 90% confidence intervals computed using wild bootstrap with with 1000 replications and 100 rotations per bootstrap draw. The dashed line reports the counterfactual impulse response computed keeping credit spreads at their unconditional mean values.