Bremia: A study of the impact of Brexit based on bond prices

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September 2018

Preliminary draft – for comment only

Abstract

Many financial prices reacted violently to the result of the UK’s advisory referendum held on 23 June 2016. Subsequently financial prices have proved significantly less volatile, both unconditionally and in response to Brexit-related news. We particularly want to understand what sovereign bond prices might have been telling us about the likely state of the British economy under an exit from the European Union. To do so, we develop an affine model of the term structure of interest rates in which bond yields are driven by observable and unobservable macroeconomic factors as well as by central bank communication, which we quantify using text mining techniques. We then map our findings about the determinants of the yield curve to movements in response to Brexit news. We find that bond yields declined in the direct aftermath of the referendum as the result of a combined effect: 1) a worsening in the economic outlook and the anticipation of more expansionary monetary policy in response to it lowered expectations about future risk-free rates; 2) the term premium declined as investors increased their demand for government bonds as safe haven assets.

JEL Classification: E32, E43, E44, E52

Keywords: Costs of Brexit; Macro-finance yield curves; Risk premia and activity; Central bank communication

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1 Introduction

The outcome of the Brexit referendum hit financial markets by surprise. In the morning after the referendum, the stock market contracted by 3 per cent and Sterling depreciated by 8 per cent against the US dollar. While nothing fundamental had altered the state of the economy over night, expectations adjusted to accommodate a Britain outside of the European Union. At the same time, 10-year government bond yields fell by around 30 basis points on the day after the referendum (Figure 1). There was wide consensus among economists that the impact of Brexit on the future state of the economy would be negative because of reductions in trade and FDI, a decline in net migration and potentially lower productivity growth (e.g. Treasury Committee 2016, Ebell et al. 2016). The fall in equity prices has been explained by a worsening in the economic outlook and expectations of trade barriers between the UK and the EU: Bréïlich et al. (2018) find that firms with stronger reliance on the domestic or EU market experienced larger falls in share prices compared to generally more recession-proof, international firms. Similarly, Davies and Studnicka (2018) estimate that the equity market reaction for companies that are part of complex global value chains was more substantial compared to less vulnerable peers, in particular in the direct aftermath of the referendum. These effects also proved long-lasting and largely unaltered by subsequent Brexit news. This suggests that investors priced changes in expectations almost immediately and political events after the referendum did not change the new outlook. Similarly, the depreciation of Sterling proved persistent, with the currency continuing to trade around 7 per cent lower than the US dollar for most of the post-referendum period. By contrast, the response of the bond market is far less clear. We therefore ask: Is there a Brexit premium, or "Bremium"? If so, what does it tell us about investors’ expectations about future state of the economy?

In theory, Brexit can affect long-term government bond yields through a number of channels. Firstly, the Brexit referendum result may have been interpreted as a news shock about future productivity. Barsky and Sims (2011) find that in response to positive news shocks, real interest rates rise. Vice versa, we would expect the component in long-run yields that captures expectations about future risk-free rates to decline in response to negative Brexit news (news effect). Secondly, the referendum result caused substantial uncertainty about the future trading relationship with the EU, and economic policy. Uncertainty itself can reduce firms’ willingness to hire and invest, and consumers’ intention to spend, thereby reducing employment and output growth (Bloom 2014). The effect of Brexit-related uncertainty on expectations about future policy rates may therefore be ambiguous. Yet investors are likely to ask for a higher compensation given the future state of the economy is unknown and hence price risk premia (uncertainty effect). Nevertheless, given a rise in risk, investors may, thirdly, feel the need to rebalance their portfolios towards safer assets such as government bonds (safe haven effect). An increase in demand for government bonds would decrease the liquidity of this asset class, causing bond prices to rise and hence the liquidity-related yield component to decrease. Finally, interest rates in the short and long term will depend on expectations of how the monetary authority will react (policy anticipation effect). A central
bank mostly concerned about inflationary pressure that may arise from higher trade costs could be expected to tighten policy, leading to a rise in short-term rate expectations. On the other hand, a central bank more concerned about mitigating output responses would bring forward future interest rate cuts, which would lead to lower expectations about future policy rates. It may additionally be expected to redeploy unconventional monetary tools, such as quantitative easing. There is much debate about the way quantitative easing affects long-term interest rates. Bauer and Rudebusch (2014) find that QE can serve as a signal to markets that policy rates will remain low for longer, thereby reducing short-term rate expectations. Joyce et al. (2012) and Chadha and Waters (2014) show that in the UK the Bank of England’s Asset Purchase Programmes had a substantial portfolio rebalancing effect, whereby the central bank decreased the supply of safe assets like government bonds which reduced their yields. Chadha and Hantzsche (2018) find that the Bank of England’s QE programme also generated substantial international portfolio rebalancing effects, impacting for instance German Bund yields.

In this paper, we test these competing hypotheses about the response of markets for UK gilts to Brexit news. To do so, we first present a simple model of debt supply to illustrate what may drive movements in long-term bond yields relative to short-term risk-free rates. Long-term yields reflect expectations about the structure of the economy and monetary policy preferences. Because the referendum likely changed expectations about both these aspects, we analyse the response of yields to changes in the state of the economy as well as messages conveyed by monetary policymakers. Building on Adrian et al. (2013), we decompose UK 10-year yields into a component capturing expectations about future risk-free
rates and a term premium. We further seek to estimate new measures of the monetary policy stance which we extract from published communication by the Bank of England. More specifically, we apply several text mining techniques to the Bank of England monetary policy summaries and minutes of the Monetary Policy Committee (MPC). We use dictionary methods and a Latent Dirichlet Allocation algorithm, as first formulated by Blei et al. (2003), to generate three indicators capturing hawkish relative to dovish tone, general uncertainty, and Brexit-related uncertainty. Finally, we map our findings about yield curve determinants to movements in bond yield components on days when news about Brexit were made public.

We find that expectations about future policy rates generally decline when economic growth slows or MPC members become more dovish in their communication. The term premium component tends to decline for some time when uncertainty features more prominently in discussions. We interpret this as the result of safe haven effects that leads investors to shift portfolios towards safer government bonds. We also find that uncertainty in the context of the Brexit referendum was one of the latent topics most heavily discussed at MPC meetings since 2016. In response to Brexit uncertainty, as expressed by the MPC, we also estimate a decline in the term premium. Mapping these findings to movements in bond yield components on days when news about Brexit emerged, we conclude that the decline in the bond yield after the referendum most likely resulted from a deterioration in the economic outlook, a change in expectations about monetary policy towards a more expansionary policy stance, and safe haven effects that benefitted government bonds. Other occasions subsequent to the referendum that are associated with new information about Brexit do not appear to have changed investors’ expectations much.

The next section lays out a simple model of debt supply and the term premium. Section 3 explains our empirical approach to decomposing bond yields, describes the methodology used to extract quantitative measures of central bank communication and presents results from a macro-finance model of the UK yield curve and effects of monetary policy. In Section 4 we then map the response of bond markets at high frequency to Brexit news to findings about yield curve determinants. Section 5 concludes.

2 A simple model of debt supply and term premium

We shall model this economy in two stages. First, we can consider the government’s issuance of short and long-run debt to households, which we can think of as a transfer to provide insurance against income shocks. And secondly, we can then model the standard household problem in an endowment economy, Lucas (1982), in which there is a continuum of identical, infinitely lived households. They have standard preferences over consumption and are given a non-storable endowment. The wealth of each household consists of money, one-period nominal bonds, subsequently referred to as T-bills, and long-term bonds, which we shall model as consols.

The holdings of all bonds are subject to inflation risk and pay off a unit of currency after
one period. We allow some fraction of the T-bill to act as currency in this set-up, and so its price can deviate from the standard pricing kernel. The consol holdings are also subject to inflation risk and pay off a unit of currency but their price varies with supply. We shall aim to price both bonds in terms of household utility.

At the beginning of each period, households are given a money and income endowment that is publicly observed, $M_t$ and $y_t$. They also gain a payoff to bonds held and then must decide how to allocate wealth across money balances, $M^d_t$, T-bills, $z^N_t$, and consols, $z^c_t$. They further receive a lump-sum transfer from the monetary-fiscal authority. The representative household thus solves:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t u(c_t), \quad 0 < \beta < 1,$$

subject to the following three constraints. The conditional expectations operator, $E_0$, is defined with a time subscript, $\beta$ is the rate of time preference and $u(c_t)$ is the representative household’s utility function in terms of per period consumption, $c_t$.

**The government budget constraint**

The government budget constraint is given by:

$$\frac{x_t}{p_t} z^N_t + \frac{V_t z^c_t}{p_t} - \frac{1}{p_t} z^N_{t-1} - \frac{(1 + V_t) z^c_{t-1}}{p_t} - \frac{\Theta_t}{p_t} = T_t$$

where the government issues T-bills and consols. The previous one-period T-bills are redeemed at face value and the previous issuance of consols pay one unit of currency. In addition to the change in the issuance of debt, the consolidated monetary sector can increase its balance sheet, $\frac{\Theta_t}{p_t} = \frac{M^d_t}{p_t} - \frac{M^d_{t-1}}{p_t}$. These flows pin down the size of lump sum transfers to the household. These transfers can be thought of an insurance device to offset stochastic deviations in the income endowment. This government constraint can be placed into the household budget constraint.

**Household flow budget constraint**

$$\frac{p_{t-1}}{p_t} c_{t-1} + \frac{x_t}{p_t} z^N_t + \frac{V_t z^c_t}{p_t} + \frac{M^d_t}{p_t} y_{t-1} + \frac{1}{p_t} z^N_{t-1} + \frac{(1 + V_t) z^c_{t-1}}{p_t} + \frac{M^d_{t-1}}{p_t} + \frac{T_t}{p_t}$$
Cash-in-advance constraint

\[ c_t \leq \frac{M_t^d}{p_t} + \phi \frac{z_t^N}{p_t}. \]  

(4)

The household budget involves the receipt of an endowment, \( y_t \), that cannot be spent until the following period so it is subject to inflation risk, \( \frac{p_{t+1}}{p_t} \), the value of maturing T-bills is \( z_t^N \) and the real price is deflated by the price level, \( p_t \). Similarly, the value of the payoff from consols, \( z_t^c \), is deflated by the price level. The household must then decide how to allocate this wealth across consumption and money balances that are required to affect a given consumption plan and purchases of T-bills and consols at prices of \( x_t \) and \( q_{t+1} \), respectively. At the end of the period, after the household has made its choice but before the market closes, there is an announcement about the level of output which leads to the issuance of debt by the government or an opportunity for the household to sell some of its one-period T-bills.

The first-order conditions

The Lagrange multiplier associated with the household budget constraint is \( \lambda_t \) and that associated with the cash-in-advance constraint is \( \mu_t \). The first-order conditions associated with this problem then are:

\[ u'(c_t) = \beta E_t \lambda_{t+1} \frac{p_t}{p_{t+1}} + \mu_t, \]

(5)

for consumption.

\[ \lambda_t \frac{x_t}{p_t} = \beta E_t \lambda_{t+1} \frac{1}{p_{t+1}} + \phi \frac{\mu_t}{p_t} \]

(6)

for the T-bill.

\[ \lambda_t \frac{V_t}{p_t} = \beta E_t \lambda_{t+1} \frac{(1 + V_{t+1})}{p_{t+1}} \]

\[ q_t \equiv \frac{V_t}{(1 + V_{t+1})} = \beta E_t \lambda_{t+1} \frac{p_t}{p_{t+1}} \]

(7)

for the consol price.
\[
\begin{align*}
\lambda_t \frac{1}{pt} &= \beta E_t \lambda_{t+1} \frac{1}{pt+1} + \mu_t \frac{1}{pt} \\
\lambda_t &= \beta E_t \lambda_{t+1} \frac{pt}{pt+1} + \mu_t \\
\end{align*}
\]  

(8)

for real money balances.

Now we can solve for the price of the T-bill and the consol price. First substitute (8) into (5) and then into (9).

\[
\begin{align*}
u' \left( c_t \right) \frac{x_t}{pt} &= \beta E_t u' \left( c_{t+1} \right) \frac{1}{pt+1} + \phi \mu_t \frac{1}{pt} \\
u' \left( c_t \right) \frac{x_t}{pt} &= \beta E_t u' \left( c_{t+1} \right) \frac{1}{pt+1} + \phi \left( \lambda_t \frac{1}{pt} - \beta E_t \lambda_{t+1} \frac{1}{pt+1} \right) \\
u' \left( c_t \right) \frac{x_t}{pt} &= \beta E_t u' \left( c_{t+1} \right) \frac{1}{pt+1} + \phi \left( u' \left( c_t \right) \frac{1}{pt} - \beta E_t u' \left( c_{t+1} \right) \frac{1}{pt+1} \right) \\
x_t &= \beta E_t \frac{u' \left( c_{t+1} \right)}{u' \left( c_t \right)} \frac{pt}{pt+1} + \phi \left( u' \left( c_t \right) \frac{pt}{u' \left( c_t \right) pt} - \beta E_t \frac{u' \left( c_{t+1} \right)}{u' \left( c_t \right)} \frac{pt}{pt+1} \right) \\
x_t &= \beta E_t \frac{u' \left( c_{t+1} \right)}{u' \left( c_t \right)} \frac{pt}{pt+1} + \phi \left( 1 - \beta E_t \frac{u' \left( c_{t+1} \right)}{u' \left( c_t \right)} \frac{pt}{pt+1} \right) \\
\end{align*}
\]

(9)

The price of the T-bill, \( x_t \), is thus given by the intertemporal rate of substitution in nominal consumption plus a term that relates to the liquidity demand, \( \phi \), for these nominal bonds. We can immediately see that the hypothetical price of the consol will be:

\[
q_t \equiv \beta E_t \frac{u' \left( c_{t+1} \right)}{u' \left( c_t \right)} \frac{pt}{pt+1} \\
\]

(10)

And so,

\[
x_t = (1 - \phi) q_t + \phi
\]

No-arbitrage condition for bonds

We will introduce traders who ensure that there is no arbitrage between the market price of consols and that of T-bills but at some cost:

\[
q'_t = \frac{q_t}{e^{\psi \left( b_t - \bar{b} \right)}} \\
\]

\[
\]

(11)
so that as the total stock of debt, $b$, increases above its steady-state, $\bar{b}$, then the market price of consols, $q'_t$, relative to T-bills falls.

**Proposition 1** When $\phi = 0$ and $b = \bar{b}$, the price of a T-bill and the market price of a one-period return on consols will be the same as the hypothetical one-period bond price:

$$
\beta E_t \frac{u'(c_{t+1})}{u'(c_t)} \frac{p_t}{p_{t+1}} = x_t = \frac{1}{1 + r_t^N} = q_t = \frac{1}{1 + r_t^c}.
$$

But generally the relationship between the market price of long-term consols to T-bills is given by the following expression:

$$
q'_t = \frac{x_t - \phi}{(1 - \phi) e^{\psi(b_t - \bar{b})}}.
$$

**Proposition 2** The market price of consols falls in $\phi$ and the issuance of bonds, $b$.

Figure 2 illustrates such a relationship between the prices of consols and T-bills. The difference between the price for consols and hypothetical one-period returns can be interpreted as term premium. We have shown that it can be modelled as a function of the liquidity of
the debt stock. For instance, if the government reduces the supply of long-term bonds $b_t$, e.g. by adopting quantitative easing, we would expect the difference between the prices of consols and hypothetical returns to widen, or the bond yield premium to fall. Similarly, a rise in the preference for holding bonds instead of money would also be expected to widen the price wedge and lower the yield premium.

3 The pricing of uncertainty and central bank communication on bond markets

3.1 Long-term bond yield decomposition

In order to analyse the effect of Brexit news on long-term relative to short-term rates, we decompose gilt yields into a component capturing expectations about future risk-free rates and a residual term premium component that reflects compensation required by investors for liquidity risks (as shown in the previous section) but which may further reflect compensation for uncertainty about the monetary policy stance or general market risk. To do so, we apply a three-step estimation approach proposed by [Adrian et al.] (2013) to estimates of zero-coupon gilt yields at different maturities provided by the Bank of England.

From the cross-sectional dispersion in yields across different maturities five pricing factors are extracted using principal components analysis. These pricing factors are assumed to follow dynamic processes:

$$X_{t+1} = \mu + \Phi X_t + v_{t+1}$$

where $X_{t+1}$ are the pricing factors, $\mu$ is a constant term and $\Phi$ is the autoregressive parameter. Innovations $v_{t+1}$ are assumed to follow a Gaussian distribution, conditional on the history of $X_t$. With affine market prices of risk $\lambda_t = \Sigma^{-\frac{1}{2}}(\lambda_0 + \lambda_1 X_t)$, an exponentially affine pricing kernel $M_{t+1}$ for the evolution of prices of bonds of maturity $n$, $P_{t+1}^n = E_t[M_{t+1} P_{t+1}^{(n-1)}]$, is assumed to follow

$$M_{t+1} = \exp(-r_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\frac{1}{2}v_{t+1}).$$

$r_t$ represents the continuously compounded risk-free rate. It can be used to obtain log excess holding returns

$$r_{x(t+1)}^{(n-1)} = \ln P_{t+1}^{(n-1)} - \ln P_{t}^{(n)} - r_t.$$  

Excess returns can then be written as

$$r_{x(t+1)}^{(n-1)} = \beta^{(n-1)'}(\lambda_0 + \lambda_1 X_t) - \frac{1}{2}(\beta^{(n-1)'}\sigma^2) + \beta^{(n-1)'}v_{t+1} + \epsilon_{t+1}^{(n-1)}$$

where $\epsilon_{t+1}^{(n-1)}$ are return pricing errors that are orthogonal to factor innovations $v_{t+1}$ and conditionally independently and identically distributed with variance $\sigma^2$. The first term of
the equation captures the excess return that can be expected from the contemporaneous level of pricing factors. The second term allows for a convexity adjustment and the third term is the effect of factor innovations on excess returns.

We first estimate equation (12) is estimated by ordinary least squares. Following Adrian et al. (2013), we then regress excess returns on a constant term, lagged pricing factors and factor innovations stacked into a matrix $\hat{V}_t$

$$r x_{t+1}^{(a-1)} = aI_t + \beta' \hat{V}_t + cX_t + E_{t+1}. \quad (16)$$

This yields estimates of parameter $\beta$ of equation (15). Residuals from equation (16), $\hat{E}_{t+1}$, are employed to obtain an estimate of $\sigma^2$.

Third, price of risk parameters $\lambda_0$ and $\lambda_1$ are estimated by cross-sectional regression across yields at different maturities. Finally, we calculate expectations of risk-free short-term rates by setting parameters $\lambda_0$ and $\lambda_1$ to zero. The term premium is obtained as the difference between short-term rate estimates and observed yields.

We estimate both bond yield components at monthly frequency and then use daily data and estimated parameters to construct time series at daily frequency. Figure 3 shows that expectations about risk-free rates declined since the late 1990s but dropped substantially as the financial crisis hit and the Bank of England cut their policy rate to historically low levels. By contrast, the term premium component increased sharply at the height of the financial crisis but has since followed a downward trend.
3.2 Applying text mining approaches to the Bank of England’s minutes

In recent years, an increasing number of scholars and policymakers have commenced to apply text mining (also known as natural language processing) to different sets of documents that are publicly disclosed by central banks. The main benefits from the use of these techniques lie in the fact that analytical steps involved are mostly automated, easily replicable, and, more importantly, the researcher-induced bias is highly reduced relative to other narrative approaches. In a nutshell, conducting text mining offers the researcher the opportunity to quantifying unstructured text data under new lenses and, consequently, gather new insights and perspectives of analysis. More specifically, these techniques allow a quantification and extrapolation of different dimensions of the content included in an individual document or a set of documents.

In this study, we apply several of these techniques to a corpus of Bank of England monetary policy summaries and minutes of MPC meetings. Our sample spans from January 1999 to August 2018 (generating a corpus of 228 documents in total). We construct measures of hawkishness in tone and the degree to which uncertainty about the economy, and Brexit in particular, are being discussed.

3.2.1 Introducing the Bank of England’s monetary policy summary and minutes

The monetary policy summary and minutes from the MPC’s meetings count amongst the documents released by the central bank that are most scrutinised by financial markets. They are part of the Bank of England’s set of unconventional policy tools for transmitting signals about the likely future monetary policy stance. More specifically, the content of these minutes aims to inform the public about the MPC’s personal insights and assessment of the current and likely condition of the macroeconomy, financial market developments, and the rationale behind decisions around the target policy interest rate. More recently, the MPC’s decisions about unconventional measures have also gained attention.

Since 1998, the Bank of England has released a summary and minutes of MPC meetings with a short time lag. Over the years, several aspects of the Bank of England’s communication practice changed. For instance, before July 2015, the Bank used to release the minutes on the Wednesday of the second week after the MPC meeting. The frequency of meetings per year also varied significantly in the last two decades. Indeed, until 2015 the MPC used to meet monthly. Currently, the Bank of England releases its summary minutes in the inter-meeting period at 12 noon on the Thursday after the meetings, which take place eight times a year.

Turning to an application of text mining methods, a few methodological steps are required to deal with unstructured text data. Firstly, we convert the whole set of files (downloaded in PDF format) into plain text format by grouping bunches of words at the level of individual minutes files. For each of the minutes, we then strip out the cover page and the part

2 See Bholat et al. (2015) for an extensive survey of text mining techniques and related applications on central bank documents.

3 Summaries and minutes are taken from the website https://www.bankofengland.co.uk/monetary-policy-summary-and-minutes/monetary-policy-summary-and-minutes, accessed on 29 August 2018.
concerning the final voting process, as well as related bullet points. The next step involves a more technical processing where we first transform the content of the raw text data into a sequence of items (also called tokens) that can be either a word, number or symbol included in the document. Then we remove white spaces, punctuation, numbers, and capitalisation. A more tailored pre-processing is required when applying text mining. We provide further explanation in the following subsections.

3.2.2 Hawkishness and uncertainty indices via dictionary methods

In recent years, an increasing literature has investigated the semantic orientation of traditional central banks communication by applying text mining (for instance, Apel and Grimaldi [2014], Cannon et al. [2015], Hansen and McMahon [2016]). One of the most common techniques is to employ a dictionary method by which one can extract the semantic orientation of a document by relying on a ‘search-and-count-words’ approach referred to a pre-specified dictionary. In other terms, the sentiment orientation of a document is expressed in terms of frequency of the occurring words composing the dictionary built ex-ante. In the current literature many dictionaries are available to define different sentiments from text data. However, following recent empirical studies applying specific dictionary methods to central banks documents (Apel and Grimaldi [2014], Tobback et al. [2017] and Bennani and Neuenkirch [2017]), we opt for a dictionary tailored to the monetary policy context, but more importantly able to extract the Bank of England’s hawkish or dovish tone or sentiment (H-D tone).

The measure of H-D tone at the meeting level is given as follows:

\[
Tone_{H-D_m} = \frac{\sum_{h \in H} h_m - \sum_{d \in D} d_m}{\sum_{h \in H} h_m + \sum_{d \in D} d_m}
\]  

(17)

where \( h \) is a hawkish token occurring in a monthly MPC minutes document \( m \) and belonging to the pre-specified hawkish-dictionary \( H \). The same logic applies for a dovish term defining a dovish-dictionary \( D \). The full word list of both dovish and hawkish dictionaries are reported in Table [A1] in the Appendix. Finally, the indicator is normalised by the sum of hawkish and dovish terms occurring in each document so that \( Tone_{H-D_m} \) is bound between +1 (hawkish) and -1 (dovish).

The H-D tone is an artificial proxy for the monetary policymakers’ preferences, but more importantly it is part of the Bank of England’s set of tools aiming at providing policy signals to both markets and private agents. Indeed, the signalling content of the MPC meetings minutes are meant to anchor market and private expectations so as to ensure a more effective implementation of monetary policy.

Figures [I] plot the times series of \( Tone_{H-D_m} \) against both short-rate expectations (b) and residual term premium (a) components, respectively. Plotted time series provide evidence of

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4 Usually the voting information is included at the end of the document representing the last points of the meeting minutes.

5 See Cannon et al. [2015] for a more detailed critique of the adoption of too broad dictionaries for extracting central bank communication indicators.
a strong correlation between Bank of England’s communication and markets’ expectations. We can see that the evolution of the short-term expectations follows closely the H-D tone; an opposite relationship seems to be apparent from the comparison with the term premium.

Following the text mining procedure of Hansen and McMahon (2016) for FOMC statements, we also construct a measure of general uncertainty from the MPC minutes by employing the ‘uncertainty’ word list of Loughran and McDonald (2011) as follows:

\[
\text{Uncertainty}_m = \frac{\sum_{u \in U} u_m}{\sum t_m}
\] (18)

We normalise the frequencies of uncertain tokens \(u\) by the total amount of words occurring in a document \(\sum t_m\).

We plot the series of \(\text{Uncertainty}_m\) against both the term premium and short-rate expectations components in Figures 5. However, at this stage we should make the reader
aware that this proxy of uncertainty is not representative for an idiosyncratic measure of uncertainty and, consequently it should not be confused with any kind of shock. It rather represents a mere quantification of general uncertainty conveyed by the MPC to the public based on the frequency of words expressing an uncertainty sentiment. Taking that into account, we can notice that the MPC’s minutes were characterised by higher volumes of uncertainty content over the years preceding the 2007-2009 global financial crisis.

3.2.3 A Brexit uncertainty index via LDA

In this section we present a idiosyncratic measure of uncertainty about Brexit extracted directly from the MPC minutes and able to capture the Brexit event discussion embodied in their content. To this end, and following an approach different from dictionary methods, we employ an unsupervised algorithm developed by [Blei et al. (2003)] called Latent Dirichlet Allocation (LDA) that allows us to identify a ‘latent’ thematic structure in the large archive of MPC minutes. LDA is a very popular algorithm in text mining and is applied in numerous research disciplines (see, for instance, [Hansen and McMahon, 2016] and [Hansen et al., 2017] for its implementation on documents released by the Federal Reserve). It requires two main inputs: the corpus of documents and a hyperparameter \( K \) that represents the number of latent topics generated by LDA. Based on a hierarchical Bayesian analysis,\(^6\) the two main outputs are

1. A term-topic matrix that displays the distribution over the wordlist of unique tokens, \( V \), occurring in the corpus of documents, for each \( K \) latent topic;

2. A document-topic matrix that represents the distribution over the tokens for each document; in other words, the predicted topic mixture for each meeting minutes.

In a nutshell, the first output is the cluster of words that have the highest probabilities to define and be grouped under a specific topic. The second matrix represents the topic mixture for each document composing the corpus.\(^7\)

In terms of labelling the hidden topics, the algorithm does not provide any indication. Therefore, the attribution of the label for each topic requires some subjective judgement. [Blei (2012)] leaves the choice of setting the value \( K \) to the researcher’s interpretation. We set \( K = 40 \) by relying on the methodology of [Deveaud et al., (2014)]. Moreover, we run LDA for different topic structures of the corpus by varying \( K \) from 40 to 50 as robustness checks.

Before implementing LDA, additional pre-processing needs to be applied across the corpus of raw text data. After applying the cleaning steps mentioned in the previous sub-section, we delete irrelevant content (we stripped out the introductory words of the minutes ‘before turning to its immediate policy decision’ that are consistently repeated in each document) and repetitive words (also called stopwords) which offer little meaning and contribution to

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\(^6\)The technical hierarchical Bayesian structure of the algorithm is presented in Appendix A. Please refer to [Blei et al. (2003)] and [Blei (2012)] for an extensive explanation.

\(^7\)In the Appendix we report the distribution of the complete topics structure in Table A2.
Finally, we stem each word in order to have common root for each remaining token (for instance, stemming words such as ‘leave’, ‘leaves’, ‘leaved’, and ‘leaving’ generates a unique token ‘leav’).

Table 1: Top 20 most probable tokens (stemmed) defining Topic 38 (interpreted as Brexit uncertainty)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Token</th>
<th>Rank</th>
<th>Token</th>
<th>Rank</th>
<th>Token</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>referendum</td>
<td>6</td>
<td>measur</td>
<td>11</td>
<td>market</td>
</tr>
<tr>
<td>2</td>
<td>uncertainti</td>
<td>7</td>
<td>vote</td>
<td>12</td>
<td>suppli</td>
</tr>
<tr>
<td>3</td>
<td>financi</td>
<td>8</td>
<td>sterl</td>
<td>13</td>
<td>lower</td>
</tr>
<tr>
<td>4</td>
<td>invest</td>
<td>9</td>
<td>effect</td>
<td>14</td>
<td>result</td>
</tr>
<tr>
<td>5</td>
<td>asset</td>
<td>10</td>
<td>period</td>
<td>15</td>
<td>household</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20 support</td>
</tr>
</tbody>
</table>

From Table 1 we can assess the reliability of the Brexit uncertainty topic generated by LDA. Indeed, the Topic 38 of the document-topic structure captures significant words related to the Brexit referendum and the surrounding uncertainty, including words such as ‘referendum’, ‘uncertainti’, ‘vote’, ‘sterling’, ‘effect’, ‘risk’, ‘survey’, etc.

Figures 6 also show clearly that the Brexit uncertainty index captures quite well the uncertainty sentiment of the Bank of England extracted by its minutes. For instance, the peak of the series is on the 14th of July 2016 which was the day of the first MPC meeting after the referendum held on 23rd June 2016.

Finally, Figure 6a shows a very interesting aspect of the dynamics characterising the months around the Brexit referendum. Indeed, in the span of time between May 2016 to September 2016, we witnessed to a sharp fall of the term premium component, while the Bank of England’s uncertainty around the Brexit discussion was at its highest levels. Differently, Figure 6b does not seem to suggest a strong relation between the uncertainty index and short-terms expectations.

We apply two stopword lists. The first is available on Bill McDonald’s Word Lists Page (www.sraf.nd.edu/textual-analysis/resources; site accessed 6th September 2018). The second list is based on our personal judgement and is reported in the Appendix in Table A3.
3.3 Macro-finance model of the yield curve

3.3.1 Empirical model

In order to analyse the response of bond yield components to central bank communication, we employ the local projections method proposed by Jordà (2005). Compared to the use of vector autoregressions (VAR), the local projections method has several advantages such as its flexibility and robustness to model misspecification. We estimate a system of equations composed of a process for the term premium \( t_p \), the expected risk-free rate \( i \) and annual GDP growth \( g \):

\[
\begin{align*}
  t_{p,t+k} - t_p &= \beta_{1,0,k} + \beta_{1,1,k} \Delta t_p + \sum_{j=1}^{J} \beta_{1,2,j,k} \Delta g_j + \Delta C_i \beta_{1,3,k} + \Delta X_i \beta_{1,4,k} + \epsilon_{1,t,k} \tag{19}
  \end{align*}
\]

\[
\begin{align*}
  i_{t+k} - i_t &= \beta_{2,0,k} + \beta_{2,1,k} \Delta i_t + \sum_{j=1}^{J} \beta_{2,2,j,k} \Delta g_j + \Delta C_i \beta_{2,3,k} + \Delta Y_i \beta_{2,4,k} + \epsilon_{2,t,k} \tag{20}
  \end{align*}
\]

\[
\begin{align*}
  g_{t+k} - g_t &= \beta_{3,0,k} + \sum_{j=1}^{J} \beta_{3,1,j,k} \Delta g_j + \beta_{3,2,k} \Delta t_p + \beta_{3,3,k} \Delta i_t + \Delta Z_i \beta_{3,4,k} + \epsilon_{3,t,k} \tag{21}
  \end{align*}
\]

where matrix \( C \) collects our measures of central bank communication, i.e. the indices of hawkishness, uncertainty and Brexit uncertainty in Bank of England minutes. Matrices \( X, Y, Z \) collect control variables including the annual rate of consumer price inflation, the Sterling exchange rate relative to the US dollar, and the VIX as a measure of global risk.

By varying forward lags \( k = 1, \ldots, 12 \), we are able to construct impulse responses for each dependent variable and regressor. For instance, the sequence \( \beta_{1,1,1}, \ldots, \beta_{1,1,12} \) would provide the dynamic response of the term premium to changes in the growth rate of GDP over a twelve-months horizon. To account for contemporaneity in the shocks to each variable, we allow the errors \( \epsilon_{v,t,k} \) to be correlated across equations. This is implemented using the Seemingly Unrelated Regression approach.

Bond yield components are estimated as explained above and available at monthly frequency. Measures of central bank communication are allocated to each month, and linearly interpolated when no MPC meeting was scheduled in a particular month. By obtaining a monthly estimate of GDP growth from the National Institute of Economic and Social Research’s database. Financial variables, i.e. the exchange rate and VIX, are obtained from Datastream. A monthly series of CPI inflation is provided by the Office for National Statistics. The sample spans over January 1999 to April 2018.

\[\text{From 1999 to 2015, the MPC had twelve meetings each month. In 2016, only 11 meetings were held. From 2017 the Committee has been meeting 8 times per year.}\]
3.4 Impulse responses

In Figures 7 to 8 we first plot the response of expectations about risk-free rates to shocks to our main variables. Given that these expectations are a market-based measure of the central bank’s reaction function, this serves as a check whether our model is able to produce plausible results. We find that interest rate expectations pick up as economic growth strengthens, in line with standard monetary policy reaction functions. In line with standard uncovered interest parity assumptions, the expected short-term rate declines as the currency appreciates. As communication by the MPC becomes more hawkish, expectations about risk-free rates increase, albeit with a substantial delay of half a year. By contrast, risk-free rates seem not to react to rising levels of uncertainty as debated by MPC members.

Turning next to responses of the term premium to macroeconomic and policy shocks (Figures 9 to 10), we find a strong negative reaction to improvements in the economic cycle. A depreciation in the exchange rate appears to increase the term premium, presumably because it has been associated with higher financial market risk in the recent past. As the central bank turns more hawkish in its communication, thereby signalling a stronger economic outlook, the term premium declines. Interestingly, we find that during periods when the central bank debates the issue of uncertainty more intensely, the term premium initially declines, before moving back to its previous level after 8 months. We interpret this is the result of a safe haven effect. As uncertainty increases, investors become less risk-seeking, rebalancing their portfolios towards safer government bonds and thereby increasing prices of these assets.

We do not find a significant response of the business cycle to changes in the term premium and risk-free rate in our sample. Adding both variables to an equation explaining GDP growth does not yield statistically significant results (Figures A1 in the Appendix).
(a) Impulse response to Bank of England hawkishness shock, 90% confidence interval
(b) Impulse response to Bank of England uncertainty shock, 90% confidence interval

Figure 8: Risk-free rate reaction (continued)

(a) Impulse response to +1pp GDP growth shock, 90% confidence interval
(b) Impulse response to +1 GBP/USD shock, 90% confidence interval

Figure 9: Term premium reaction

(a) Impulse response to Bank of England hawkishness shock, 90% confidence interval
(b) Impulse response to Bank of England uncertainty shock, 90% confidence interval

Figure 10: Term premium reaction (continued)
3.5 Additional results

We next add to the specification our index measuring the intensity with which Brexit and the referendum are being discussed at MPC meetings (Figures 11). An increase in our LDA-based index is followed by a sharp and persistent decline in the expectations of risk-free rates. The term premium also declines within around two months but this decline is soon reversed.

3.6 Robustness checks

We check the robustness of our results by including additional control variables such as the FTSE 100 share price index, the oil price and the spread between UK and US 10-year yields which do not substantially alter our main results. Results also remain consistent if we exclude the third equation (for GDP growth) from our model. We have further experimented with including a dummy variable taking the value of 1 from June 2016 onwards which does not change our main results.\footnote{Results are available from the authors upon request.}

4 Bond market response to Brexit news

In this section, we map our findings about yield curve determinants to movements in bond yields we observe on days when new information about the Brexit process was made public. We first single out a set of relevant events, report daily movements in bond yield components and then discuss what these movements might imply about the change in expectations triggered by Brexit events.
4.1 Brexit news

We select a series of days on which substantial news emerged about the United Kingdom exiting the European Union and policy responses to it. We start with the 23 June 2016, in the late evening of which the result of the Brexit referendum became known. Contrary to most market participants’ expectation, the British public voted with a majority of 51.9 % in favour of Brexit. After deciding at its July meeting to observe the response of the economy before changing policy, the Bank of England Monetary Policy Committee announced on 4 August 2016 to lower its policy rate by 25 basis points to 0.25 per cent, to adopt a new term funding scheme, purchase £10 billion of corporate bonds and, crucially for long-term gilt yields, implement a new programme of quantitative easing by adding £60 billion of government bonds to its balance sheet. The Prime Minister used her speech on 5 October 2016 at the Conservative Party convention to lay out her plans for Brexit, including triggering Article 50 in March 2017 that would mean Britain would have to formally leave the EU two years after. The legality of Brexit was challenged in the Supreme Court, not much hindering the process that had been started. In her 17 January 2017 Lancaster House speech, Prime Minister May provided more detail about her plans for the trade relationship between the UK and the EU after Brexit. The probability of Brexit to go ahead unchallenged was lowered somewhat by the Supreme Court decision to make parliamentary approval a requirement for the final Brexit bill. On 29 March 2017, Article 50 was triggered as had been planned and expected. Later that year, on 8 December 2017, the so-called ”Phase 1” agreement between British and EU negotiators was made public that highlighted to market participants that a close economic relationship between the Republic of Ireland and Northern Ireland, and implicitly between the UK and the EU, would be needed in order to fulfill both sides’ demands not to erect hard borders on the Irish isle or between Great Britain and Northern Ireland.

Table 2: Brexit-related events

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>23/06/2016</td>
<td>Referendum</td>
</tr>
<tr>
<td>04/08/2016</td>
<td>Bank of England cuts interest rates, new QE programme</td>
</tr>
<tr>
<td>05/10/2016</td>
<td>May speech at Conservative Party convention</td>
</tr>
<tr>
<td>03/11/2016</td>
<td>Legality of Brexit challenged in Supreme Court</td>
</tr>
<tr>
<td>17/01/2017</td>
<td>May Lancaster House speech</td>
</tr>
<tr>
<td>24/01/2017</td>
<td>Supreme Court ruling requiring parliamentary approval of Brexit bill</td>
</tr>
<tr>
<td>29/03/2017</td>
<td>Invocation of Article 50</td>
</tr>
<tr>
<td>08/12/2017</td>
<td>Phase 1 agreement between UK and EU</td>
</tr>
</tbody>
</table>

4.2 One-day movement of bond yield components

The movement in the whole yield curve after the day of the Brexit referendum is plotted in Figure 12. We observe both a fall in the level as well as a flattening of the curve.

Next, we report the responses of our estimated bond yield components to each of the Brexit events in Table 2 and contrast them with movements in the exchange rate within a day of the event 9Table 3. We find the largest financial market movements in the direct aftermath of the referendum, i.e. between market close on 23 June 2016 and the end of
Figure 12: Yield curve reaction to the Brexit referendum

24 June 2016. The term premium fell by 10 basis points and expectations about future risk-free rates declined even more sharply by around 16 basis points. In other words, around 60% of the decline in bond yields can be attributed to changed expectations about future short-term rates. Relative to movements on all other event days, the pound depreciated most strongly on 24 June 2016, by 8.6% relative to the US dollar. The event triggering the second largest term premium movement within our sample of Brexit-related news events is the MPC announcement on 4 August 2018. It also triggered a further reduction in risk-free rate expectations and the value of Sterling. Bond and exchange rate movements on all other event days remained relatively muted. May’s 2016 party conference speech and the publication of the Phase 1 agreement led to a reversal of some of the term premium decline, while short-term rate expectations and the exchange rate did not move significantly.\footnote{The 24 June 2016 is also the day with the largest bond yield movement (26 basis points) during the whole of the period January 2016 to April 2018 (see Figure A2 in the Appendix). The size of the yield movement that day is a rare observations across the whole length of our sample from January 1999 to April 2018 (see Figure A2 in the Appendix).}

4.3 Discussion

We next aim to map the bond market movements we observe on days with relevant Brexit news to results from our macro-finance model of the yield curve. Overall, our findings seem to suggest that responses of the bond market in the direct aftermath of the Brexit referendum were driven by a combination of safe haven effects and adjustments in expectations about the monetary policy stance. Subsequent Brexit-related events only led to at best marginal
Table 3: Bond yield and exchange rate response (within one day around event)

<table>
<thead>
<tr>
<th>Date</th>
<th>Term premium (bp)</th>
<th>Risk-free rate (bp)</th>
<th>GBP/USD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23/06/2016</td>
<td>-10.0</td>
<td>-16.2</td>
<td>8.6</td>
</tr>
<tr>
<td>04/08/2016</td>
<td>-15.0</td>
<td>-1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>05/10/2016</td>
<td>5.6</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>03/11/2016</td>
<td>2.2</td>
<td>0.5</td>
<td>-1.1</td>
</tr>
<tr>
<td>17/01/2017</td>
<td>-4.2</td>
<td>1.7</td>
<td>-2.6</td>
</tr>
<tr>
<td>24/01/2017</td>
<td>0.7</td>
<td>-0.6</td>
<td>-0.1</td>
</tr>
<tr>
<td>29/03/2017</td>
<td>0.3</td>
<td>-4.1</td>
<td>1.0</td>
</tr>
<tr>
<td>08/12/2017</td>
<td>4.8</td>
<td>-2.1</td>
<td>0.3</td>
</tr>
</tbody>
</table>

The safe haven effect, which we find regularly leads to reductions in term premia once monetary policymakers become more uncertain about the future, appears to be mainly responsible for the reduction in term premia observed on the day after the referendum, and in response to the Bank of England press conference in August 2016. However, our estimates also suggest that safe haven effects do usually not last longer than a few months. Subsequent movements in the term premium on Brexit event days seem to show that investors continued to be sensitive to changes in risk. The Prime Minister’s party conference speech in 2016 seems to calmed down markets somewhat, leading to a partial reversal in the safe haven effect and an increase in the term premium. This is in contrast to May’s Lancaster House speech which led to a renewed increase in uncertainty. At the end of 2017, the publication of the Phase 1 agreement appears to have lowered uncertainty again, reducing the price of safe long-term bonds and thereby increasing the risk premium somewhat.

We interpret the decline in risk-free rate expectations on 24 June 2016 as the result of an expected loosening of monetary policy, relative to before the referendum result was known. This could have come about because Brexit may have led to a downward revision in the economic outlook on behalf of market participants. While we do not find significant effects of uncertainty on risk-free rates, we find that more dovish policy statements tend to gradually push down rate expectations. Given that the response of risk-free rates to the referendum was quite pronounced, markets appear to have priced a relatively stark turn in Bank of England interest rate setting. Once the Bank reduced its policy rate two months later, these expectations were confirmed.

The model introduced in Section 2 suggests that a decline in the term premium could have also come about through markets’ expectation of a new asset purchase programme that limits the supply of long-term bonds. [Joyce et al. (2012)] find that the Bank of England’s QE1 programme of 200 billion of purchases, which came largely as a surprise during a time of severe market distress, lowered gilt yields by an average of 125 basis points, or by 0.62 basis points for each additional 1 billion purchased. If the fall in yields after the Brexit referendum were to be explained entirely by expectations of an additional QE programme, the 30 basis point fall in the 10-year yield would suggest purchases of around 18 billion were expected. In fact, on 4 August the Bank announced to buy 60 billion of government bonds, and an additional 10 billion of corporate bonds.

Our interpretation that the Brexit referendum led to an increase in uncertainty, while
also raising the expectation of more accommodative monetary policy is supported by Table 4 which reports the movement in global and UK-specific market risk variables. Global volatility measured by the VIX increased by nearly 50 per cent once referendum results became known. Similarly, the risk premium on Italian government bonds, since the euro area crisis often considered a risky asset, increased by nearly 20 basis points as investors shifted portfolios towards safer assets. By contrast, uncertainty in the UK appears to be offset by expectations about more expansionary monetary policy. The local equivalent of the VIX, implied volatility of FTSE100-listed shares actually declined on the day after the referendum, and fell further when the Bank of England announced its policy shift in August 2016. The picture is very similar for spreads between risky and safe UK corporate bonds. Financial market risk measures did not move substantially on the other days in our sample (apart from the VIX which increased by 14 per cent on 3 November 2016, most likely for reasons unrelated to Brexit).

Table 4: Response of financial market risk measures

<table>
<thead>
<tr>
<th>Date</th>
<th>VIX (%)</th>
<th>Term premium IT (bp)</th>
<th>FTSE vol (%)</th>
<th>BBB-AAA Spread (bp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23/06/2016</td>
<td>49.3</td>
<td>19.1</td>
<td>-5.5</td>
<td>-2.8</td>
</tr>
<tr>
<td>04/08/2016</td>
<td>-3.4</td>
<td>-6.2</td>
<td>-12.2</td>
<td>-14.6</td>
</tr>
<tr>
<td>05/10/2016</td>
<td>0.4</td>
<td>8.9</td>
<td>-3.4</td>
<td>4.9</td>
</tr>
<tr>
<td>03/11/2016</td>
<td>14.3</td>
<td>4.5</td>
<td>2.6</td>
<td>1.3</td>
</tr>
<tr>
<td>17/01/2017</td>
<td>5.7</td>
<td>3.5</td>
<td>5.9</td>
<td>-0.9</td>
</tr>
<tr>
<td>24/01/2017</td>
<td>-5.9</td>
<td>1.3</td>
<td>-2.1</td>
<td>-0.8</td>
</tr>
<tr>
<td>29/03/2017</td>
<td>-1.0</td>
<td>0.6</td>
<td>-3.2</td>
<td>-1.7</td>
</tr>
<tr>
<td>08/12/2017</td>
<td>-5.7</td>
<td>-2.7</td>
<td>1.5</td>
<td>6.9</td>
</tr>
</tbody>
</table>

So, what then is the size of the Brexit premium, or Bremium? The interpretation of our results suggests that long-term government bonds actually benefitted from the result of the referendum. The government’s borrowing costs declined as demand for safer government assets increased in the face of higher uncertainty. At the same time, bond markets started to rely more strongly on action by the Bank of England to offset potential negative effects on the UK economy emanating from the process of exiting the EU.

However, a number of caveats should be mentioned. In our analysis, we assume that central bank communication is exogenous to movements in macroeconomic fundamentals and the term structure of interest rates. While we safeguard ourselves against concerns of direct endogeneity by considering only lagged effects of communication measures on bond yield components, central bankers may nevertheless hold fairly accurate expectations about the state of the economy (see discussion in [Cloyne and Hürtgen, 2016]). In subsequent work, we aim to construct communication shocks that cannot be explained by expectations. In future iterations, we will also assess in more detail how expectations of quantitative easing and other unconventional monetary policy tools affect long-term bond yield components.
5 Conclusion

This paper assesses whether there is a Brexit premium priced on markets for UK government bonds. To address this question, we decompose long-term gilt yields into a component capturing expectations about future risk-free rates and a risk premium. We propose new quantitative measures of communication among members of the Bank of England’s Monetary Policy Committee, reflecting the degree of hawkishness in minutes, the intensity with which uncertainty is discussed and how much the Brexit referendum features in decision-making. We then estimate the dynamic relationship between central bank communication and bond yield components, controlling for macroeconomic fundamentals. We find that expectations about risk-free rates increase with the growth outlook and the extent to which MPC members use hawkish wording in their discussions. Term premia, on the other hand, tend to exhibit a short-lasting decline as uncertainty increases, which we attribute to safe haven effects. As a final step, we map these general results to market movements observed on days when Brexit-relevant events took place.

We observe that the Brexit premium on sovereign bond yields is negative. In other words, there does not seem to be a ”Bremium” that could have increased the government’s cost of debt service. We interpret this to be the result of two effects: First, a safe haven effect leading to a reallocation of international bond portfolios in the face of Brexit-induced uncertainty, away from risky assets towards government bonds. Second, a deterioration in the economic outlook as a result of the referendum result appears to have altered investors’ expectations about the monetary policy stance. The Bank of England was thought to intervene with expansionary measures, an expectation that materialised some six weeks after the referendum when the Bank cut its policy rate to a historical low and announced a new asset purchase programme. However, a number of questions remains and we aim to address these questions and provide more conclusive results in future extensions of this research project.
References


Treasury Committee (2016), The economic and financial costs and benefits of the UK’s EU membership, Technical report, HM Treasury.
Appendix A. The LDA algorithm (Blei et al., 2003)

LDA is an unsupervised topic modelling algorithm able to identify hidden topics structure characterising a corpus of documents. In this study, we consider the set of Bank of England meeting minutes from January 1999 to August 2018 to be our corpus of documents, \( C = d_1, d_2, d_3, \ldots, d_C \), characterised by a vocabulary of unique words (tokens), \( V = w_1, w_2, w_3, \ldots, w_V \).

The main intuition of the functioning of LDA is that this algorithm works as a generative probabilistic process for documents which are defined by a mixtures of topics, and where the latter are probabilities over the words. More technically, the LDA’s generative process is defined by the following hierarchical structure:

1) a \( V \)-dimensional Dirichlet distribution, \( \beta_K \) over the dictionary \( V \), with hyperparameter \( \alpha \), is drawn for each topic;

2a) a \( K \)-dimensional Dirichlet distribution over the set of topics \( K \), \( \theta_d \), with hyperparameter \( \eta \), is drawn for each document;

2b) a multinomial distribution governed by \( \theta_d \) is drawn for each word \( w \) in order to draw its assignment into topics, \( z_{d,w} \);

2bi) depending on \( z_{d,w} \) and the topics structure defined in step 1), each \( w \) is drawn by following a multinomial distribution governed by \( \beta_{z_{d,w}} \).

We recall that the generative probabilistic process deals with both observed and unobserved (latent) variables: words defining the documents falls in the first category; oppositely, the topics, \( \beta_K \), their distributions, \( \theta_d \), and words assignments \( z_{d,w} \) are hidden components falling in the second category. Given that, the joint probability distribution defined by this process is as follows:

\[
P(\beta, \theta, z, w) = \sum p(\beta) \sum p(\theta) \left[ \sum p(z|\theta) p(w|\beta, z) \right]
\]

The final step concerns the definition of a posterior distribution representing the latent topic structure. Based on a Bayesian formulation, the conditional distribution of latent variables given the observed text data is

\[
p(\beta, \theta, z | w) = \frac{p(\beta, \theta, z | w)}{p(w)}
\]

where the denominator (e.g. the probability of observing the content of our documents under any topic structure) is intractable. In this situation, following the existing literature, we adopt a Gibbs sampling algorithm proposed by Griffiths and Steyvers (2004) for approximating the posterior distribution.

\(^{12}\)We rely on Griffiths and Steyvers (2004) for the selection of both hyperparameters by setting set \( \alpha = 50/K \) and \( \eta = 0.1 \).
Table A1: List of hawkish and dovish terms

<table>
<thead>
<tr>
<th>Dovish (D)</th>
<th>Hawkish (H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>accommod</td>
<td>fell</td>
</tr>
<tr>
<td>assetpurchas</td>
<td>loos</td>
</tr>
<tr>
<td>contract</td>
<td>loosen</td>
</tr>
<tr>
<td>contractionari</td>
<td>lower</td>
</tr>
<tr>
<td>cool</td>
<td>movedown</td>
</tr>
<tr>
<td>cut</td>
<td>putdownward</td>
</tr>
<tr>
<td>dampen</td>
<td>recess</td>
</tr>
<tr>
<td>decay</td>
<td>reduc</td>
</tr>
<tr>
<td>declin</td>
<td>reduct</td>
</tr>
<tr>
<td>depress</td>
<td>slack</td>
</tr>
<tr>
<td>deterior</td>
<td>slower</td>
</tr>
<tr>
<td>drop</td>
<td>sluggish</td>
</tr>
<tr>
<td>eas</td>
<td>soft</td>
</tr>
<tr>
<td>expansionari</td>
<td>soften</td>
</tr>
<tr>
<td>fall</td>
<td>softer</td>
</tr>
<tr>
<td>fallen</td>
<td>trim</td>
</tr>
</tbody>
</table>

Notes: The tokens inserted in this table are stemmed items. Some of them are preprocessed in order to capture a string of more words.
Table A2: Top 5 most likely (stemmed) terms defining the term-topic matrix

<table>
<thead>
<tr>
<th>Topic 1</th>
<th>Topic 2</th>
<th>Topic 3</th>
<th>Topic 4</th>
<th>Topic 5</th>
<th>Topic 6</th>
<th>Topic 7</th>
<th>Topic 8</th>
<th>Topic 9</th>
<th>Topic 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>household</td>
<td>growth</td>
<td>growth</td>
<td>inflat</td>
<td>pay</td>
<td>rate</td>
<td>rate</td>
<td>growth</td>
<td>growth</td>
</tr>
<tr>
<td>2</td>
<td>spend</td>
<td>member</td>
<td>market</td>
<td>weak</td>
<td>term</td>
<td>reduct</td>
<td>rise</td>
<td>price</td>
<td>remain</td>
</tr>
<tr>
<td>3</td>
<td>risk</td>
<td>project</td>
<td>sector</td>
<td>sector</td>
<td>euro</td>
<td>cost</td>
<td>increas</td>
<td>fall</td>
<td>recent</td>
</tr>
<tr>
<td>4</td>
<td>consumpt</td>
<td>possibl</td>
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<td>indic</td>
<td>area</td>
<td>member</td>
<td>risen</td>
<td>repo</td>
<td>inflat</td>
</tr>
<tr>
<td>5</td>
<td>incom</td>
<td>risk</td>
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Table A3: Personal stopwords list

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(a) Impulse response to +1pp risk-free rate shock, (b) Impulse response to +1pp term premium shock, 90% confidence interval

Figure A1: GDP growth reaction

(a) Basis points, Jan 2016 - Apr 2018
(b) Basis points, Jan 1999 - Apr 2018

Figure A2: Distribution of daily changes in UK 10-year yields