

INTERNATIONAL MONETARY FUND

Deciphering Delphic Guidance:

The Bank of England and Brexit

Jagjit S. Chadha, Corrado Macchiarelli, Satyam Goel, Arno
Hantzsche, Sathya Mellina

WP/24/160

IMF Working Papers describe research in progress by the author(s) and are published to elicit comments and to encourage debate.

The views expressed in IMF Working Papers are those of the author(s) and do not necessarily represent the views of the IMF, its Executive Board, or IMF management.

**2024
JUL**



WORKING PAPER

IMF Working Paper

Money and Capital Markets Department

Deciphering Delphic Guidance: The Bank of England and Brexit**Prepared by Jagjit S. Chadha, Corrado Macchiarelli, Satyam Goel, Arno Hantzsche, Sathya Mellina***

Authorized for distribution by Jaewoo Lee

July 2024

IMF Working Papers describe research in progress by the author(s) and are published to elicit comments and to encourage debate. The views expressed in IMF Working Papers are those of the author(s) and do not necessarily represent the views of the IMF, its Executive Board, or IMF management.

ABSTRACT: In response to the 2016 referendum on EU Membership and the ensuing uncertainty as to the eventual consequences of Brexit, the Bank of England (BoE) adopted various methods of influencing market rates, including conventional, unconventional monetary policy measures and communications on forward guidance. To investigate the effectiveness of BoE's communication, we first decompose long-dated yields into a risk neutral and term premium component. Text-based analysis of Monetary Policy Committee minutes is then used to measure the stance of policy, attitudes to QE and Brexit. We show that the Bank's communication strategy acted to complement the stance of monetary policy, which had responded by lowering Bank rate and expanding QE, and acted to lower the term premium that might otherwise have risen in response to Brexit uncertainty.

RECOMMENDED CITATION: Chadha et al. (2024), Deciphering Delphic Guidance: The Bank of England and Brexit, IMF Working Paper WP/24/160

JEL Classification Numbers:	E32, E43, E44, E52
Keywords:	UK referendum; Brexit; risk premium; monetary policy; central bank communication; text mining
Author's E-Mail Address:	Cmacchiarelli@imf.org

* The authors would like to thank Richard Barwell, Oliver de Groot, Kerstin Hoette, Michael McMahon, and Gurnain Kaur Pasricha, as well as participants at the Oxford-CEPR RPN Workshop on Central Bank Communication 2024, the 14th International Conference on Computational and Financial Econometrics, the Royal Economic Society Annual Conference (2021 and 2024) and seminars at the National Institute of Economic and Social Research, London School of Economics and Political Science, University of Liverpool, and Brunel University London for their insightful comments and suggestions. The views expressed in this paper reflect those of the authors and do not necessarily reflect views of the institutions they are affiliated with. Any remaining errors are the authors' responsibility.

WORKING PAPERS

Deciphering Delphic Guidance: The Bank of England and Brexit

Prepared by Jagjit S. Chadha, Corrado Macchiarelli, Satyam Goel, Arno Hantzsche, Sathya Mellina¹

¹ The authors would like to thank Richard Barwell, Oliver de Groot, Kerstin Hoette, Michael McMahon, and Gurnain Kaur Pasricha, as well as participants at the Oxford-CEPR RPN Workshop on Central Bank Communication 2024, the 14th International Conference on Computational and Financial Econometrics, the Royal Economic Society Annual Conference (2021 and 2024) and seminars at the National Institute of Economic and Social Research, London School of Economics and Political Science, University of Liverpool, and Brunel University London for their insightful comments and suggestions. The views expressed in this paper reflect those of the authors and do not necessarily reflect views of the institutions they are affiliated with. Any remaining errors are the authors' responsibility.

Contents

Glossary	4
Executive Summary	5
Introduction	6
Related literature	10
A model of debt supply and term premium	12
Applying text mining to Bank of England minutes	16
Determinants of the yield curve	22
Empirical model and results	24
Policy implications	29
Conclusions	30
Annex I. Long-term bond yield decomposition	32
Annex II. The LDA algorithm	34
Annex III. Uncertainty Indices	37
References	38
FIGURES	
Figure 1: Reaction of financial market to the Brexit referendum	6
Figure 2: Evolution of the BoE's monetary policy and bond yield components (January 2016–January 2020)....	7
Figure 3: Yield curve reaction to the Brexit referendum	8
Figure 4: Relationship between consol and T-bill prices	15
Figure 5: Bank of England MPC communication	19
Figure 6: Monetary Policy Shocks	23
Figure 7: Response of Yield Curve Determinants to GDP Growth, 95% and 68% confidence intervals (CI)	25
Figure 8: Response of Yield Curve Determinants to Policy rate Shock, 95% and 68% CI	26
Figure 9: Classification of Bank of England's Unconventional Strategies	26
Figure 10: Response of Term premium to QE Communication Shock, 95% and 68% CI	27
Figure 11: Response of Term Premium to Tone Shock, 95% and 68% CI	27
Figure 12: Response of Term Premium to Brexit Communication Shock, 95% and 68% CI	28
Figure 13: Significance of BoE Strategies in Reducing the Term Premium (95% CI)	29
Figure 14: Comparing text-based measures of uncertainty with Economic Policy Uncertainty (EPU) Index	37
Figure 15: Comparing text-based measures of uncertainty with EPU Index after 2016	37

TABLES

Table 1: Timeline of Brexit-related events, BoE actions and market reactions (bond-yield and exchange rate responses within one day around the event).	9
Table 2: Top 20 most probable tokens (stemmed) defining Topic 19 (interpreted as QE-related)	20
Table 3: Top 20 most probable tokens (stemmed) defining Topic 16 (interpreted as Brexit-related indicator)... ..	20
Table 4: Response of financial market risk measures	30
Table 5: List of hawkish and dovish terms	35
Table 6: Personal stopwords list	35
Table 7: Top 5 most likely terms defining each topic	36

Glossary

BoE = Bank of England

CPI = Consumer Price Index

FTSE 100 = Financial Times Stock Exchange 100 Index

GDP = Gross Domestic Product

GFC = Global Financial Crisis

LDA = Latent Dirichlet Allocation

MPC = Monetary Policy Committee

ONS = Office for National Statistics

QE = Quantitative Easing

TF-IDF = Term Frequency-Inverse Document Frequency

VAR = Vector Autoregression

VIX = Chicago Board Options Exchange's CBOE Volatility Index

Executive Summary

This paper examines the Bank of England's (BoE) monetary policy response to the result of the June 2016 advisory referendum, the UK's decision to withdraw from the EU (what has become known as Brexit) and its impact on UK government bond yields. Our investigation centers around three critical questions: the impact of BoE's monetary policies on government bond yields, the role of its communication strategy on market perceptions of risk, and the overall effectiveness of these measures in managing the uncertainties triggered by Brexit. To address these issues, we develop a model of sovereign debt supply to understand the drivers of bond yield risk premia, which we complement with an empirical analysis that assesses the response of BoE's monetary policy actions and words on the components of bond yields.

An important contribution of our empirical approach is the use of text mining and machine learning techniques to scrutinize the BoE's published communications. We utilize these methods to extract novel quantitative measures of the BoE's policy stance from its monetary policy summaries and MPC minutes, capturing the subtleties of the BoE's monetary policy communication strategy in order to understand better how communication or forward guidance may have supported the overall stance of monetary policy. Our new measures, which give an indication of the degree of hawkishness or dovishness in BoE communication, its focus on Quantitative Easing (QE), and specific communications addressing Brexit-related uncertainty, are then used to infer the causal effect of central bank communications on long term yields' components through local projections.

Our findings reveal that the BoE adopted a multilayered approach in explaining its reaction function in response to such an unusual sequence of events that significantly impacted UK bond yields. The central bank's communication, particularly regarding Brexit, played a significant role in shaping market expectations and reducing risk premia. The analysis shows that the BoE's adopted a "mixed strategy" that not only contributed to lowering the term premium – a proxy for investors' duration risk – but also contributed to adjust market expectations towards more expansionary monetary policy, counterbalancing potential increases in risk due to Brexit. An intriguing aspect of our findings is the complementarity and interplay among QE, Brexit-related communication, and the BoE's tone. This interplay suggests the relative impact of each communication component varies within time, highlighting the importance of a dynamic and adaptive policy framework for central bank communication in response to economic shocks.

In offering a comprehensive evaluation of the BoE's approach to influencing the long-term interest rates in the face of Brexit, the study highlights the effectiveness of a coordinated monetary policy strategy that combines various monetary tools with proactive communication (forward guidance). Using Brexit as a case study, such insights contribute to our understanding of the importance of central bank communication strategies in times of geopolitical and economic fragmentation.

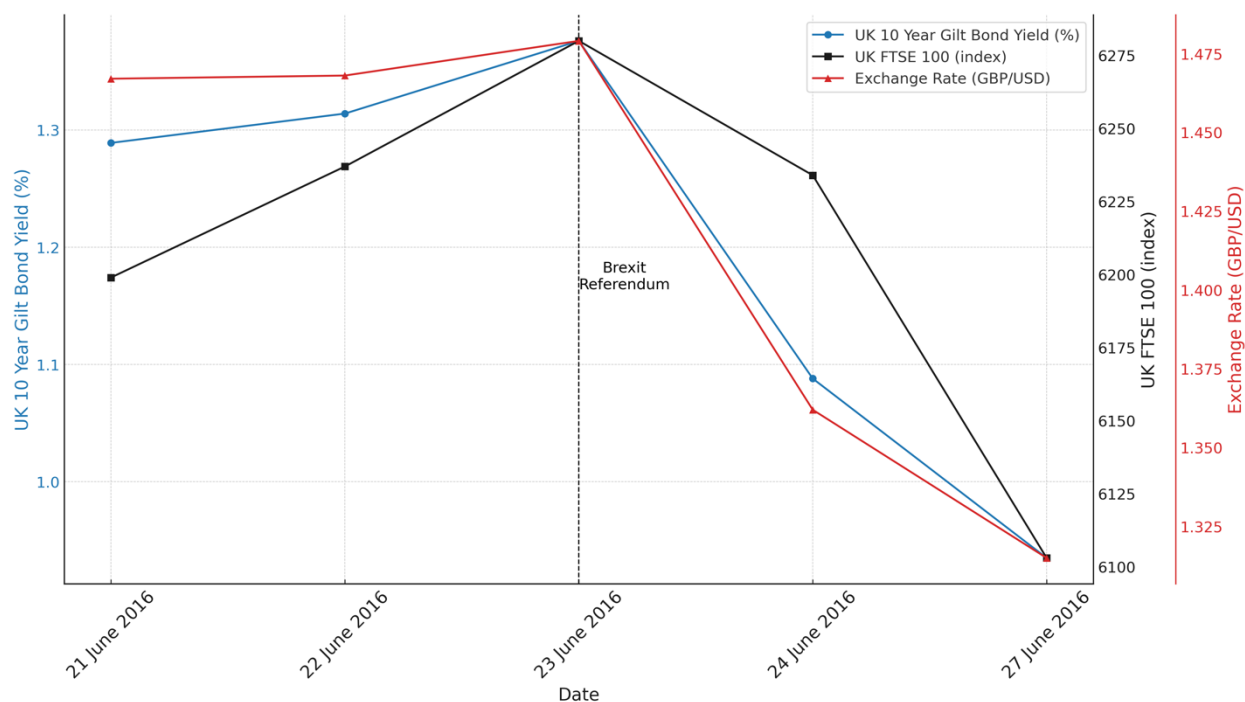
Introduction

“That is one of the advantages of guidance in this context. It’s giving a better sense, to use the technical term, of the MPC’s reaction function. It is not a change in the reaction function, but it gives a better sense of the MPC’s reaction function to financial market participants.”

Governor Mark Carney, Quarterly Inflation Report Q&A, August 2013.

The result of the United Kingdom’s (UK) referendum on whether to leave the European Union (EU), on 23 June 2016, led to elevated and prolonged economic uncertainty, which was quickly reflected in financial market fluctuations. On the day following the referendum, the UK stock market contracted by 3%, the pound depreciated by approximately 8% against the US dollar, and UK 10-year government bond yields declined by 30 basis points (Figure 1). These large responses to the surprise referendum result placed the monetary policy strategy of the Bank of England under a severe examination, where both actions and words were required to help stabilize bond markets and limit the disruption to economic activity. In this paper we focus on proving some quantitative measure on the impact of central bank communications, or what has been termed forward guidance (Barwell and Chadha, 2014).

Figure 1: Reaction of financial market to the Brexit referendum

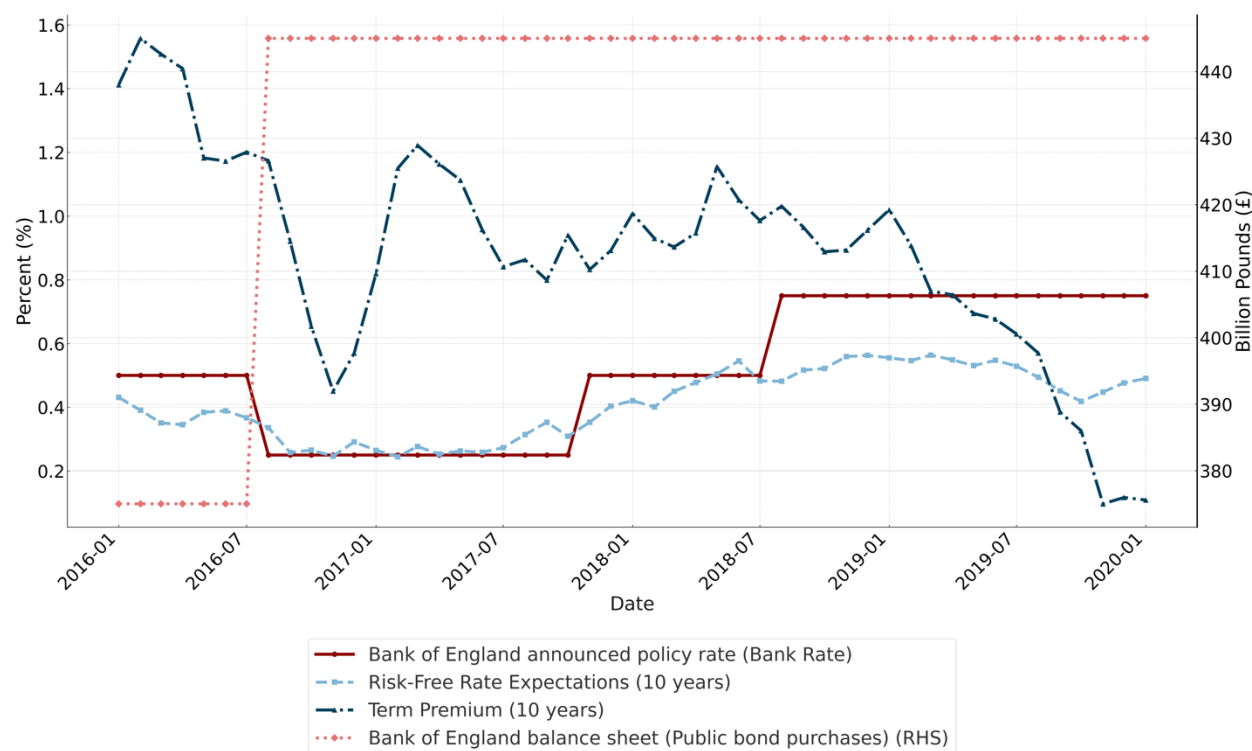


The referendum generated a large, broad-based, and long-lasting impact on the UK economy, reflecting significant shifts in investor expectations in the face of the UK’s future outside the European Union (International Monetary Fund, 2016; Bank of England, 2019). A marked decline in long-term risk-free rate expectations can be immediately observed post-referendum, which reflected expectations that the Bank of England (BoE) would take

accommodative policy action. On 4 August 2016, the BoE cut policy rates from 0.50% to 0.25%. This decision, which was part of a broader strategy, was accompanied by an expansion of its Quantitative Easing (QE) programme, aimed at supporting the UK economy (Figure 2)¹. But as we make clear in this paper also involved signalling, in monetary policy minutes and briefings, about how the BoE might respond as the economy evolved under the shadow of impending Brexit.

The UK bond market displayed notable movements that coincided with the period following the Brexit referendum and subsequent policy statement and adjustments by the Bank of England. A visual inspection of the data suggests a pronounced downward shift in the yield curve in the year following the referendum (Figure 3a). Moving into the latter half of 2017 and approaching June 2018—two years post-referendum—there was a gradual recalibration of the Bank's monetary policy stance, seemingly in reaction to rising inflation, which has been partially attributed to the depreciation of the pound post-referendum (Breinlich et al., 2022). The Bank's approach to increasing policy rates, coupled with market anticipations of further hikes, is also visible from a pivot in the yield curve post-2017. By the end of the Brexit transition period in January 2020, the yield curve had flattened significantly (Figure 3b).²

Figure 2: Evolution of the BoE's monetary policy and bond yield components³ (January 2016–January 2020)



¹ The Bank Rate was adjusted downward as part of the conventional measures, while an increase in the stock of UK government bonds purchased by £60 billion constituted part of the unconventional measures (Dell'Ariccia et al., 2018). The measures of the Bank of England lowered the 10-year gilt yield, as indicated in their 2016 Inflation Report (Bank of England, 2016a).

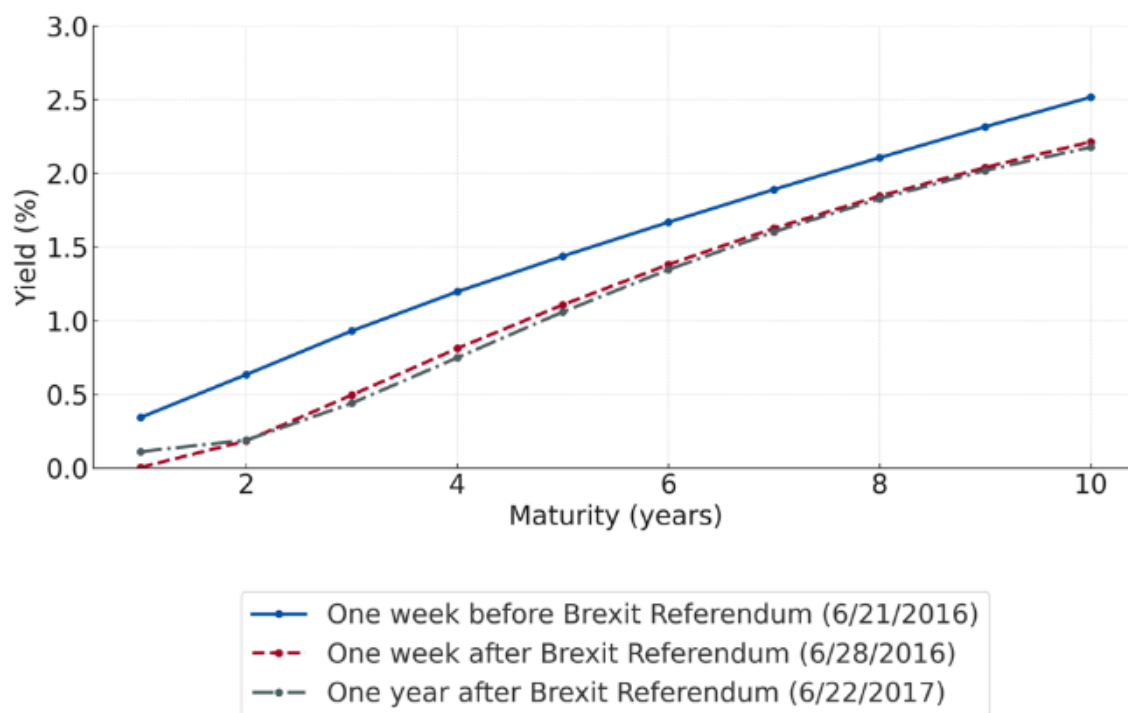
² From June 2016 to early 2020, the BoE implemented two rate hikes. November 2017 saw the first rate increase in over a decade, from 0.25% to 0.50%. In August 2018, rates were raised from 0.50% to 0.75% (Figure 2), the highest since March 2009. These hikes, aimed at countering inflationary pressures, were part of the Bank's strategy to approach its 2% inflation target. From 2017 onwards, a rise in interest rate expectations was evident, coinciding with the BoE's decision to taper its QE programme and adjust its base rate.

³ The long-term bond yields are decomposed into their constituents i.e. the risk-free rate expectations and term premium using the decomposition method proposed by Adrian et al, (2013). Please refer to Annex I for details.

Turning to long-term bond market reactions, Table 1 outlines a series of critical Brexit-related events, BoE actions, and the corresponding (unconditional) responses in 10-year UK bond yields' components around these events. Substantive bond market shifts occurred immediately following the referendum, specifically from the market close on 23 June 2016 to the end of 24 June 2016. Within one day, the term premium (a proxy for investors' risk perception) dropped by 10 basis points, while expectations about future risk-free rates plummeted by approximately 16 basis points, in anticipation of further monetary policy accommodation. Based on this, around 60% of the decline in bond yields can be attributed to changed expectations about future short-term rates. The pound depreciated on June 24, 2016, by around 8% relative to the US dollar. The second largest movement was a result of the Monetary Policy Committee (MPC) announcement on August 4, 2016. Theresa May's 2016 party conference speech and the publication of the Phase 1 agreement led to some increase in the risk premium, and further depreciations in the exchange rate.⁴

Figure 3: Yield curve reaction to the Brexit referendum

a) Pre-Brexit to One Year Post-Brexit Referendum



⁴ While there were actions by the Bank of England after January 2020, they were largely in response to the COVID-19 pandemic rather than directly associated with Brexit.

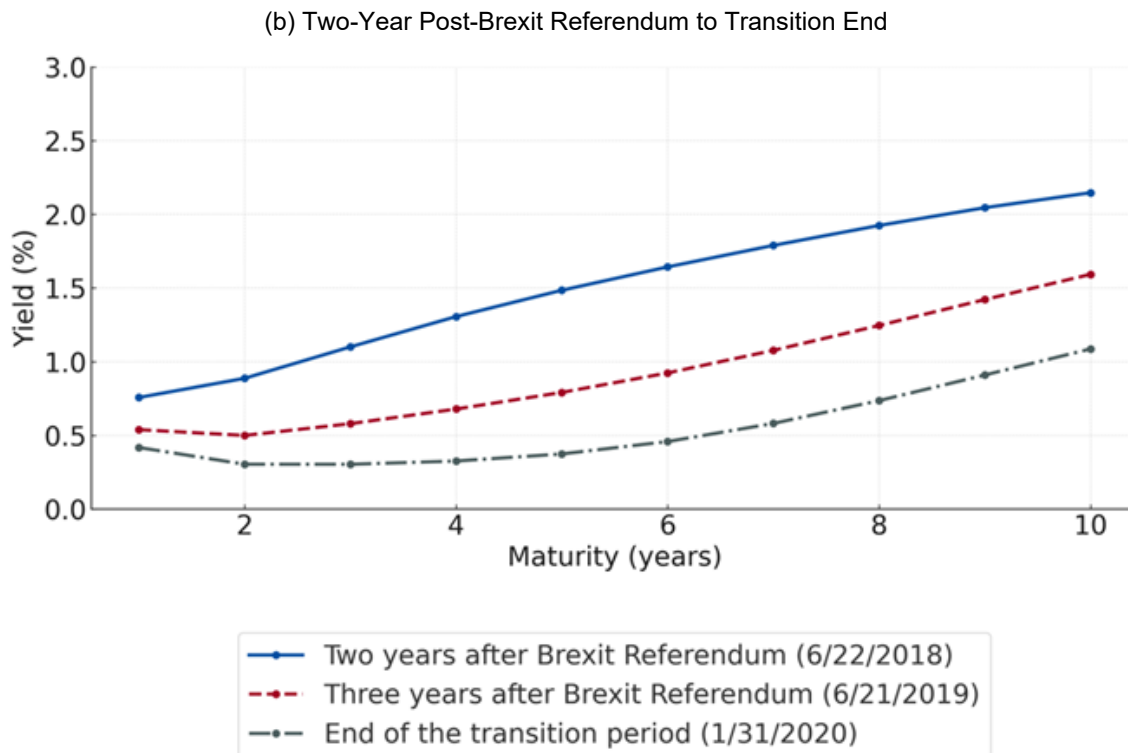


Table 1: Timeline of Brexit-related events, BoE actions and market reactions (bond-yield and exchange rate responses within one day around the event).

Key Dates	Brexit-related Events	Bank of England Actions	Term Premium (bp)	Risk-Free Rate (bp)	GBP/USD (%)
23 Jun 16	UK-EU membership referendum.	-	4.7	-0.5	0.8
24 Jun 16	PM David Cameron announces resignation.	Mark Carney's address on BoE's preparedness to stabilize markets and ensure UK's financial system resilience.	-9.8	-16.4	-8.0
4 Aug 16	-	QE expansion by £60 billion; rate cut to 0.25%.	-14.4	-2.2	-1.5
05 Oct 16	Theresa May's speech at Conservative Party convention.	-	5.3	0.7	-0.1
03 Nov 16	Brexit legality challenged in Supreme Court.	-	2.1	0.6	1.1
17 Jan 17	Theresa May's Lancaster House speech.	-	-4.0	1.6	2.7
24 Jan 17	Supreme Court requires Parliamentary approval of Brexit bill.	-	0.7	-0.6	0.1
29 Mar 17	Invocation of Article 50.	-	0.3	-4.1	-0.1
2 Nov 17	-	Rate raised to 0.50%.	0.2	-8.5	-1.4
08 Dec 17	UK-EU Phase 1 agreement.	-	4.6	-1.9	-0.3
2 Aug 18	-	Rate raised to 0.75%.	7.8	-8.3	-0.7
31 Jan 20	Transition period ends.	-	-3.4	1.4	0.6

Note: The UK 10-year bond yield data is sourced from NIESR's Sovereign Bond Term Premia Series, decomposed into term premium and risk-free rate expectations as per Adrian et al. (2013). Exchange rate data is obtained from ONS.

The relationship between Brexit and the UK's bond yield responses, combined with the Bank of England's monetary policy actions, raises three questions: i) How did the BoE's monetary policy (both conventional and

unconventional) influence UK government bond yields after Brexit? ii) What role did the BoE's communication strategy, encompassing forward guidance, play in shaping markets' risk perceptions? iii) Was the BoE's approach effective in navigating Brexit-related uncertainty?

In exploring the reactions of UK bond yields to Brexit, we begin with a simple theoretical model of sovereign debt supply. This model highlights the drivers of movements in long-term bond yields relative to short-term risk-free rate expectations in terms of liquidity preference and bond supply. Subsequently, we delve into an empirical analysis of bond yield responses, to changes in key macroeconomic variables as well as messages conveyed by monetary policymakers.

Our empirical analysis of UK bond yield responses consists of different stages. First, we use the standard three-step regression approach proposed by Adrian et al. (2013) to decompose UK 10-year bond yields into components that capture expectations about future risk-free rates and then also a term premium. Next, we use text-mining techniques (including dictionary methods and the Latent Dirichlet Allocation algorithm; see Blei et al., 2003) to extract measures of the monetary policy stance from the Bank of England's monetary policy summaries and MPC minutes. This analysis yields three novel indicators that run from 1999 to 2020. The 'tone index', captures the relative importance of the BoE's hawkishness versus its dovish 'tone', essentially, we are looking for the likely stance of policy towards tightening or loosening. Our other two indices quantify discussions on Brexit and QE in those same Bank communications. We then use the narrative approach (Romer and Romer, 2004; Cloyne and Hürtgen, 2016) to ascertain policy shocks from these indices. And finally we use local projection methods (Jordà, 2005) to infer the causal effect of central bank communication on long term yields' components.

To preview the results, our analysis suggests that the BoE's responses contributed significantly to a reduction in the market perception of risk, as well as shifting market expectations towards more expansionary monetary policy, which may have offset Brexit-related increases in risk. In this sense, our findings point to the effectiveness of the interplay between QE-communication, as well as communication strategies concerning Brexit, and the BoE's tone. It turns out that each of these influenced the UK risk premium across different time frames: QE, Brexit-related communication strategies, and tone are found to be most effective over 1 to 5 month, 4 to 8 month and at greater than 11-month horizon, respectively. This suggests that, while each policy holds its own importance, their relative influence depends on its strategic complementarity with other measures. The remainder of the paper is organized as follows: Section 2 delves into a review of the literature; Section 3 lays out a theoretical model of debt supply, liquidity and the term premium; Section 4 outlines our methodology for extracting quantitative measures of central bank communications; Section 5 presents our empirical model. Section 6 details our findings from a model of UK yield curve factors concerning the effects of monetary policy. Section 7 discusses the policy implications. And finally, Section 8 concludes.

Related literature

The result of the Brexit referendum significantly changed the UK's economic outlook, and this was quickly reflected in financial market prices. A notable consequence of Brexit was the heightened uncertainty regarding future policy directions (Dhingra and Sampson, 2022). Within this context, Born et al. (2019) analyzed the impact of the Brexit referendum on future expectations about the UK economy. They suggested that a considerable portion of the Brexit cost was attributable to lowered economic expectations. In a similar vein, Bloom et al. (2019) observed a sustained rise in uncertainty, reduced investment, as well as a drop in UK productivity in the three years following the referendum.

While it is evident that the financial markets (exchange rates, bond yields and stock markets) responded sharply to Brexit with, for example, the fall in equity prices explained by a worsening in the economic outlook.

Breinlich et al. (2018) find that firms with stronger reliance on the domestic or EU market experienced larger falls in share prices compared to more diversified international firms. Similarly, Davies and Studnicka (2018) estimate that the equity market reaction for companies that are part of complex supply chains was more substantial compared to less vulnerable peers. These observations highlight the rapid realignment of investors' expectations in light of the changed circumstances following the Brexit vote.

The bond market also displayed Brexit-induced disturbances. Belke et al. (2018) linked an increased Brexit probability to a decline in the UK's long-term interest rates. Conversely, they also noted an increase in the sovereign Credit Default Swap (CDS) for the UK's 10-year bonds, signaling an increased perception of risk. Complementing this analysis, Kadiric (2022) found that the announcement of the Brexit referendum result led to a surge in the risk premia in the UK and various European government bond markets. The study argues that Brexit significantly impacted yield spreads, leading to higher sovereign risk premiums in the UK and most other selected European countries. This could potentially suggest a degree of diminished confidence in the UK government bond as a safe asset, subjecting the UK's financial market and economy to new challenges. By using yield spreads as a proxy for risk premium, they highlight the complexities of investor risk assessment in times of significant political and economic shifts, such as Brexit.

Building on the understanding of the bond market responses, Opatryny (2021) offers a counterfactual analysis highlighting the potential path of the UK stock exchange, long-term government bonds, and exchange rate in the absence of the Brexit vote. This study revealed a substantial Brexit-induced negative effect on the 10-year bond yield, estimated to be 1.2 percentage points lower than the counterfactual 'no-Brexit' scenario. This effect can be compared to the impact of the Bank of England's Quantitative Easing (QE) implemented in February 2010, which resulted in a 100-basis point reduction in the 10-year bond yield (Joyce et al., 2011). Against this backdrop of bond market volatility and adjustments post-Brexit, the BoE's monetary policy decisions (including the use of unconventional tools such as QE), assumed heightened significance. There is much debate about the way QE 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. Additionally, Joyce et al. (2012), Christensen and Rudebusch (2012), and Chadha and Waters (2014) show that in the UK the Bank of England's Asset Purchase Programme's had a substantial portfolio rebalancing effect, whereby the central bank decreased the supply of safe assets like government bonds which reduced their yields. Moreover, Chadha and Hantzsche (2018) shed light on the international ripple effects of these measures, with the BoE's QE program notably impacting German Bund yields.

Our study examines the relationship between the Bank of England's (conventional and unconventional, including forward guidance from communications) monetary policy strategies and the behavior of UK long-term government bond yields against the backdrop of Brexit. Our empirical analysis, underpinned by advanced text-mining techniques, introduces three novel indicators that enhance our understanding of the BoE's communication strategies. By shedding light on the complementary roles of QE, Brexit-related communication strategies, and forward guidance on reducing the term premium across varied time horizons, this study not only contributes to the existing literature on the UK's bond yield responses to Brexit but also offers an understanding of the importance of central bank communications as part of the monetary policy strategy during turbulent times.

A model of debt supply and term premium

In theory, Brexit's impact on long-term government bond yields can be understood through multiple, sometimes competing, channels. Firstly, Brexit can be interpreted as a news shock about future nominal income growth (IMF, 2016). Barsky and Sims (2011), for example, find that real interest rates rise in response to positive productivity news. Conversely, one can expect the component of long-term yields reflecting future risk-free rate expectations to decline in response to negative news (*news effect*).

Secondly, uncertainty itself can reduce firms' propensity to hire and investment and consumers' intention to spend, leading to reduced employment and output growth (Bloom, 2014). However, investors may demand a higher compensation given the unknown future state of the economy, thus pricing risk premia (*uncertainty effect*).

Third, interest rates in the short and long-term are also influenced by the expectations of how the monetary authority will react (*policy anticipation effect*). A central bank mostly concerned about potential inflation pressures from higher trade costs might lean towards a tighter monetary policy, leading to a rise in short-term rate expectations. In contrast, a central bank more concerned about mitigating output responses may choose to bring forward future interest rate cuts, leading to expectations of lower future policy rates. It may additionally be expected to redeploy unconventional monetary tools, such as Quantitative Easing, adding another layer of complexity. How these expectations evolve will be affected by the communications published by the central bank about its view on the state of the economy and the central bank's likely reaction function.

In this section, we outline a stylized model of debt supply and risk premium. 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.⁵ Secondly, we model the standard household problem in an endowment economy, as in 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 receive a payoff to bonds held and then must decide how to allocate wealth across money balances, M_t^d , T-bills, z_t^N , and consols, z_t^c . They further receive a lump-sum transfer from the monetary-fiscal authority. The representative household thus solves:

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

subject to the following three constraints. The conditional expectations operator, E_0 , is defined with a time subscript, β 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 .

⁵ The government here acts as a combined monetary-fiscal authority.

The government budget constraint

The government budget constraint is given by:

$$\frac{x_t}{p_t} z_t^N + \frac{V_t z_t^c}{p_t} - \frac{1}{p_t} z_{t-1}^N - \frac{(1+V_t)z_{t-1}^c}{p_t} - \frac{\theta_t}{p_t} = \frac{T_t}{p_t} \quad (2)$$

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, $\frac{\theta_t}{p_t} = \frac{M_t^d}{p_t} - \frac{M_{t-1}^d}{p_t}$. 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

$$\frac{p_{t-1}}{p_t} c_{t-1} + \frac{x_t}{p_t} z_t^N + \frac{V_t z_t^c}{p_t} + \frac{M_t^d}{p_t} = \frac{p_{t-1}}{p_t} y_{t-1} + \frac{1}{p_t} z_{t-1}^N + \frac{(1+V_t)z_{t-1}^c}{p_t} + \frac{M_{t-1}^d}{p_t} + \frac{T_t}{p_t} \quad (3)$$

The household flow budget constraint balances the household's real income and expenditures. Real income includes the previous period's endowments y_{t-1} , bond revenues z_{t-1}^N and z_{t-1}^c , money holdings M_{t-1}^d , and government transfers T_t . Expenditures encompass the previous period's consumption c_{t-1} and the current period's allocation towards new bond purchases z_t^N and z_t^c and money balances M_t^d .⁶

The household decides how to allocate their 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.

Cash-in-advance constraint

$$c_t \leq \frac{M_t^d}{p_t} + \phi \frac{z_t^N}{p_t} \quad (4)$$

This constraint bounds the household's consumption to the real value of its liquid assets, namely, the real balances of money, $\frac{M_t^d}{p_t}$, and a portion of T-bills, $\phi \frac{z_t^N}{p_t}$, which are liquid enough to be used for immediate consumption, akin to the role of currency. It highlights the necessity for households to have liquid funds readily available for their consumption plans.

The first-order conditions

Given their constraints and objectives, households make decisions regarding their consumption levels (c_t), bond purchases (z_t^N, z_t^c), and money holdings (M_t^d). This optimization (utility maximization problem) yields first-order conditions that determine the pricing of T-bills and consols.

⁶ 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 Lagrange multiplier associated with the household budget constraint is λ_t and that associated with the cash-in-advance constraint is μ_t . The first-order conditions associated with this problem then are:

$$u'(c_t) = \beta E_t \lambda_{t+1} \frac{p_t}{p_{t+1}} + \mu_t, \quad (5)$$

for consumption.

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

$$x_t = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{p_t}{p_{t+1}} + \phi \frac{\mu_t}{\lambda_t} \quad (6)$$

for the T-bill.

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

$$q_t \equiv \frac{V_t}{(1 + V_{t+1})} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{p_t}{p_{t+1}} \quad (7)$$

for the consol price.

$$\lambda_t \frac{1}{p_t} = \beta E_t \lambda_{t+1} \frac{1}{p_{t+1}} + \mu_t \frac{1}{p_t}$$

$$\lambda_t = \beta E_t \lambda_{t+1} \frac{p_t}{p_{t+1}} + \mu_t \quad (8)$$

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).

$$u'(c_t) \frac{x_t}{p_t} = \beta E_t u'(c_{t+1}) \frac{1}{p_{t+1}} + \phi \frac{\mu_t}{p_t}$$

$$u'(c_t) \frac{x_t}{p_t} = \beta E_t u'(c_{t+1}) \frac{1}{p_{t+1}} + \phi \left(\lambda_t \frac{1}{p_t} - \beta E_t \lambda_{t+1} \frac{1}{p_{t+1}} \right)$$

$$u'(c_t) \frac{x_t}{p_t} = \beta E_t u'(c_{t+1}) \frac{1}{p_{t+1}} + \phi \left(u'(c_t) \frac{1}{p_t} - \beta E_t u'(c_{t+1}) \frac{1}{p_{t+1}} \right)$$

$$x_t = \beta E_t \frac{u'(c_{t+1})}{u'(c_t)} \frac{p_t}{p_{t+1}} + \phi \left(\frac{u'(c_t) p_t}{u'(c_t) p_t} - \beta E_t \frac{u'(c_{t+1})}{u'(c_t)} \frac{p_t}{p_{t+1}} \right)$$

$$x_t = \beta E_t \frac{u'(c_{t+1})}{u'(c_t)} \frac{p_t}{p_{t+1}} + \phi \left(1 - \beta E_t \frac{u'(c_{t+1})}{u'(c_t)} \frac{p_t}{p_{t+1}} \right) \quad (9)$$

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, ϕ , for these nominal bonds. We can immediately see that the hypothetical price of the consol will be:

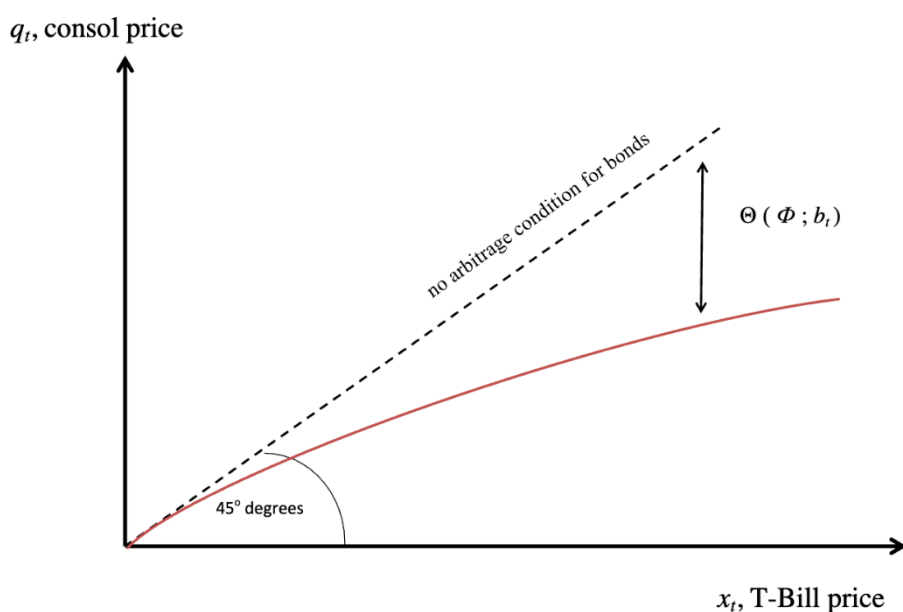
$$q_t \equiv \beta E_t \frac{u'(c_{t+1})}{u'(c_t)} \frac{p_t}{p_{t+1}} \quad (10)$$

And so,

$$x_t = (1 - \phi)q_t + \phi$$

The pricing formula for T-bills, x_t , illustrates a weighted sum of two components. The first term, $(1 - \phi)q_t$, mirrors the consol's price, reflecting the nominal rate of substitution between current and future consumption, adjusted for the lack of liquidity $(1 - \phi)$. The second term, ϕ , introduces the liquidity premium associated with T-bills. This premium signifies the additional value attributed to T-bills due to their higher liquidity relative to consols.

Figure 4: Relationship between consol and T-bill prices



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:

$$q_t' = \frac{q_t}{e^{\psi(b_t - \bar{b})}}$$

so that as the total stock of debt (both T-bills and consols), b , increases above its steady-state, \bar{b} , then the market price of consols, q'_t , relative to T-bills falls.⁷

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:

$$q'_t = \frac{x_t - \phi}{(1 - \phi)e^{\psi(b_t - \bar{b})}} \quad (11)$$

Proposition 2 The market price of consols relative to T-Bills falls in liquidity (ϕ) and in the issuance of bonds, (b).

The difference between the hypothetical price for consols (in the absence of arbitrage) and hypothetical one-period returns – equation (11) – can be interpreted as term premium. We have shown that it can be modelled as a function of the liquidity and size of the debt stock. For instance, if the government reduces the net supply of long-term bonds b_t , for instance, by adopting Quantitative Easing, we 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 T-bills or money instead of bonds would also be expected to widen the price wedge and increase the yield premium during periods of elevated risk aversion. Any credible announcements about increases in the net supply of bonds or events that increase the demand for liquidity may be expected to increase term premia. The BoE may this have an incentive to adopt a communication strategy that mitigates against these effects if they do not match the intended stance of policy.

Applying text mining to Bank of England minutes

A key element of contemporary central banking strategy, including that of the Bank of England, is not only to implement effective monetary policies but also to clearly convey the reasoning underpinning such decisions (Apel and Grimaldi, 2012). The Bank of England's Monetary Policy Committee's (MPC) summaries and minutes offer detailed 'post-meeting assessments' that articulate the economic analysis influencing proposed changes and the subsequent adjustments in monetary policy. The nine-member MPC evaluates economic performance and its potential impact on inflation and growth. The minutes provide an exhaustive and, importantly, contemporaneous overview of their financial market assessments and macroeconomic conditions, which guide decisions on maintaining price stability and supporting the government's objectives on growth. To obtain quantitative measures of the central bank's communication narrative, we apply several text-mining techniques to the corpus of Bank of England monetary policy summaries and minutes of MPC meetings⁸ for our sample spanning from

⁷ The parameter ψ represents the non-linear costs or frictions that arise to prevent arbitrage. The exponential term denotes that these costs increase as the debt stock deviates more significantly from its steady state.

⁸ 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 25 Feb 2021.

January 1999 to December 2019.⁹ We go on to construct measures of hawkishness in tone and the degree to which asset purchase programmes and Brexit-related communication are discussed at the MPC.¹⁰

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 carefully scrutinised by financial market participants. They are part of the Bank's set of 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 insights and assessment of the current and expected condition of the macroeconomy, financial market developments, and the rationale behind decisions around the policy interest rate.¹¹

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 released the minutes on the Wednesday of the second week after the MPC meeting. The frequency of meetings per year also varied over the past two decades. Indeed, until 2015 the MPC used to meet monthly. Since 2016, 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. We capture all these minutes and publications in our text mining.

Turning to our 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 concerning the final voting process, as well as related bullet points.¹² 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 capitalisations.

A more tailored pre-processing is required when applying text mining. We provide further explanations related to these techniques in the following subsections and in the Annex. To illustrate how our algorithms might function, we highlight specific examples drawn from the Bank of England's Minutes of the Monetary Policy Committee meetings. For instance, the following quote from the BoE's Minutes of the MPC meeting is likely to be picked up by the algorithm for its relevance to Brexit-related uncertainty:

"Taken together, developments in financial markets suggested that participants were placing less weight than in February on downside risks materialising in the near term. A number of risks to the global economy remained, including from emerging markets and from weak advanced economy productivity growth. The outcome of the referendum on EU membership continued to be the largest domestic risk."

Bank of England's Minutes of the Monetary Policy Committee Meeting ending on 11 May 2016

⁹ See Bholat et al. (2015) for an extensive survey of text mining techniques and related applications on central bank documents.

¹⁰ Instances of disagreements are also recorded in these meetings. For example, the August 2016 MPC report (Bank of England, 2016b), post-Brexit referendum, sheds light on committee disagreements, as evidenced in points 40 and 41. Such details unveil the underpinnings of consensus and disagreements within the monetary policy committee, contributing to the discourse on central bank disagreement dynamics. Some recent studies such as Madeira et al. (2023); Falck et al. (2017) have tried to study this.

¹¹ Other potential forms of Bank of England communication to analyze include the Inflation Report and MPC members' speeches. However, the former is released quarterly and provides mainly information about the Bank's economic forecasts. The latter are relatively unstructured text data with irregular frequencies that would cause several methodological challenges to text mining approaches.

¹² Usually, the voting information is included at the end of the document representing the last points of the meeting minutes.

Furthermore, in exploring the topic of QE, the algorithm is likely to identify relevant sentences, such as the following from the MPC meeting minutes:

“The MPC also considered an expansion of its asset purchase programme for UK government bonds, financed by the issuance of central bank reserves. This would trigger portfolio rebalancing into riskier assets, lowering the real cost of borrowing for households and companies. The Committee was mindful of the fact that an expansion of its asset purchase programme would be within the context of an already low interest rate environment.”

Bank of England’s Minutes of the Monetary Policy Committee Meeting ending on 3 Aug. 2016

Measuring central bank hawkishness vs dovishness (tone) using 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 based on a pre-specified dictionary. Put differently, the sentiment orientation of a document is expressed in terms of the frequency of words which are part of an ex-ante built dictionary. The existing literature has proposed several dictionaries to define different sentiments from text data. Following recent empirical studies applying specific dictionary methods to central bank documents (Apel and Grimaldi, 2014, Tobback et al., 2017, and Bennani and Neuenkirch, 2017), we build a dictionary tailored to the monetary policy context, but, more importantly, are able to extract the Bank of England’s hawkish or dovish tone (“hawkishness”).¹³

The measure of hawkishness, which we call ‘tone’, at the meeting level is given as follows:

$$\text{Tone}_{(H-D)_m} = \frac{\sum_{h \in H} (h_m w_h) - \sum_{d \in D} (d_m w_d)}{\sum_{h \in H} (h_m w_h) + \sum_{d \in D} (d_m w_d)} \quad (12)$$

where h is a hawkish token occurring in a monthly MPC minutes document m and belonging to the pre-specified hawkish-dictionary H . w_h is the related weight defined by the term frequency-inverse document frequency (tf-idf).¹⁴ The same logic applies for to dovish terms d taken from a dovish dictionary D . The full word list of both dovish and hawkish dictionaries is reported in Annex II (Table 5). The indicator is normalised by the sum of hawkish and dovish terms occurring in each document so that $\text{Tone}_{(H-D)_m}$ is bound between +1 (hawkish) and -1 (dovish).

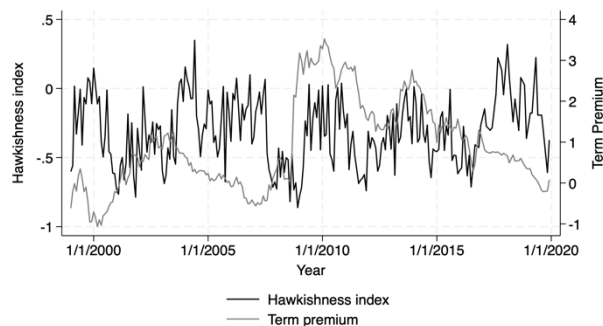
The signalling content of MPC minutes is meant to anchor market and private-sector expectations so as to ensure a more effective implementation of monetary policy. We interpret this as a measure of the Bank of England’s tone aiming at providing policy signals to both markets and individual agents.

¹³ See Cannon et al., 2015 for a more detailed critique of the adoption of too broad dictionaries for extracting central bank communication indicators.

¹⁴ The tf-idf weight is widely adopted in text mining to weight words in large archives of documents. The weight is defined by two components: the ‘term frequency’ that is given by the ratio between the frequency of a term appearing in a document and the total number of terms in the document; the ‘inverse document frequency’ that is the natural logarithm of the ratio between the number of documents and the number of those documents containing the specific term.

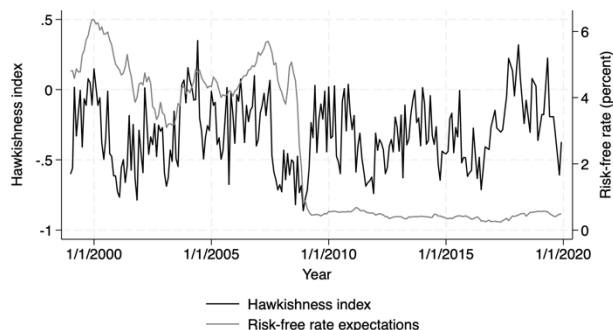
Figure 5: Bank of England MPC communication

(a) H-D tone vs term premium



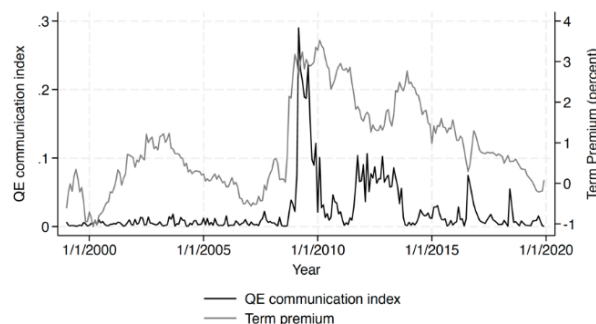
Note: H-D tone (black line, left scale), against the term premium (grey line, right scale)

(b) H-D tone vs risk-free rate



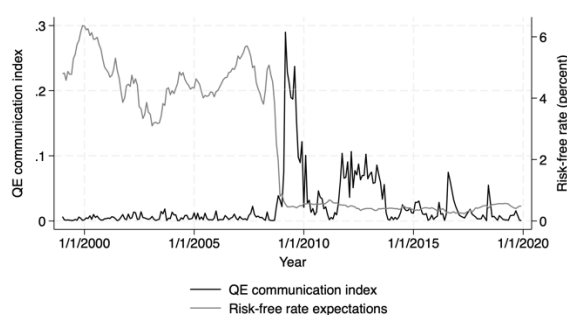
Note: H-D tone (black line, left scale), against the risk-free rate (grey line, right scale)

(c) QE communication vs term premium



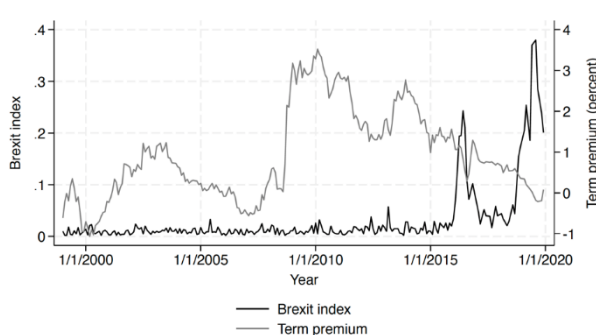
Note: QE communication (black line, left scale), against the term premium (grey line, right scale)

(d) QE communication vs risk-free rate



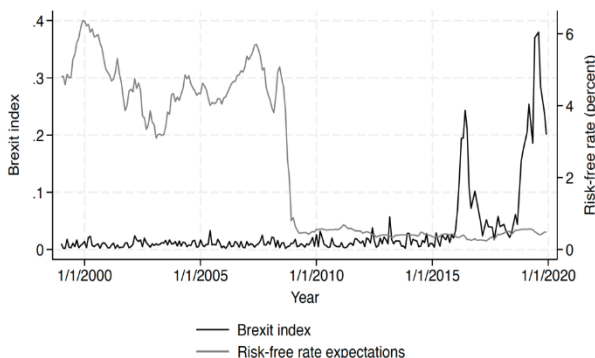
Note: QE communication (black line, left scale), against the risk-free rate (grey line, right scale)

(e) Brexit-related communication vs term premium



Note: Brexit focused communication (black line, left scale), against the term premium (grey line, right scale)

(f) Brexit-related communication vs risk-free rate



Note: Brexit focused communication (black line, left scale), against the risk-free rate (grey line, right scale)

For instance, Figure 5a and 5b plot the time series of the BoE hawkishness vs dovishness (H-D), i.e., $Tone_{(H-D)_m}$, against the term premium and short-rate expectations, respectively.¹⁵ Plotted time series illustrate some correlation between Bank of England tone and markets' expectations, until 2009. We can see that the evolution of the short-term rate expectations follows the BoE's tone measure closely; an opposite relationship seems to be apparent from the comparison with the term premium.

Measuring QE and Brexit-related communication using the LDA algorithm

Next, 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 popular algorithm in text mining and is applied in numerous research disciplines.¹⁶ 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 analysis¹⁷, 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.

Table 2: Top 20 most probable tokens (stemmed) defining Topic 19 (interpreted as QE-related)

1	purchas	6	broad	11	lend	16	polic
2	asset	7	bond	12	gilt	17	meet
3	programm	8	sector	13	yield	18	financi
4	fall	9	increas	14	stimulus	19	gdp
5	economi	10	corpor	15	spread	20	reserv

Table 3: Top 20 most probable tokens (stemmed) defining Topic 16 (interpreted as Brexit-related indicator)

1	uncertainty	6	invest	11	taken	16	drag
2	referendum	7	household	12	financial	17	outcome
3	asset	8	lead	13	delay	18	exchange
4	risk	9	return	14	effect	19	investor
5	capital	10	leave	15	risky	20	look

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

¹⁵ For a detailed outline of the long-term bond yield decomposition process into the risk-free rate expectations and term premium, please refer to Annex I. This decomposition utilizes the three-step estimation approach proposed by Adrian et al. (2013).

¹⁶ See, for instance, Hansen and McMahon, 2016, and Hansen et al., 2017, for an application of LDA to documents released by the Federal Reserve.

¹⁷ The technical hierarchical Bayesian structure of the algorithm is presented in Annex II. Please refer to Blei et al. (2003) and Blei (2012) for an extensive explanation.

to the researcher's interpretation. We set $K = 44$ 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 60 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 our specific analysis.¹⁸ 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').

In Table 7 in Annex II, we report the top five terms specifying each of the 44 topics identified by the algorithm. Two topics caught our attention. Their 20 most likely tokens are shown in Tables 2 and 3, respectively, with the order of words defined by the posterior distribution. Topic 19 (Table 2) is defined by terms highly associated with the Bank's asset purchase programmes, such as "purchase", "asset", "program", "bond", "corporate", "gilt", "yield", "stimulus", "reserve". We therefore measure the intensity with which this topic features in MPC minutes and construct an index of QE communication. Figure 5c and 5d plot the proportion in MPC minutes allocated to the QE topic against the term premium and risk-free rate expectations, respectively. The QE measure exhibits significant spikes around the multiple announcements of the programme by the Bank of England. The first spike corresponds to the first QE intervention in 2009. The second wave of high topic proportions occurs around the second QE implementation that commenced in October 2011. Finally, high volumes of QE-related discussions are reported around the third QE intervention starting in August 2016.

Topic 16 (Table 3) encompasses words that are clearly related to the uncertainty surrounding the referendum, for instance. The topic includes terms like "referendum", "uncertainty", "risk", "capital", "invest", "leave", "risk", "exchange". Figure 5e and 5f show that the Brexit-related measure constructed using the intensity of the topic captures well the uncertainty sentiment of the Bank of England extracted from its minutes.¹⁹ For instance, the series peaks on 14 of July 2016 which was the day of the first MPC meeting after the referendum held on 23 June 2016. Figure 5e shows an interesting aspect of the dynamics during the months around the Brexit referendum. Between May 2016 to September 2016, we observe 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 5f does not seem to suggest a strong relationship between the Brexit uncertainty index and short-term rate expectations.

¹⁸ 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 reported in Annex II (Table 5).

¹⁹ While we are able to construct general indicators focused on a broader definition of uncertainty from the MPC, those measures largely overlap with communication which is Brexit-related (the correlation between the two is 0.65 in the post-Brexit sample). In our empirical analysis, we decide to include Brexit-related communication only and control for general uncertainty as described by indicators of ex-post financial market volatility such as the VIX indicator; see section 5.3 and Annex III.

Determinants of the yield curve

Data

Bond yield components are estimated as explained in Annex I and are available at a monthly frequency. We obtain a monthly estimate of GDP growth from the National Institute of Economic and Social Research (NIESR) database. Financial variables, i.e., the exchange rate, FTSE100 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 December 2019, and becomes irregular from late 2016 onwards to accommodate the altered frequency of Monetary Policy Committee (MPC) meetings since then. In order to mitigate any potential spurious correlations, we estimate the model using the irregular sample, rather than employing any interpolation techniques ensuring the validity of our analysis.

While the Brexit vote was in 2016, the UK's formal exit occurred on 31 January 2020. We exclude the latter part of the transition period, positing that market reactions to Brexit were largely anticipated. Furthermore, to avoid identification issues from potential spillover related to global trade and health shocks, such as COVID-19, our analysis primarily focuses on data up to December 2019.

Extracting central bank communication shocks

In the empirical model, the measures of central bank communication are orthogonalized to contemporaneous macroeconomic information, thereby functioning as pure exogenous shocks. In practice, central bank communication aims at steering expectations on financial markets at least as much as it responds to previous, contemporaneous and expected changes in the economic outlook. We therefore follow the narrative approach of Romer and Romer (2004) and Cloyne and Hürtgen (2016) – the latter previously employed for the BoE – and strip out systematic, i.e., predictable, components.

To make sure our shock measures are orthogonal to present and past information, we employ real-time forecasts for GDP growth, inflation and unemployment from the historical NIESR forecast database to isolate innovations to series of conventional (Bank Rate) and unconventional tools (tone, QE, and Brexit-related indices extracted from the Bank's minutes).²⁰

More specifically, to strip Bank rate of systematic, forecastable components, we run the following regression (Romer and Romer, 2004):

$$\begin{aligned} \Delta r_m = & \alpha + \beta_1 r_m^{b14} + \sum_{-1}^2 \lambda_{1,i} y_{m,i}^f + \sum_{-1}^2 \gamma_{1,i} \pi_{m,i}^f + \sum_{-1}^2 \zeta_{1,i} (y_{m,i}^f - y_{m-1,i}^f) \\ & + \sum_{-1}^2 \delta_{1,i} (\pi_{m,i}^f - \pi_{m-1,i}^f) + \theta_1 (\mu_{m,0} - \mu_{m-1,0}) + \xi_m^{MP} \end{aligned} \quad (13)$$

where the dependent variables is the change in Bank Rate announced on day m (i.e., change of the policy rate between two meetings) and r_m^{b14} is the rate two weeks prior to the meeting m .²¹ We regress the change in the

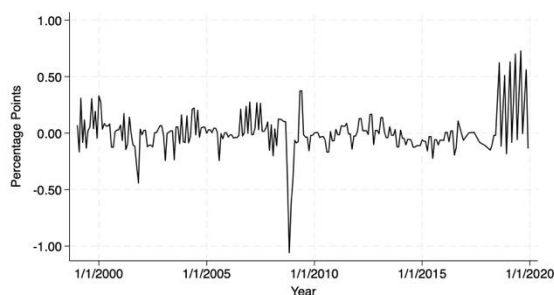
²⁰ Following Cloyne and Hürtgen (2016), we assume that forecasts from NIESR are a good proxy for the real-time information set held by Bank of England policymakers.

²¹ Since MPC meetings fall on different days of the month, generally the first 10 days, a convenient approach is to consider the policy rate that prevailed 14 days before.

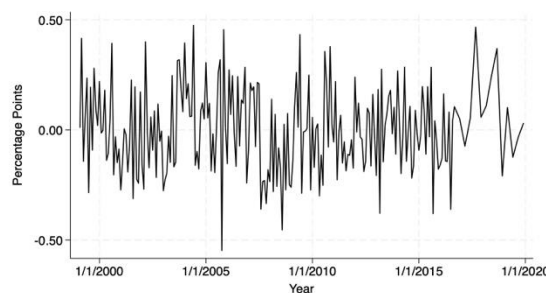
policy rate on estimates of real GDP growth for one month back and the current month as well as on one and two-month ahead forecasts of real GDP growth y^f ,²² and similarly for inflation, π^f . For the same variables and forecasting horizons, we include related forecast revisions, i.e., the changes in estimates and forecasts from one month to the next. We also control for the current month forecast revision of unemployment $\mu_{m,0} - \mu_{m-1,0}$.²³ Finally, the error term ξ_m^{MP} then captures the component of Bank Rate that cannot be predicted from real-time information on GDP growth, inflation, and unemployment.²⁴

Figure 6: Monetary Policy Shocks

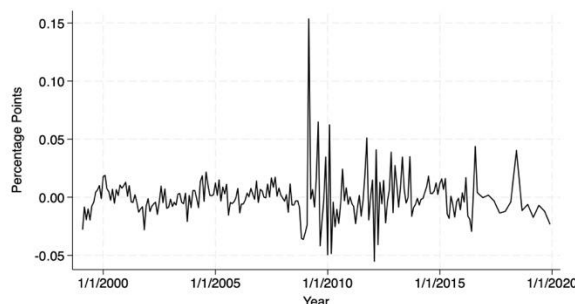
(a) Policy rate shock



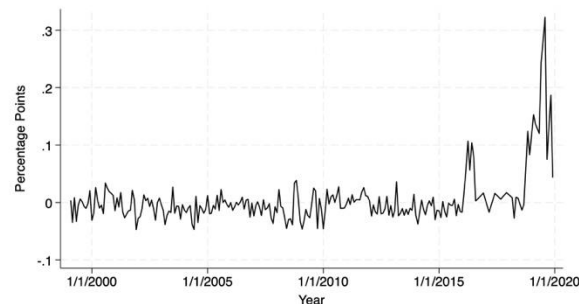
(b) Tone shock



(c) QE communication shock



(d) Brexit communication shock



Note: The shocks are indices of central bank communication orthogonalized to contemporaneous information using a Romer and Romer (2004) regression. The sample is irregular as, since 2016, BoE MPC releases changed from 12 to 8 times a year.

²² Under the plausible assumption that the real-time GDP forecast revisions in the Romer and Romer (2004) regressions capture expected changes in fiscal stances, including any budgetary adjustments, our regression structure ensures that the identified monetary policy shocks are orthogonal to underlying fiscal dynamics. By systematically accounting for any fiscal response present in the GDP forecast, we ensure that our monetary policy shocks remain uncorrelated with anticipated fiscal shifts.

²³ This factor differs from the specification of both Romer and Romer (2004) and Cloyne and Hürtgen (2016). The former uses the level of the current-quarter forecast of unemployment. The latter include three monthly lags of unemployment. However, our baseline specification is based on Bayesian information criteria and the results are robust to the Romer and Romer (2004) specification since we deal with quarterly forecasts.

²⁴ To capture the variation in averages before and after the Global Financial Crisis (GFC) of 2007, we conduct separate regression analyses on two distinct samples: one pre-crisis and one post-crisis. Our measure of monetary policy shock is derived from the cumulative effect of these individually estimated shocks from both periods.

Similarly, we model changes in tone, QE, and Brexit-related communication measures between two meetings ($J = \text{Tone}_{(H-D)_m}, \text{QE}, \text{Brexit}$) as:

$$\Delta J_m = \alpha + \beta_2 J_{m-1} + \rho_1 \xi_m^{MP} + \sum_{-1}^2 \lambda_{2,i} y_{m,i}^f + \sum_{-1}^2 \gamma_{2,i} \pi_{m,i}^f + \sum_{-1}^2 \zeta_{2,i} (y_{m,i}^f - y_{m-1,i}^f) + \sum_{-1}^2 \delta_{2,i} (\pi_{m,i}^f - \pi_{m-1,i}^f) + \theta (\mu_{m,0} - \mu_{m-1,0}) + \xi_m^J \quad (14)$$

After controlling for movements in Bank Rate through the policy rate shock, we refer to the innovations ξ_m^{MP} , ξ_m^{TONE} , ξ_m^{QE} and ξ_m^{Brexit} as "policy rate shock", "tone shock", "QE shock" and "Brexit shock", respectively. We construct the QE shock variable when the minutes started including information content related to purchases of government securities, as the Bank of England announced the first QE programme in March 2009.

Figure 6a and 6b show the indices for the policy rate and tone shocks, while Figure 6c and 6d portray the shocks for the Quantitative Easing (QE) and Brexit-focused communication. We find that the reductions in Bank Rate implemented during the Great Recession of 2009 exceeded what could have been inferred from macroeconomic information available in real time. Our policy rate shock index falls by more than 50 basis points. At the same time, the BoE appears to have surprised markets with more hawkish communication at that time, compared to what the change in macroeconomic information would have suggested. Figure 6c shows that in particular the first announcement of quantitative easing came as a surprise: our QE communications shock index rises by more than five standard deviations in 2009.

Even preceding the UK's referendum decision to withdraw from the European Union in June 2016, Brexit-related communication increased, providing an early indication of growing apprehensions about the potential impact of the UK's exit from the European Union. The Monetary Policy Committee's (MPC) choice to initiate QE again in August 2016 (Bank of England, 2016) is captured in the rise of the QE shock.

Empirical model and results

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.

Our primary identification strategy draws upon local projections, incorporating both endogenous and exogenous variables. The endogenous constituents consist of the bond yield elements, specifically the term premium and risk-free rate, estimated through the three-step estimation method advanced by Adrian et al. (2013) (see Annex I). This is complemented by macroeconomic indicators such as GDP growth and inflation, to allow shocks' cross-correlation. The estimation also includes the previously identified shocks – tone, Brexit, and QE – and includes the interaction term between the term premium and a Brexit dummy.²⁵ We denote these variables by the matrix

²⁵ To address the identification problem arising from simultaneous crises periods and the surge of the term premium in the UK, we introduce exogenous dummy variables to control for large residual outliers. These dummies are then employed as exogenous variables in the local projections. The dummy for Global Financial Crisis (GFC) is defined from December 2007 to June 2009. The Brexit dummy starts from July 2016. The euro area sovereign crisis dummy is defined from May 2010 to July 2012.

$\mathbf{Y}_t \equiv (\mathbf{y}_{t+1}, \dots, \mathbf{y}_{t+h})$, where h , the forecast horizon is set to 12 in our model, and provides the dynamic response over a twelve-months horizon.

The matrix $\mathbf{X}_t \equiv (\mathbf{y}_{t-1}, \mathbf{y}_{t-2}, \dots, \mathbf{y}_{t-p})$ contains the lagged values of the endogenous variables up to a given order p .

Moreover, we also incorporate a series of exogenous variables into our model. These include the US term premium, the volatility index (VIX), the exchange rate (Pound to US Dollar), the FTSE 100 (stock market index), and dummies for the global financial crisis, the Euro debt crisis, and Brexit, which we collect in matrix \mathbf{Z}_t .²⁶ Given these components, we estimate the following joint system:

$$\mathbf{Y}_t = \mathbf{X}_t \boldsymbol{\Psi} + \mathbf{Z}_t \boldsymbol{\Theta} + \mathbf{V}_t \boldsymbol{\Phi} \quad (15)$$

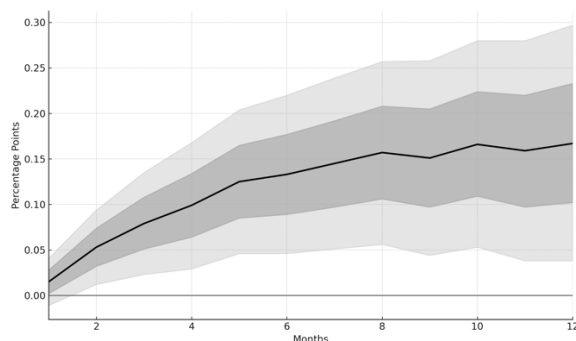
Here, $\boldsymbol{\Psi}$, $\boldsymbol{\Theta}$ and $\boldsymbol{\Phi}$ are the matrices of coefficients that we aim to estimate. This specification captures how the endogenous variables respond to their own past values (through \mathbf{X}_t), the exogenous variables (through \mathbf{Z}_t), and system shocks (through \mathbf{V}_t).

Results

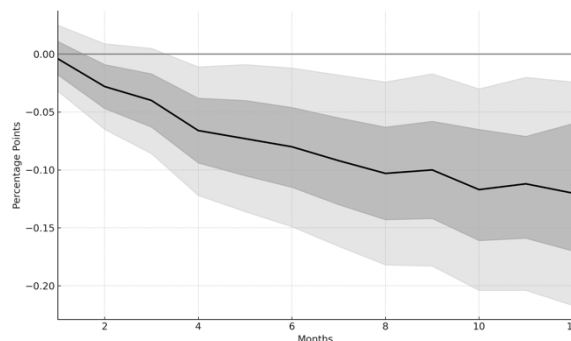
This section presents our main results. Prior to examining how conventional policy rate shocks influenced yield curve determinants, we illustrate the reaction of these determinants to a shock in GDP growth. This analysis not only shows the evolution of the yield curve in response to a change in economic growth but also serves to validate the model's regularity. Figure 7 presents the relationship between risk-free interest rate expectations (sub-figure 7a) and the term premium (sub-figure 7b) in response to changes in GDP growth.

Figure 7: Response of Yield Curve Determinants to GDP Growth, 95% and 68% confidence intervals (CI)

(a) Risk-free rate, GDP growth



(b) Term premium, GDP growth



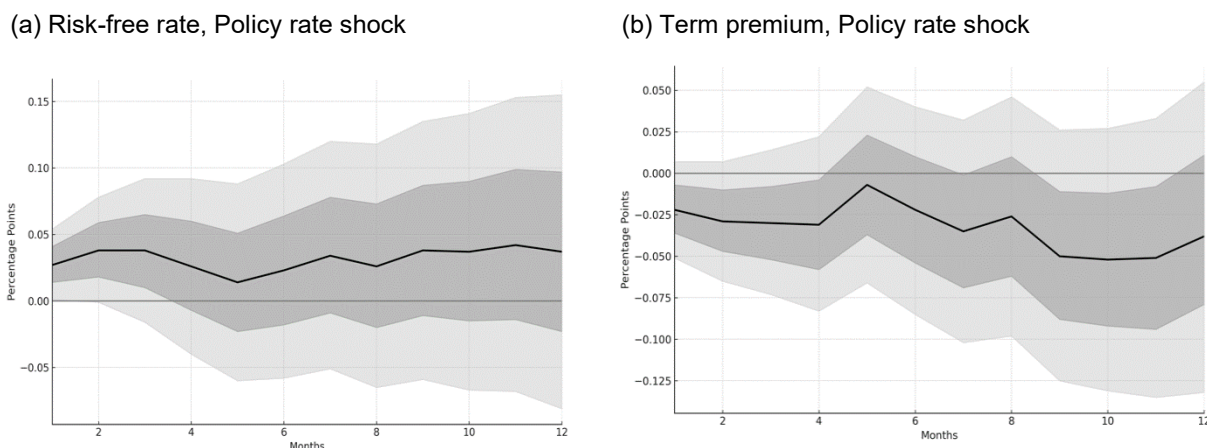
The impulse response functions indicate that as economic growth strengthens, the risk-free interest rate expectations are in line with the patterns typically observed in conventional monetary policy reaction functions (Figure 7a). As the central bank adjusts the policy rate upwards, in response to higher GDP growth it subsequently shapes investor expectations of the risk-free rate. The gradual pace of adjustment may be explained by a learning process on financial markets in response to shocks of average size which are not immediately priced into expectations about future rates. Similarly, further to a GDP growth shock, the risk

²⁶ The US term premium is used as a proxy for global bond market movements. Other exogenous variables, such as the volatility index (VIX), capture the influence of external factors beyond the UK, such as the US taper tantrum episode in 2013. We previously experimented using the exchange rate as an endogenous variable. While the results are broadly robust, in the end, we opted to use the exchange rate as one of variables in the information set instead (see also Greenwood et al 2023).

premium decreases (Figure 7b); that is to say that economic agents demand less compensation for holding longer-term bonds instead of shorter-term ones, thus justifying the fall in the term premium.

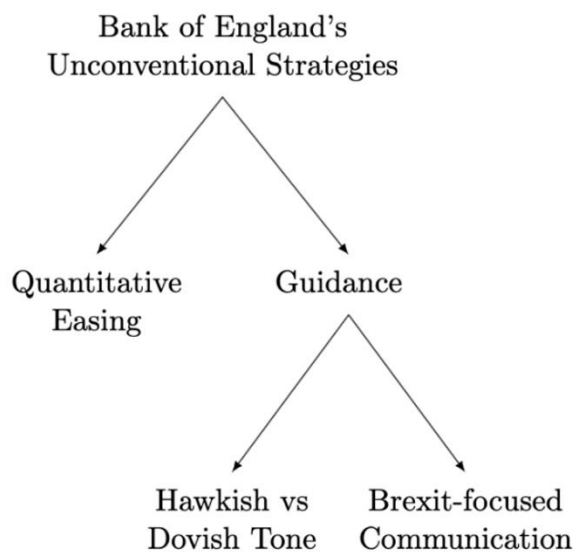
In examining the effect of a conventional monetary policy shock, we observe that an increase in the policy rate corresponds to an increase in the risk-free rate expectations (Figure 8a). While a policy rate shock is consistent with a reduction in risk premium (Figure 8b), the impact of a standard monetary policy shock does not yield statistically significant results, suggesting that an influence on the risk premium might be exerted through unconventional rather than conventional monetary policy (Figure 8b).

Figure 8: Response of Yield Curve Determinants to Policy rate Shock, 95% and 68% CI



The unconventional strategies employed by the Bank of England, consisted of three key channels: Quantitative Easing, tone and Brexit-related communication/guidance (Figure 9; see also Carney, 2018).

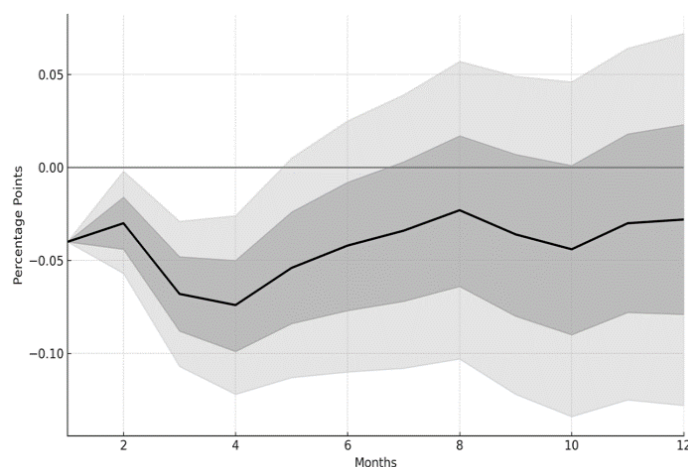
Figure 9: Classification of Bank of England’s Unconventional Strategies



Firstly, BoE's QE-related communication had a noticeable effect on reducing the term premium (Figure 10), serving as a clear indication of the Bank of England's commitment to reduce risk at the long-end of the yield distribution. Concurrently, the effect of QE-focused communication (rather than QE implementation itself) influences expectations of risk-free rates only marginally and should be interpreted with the caveat that nominal rates are at zero.

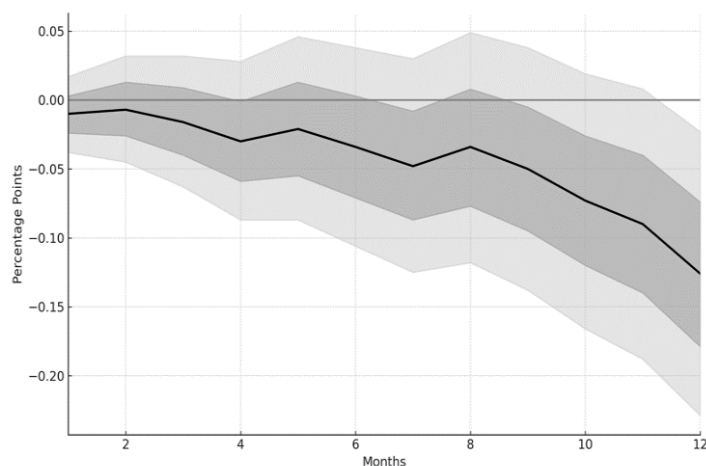
QE operates through various channels, including signalling, duration, as well as portfolio rebalancing (see, e.g., McMahon and Macchiarelli, 2020). The signalling channel of QE, in particular, is expected to interact with forward guidance. For example, QE asset purchases may signal the central bank's commitment to keep interest rates low over the long term, thus reducing sovereign borrowing costs and stimulating demand. This intention may be publicly announced by the central bank through forward guidance. However, forward guidance in isolation may lack credibility. This is where QE and forward guidance serve to reinforce one another. Our findings suggest that QE and forward guidance seemed to have operated in a way that is mutually reinforcing. This supports the argument that while the lags of the QE shock had an almost immediate and significant impact in reducing the term premium, the effect of the BoE tone become effective later. This might reflect the gradual adjustment of market expectations to the central bank's communicated policy path (see also Krishnamurthy and Vissing-Jorgensen, 2011).

Figure 10: Response of Term premium to QE Communication Shock, 95% and 68% CI



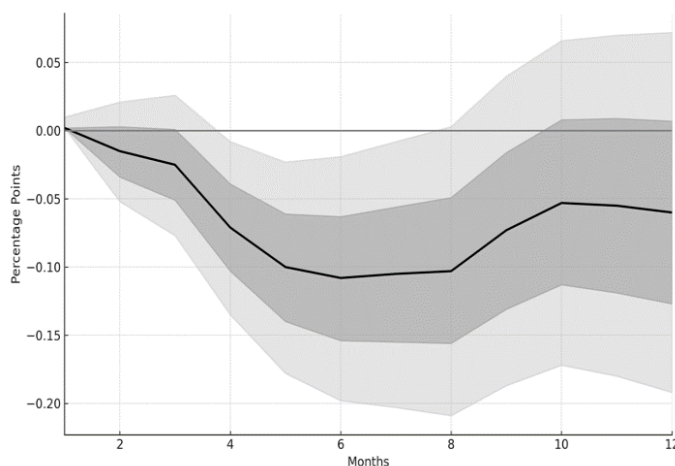
The BoE's use of the tone proved to be highly effective. This strategy equally contributed to a reduction of the term premium, with its effects that became statistically significant towards the end of the 12-month projection period (particularly in the months beyond the eleventh) (see Figure 11). In line with theory, a tone (hawkishness) shock also raised future short-term interest rate expectations. Our findings indicate a notable positive correlation between the tone of central bank communications and movements in risk-free rates. Specifically, as the central bank's communications adopted a more hawkish tone, expectations for future short-term interest rates adjusted upwards (not shown here).

Figure 11: Response of Term Premium to Tone Shock, 95% and 68% CI



Finally, the Bank of England's communication regarding Brexit, which intensified after 2016, appeared to be successful in reducing the term premium (Figure 12), particularly, between months 4-8. Notably, when the effectiveness of quantitative easing and tone waned, communication concerning Brexit seemed to have effectively bridged any central bank's communication gaps (Figure 13).²⁷

Figure 12: Response of Term Premium to Brexit Communication Shock, 95% and 68% CI



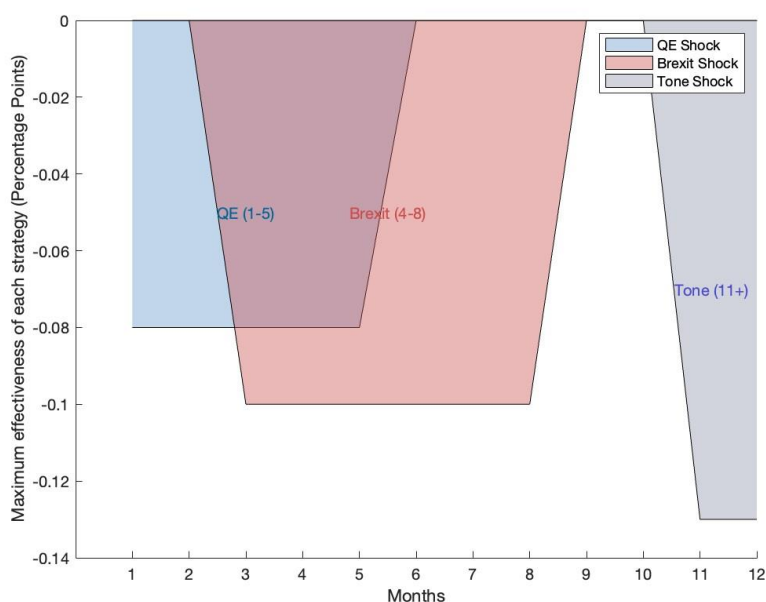
In the context of our findings, the communications by the Bank of England regarding Brexit uncertainty can be understood through the lens of the broader debate on monetary policy transparency and its effects on market perceptions and outcomes (Chadha and Nolan, 2001). The Bank of England's efforts to communicate about Brexit-related uncertainty likely served to enhance transparency in a period marked by significant political and economic ambiguity. Increased transparency can have profound effects on market expectations and behaviours, primarily through the dissemination of more explicit information regarding the central bank's outlook and policy intentions. The BoE's communications may have functioned to mitigate market uncertainty by providing clearer

²⁷ As a robustness check, we also explore an alternative scenario, cutting our sample at the close of the year 2016, prior to the Brexit referendum. Unsurprisingly, under this specification, Brexit-related communications is not significant in our analysis. The influences of Quantitative Easing (QE) and forward guidance (FG) retain their effects. This provides compelling evidence that the effect of these policy measures are not Brexit-related. This confirms the findings that the impulse response function of the term premium is sensitive to the BoE's Brexit-focused communication. A further robustness test could involve using an alternative Brexit metric, derived from Parliamentary documents and detailed in the recent study by Geiger and Guntner (2022).

guidance on the potential monetary policy paths in the face of Brexit. This reduction in uncertainty could help explain a decrease in the term premium. The communications effectively signalled a commitment to managing Brexit-induced risks, which, in turn, did not have a long-lived impact on expectations around future interest rates path, which was rather influenced via other channels such as conventional monetary policy and the interaction between QE and the use of its tone.

To conclude, our examination of the interplay among three distinct channels — QE, communication relating to Brexit uncertainty, and hawkish tone shocks — shows the complementarity of these measures. From a quantitative perspective, one policy did not outperform the others significantly. Each channel's influence on the risk premium, which cumulatively decreased by about 30 basis points (within a 95% confidence interval), is broadly similar. Yet, when viewed from a qualitative standpoint, each policy displays some effectiveness in influencing the risk premium across varied time frames. QE proves statistically significant during the initial five months; Brexit-related communication strategies proved significant in months 4-8; while the impact of the BoE's tone became apparent in months 11+. Such complementarity, as depicted in the timeline (Figure 13), emphasizes the collective contribution of these distinct strategies in reducing the term premium (see also Hansen et al., 2019).

Figure 13: Significance of BoE Strategies in Reducing the Term Premium (95% CI)



Note: This figure plots the peak impulse responses of the risk premium to shocks from QE communication, tone, and Brexit communication (corresponding to Figures 10, 11, and 12, respectively) within a 95% confidence interval.

Policy implications

Our findings suggest that responses of the bond market in the direct aftermath of the Brexit referendum were driven by adjustments in expectations about the monetary policy stance which offset any positive risk premia.

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 expectations before the referendum result was known. Brexit led to a downward revision in the economic outlook, representing a (supply-side) structural break. Given that the response of risk-

free rate expectations to the referendum was quite pronounced, markets appear to have priced a relatively stark turn in Bank of England interest rates, in anticipation of the Bank's cut in its policy rate two months later.

Our model suggests that a decline in the term premium first and foremost came about through markets' expectation of a new asset purchase programme to reduce the net supply of debt. In our empirical analysis, we generally find a persistent negative response of the term premium to QE-related communication in the MPC minutes. Looking at the term premium duration and persistence, the substantial decline in the term premium appears to be explained by expectations of unconventional monetary policy responses. The sizeable package of conventional and unconventional measures announced by the Bank of England after August 4, 2016, then seems to have taken markets by surprise as the term premium continued to decline.

The anticipation of unconventional monetary policy measures appears to have outweighed any increase in risk premia in the immediate aftermath of the referendum. 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 movement in global and UK-specific market risk variables, reported in Table 4 below. This is complemented by observations that uncertainty in the UK appears to be offset by expectations of a more expansionary monetary policy. The local equivalent of the VIX, the implied volatility of FTSE100-listed shares, declined the day after the referendum and decreased further following the Bank of England's policy package announcement in August 2016. Financial market risk measures did not move substantially on other days in our sample, suggesting that the BoE was able to anchor market's expectations that further monetary policy stimulus was on the way.

Table 4: Response of financial market risk measures

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

Since 2008, we find that the BoE's announcements about its asset purchase programmes led to a persistent reduction in the term premium, which continued to drop given the BoE's Brexit-related communication and use of the tone. Relating 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 and a change in expectations about monetary policy towards a more expansionary policy stance.

Conclusions

This paper assesses whether there is a Brexit premium priced on markets for UK government bonds. 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 asset purchase programmes are discussed, as well as uncertainty pertaining to the Brexit referendum. We then estimate the dynamic relationship between central bank policy and bond yield components, controlling for macroeconomic fundamentals.

Mapping these general results to bond market movements on days when Brexit news emerged, we find that Brexit-related uncertainty added to the pressure on sovereign bond yields. However, the anticipation of expansionary monetary policy measures in response to Brexit appear to have offset any risk premia. This may explain why we observe an overall negative response of long-term gilt yields.

The Bank of England implemented a mixed strategy involving both conventional and unconventional monetary policy measures. Quantitative easing, use of the tone, and communication surrounding Brexit uncertainty constituted key elements of such mixed strategy approach. These measures were observed to impact the term premium at different points in time, indicating their varying degrees of effectiveness and their role in shaping market expectations and reducing the term premium at the long end of the curve. We are able to ascertain that the communication around Brexit was instrumental in complementing the BoE's broader monetary policy strategy, contributing significantly to the reduction in risk premium. In this sense, the evidence points to a clear complementarity in the BoE's multipronged response.

To conclude, in this study we analysed the complex relationship between the BoE's monetary policy strategy, its Brexit-related communication, and its implications on ten-year UK bond yield. To the best of our knowledge, this constitutes the first research endeavour explicitly investigating this relationship. This study highlights the criticality of effective communication at times of high market volatility. It suggests that strategic communication during such periods can augment the effectiveness of monetary policy tools like Quantitative Easing and use of the tone, or forward guidance. As a means for risk premium reduction, effective communication can serve to navigate the economy through challenging times such as Brexit.

Annex I. Long-term bond yield decomposition

We outline the decomposition of gilt yields into two distinct components: one that reflects expectations about future risk-free rates, and a term premium that compensates investors for various risks, including liquidity, uncertainties around monetary policy stance, and general market risks. To achieve this, we apply a three-step estimation method 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:

$$X_{t+1} = \mu + \Phi X_t + v_{t+1} \quad (16)$$

where X_{t+1} are the pricing factors, μ is a constant term and Φ 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 , $P_t^n = E_t[M_{t+1} P_{t+1}^{(n-1)}]$, is assumed to follow

$$M_{t+1} = \exp\left(-r_t - \frac{1}{2} \lambda_t' \lambda_t - \lambda_t' v_{t+1}\right) \quad (17)$$

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

$$rx_{t+1}^{(n-1)} = \ln P_{t+1}^{(n-1)} - \ln P_t^{(n-1)} - r_t \quad (18)$$

Excess returns can then be written as

$$rx_{t+1}^{(n-1)} = \beta^{(n-1)'}(\lambda_0 + \lambda_1 X_t) - \frac{1}{2}(\beta^{(n-1)'} \beta^{(n-1)} + \sigma^2) + \beta^{(n-1)'} v_{t+1} + e_{t+1}^{(n-1)} \quad (19)$$

where $e_{t+1}^{(n-1)}$ are return pricing errors that are orthogonal to factor innovations v_{t+1} and conditionally independently and identically distributed with variance σ^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 (16) 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

$$rx_{t+1}^{(n-1)} = aI_T' + \beta' \hat{V}_t + cX_t + E_{t+1}. \quad (20)$$

The equation yields estimate of parameter β of equation (19). Residuals from equation (20), \hat{E}_{t+1} , are employed to obtain an estimate of σ^2 .

Third, price of risk parameters λ_0 and λ_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 λ_0 and λ_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.

To escape any criticism of non-stationarity in the bond yields data over a longer horizon, the 1970s in particular, we focus on the period since the so-called Zero Lower Bound (ZLB), which is from 2009 onward. Historical decomposition shows that the expectations about risk-free rates declined since 2009, particularly as the financial crisis hit and the Bank of England cut their policy rate to historically low levels, hitting the nominal zero.

By contrast, the term premium component - albeit continuing on its secular decline - increased sharply at the height of the financial crisis but has since continued to follow a downward trend. What can be observed is that, since 2016, expectations decoupled from the path in the term premium, and increased again, explaining much of the observed spike in sovereign bond yields. After the referendum, markets started to anticipate that a tapering phase would ensue, consequently leading to increased interest rates expectations. The years 2018-2019 saw a substantial surge in the 10-year expectations. The unprecedented arrival of the COVID-19 pandemic necessitated yet another round of bond-buying by the BoE, thereby prompting a realignment of market expectations.

Annex II. The LDA algorithm

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, $C = d_1, d_2, d_3, \dots, d_C$, characterised by a vocabulary of unique words (tokens), $V = w_1, w_2, w_3, \dots, w_V$. 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 mixture of topics, and where the latter are probabilities over the words (Blei et al., 2003). More technically, the LDA's generative process is defined by the following hierarchical structure:

- 1.) A V -dimensional Dirichlet distribution, β_K over the dictionary V , with hyperparameter α , is drawn for each topic.
- 2.) A K -dimensional Dirichlet distribution over the set of topics K, θ_d , with hyperparameter η^{28} , is drawn for each document.
- 3.) A multinomial distribution governed by θ_d is drawn for each word w in order to draw its assignment into topics, $z_{d,w}$.
- 4.) 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, β_K , their distributions, θ_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.

²⁸ We rely on Griffiths and Steyvers (2004) for the selection of both hyperparameters by setting set $\alpha = 50/K$ and $\eta = 0.1$.

Table 5: List of hawkish and dovish terms

Dovish (D)			Hawkish (H)		
accommod	fell	turndown	acceler	increas	tighten
assetpurchas	loos	weak	aggress	lift	tighter
contract	loosen	weaken	aris	moveup	unsustain
contractionari	lower	weaker	arisen	moveupward	upturn
cool	movedown		augment	overheat	
cut	putdownward		boom	pickup	
dampen	recess		bubbl	pressur	
decay	reduc		caution	putupward	
declin	reduct		cautious	rais	
depress	slack		climb	rise	
deterior	slower		destabilis	risen	
drop	sluggish		expand	rose	
eas	soft		gain	strengthen	
expansionari	soften		goup	strong	
fall	softer		hawkin	stronger	
fallen	trim		hike	tight	

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 6: Personal stopwords list

Stopwords
bank of england
bank
basis
billion
central
chancellor
committee
meeting
minutes
momentary policy committee
points

	Topic 1	Topic 2	Topic 3	Topic 4	Topic 5	Topic 6	Topic 7	Topic 8	Topic 9	Topic 10	Topic 11
1	cut	rate	rate	growth	increas	consumpt	weak	spend	rate	inflat	increas
2	downsid	recent	spend	economi	growth	growth	euro	pay	inflat	expect	extent
3	survey	earn	littl	cost	previous	wage	product	market	sterl	rate	higher
4	weaker	inflat	averag	product	relat	recent	area	month	risen	market	short
5	eas	effect	hous	market	price	slight	continu	data	rise	report	manufactur
	Topic 12	Topic 13	Topic 14	Topic 15	Topic 16	Topic 17	Topic 18	Topic 19	Topic 20	Topic 21	Topic 22
1	growth	output	inflat	data	uncertainti	pressur	rate	purchas	increas	firm	project
2	market	lend	price	report	referendum	demand	expect	asset	growth	remain	inflat
3	expect	product	increas	expect	asset	output	staff	programm	trade	employ	growth
4	indic	cost	risk	yield	risk	price	wage	fall	previous	growth	rate
5	report	littl	expect	bond	capit	domest	survey	economi	forecast	balanc	market
	Topic 23	Topic 24	Topic 25	Topic 26	Topic 27	Topic 28	Topic 29	Topic 30	Topic 31	Topic 32	Topic 33
1	price	growth	polic	activ	money	consumpt	recoveri	demand	inflat	slowdown	increas
2	oil	data	unemploy	prospect	output	household	market	trade	remain	growth	hous
3	report	stronger	financi	impact	declin	repo	price	export	term	inflat	rise
4	suggest	level	guidanc	factor	credit	recent	survey	expect	increas	fall	rate
5	retail	littl	recoveri	recoveri	compani	equiti	increas	possibl	medium	economi	demand
	Topic 34	Topic 35	Topic 36	Topic 37	Topic 38	Topic 39	Topic 40	Topic 41	Topic 42	Topic 43	Topic 44
1	market	growth	inflat	effect	rate	growth	rate	rate	inflat	market	price
2	financi	polic	target	price	revis	continu	growth	reduct	term	credit	growth
3	euro	project	polic	liquid	fallen	economi	output	interest	cpi	survey	inflat
4	area	member	monetari	fund	price	expect	rise	level	risen	price	oil
5	develop	risk	credit	addit	term	recent	price	index	indic	fallen	fallen

Table 7: Top 5 most likely terms defining each topic

Annex III. Uncertainty Indices

In our analysis, we construct text-based measures of Brexit-related uncertainty and general uncertainty: correlation between the two is 0.65 in the post-Brexit sample. These measures which are broadly comparable with other, well-known uncertainty measures, such as the Economic Policy Uncertainty (EPU) Index developed by Baker et al. (2016). When considering our index of Brexit-specific uncertainty, correlation with EPU is 0.4 whether we consider the post-Brexit sample or not. Across the entire sample, the correlation between our general uncertainty measure plus our Brexit-related uncertainty measure and the EPU is higher, at 0.56.

Figure 14: Comparing text-based measures of uncertainty with Economic Policy Uncertainty (EPU) Index

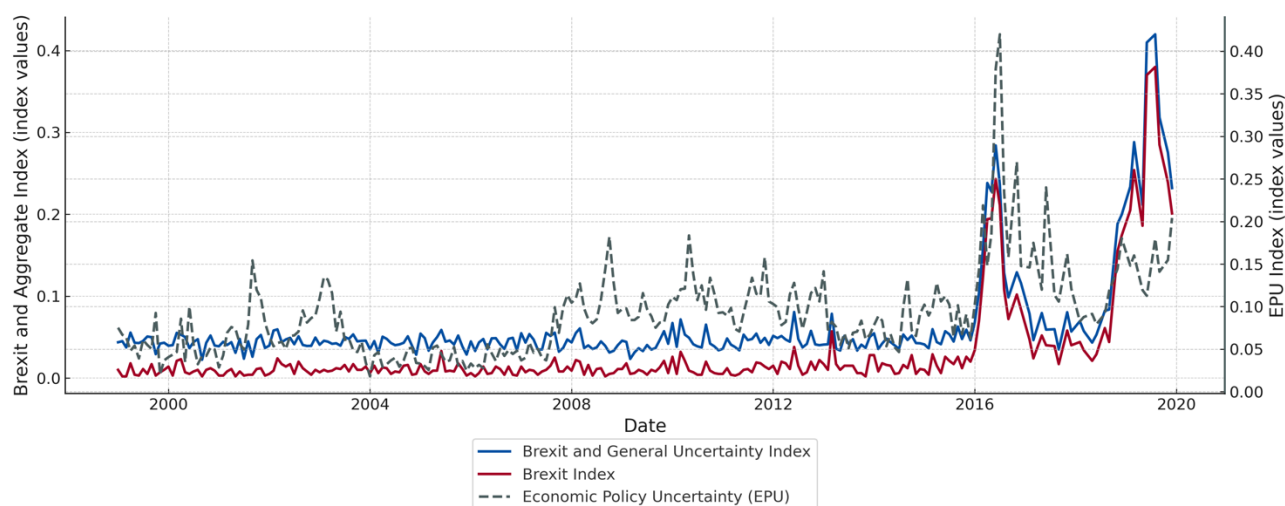
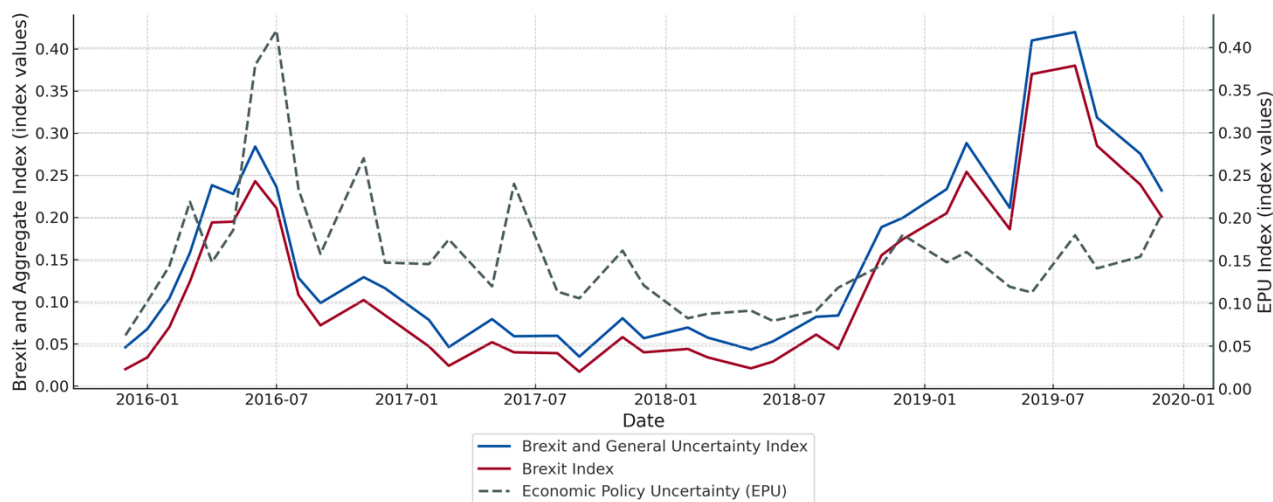


Figure 15: Comparing text-based measures of uncertainty with EPU Index after 2016



References

- Adrian, T., Crump, R. K. and Moench, E. (2013), 'Pricing the term structure with linear regressions', *Journal of Financial Economics* 110(1), 110–138.
- Apel, M. and Grimaldi, M. (2012), 'The information content of central bank minutes', *Riksbank Research Paper Series* 1(92).
- Apel, M. and Grimaldi, M. B. (2014), 'How informative are central bank minutes?', *Review of Economics* 65(1), 53–76.
- Baker, S. R., Bloom, N., & Davis, S. J. (2016). Measuring economic policy uncertainty. *The quarterly journal of economics*, 131(4), 1593-1636.
- Bank of England (2016a), Inflation report November 2016, Report, Bank of England. URL: <https://www.bankofengland.co.uk/inflation-report/2016/november-2016>
- Bank of England (2016b), Monetary policy summary and minutes of the monetary policy committee meeting ending on 3 august 2016, Report, Bank of England.
- Bank of England (2019), Monetary policy report - november 2019, Technical report, <https://www.bankofengland.co.uk/monetary-policy-report/2019/november-2019>.
- Barsky, R. B. and Sims, E. R. (2011), 'News shocks and business cycles', *Journal of Monetary Economics* 58(3), 273–289.
- Barwell, R. and J. S. Chadha (2013), Complete forward guidance, in W. den Haan (ed.), *Forward Guidance*, VoxEU e-book, 23 October <https://cepr.org/publications/books-and-reports/forward-guidance>
- Bauer, M. D. and Rudebusch, G. D. (2014), 'The signaling channel for Federal Reserve bond purchases', *International Journal of Central Banking* .
- Belke, A., Dubova, I. and Osowski, T. (2018), 'Policy uncertainty and international financial markets: the case of brexit', *Applied Economics* 50(34-35), 3752–3770.
- Bennani, H. and Neuenkirch, M. (2017), 'The (home) bias of European central bankers: new evidence based on speeches', *Applied Economics* 49(11), 1114–1131.
- Bholat, D. M., Hansen, S., Santos, P. and Schonhardt-Bailey, C. (2015), 'Text mining for central banks', *Bank of England Centre for Central Banking Studies Handbook* 1(33).
- Blei, D. M. (2012), 'Probabilistic topic models', *Communications of the ACM* 55(4), 77–84.
- Blei, D. M., Ng, A. Y. and Jordan, M. I. (2003), 'Latent dirichlet allocation', *Journal of Machine Learning Research* 3(Jan), 993–1022.
- Bloom, N. (2014), 'Fluctuations in uncertainty', *Journal of Economic Perspectives* 28(2), 153–76.
- Bloom, N., Bunn, P., Chen, S., Mizen, P., Smietanka, P. and Thwaites, G. (2019), *The impact of brexit on uk firms*, Technical report, National Bureau of Economic Research.
- Born, B., M'uller, G. J., Schularick, M. and Sedl'áček, P. (2019), 'The costs of economic nationalism: evidence from the brexit experiment', *The Economic Journal* 129(623), 2722–2744.

- Breinlich, H., Leromain, E., Novy, D. and Sampson, T. (2022), 'The brexit vote, inflation and uk living standards', *International Economic Review* 63(1), 63–93.
- Breinlich, H., Leromain, E., Novy, D., Sampson, T., Usman, A. et al. (2018), *The economic effects of Brexit-evidence from the stock market*, Technical report, CEPR Discussion Papers.
- Carney, M. (2018), 'Guidance, Contingencies and Brexit', Speech given by the Governor of the Bank of England at the Society of Professional Economists 24 May www.bankofengland.co.uk/-/media/boe/files/speech/2018/guidance-contingencies-and-brexit-speech-by-mark-carney.pdf
- Cannon, S. et al. (2015), 'Sentiment of the FOMC: Unscripted', *Economic Review-Federal Reserve Bank of Kansas City* 5.
- Chadha, J. S., & Nolan, C. (2001). Inflation targeting, transparency and interest rate volatility: ditching "monetary mystique" in the UK. *Journal of Macroeconomics*, 23(3), 349-366.
- Chadha, J. and Hantzsche, A. (2018), *The impact of the ECB's QE programme: core versus periphery*, Technical report, National Institute of Economic and Social Research.
- Chadha, J. S. and Waters, A. (2014), 'Applying a macro-finance yield curve to UK quantitative easing', *Journal of Banking & Finance* 39, 68–86.
- Christensen, J. H. and Rudebusch, G. D. (2012), 'The response of interest rates to US and UK quantitative easing', *The Economic Journal* 122(564), F385–F414.
- Cloyne, J. and Hürtgen, P. (2016), 'The macroeconomic effects of monetary policy: a new measure for the United Kingdom', *American Economic Journal: Macroeconomics* 8(4), 75–102.
- Davies, R. B. and Studnicka, Z. (2018), 'The heterogeneous impact of Brexit: early indications from the FTSE', *European Economic Review* .
- Dell'Ariccia, G., Rabanal, P. and Sandri, D. (2018), 'Unconventional monetary policies in the euro area, japan, and the united kingdom', *Journal of Economic Perspectives* 32(4), 147–172.
- Deveaud, R., SanJuan, E. and Bellot, P. (2014), 'Accurate and effective latent concept modeling for ad hoc information retrieval', *Document numérique* 17(1), 61–84.
- Dhingra, S. and Sampson, T. (2022), 'Expecting brexit', *Annual Review of Economics* 14, 495–519.
- Falck, E., Hoffmann, M. and Hürtgen, P. (2017), 'Disagreement and monetary policy'.
- Geiger, M. and Güntner, J. (2022), *The chronology of brexit and uk monetary policy*, Technical report, Working Paper.
- Greenwood, R., Hanson, S., Stein, J.C., Sunderam, A. (2023), 'A Quantity-Driven Theory of Term Premia and Exchange Rates', *The Quarterly Journal of Economics*, 138(4), 2327–2389.
- Griffiths, T. L. and Steyvers, M. (2004), 'Finding scientific topics', *Proceedings of the National Academy of Sciences* 101(suppl 1), 5228–5235.
- Hansen, S. and McMahon, M. (2016), 'Shocking language: Understanding the macroeconomic effects of central bank communication', *Journal of International Economics* 99, S114–S133.
- Hansen, S., McMahon, M. and Prat, A. (2017), 'Transparency and deliberation within the FOMC: a computational linguistics approach', *The Quarterly Journal of Economics* 133(2), 801–870.

- Hansen, S., McMahon, M. and Tong, M. (2019), 'The long-run information effect of central bank communication', *Journal of Monetary Economics*, 108, pp. 185-202
- International Monetary Fund (IMF). (2016). *Global Financial Stability Report, October 2016: Fostering Stability in a Low-Growth, Low-Rate Era*. International Monetary Fund.
- Jordà, O. (2005), 'Estimation and inference of impulse responses by local projections', *American Economic Review* 95(1), 161–182.
- Joyce, M. A., McLaren, N. and Young, C. (2012), 'Quantitative easing in the United Kingdom: evidence from financial markets on QE1 and QE2', *Oxford Review of Economic Policy* 28(4), 671–701.
- Joyce, M., Lasasosa, A., Stevens, I. and Tong, M. (2011), 'The financial impact of quantitative easing in the United Kingdom', *International Journal of Central Banking* 7(3), 113–61.
- Kadiric, S. (2022), 'The determinants of sovereign risk premiums in the UK and the European government bond market: the impact of Brexit', *International Economics and Economic Policy* 19(2), 267–298.
- Krishnamurthy A., and Vissing-Jorgensen A. (2011), 'The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy', *Brookings Papers on Economic Activity*, Fall.
- Lucas, R. E. (1982), 'Interest rates and currency prices in a two-country world', *Journal of Monetary Economics* 10(3), 335–359.
- Madeira, C., Madeira, J. and Monteiro, P. S. (2023), 'The origins of monetary policy disagreement: The role of supply and demand shocks', *Review of Economics and Statistics* pp. 1–45.
- McMahon, M. and Macchiarelli, C. (2020), 'Quantitative easing and monetary financing: what's the difference?', Technical report, The Economics Observatory.
- Opatry, M. (2021), 'The impact of the Brexit vote on UK financial markets: a synthetic control method approach', *Empirica* 48(2), 559–587.
- Romer, C. D. and Romer, D. H. (2004), 'A new measure of monetary shocks: Derivation and implications', *American Economic Review* 94(4), 1055–1084.
- Tobback, E., Nardelli, S. and Martens, D. (2017), 'Between hawks and doves: measuring central bank communication', *European Central Bank Working Paper Series* 1(2085).



PUBLICATIONS