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ORIGINAL RESEARCH

Does Fed communication affect uncertainty and risk aversion?

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Abstract
This paper examines whether the Federal Reserve (Fed) communication has significant impact on the level of uncertainty and risk aversion in the U.S., U.K., and Eurozone equity markets. We first apply computational linguistic tools to the Federal Open Market Committee (FOMC) meeting minutes to measure the tone of Fed communication and then decompose the option-implied volatility into proxies for risk aversion and expected market volatility ("uncertainty"). We provide novel evidence that the Fed's optimistic tone decreases both uncertainty and risk aversion in global equity markets, with the former effect being stronger. We also find a stronger response of market participants to central bank communication during recessions and in periods of high policy uncertainty. Further analysis reveals that, in formulating their risk preferences, investors pay particular attention to FOMC's discussion about financial market, credit condition, employment, and growth. Overall, our results suggest that central bank communication plays an important role in shaping perceptions and risk appetite of financial market participants.

Keywords Monetary policy · Central bank communication · Risk aversion · Uncertainty · Textual analysis · Topic modelling

JEL Classification G10 · G12 · E52 · E58

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1 Introduction

In the wake of the 2007–2008 global financial crisis, central banks in major economies have decreased the policy rate to near zero lower bound to safeguard the stability of financial markets. As a result, central bank communication has emerged as a key tool for central bankers to shape market expectations and to achieve monetary policy objectives. Speaking at a conference in March 2015, the former chair of the Federal Reserve (Fed) Ben Bernanke made this very point: "monetary policy is 98 percent talk and only two percent action" (Bernanke 2015). Hence, it is important for policy makers to understand whether and to what extent central bank communication affects financial markets and economic outlook. Recent studies show that apart from policy decisions (*actions*), central bank communications (*words*) also had a substantial impact on asset prices (Schmeling and Wagner 2024), currency risk (Dossani 2021), term premium (Hansen et al. 2019), and economic activities (Luangaram and Wongwachara 2017).[1] The aforementioned studies have contributed significantly to our understanding of how central bank communication can affect financial decisions and economic outcomes. What is still not clear is the mechanism by which it influences investors' demand for risky assets.

Bernanke and Kuttner (2005) argues that monetary policy actions affect stock returns through at least two channels, i.e., by shaping market participants' risk expectations (signalling effect) or by changing their risk tolerance (risk-taking effect). There is an emerging literature showing that a surprise decrease in the policy rate reduces uncertainty and risk aversion in equity markets (Gospodinov and Jamali 2012; Bekaert et al. 2013). However, the literature has focused primarily on policy decisions and there is no empirical evidence on the potential impact of central bank communication on investor perception and appetite for risk. This paper attempts to fill this gap in the literature and examines for first time the effects of Fed communications (*words*) on the level of uncertainty and risk aversion in equity markets. First, we employ tools from computational linguistics ("bag-of-words" method) to extract the Fed's tone from its qualitative communications.[2] Then, following Bekaert et al. (2013), we decompose option-implied volatility into two components to investigate whether central bank tone has significant effects on time-varying risk aversion and uncertainty in the marketplace. This novel empirical approach allows us to address important questions regarding the channels through which central bank communications (*words*) affect asset prices.

Akhtar et al. (2011) points out that there exists a "negativity bias" and investors may give greater value to negative information than for positive information. We contribute to this literature by exploring the *asymmetric* market reactions to central bank communications. Specifically, we examine whether optimistic and pessimistic communication by the Fed affect investor's risk expectation equally and, if not, we further investigate in what form such asymmetry exists. To our knowledge, this is the first paper that studies central bank communication from that angle. For a deeper understanding, we also identify distinct topics in the minutes of FOMC meetings and extract each topic's tone from these communications.[3] Jegadeesh and Wu (2017) shows that the Fed's discussions about policy stance,

[1] Blinder et al. (2024) provides an excellent survey of the literature on central bank communication.

[2] We follow Hubert and Labondance (2017) and use the directional dictionary of Apel and Grimaldi (2014) to convert qualitative information in the FOMC minutes to a quantitative measure of the Fed's tone.

[3] We employ a technique called Latent Dirichlet Allocation (LDA) to identify different topics and the relative importance of each topic in FOMC meeting minutes. Appendix A provides a more detailed description of topics in central bank communications.

inflation, financial market, and consumption determine changes in equity prices. We extend this stream of literature by examining the *heterogeneous* impact of Fed's views about various economic topics on the market participant's appetite for risk.

This paper also adds to the growing literature considering the *state-dependent* response of investor's expectation to central bank communications. Prior studies suggest that investor's reaction to monetary policy announcements is much stronger during tough economic times. For instance, Basistha and Kurov (2008) finds that an unexpected change in policy rate has a larger impact on equity returns during recessionary periods. Kurov (2012) shows that a surprise increase in the future path of the policy rate has a positive impact on equity markets during recessions and a negative impact during recoveries. Similarly, the information content of central bank communication may also depend upon the degree of uncertainty regarding the future economic and monetary policy. Kurov and Stan (2018) finds that monetary policy uncertainty drives stock market reaction to macroeconomic news. In this paper, we study the change in response of investor's risk attitude to the Fed's communication during the period when uncertainty regarding future economic and monetary policy is higher than normal.[4]

Previous research provides evidence on the role of Fed's announcements in changing investor's expectation and behaviour in equity markets of other developed nations. Nave and Ruiz (2015), for instance, documents a significant reduction in investor's risk aversion in the European stock markets in response to a surprise decrease in Fed's policy rate. Hayo et al. (2010) finds that information embedded in Fed's communication significantly influences the European equity markets. Hence, this paper aims to extend the literature by investigating the potential *spillover* effect of Fed communication tone on time-varying risk aversion and uncertainty in the U.K. and Eurozone markets.

This paper is different from previous studies in several ways. First, unlike Jegadeesh and Wu (2017) which analyzes the impact of Fed's tone on prices of fixed income assets, we examine for the first time whether Fed's words affect uncertainty and risk aversion. Second, our work is also different from Schmeling and Wagner (2024) who extracts the tone from the European Central Bank (ECB) press conference using the frequency of a single word (unigram). Picault and Renault (2017) points out that categorizing the tone of central bank communications based on the frequency of a single word may lead to misspecification of context in the textual analysis. For example, "high" is a positive word but "high risk" is a negative concept in the context of central bank communication. In this paper, we follow Apergis and Pragidis (2019) and apply directional phrases (bigrams), a combination of noun and adjectives, to extract the Fed's tone.[5] Third, another distinguishing feature of this paper is our investigation of the impact of Fed unique topic's tone on the investor's appetite for risk. Our results reveal an interesting finding of investor response to central bank communications. As expected, the Fed's optimistic discussion about financial market, credit conditions and economic growth reduces market uncertainty; on the contrary, the Fed's optimism related to policy stance increases investor risk aversion. This suggests that market participants interpret central bank optimism about the policy stance as an indication of future contractionary policy and consider it as bad news.

[4] We use the economic policy uncertainty (EPU) and monetary policy uncertainty (MPU) indices of Baker et al. (2016) to identify period when uncertainty regarding future policy is higher than normal. These indices are available at: http://www.policyuncertainty.com.

[5] The phrases are combination of nouns (concepts) and adjectives (tone modifiers) developed by Apel and Grimaldi (2014) specifically for the content analysis of central bank communication.

Overall, our results show that Fed's optimistic tone reduces both uncertainty and risk aversion in global equity markets, with the former (i.e., signalling) effect being stronger. This finding is consistent with that of Jegadeesh and Wu (2017) who finds that a positive Fed's tone decreases the unexpected volatility in equity market. However, this differs from the finding of Bekaert et al. (2013) that policy *actions* affect prices primarily through the 'risk-taking' channel i.e., by shaping market participants' perception of risk. Taken together, our findings uncover an important 'signalling' channel through which information embedded in central bank communications (*words*) transmits to financial markets i.e., investors change their risk expectations in response to new information communicated through the FOMC minutes. In general, investors perceive the Fed's optimistic (pessimistic) tone as a signal of good (bad) outlook of the economy and financial conditions; these signals of future economic situation would then affect risk appetite and uncertainty in global equity market.[6] The results of our paper remain statistically significant after controlling for changes in policy rate, business cycles, macroeconomic fluctuations, and Fed's forecasts. Additional robustness checks also confirm that our findings hold after changing the term weighting scheme, communication tool, directional lexicon, and response window.[7]

The paper proceeds as follows. In the next section we briefly discuss the prior literature. Section 3 describes our research design and identification strategy. Section 4 presents the empirical results, and Sect. 5 reports various robustness tests and additional results. Section 6 concludes and discusses the policy implications of the study and avenues for further research.

2 Related literature

2.1 Effects of central bank decisions and communications

The academic literature on the impact of monetary policy on financial markets is large and rapidly growing. The general consensus is that monetary policy strongly affects asset prices. For example, Nikkinen and Sahlström (2004) shows that there is a significant reduction in the implied volatility of S&P500 index on the days of policy announcement.[8] Gospodinov and Jamali (2012) divides the change in federal fund rate into expected and unexpected components and finds only the surprise changes in policy rate significantly affected market uncertainty. Bekaert et al. (2013) investigates the impact of monetary policy decisions on changes in risk aversion and uncertainty in financial markets. Their results based on the structural vector autoregressive model reveal that a lax monetary policy decreases risk aversion and uncertainty. Using the shadow interest rate as a proxy for monetary policy stance, Hahn et al. (2017) provides additional support for the effects of monetary policy on risk aversion and uncertainty in periods of unconventional monetary policies.

In addition to the policy decisions (*actions*), central bank communications (*words*) are also closely followed by market participants and are extensively covered by financial press.

[6] Previous studies support the notion that monetary policy announcements (*actions*) contain vital information about future economic conditions (Melosi 2017), which can in turn affect the perception of risk in financial markets (Bekaert et al. 2013; Hahn et al. 2017).

[7] Appendix B contains the results of these robustness checks and additional analyses.

[8] Option-implied volatility is one of the most widely used measures of equity market uncertainty (Whaley 2000).

Several studies have indeed documented significant effects of central bank communications (e.g., policy statements, speeches, press conferences and minutes of committee meeting) on stock return and volatility. For instance, Jubinski and Tomljanovich (2017) finds both FOMC decisions (*actions*) and FOMC minutes (*words*) have a significant impact on the volatility of individual equity returns in the U.S., albeit the central bankers' actions tend to speak louder than their words. Kohn and Sack (2003) notes that both the forward guidance and the assessment of future financial market conditions by central banks matter for asset prices. Considering a wider range of central bank communications, Rosa (2016) concludes that the statements, minutes of FOMC meetings, and speeches made by the Fed chairman, increase the trading volume and volatility in fixed income and equity markets. Moreover, Leombroni et al. (2021) finds the ECB's communications contain information relevant for the yield curve of countries in the Euro area. Employing the standard textual analysis, Schmeling and Wagner (2024) shows that central bank tone revealed in the ECB's press conferences had a significant effect on equity prices, credit spread, and volatility risk premium in the European markets. Their results suggest that communication is a powerful instrument of monetary policy for central bankers to influence investors' risk appetite and the risk premia they require.

Nevertheless, prior studies have been primarily concerned with policy decisions and little research has been conducted on the role of central bank communication in influencing market expectations. This lack of research is, perhaps, surprising given the growing importance of communication as a powerful instrument of the monetary policy toolkit. The current paper represents the latest attempt of such efforts to address these important issues.

2.2 Transmission channels of central bank communications

The literature suggests two types of signals embedded in central bank communications. Romer and Romer (2000) explains the first, as the 'information effect' of the central bank's signals about the assessment of near term economic and financial outlook. This information alters investor's expected risk and return, which then shift the equity prices. Nakamura and Steinsson (2018) finds that the information related to economic activities drives the impact of monetary policy shocks on the expectations and behaviour of investors. Masciandaro et al. (2024) analyses social media content by policy makers and demonstrates that central bank communication affected investor beliefs and, subsequently, behaviour in financial markets. Additionally, the central bank communications contain a second type of signal indicating the future path of the policy rate. Woodford (2001) shows the changes in expectations about the future path of short-term interest rates affect the perceived risk and return of an investment. Kohn and Sack (2003) confirms the publications of forward guidance and economic outlook help the central bank achieve its macroeconomic objectives. Finally, it is widely accepted that the 'signalling effect' of monetary policy can help stabilize financial markets by providing vital information about central bank's assessment of future inflation and output gap (Melosi 2017).

Borio and Zhu (2012) points out that monetary policy announcements affect risk premium by shifting the risk appetite of market participants. They identify three transmission mechanisms through which the 'risk-taking' channel operates. Firstly, an unexpected change in the nominal interest rate affect the overall wealth of investors, or the value of collateral assets of a firm, which in turn may lead to a significant shift in risk appetite. Secondly, an ambition to achieve a target return after an expansionary monetary policy could increase the risk-bearing capacity of market participants. For instance, a fund manager is

willing to take more risk during consistently low policy rate regimes to achieve benchmark returns and to earn a higher compensation. Thirdly, the commitment of central banks for a consistent expansionary policy reduces the uncertainty in financial market and thus lowers the overall market risk premium.

Bernanke and Kuttner (2005) finds the impact of monetary policy on equity prices is largely due to a shift in the perceived risk of investment or the risk-bearing capacity of investors. This conclusion is corroborated by the finding of Bekaert et al. (2013) who shows that unexpected monetary policy easing significantly reduces risk aversion by market participants. Kurov (2012) provides further evidence that policy statements contain additional information about the outlook of the economy, which can affect investors' risk assessment and tolerance. Drechsler et al. (2018) develops a dynamic asset pricing model to describe the effect of a policy rate change on asset prices. In their model two agents with different risk-bearing capacity interact in response to a change in nominal interest rate, which in turn impacts on the aggregate risk aversion in the economy. Leombroni et al. (2021) expands the literature and demonstrates that the effectiveness of monetary policy depends on central banks' ability to shape market expectation using instruments such as president speeches, statements, and press conferences. They provide evidence that central bank communications can shape long-term interest rates by changing risk premia.

3 Research design and variables identification

3.1 Quantifying the tone of central bank communication

3.1.1 Dictionary-based content analysis

A number of techniques have been put forward in the literature to quantify the tone from central bank communications (e.g., Picault and Renault 2017; Hansen et al. 2019).[9] This paper uses the "bag-of-words" approach to extract central bank communication tone. Several studies have applied a similar dictionary-based technique to estimate central bank tone. For instance, Schmeling and Wagner (2024) measures central bank tone using a list of negative words in the financial dictionary developed by Loughran and McDonald (2011). On the other hand, Hansen and McMahon (2016) extracts central bank tone with the directional dictionary of Apel and Grimaldi (2014). The selection of a suitable dictionary (lexicon) is crucial for capturing the tone effectively and for avoiding spurious correlations in regression analysis. As Loughran and McDonald (2011) financial dictionary is developed to capture primarily the tone from corporate reports, in this paper we use the dictionary of Apel and Grimaldi (2014) that is designed to facilitate research in central bank communications.

Picault and Renault (2017) argues that counting the frequency of single word to estimate central bank tone without analysing the context of the word may lead to misinterpretation. For instance, "decrease" is a negative word but "decrease in unemployment" is a positive

[9] Bholat et al. (2015) describes in more detail the various content analysis techniques that are available for analysing central bank communications. The techniques differ on the degree of subjective judgment involved. On the one extreme, the narrative approach relies totally on the subjective interpretation of the researcher. On the other side, a fully automated (computational) content analysis such as Latent Semantic Analysis (LSA) is a machine learning technique with minimum human involvement. The semi-automated methods such as dictionary-based content analysis ("bag-of-words") are in between these two extremes.

concept. To lessen this concern our study follows Apergis and Pragidis (2019) to count the frequency of phrases (bigrams) based on the directional words list of Apel and Grimaldi (2014). Specifically, we develop phrases combining of positive and negative nouns (concepts) and optimistic and pessimistic adjectives (tone modifiers). A sentence containing an optimistic phrase (a positive noun along with an optimistic adjective) representing the central bank optimism. Similarly, a sentence with the pessimistic phrase (a positive noun along with pessimistic adjective) representing central bank's pessimistic view about that concept.[10] Next, we count the frequency of pre-specified directional phrases in each paragraph of communication document. After counting these phrases in each paragraph, we aggregate total optimistic (pessimistic) phrases (i) in each document (D).

$$Optimistic_{(D)} = \sum_{i=1}^{n} Optimistic_{i,(p)} \tag{1}$$

$$Pessimistic_{(D)} = \sum_{i=1}^{n} Pessimistic_{i,(p)} \tag{2}$$

After that, we calculate the optimistic (pessimistic) tone by dividing the number of optimistic (pessimistic) phrases with the total number of phrases in each document. Finally, we estimate the *net* optimistic tone by subtracting the number of pessimistic phrases from the number of optimistic phrases and dividing it with the total number of phrases in each document.

$$Optimistic\ Tone_{(D)} = \frac{Optimistic_{(D)}}{Total\ Number\ of\ Phrases_{(D)}} \tag{3}$$

$$Pessimistic\ Tone_{(D)} = \frac{Pessimistic_{(D)}}{Total\ Number\ of\ Phrases_{(D)}} \tag{4}$$

$$NetOptTone_{(D)} = \frac{Optimistic_{(D)} - Pessimistic_{(D)}}{Total\ Number\ of\ Phrases_{(D)}} \tag{5}$$

Since all the text documents in our corpus (collection of documents) are in chronological order, we can estimate a time series measure of Fed's tone for the period under investigation.

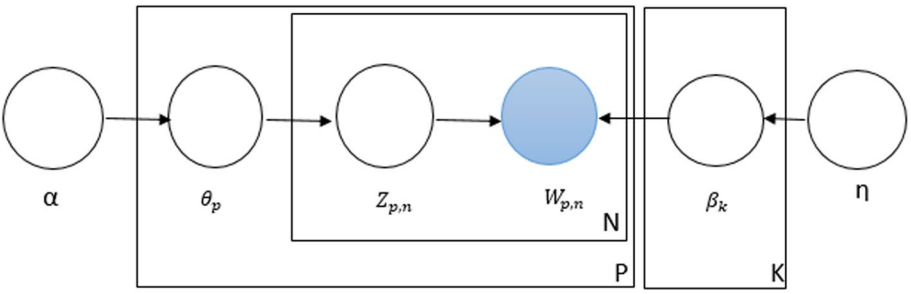
3.1.2 Latent Dirichlet allocation

Fed's communications contain a detailed discussion of committee members' views about a variety of topics. For instance, the FOMC members frequently discuss the current and future economic conditions, key macroeconomic indicators, exchange rate positions, financial markets outlook, trade situations, rationale for their monetary policy decisions, and the future path of the short-term interest rate. In this paper we use Latent Dirichlet Allocation

[10] A phrase combining a negative noun and a pessimistic tone modifier will produce an optimistic phrase. For example, "declining risk" is an optimistic phrase. Table A4 of Appendix A shows the list of positive (negative) nouns and optimistic (pessimistic) adjectives.

(LDA) method, a very popular algorithm developed by Blei (2012), to identify unique topics (themes) that were discussed at each FOMC meeting.[11]

LDA classifies the large texts into different topics using the latent probabilistic distributions. The process can be explained graphically: the hyperparameters α and η expresses the Dirichlet distributions which provide topic's distribution over paragraphs θ_p and word's distribution over topics β_K, respectively. For the first latent distribution, LDA assumes that each paragraph is a combination of various topics. The second distribution assumes that each topic is a combination of different words. To estimate parameters of these two latent distributions, LDA uses Bayesian method.



(6)

Source: Blei (2012)

LDA has two main outputs, first, it provides the relative weight of each word, beta (β), which measures the probability of each word appearing in a topic.

$$\hat{\beta}_{it} \equiv P_{it}(Term_1), P_{it}(Term_2), \ldots\ldots\ldots, P_{nt}(Term_n)$$

Beta is the vector of probabilities for observing each term in a particular topic. For instance, words like employment, labour, and wages get higher weights for the topic of employment. Similarly, the words such as financial, credit, yield, and returns pose higher beta weights for financial market compared to other topics. The second output of LDA is known as theta (θ) which estimates the probability of each topic appearing in each paragraph. More specifically, the theta measures the proportion of each paragraph allocated to a topic.

$$\widehat{\theta_{ip}} \equiv P_{ip}(Topic_1), P_{ip}(Topic_2), \ldots\ldots\ldots, P_{kp}(Topic_K) \quad (7)$$

Each paragraph in the corpus is a mixture of K topics and the theta (θ) shows the portion of discussion about a particular topic in each paragraph. Using term weight (beta) we identify the topics under discussion in central bank communications and using topic proportion (theta) we measure the relative portion of each paragraph associated with a particular topic.

3.1.3 Topic-to-tone

We follow Hansen and McMahon's (2016) two-step process to extract central bank tone on each topic. In the first step, we apply LDA method explained in Sect. 3.1.2 to identify

[11] Jegadeesh and Wu (2017) finds that the Latent Dirichlet Allocation is an efficient logarithm-based dimension reduction method to identify unique topics under the discussion in FOMC meetings.

a particular topic using this topic's theta score in each paragraph of communication document. In the second step, we quantify the topic's tone by conducting a "bag-of-words" analysis (as outlined in Sect. 3.1.1) on identified paragraphs. Each topic's tone is systematically estimated using this 'Topic-to-Tone' approach combining both topic modelling technique and dictionary-based content analysis.

3.2 Measuring uncertainty and risk aversion

To examine the impact of central bank communication on market participants' risk preferences and beliefs, we follow Bekaert et al. (2013) and decompose the option-implied volatility into proxies for risk aversion and expected market volatility ("uncertainty").[12] First, we estimate the realized volatility using rolling over sum for 22 daily returns on an equity index.

$$RV_t = \sum_{i=1}^{22} r_i^2 \tag{8}$$

Next, we regress the realized variance (RV_t) on lagged squared implied volatility (IV_t^2) and lagged realized variance.

$$RV_t = \alpha IV_{t-22}^2 + \beta RV_{t-22} + \varepsilon_t \tag{9}$$

The fitted value from Eq. (9), $\widehat{RV_t}$, represents the expected realized variance. In the final step, we obtain the variance risk premium (VRP_t) after subtracting the expected realized variance ($\widehat{RV_t}$) from squared implied volatility (IV_t^2).

$$VRP_t = IV_t^2 - \widehat{RV_t} \tag{10}$$

In our empirical analysis, we use the expected realized variance ($\widehat{RV_t}$) and variance risk premium (VRP_t) as proxies for uncertainty (UC) and risk aversion (RA), respectively.

This decomposition approach provides an ideal setting to analyze the channels that drive market reaction to central bank communications. If central bank tone affects asset prices through the 'signalling' channel, a significant change in uncertainty measure (UC) is expected. On the other hand, if communications move asset prices through primarily the 'risk-taking' channel, we should find that central bank tone has a greater impact on risk aversion (RA).

3.3 Assessing the impact of central bank communication

To examine the effects of Fed's communication tone, we estimate the following specification:

$$Y_{t,t+1}^i = \alpha_i + \beta_i NetOptTone_t + \gamma_i \mathrm{X}_t + \varepsilon_{i,t} \tag{11}$$

[12] The option-implied volatility index measures the risk-neutral expected volatility from various put and call European options on the equity index. For example, in United States the implied volatility index (VIX) is derived from a large array of S&P500 put and call options, having maturity in the next 22 trading days.

where $Y^{i}_{t,t+1}$ is the dependent variable relating to the implied volatility (VIX), uncertainty (UC), or risk aversion (RA); $NetOptTone_t$ is our measure for central bank tone given by Eq. (5); and X_t is a vector of control variables including Fed's policy rate, growth of industrial production, unemployment rates, Fed's forecasts for GDP and inflation. Cieslak et al. (2019) argues the overall impact of Fed on stock market could be much larger than previously thought. They show that FOMC announcements have a strong effect on stock returns even weeks after a meeting (i.e., the full cycle of days between FOMC meetings). Hence, to assess the link between Fed's communication tone and *subsequent* changes in market expectations, we estimate our dependent variables over the 'minutes cycle' (i.e., the period between two FOMC minutes)[13] and then regress each dependent variable on the Fed's tone. More precisely, to analyze the effects of Fed's tone displayed in the FOMC minute at time t, we compute our dependent variables from the date of publication to the day before the next FOMC minutes at t + 1. We denote our dependent variables as $Y^{i}_{t,t+1}; i = VIX, UC, orRA$.[14]

To investigate the impact of Fed's tone during recessions, we multiply the tone with a dummy (D^{REC}_t) that takes value one for NBER-designated recessionary period and zero otherwise.[15]

$$Y^{i}_{t,t+1} = \alpha_i + \beta_i NetOptTone_t * D^{\mathrm{Re}\,c}_t + \omega_i NetOptTone_t * \left(1 - D^{\mathrm{Re}\,c}_t\right) + \gamma_i X_t + \varepsilon_{i,t} \quad (12)$$

Note that in Eq. (12) the strength of linkage between central bank communication tone and option-implied market expectations is allowed to vary across business cycles (βi vs. ωi). Similarly, we create two additional dummies to further study the *state-dependent* impact of Fed's tone during periods of heightened uncertainty in the economic and monetary policies. We compare the current month Economic Policy Uncertainty (EPU) and Monetary Policy Uncertainty (MPU) indices of Baker et al. (2016) with their own past 3 months rolling averages and categorise a period as high policy uncertainty when the index is higher than its past 3 month's average. Then, we form two dummies (D^{EPU}_t and D^{MPU}_t) taking value one for the months when EPU or MPU are higher than their lagged average and zero otherwise. Finally, we multiply our EPU (or MPU) dummy with Fed's tone to assess the impact of central bank communications during episodes of high and low policy uncertainty.

$$Y^{i}_{t,t+1} = \alpha_i + \beta_i NetOptTone_t * D^{EPU}_t + \omega_i NetOptTone_t * \left(1 - D^{EPU}_t\right) + \gamma_i X_t + \varepsilon_{i,t} \quad (13)$$

$$Y^{i}_{t,t+1} = \alpha_i + \beta_i NetOptTone_t * D^{MPU}_t + \omega_i NetOptTone_t * \left(1 - D^{MPU}_t\right) + \gamma_i X_t + \varepsilon_{i,t} \quad (14)$$

Next, we estimate the following equations to study the *spillover effect* of Fed's communication tone on implied volatility, risk aversion, and uncertainty in the U.K. and Eurozone. We use domestic variables to control for business cycle and economic variations. Specifically, to control for domestic macroeconomic variations, we include in Z_t the growth of industrial production, consumer price index and gross domestic production in the U.K. and

[13] During our sampling period from December 2004 to May 2018, the average time interval between the publications of two meeting minutes is approximately 3 weeks. Table A1 of appendix A contains the dates of all FOMC meetings and publication of their minutes for the period under investigation.

[14] As a robustness check, we show that our main conclusions remain unchanged when focusing only on the day Fed releases the FOMC minutes instead of 'minutes cycle' (see Sect. 5.1.4).

[15] The dates for NBER-designated recession period are available at www.nber.org/cycles/cyclesmain.html.

Euro area. We also consider Fed's policy rate to allow for the spillover impact of Fed's policy decisions while investigating the effect of Fed's communication tone.

$$Y^{i(UK)}_{t,t+1} = \alpha_i + \beta_i NetOptTone_t + \gamma_i Z_t + \varepsilon_{i,t} \tag{15}$$

$$Y^{i(EZ)}_{t,t+1} = \alpha_i + \beta_i NetOptTone_t + \gamma_i Z_t + \varepsilon_{i,t} \tag{16}$$

To explore the potential *asymmetric response* of market participants to the Fed's optimism and pessimism, we allow both $OptimisticTone_t$ and $PessimisticTone_t$ to enter the regression model as in Eq. (17).

$$Y^{i}_{t,t+1} = \alpha_i + \lambda_i Optimistic\ Tone_t + \delta_i Pessimistic\ Tone_t + \gamma_i \mathrm{X}_t + \varepsilon_{i,t} \tag{17}$$

Additionally, we also dig a little deeper to understand the information that drives investor's expectations and changes investor's risk appetite. In particular, using the procedure described in Sects. 3.1.2 and 3.1.3 to extract topic tone, we study the influence of each topic's net optimistic tone on the level of uncertainty and risk aversion in the marketplace. Again, we further evaluate whether the optimistic and pessimistic tone of each topic affect investors' risk expectations differently.

$$Y^{i}_{t,t+1} = \alpha_i + \beta_i Topic'sNetOptTone_t + \gamma_i \mathrm{X}_t + \varepsilon_{i,t} \tag{18}$$

$$Y^{i}_{t,t+1} = \alpha_i + \lambda_i Topic'sOptTone_t + \delta_i Topic'sPesmTone_t + \gamma_i \mathrm{X}_t + \varepsilon_{i,t} \tag{19}$$

4 Data descriptions and results

4.1 Data descriptions

4.1.1 FOMC meeting minutes

Like other central banks, the Fed communicates with the public through various tools e.g., policy statements, press conferences, Federal Open Market Committee (FOMC) meeting minutes, chairman speeches, testimonies to the US Congress, and Summary of Economic Projections (SEP) reports. Nevertheless, in this paper we choose to analyze the minutes of FOMC meeting for the following reasons. First, compared to other sources of communication, FOMC meetings are scheduled in advance and their minutes are closely watched by market participants and also highly reported in the press. For instance, the Wall Street Journal reports:

> "Federal Reserve officials are debating whether they will need to raise interest rates to levels sufficient to slow down a fast-growing economy to prevent it from overheating, minutes of the central bank's last policy meeting show."
>
> Source: The Wall Street Journal, 17th October 2018

Although the press conferences after each FOMC meeting may also serve as an appropriate tool to extract tone, the Fed started press conferences only after April 2011.[16] Second, our use of the computational content analysis requires a well-structured communication tool which is free from personal attributes of the speaker. Unlike the Fed chair's speeches, the composition of FOMC meeting minutes is well structured and systematic to express the committee member views on economic conditions (Boukus and Rosenberg 2006). Fed's policy statements, on the other hand, are very short and lack detailed information for macroeconomic and financial conditions. Moreover, these policy statements are announced simultaneously with monetary decisions, making it difficult to disentangle the effects of the Fed's *actions* (decisions) from *words* (communications).[17]

The Federal Open Market Committee, or FOMC, is the body within the Fed that is responsible for setting monetary policy and it meets eight times on average in a year. The Fed started publishing meeting minutes since January 1994 but before the December 2004 Fed releases minutes with irregular delays and sometimes minutes of the meeting were published after the subsequent FOMC meeting. Jubinski and Tomiljanovich (2017) argues that FOMC decisions in the subsequent meeting may provide additional new information for market participants before the publication of the previous meeting minutes. Hence, this paper focuses only on the minutes of FOMC meetings published after December 2004. Since December 2004, FOMC minutes have been released on average 21 days after the meeting. Table A1 of appendix A contains the FOMC meetings and minutes release dates for the period under investigation.

We download the minutes of FOMC meetings in HTML format from Fed's website.[18] On average, the minute (document) contains 4,000 words and about 10 to 12 pages long. Our sample covers FOMC meetings from December 2004 to May 2018 including a total of 108 meetings. The FOMC minute comprises of four major parts, the first part outlines the FOMC member names, official details, and confirmation statement for the previous meeting decisions. The second part provides each member's view about the economic situation and outlook. The third section contains the committee member projections for future economic and financial market conditions. Finally, the fourth section elaborates the rationale for policy stance and the future path of the policy. As the first part of each document describes the administration details and names of committee members, we eliminate the first part of FOMC minutes before applying the computational content analysis.

We arrange the documents in chronological order and develop a metadata file which contains all the FOMC meeting minutes (documents). Next, we prepare a corpus (collection of documents) comprising of 108 FOMC minutes. Afterwards, we process our text by striping the white spaces, transferring all the words to the lower cap, eliminating the English stop words, removing punctuations and numbers.[19] Then, we stem all the words to their common linguistic root using Porter's stemming allocation.[20] Figure A1 in appendix

[16] Using an interaction dummy variable for the period after the Fed started doing press conferences, we investigate the change in the impact of information in FOMC minutes on market expectations (see Sect. 5.2.2).

[17] Nevertheless, as an additional analysis, we also extract the Fed's tone using policy statements and investigate its impact on uncertainty and risk aversion after controlling for policy decisions (see Sect. 5.2.1).

[18] The FOMC minutes are available at The Fed—Historical Materials by Year (federalreserve.gov).

[19] The stop words are the common neutral words such as pronouns, articles, propositions, conjunctions, and auxiliary verbs.

[20] For instance, the stemming process converts the words inflationary, inflation, inflating and inflated into a common linguistic root "inflat".

A contains an example showing each step of the text cleaning process. Subsequently, we create a matrix of all the unique stemmed terms to form a Document-Term Matrix (DTM). Each row represents a paragraph from the FOMC minutes, and each column represents a unique term. The values of the matrix indicate the frequency of each term in a paragraph.

Figure 1 shows the word cloud indicating the most frequent words in the FOMC minutes during our sampling period. The font size of each word in the word cloud depicts the cumulative frequency of that term in FOMC meeting discussions. Moreover, Table A2 of appendix A contains the top 50 most frequent words with their relevant frequency of appearing. As we can observe that terms such as market, economy, financial and growth are among the top ten most frequent words. This corroborates the view that FOMC meeting minutes contain vital new information about economic and financial conditions.

4.1.2 Fed's communication tone

To extract Fed's communication tone, we use the list of directional phrases combining positive (negative) nouns and optimistic (pessimistic) adjectives. Our list of phrases is based on a directional dictionary of Apel and Grimaldi (2014) which was developed primarily for central bank communications analysis. Specifically, following Apergis and Pragidis (2019), we employ the phrases combining the concepts (nouns) and tone modifiers (adjectives) to estimate Fed's tone. Table A4 of appendix A contains the list of directional nouns and adjectives.

Figure 2 displays Fed's communication tone from December 2004 to May 2018. As we can observe that the Fed is highly pessimistic during the global financial crisis and the Eurozone sovereign debt crisis. Table 1 reports descriptive statistics for Fed's tone. The mean and standard deviation show that FOMC members are generally more pessimistic during the sample period and there is a high variation in the central bank tone.

4.1.3 Topics in FOMC minutes

To better understand the information content of FOMC minutes, we apply the Latent Dirichlet Allocation (LDA) method to identify ten distinct topics under discussion in FOMC meetings. Selecting the optimal number of topics for LDA has an important implication on the estimated results. The extremely low number of topics leads to a problem in the interpretation of results. On the contrary, choosing a high number of topics leads to the redundancy of similar concepts in different topics (Goloshchapova et al. 2019). We follow Röder et al. (2015) and use the coherence score to choose the optimal number of topics. A high coherence score depicts the higher co-occurrence of words in the text and provides the optimal number of topics. Figure A2 in appendix A indicates that the coherence score is highest at ten topics.

Table A3 of appendix A contains the top twenty most frequent words along with their term probability (Beta) appeared in each topic. The FOMC minutes contain mostly discussion about employment, investments, monetary policy, growth, financial markets, credit conditions, economy, consumption, exchange rate, and inflation. Figure 3 displays the term's probability of appearing in each topic. Similarly, Fig. 4 shows the word clouds of ten topics and the font size represents the frequency of occurrence of each word in each topic. Figure A3 in appendix A indicates the proportion of each topic discussed in FOMC meetings. It is evident that the focus of discussion in FOMC meetings changed

Fig. 1 FOMC minutes word cloud. This word cloud shows the most frequent words in the Federal Open Market Committee (FOMC) minutes from December 2004 to May 2018. The font size of each word represents the frequency of that particular term throughout the sample period. Before applying the textual analysis, we first eliminate all the punctuations, auxiliary verbs, numbers, symbols, and common words (stop words). To avoid repetition of words with similar concepts, we stem all the unique words. Stemming refers to removing the suffixes and all the words with the same epistemological root to associate with a single word

dramatically after the global financial crisis from growth and policy rate to employment and credit conditions.

Using the topics-to-tone modelling approach outlined in Sect. 3.1.3, we estimate the optimistic and pessimistic tone of each topic. Figure 5 presents the net optimistic tone of each topic over the sample period. It is evident that during the NBER designated recessionary period the FOMC member's discussion was highly pessimistic about employment, consumption, investment, and financial market. For greater clarity, we also display each topic's net optimistic tone in a separate graph (Figure A4 in appendix A).

4.1.4 Uncertainty and risk aversion

To measure risk aversion and uncertainty, we use a decomposition of the option-implied volatility index on the S&P500 index i.e., the Chicago Board of Trade (CBOT) VIX index. First, we estimate the realized monthly variance for the U.S. stock market using the daily

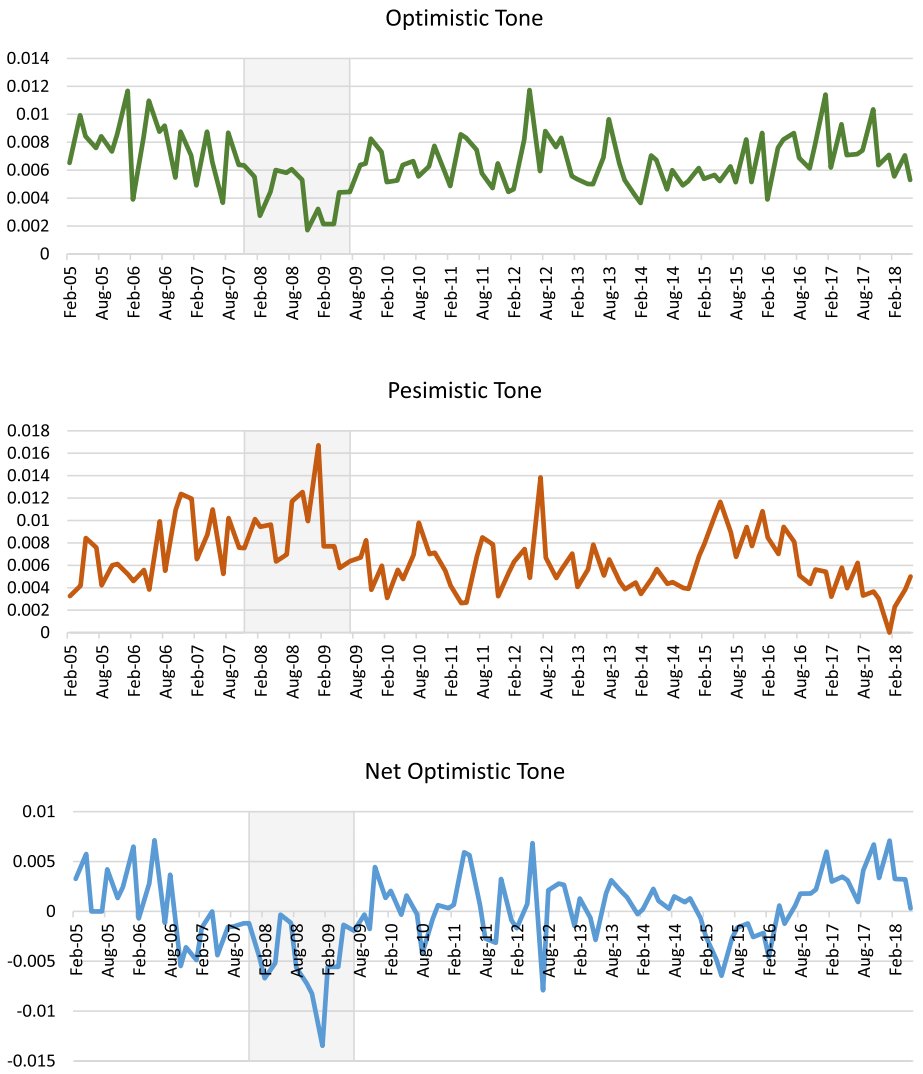


Fig. 2 Fed's communication tone. These plots show the Fed's optimistic tone, pessimistic tone, and net optimistic tone, respectively. We extract the tone using directional lexicon consisting of optimistic and pessimistic bigrams (phrases) on FOMC minutes from December 2004 to May 2018. We count the frequency of optimistic and pessimistic phrases in each document and divide them with the total number of phrases in each document (minutes). The shaded area indicates the NBER-designated recessionary period

realized volatility (which is computed using squared 5-min returns on S&P500 index).[21] Next, we run a regression of the realized variance (RV_t) on lagged squared implied volatility (VIX_t^2) and lagged realized variance, which yields:

[21] The 5-min returns are available at the "realized library" of Oxford-Man Institute of Quantitate Finance: https://realized.oxford-man.ox.ac.uk/.

Table 1 Descriptive statistics of Fed's communication tone

	Optimistic tone	Pessimistic tone	Net optimistic tone
Mean	0.786	0.825	−0.039
Standard error	0.038	0.041	0.046
Median	0.794	0.798	−0.017
Standard deviation	0.398	0.431	0.483
Kurtosis	−0.249	−0.034	0.305
Skewness	−0.272	0.174	−0.211
Minimum	0.000	0.000	−1.364
Maximum	1.634	1.833	0.949
Observations	108	108	108

This table reports descriptive statistics for the Fed's tone extracted using directional optimistic and pessimistic phrases of Apel and Grimaldi (2014) directional lexicon. We use 108 FOMC minutes from December 2004 to May 2018 to estimate the Fed's tone. Specifically, we calculate the net optimistic tone by dividing the number of net optimistic phrases with a total number of phrases in each FOMC minutes. Net optimistic phrases are calculated by subtracting the number of pessimistic phrases from a number of optimistic phrases in each FOMC minutes

$$RV_t = \underset{(0.4316)}{-0.0008} + \underset{(4.138)}{0.3948}\ VIX^2_{t-22} + \underset{(3.8555)}{0.3322}\ RV_{t-22} + \varepsilon_t \tag{20}$$

The t-statistics reported in parentheses are corrected for autocorrelation and heteroscedasticity using the Newey-West (1987) procedure. The significance of coefficients suggests that both lagged realized volatility and implied volatility affect S&P500 volatility. The fitted value from this regression, $\widehat{RV}_t$, is our proxy for uncertainty. Risk aversion is then given by the difference between the squared VIX and uncertainty. Table 2 reports descriptive statistics for the implied volatility (VIX), uncertainty (UC), and risk aversion (RA). The variations in these measures are presented in Fig. 6. One can observe that both uncertainty and risk aversion remained extremely high during the global financial crisis. In Sect. 4.2.3 we follow a similar procedure to explore the spillover effect of Fed's communications on equity markets of the United Kingdom (UK) and Eurozone (EZ). We decompose the implied volatility on FTSE-100 index (VFTSE) and STOXX-50 index (VSTOXX) to measure the level of uncertainty and risk aversion in the UK and EZ, respectively.

4.2 Results and discussion

4.2.1 Impact of Fed's communication tone

This paper explores empirically the effects of Fed's optimism on the implied volatility, uncertainty, and investor's risk aversion in the global equity markets.[22] Panel A of Table 3 shows the results for the impact of net optimistic tone on VIX index. The results suggest that Fed's optimistic communication decreases the option-implied volatility. The slope coefficient on net optimistic tone is negative and statistically significant at 5% level

[22] For our main analysis, we study the impact on the exogenous variables for the window starting from the day of FOMC minutes was published up to a day before next meeting minutes was released. Specifically, we estimate the implied volatility, uncertainty and risk aversion for the window which starts from meeting minutes publishing day up to the day before next meeting minutes was announced.

1. Employment
2. Investment
3. Monetary Policy
4. Growth
5. Financial Market
6. Credit Conditions
7. Economy
8. Consumption
9. Exchange Rate
10. Inflation

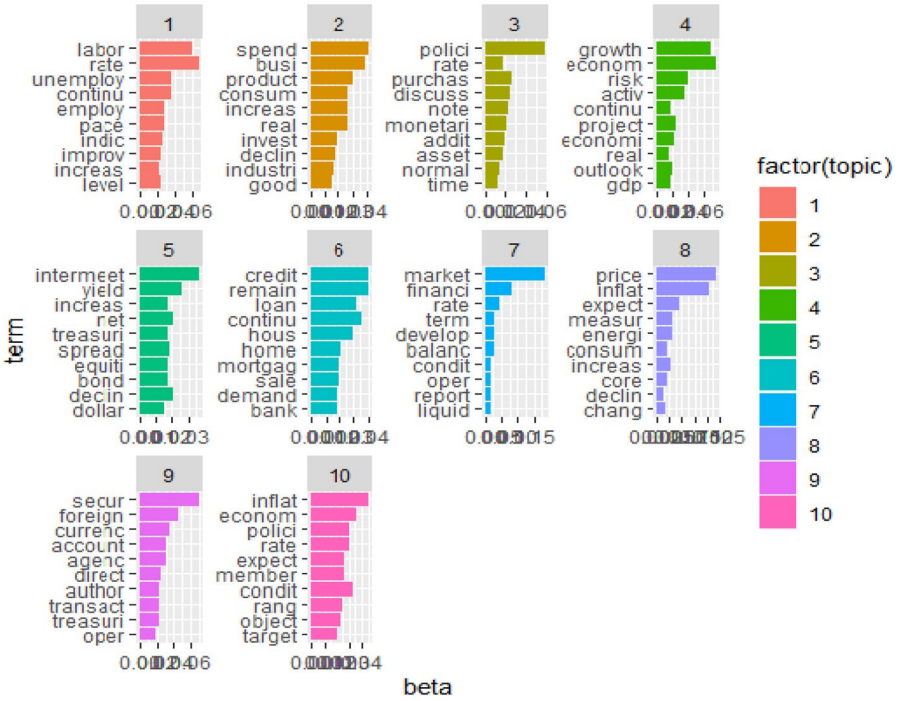


Fig. 3 Term's probability of appearing in each topic. This figure indicates the terms along with their probability of occurrence in each topic. The probability of occurrence (Beta) shows the probability of each term belongs to a particular topic. Using the Latent Dirichlet Allocation (LDA), we extract the following ten topics from FOMC minutes. The coherence score was used to choose the optimal number of topics. 1. Employment, 2. Investment, 3. Monetary Policy, 4. Growth, 5. Financial Market, 6. Credit Conditions, 7. Economy, 8. Consumption, 9. Exchange Rate, 10. Inflation

after controlling for policy rate decisions, Fed's forecasts, business cycle, and economic variations. This implies that central bank's optimistic assessment of economic conditions decreases investor fear.[23]

Panel B and C of Table 3 contain the results for the impact of Fed's tone on uncertainty and risk aversion, respectively. There is a significant decrease in uncertainty in response to the Fed's optimism. A closer inspection of panel B reveals that uncertainty decreases by 0.42 percentage points in response to one percentage point increase in the Fed's net optimistic tone. In addition, panel C in Table 3 indicates that one percentage point increase in Fed's net optimistic tone also decreases the investor's risk aversion (increases the risk-bearing capacity) by 0.38 percentage points. However, the impact on investor's risk appetite is significant only at 10% level. The adjusted R^2 shows that the Fed's tone defines almost 47%

[23] Whaley (2000) points out that VIX index is a useful gauge of investor fear in the equity market.

Fig. 4 Word clouds of ten unique topics. Each word cloud shows the 30 stemmed most frequent terms in each topic of FOMC minutes. The font size represents the frequency of occurrence of each term in each topic

and 15% of the overall variation in uncertainty and risk aversion, respectively. A comparison of results in panel B and C reveals that the Fed's tone has a higher impact on uncertainty compared to risk aversion.

These results are economically meaningful and consistent with previous studies. For example, Jegadeesh and Wu (2017) finds that the Fed's positive tone decreases the unexpected volatility of S&P500. In another study, Hansen and McMahon (2016) documents a

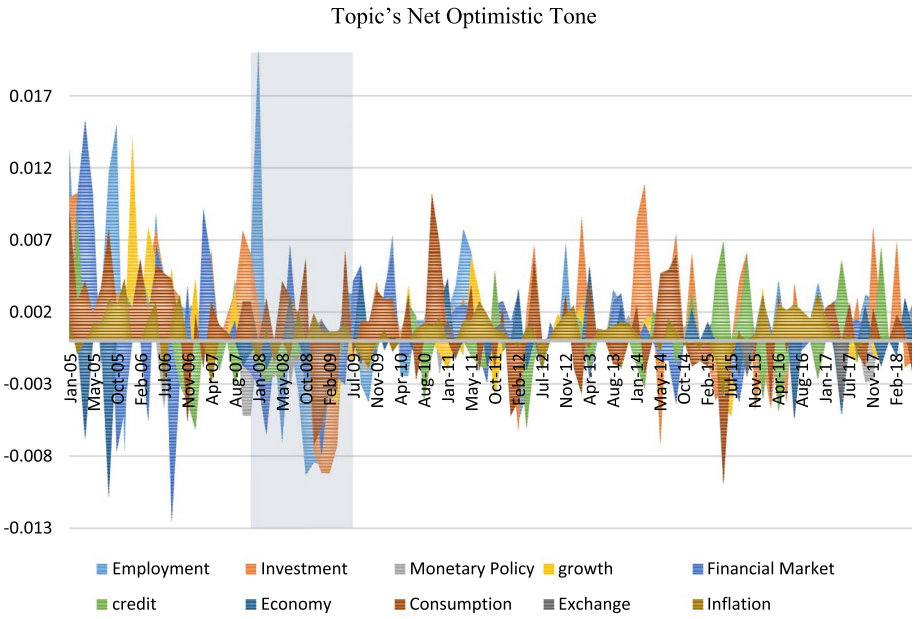


Fig. 5 Topic's net optimistic tone. This figure plots each topic's net optimistic tone extracted using the Federal Open Market Committee (FOMC) minutes for the period from December 2004 to May 2018. First, we use Latent Dirichlet Allocation to identify ten different topics from FOMC minutes. Second, we apply Apel and Grimaldi (2014) directional dictionary to classify the phrases in optimistic and pessimistic categories for each topic. Third, this paper computes the net optimistic phrases after subtracting a number of pessimistic phrases from a number of optimistic phrases. Finally, we compute the net optimistic tone after dividing the net optimistic phrases by a number of total phrases. The shaded area is the NBER designated recessionary period

decrease in implied volatility in response to the Fed's optimism revealed in monetary policy statements. Previous studies also document similar results in other major economies. Apergis and Pragidis (2019) finds that positivity in the European Central Bank's (ECB's) tone increases the mean and decreases the volatility in major European equity markets. Picault and Renault (2017) discovers that equity market volatility decreases in response to ECB's positive assessment of economic conditions. Moreover, the results of Schmeling and Wagner (2024) show that the ECB's positive tone decreases the risk premium in some European equity markets. Hansen et al. (2019) finds that BoE's forecasts for economic indicators (Information Report) carry vital signals for market participants to derive their expectation about future economic conditions.

However, the previous studies express a mixed opinion on the interpretation of the central bank's optimistic and pessimistic tone. On the one hand, some suggest that positivity (optimism) in central bank's tone is an indication of the future contractionary policy and interpreted as bad news for market participants (Neuhierl and Weber 2019). Campbell et al. (2012) distinguishes the forward guidance into Odyssean and Delphic. The Odyssean forward guidance suggests central bank commitment about the future path of the policy rate. The Delphic forward guidance indicates the forecasts about the macroeconomic fundamentals and potential policy interventions in response to macroeconomic activities. Consistent

Table 2 Descriptive statistics of implied volatility, uncertainty, and risk aversion

	Implied volatility (VIX)	Uncertainty (UC)	Risk aversion (RA)
Mean	0.098	0.074	0.048
Standard error	0.012	0.008	0.009
Standard deviation	0.123	0.083	0.091
Kurtosis	19.783	17.976	46.228
Skewness	4.076	3.859	6.100
Minimum	0.021	0.020	0.003
Maximum	0.866	0.594	0.802
Observations	108	108	108

This table reports descriptive statistics for the implied volatility, market uncertainty and investor's risk aversion of S&P500 index. We use implied volatility (VIX) index of the Chicago Board of Trade. The VIX index measures implied volatility from various European option prices. We apply Bekaert et al. (2013) decomposition methodology to divide implied volatility into market uncertainty and investor's risk aversion components. The decomposition process starts with the calculation of a realized variance. In this paper, we calculate the daily realized variance using the five minutes returns on S&P500. Later we use lagged realized and implied variance to estimate expected realized variance. The estimated realized variance represents the uncertainty in the equity market and the difference between implied variance and estimated realized variance is a measure for investor's risk aversion

with Delphic effect of central bank communications, Hansen et al. (2019) documents that a positivity in central bank communications drives market expectations.

Overall, our results are consistent with the view that investors change their risk perception and risk-bearing capacity in response to the central bank's communications. The new

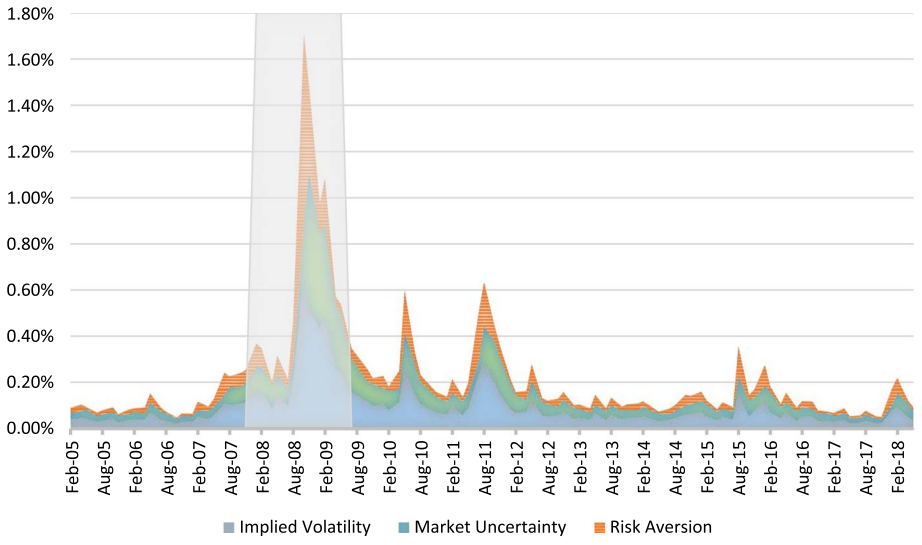


Fig. 6 Time series plots for VIX, UC and RA. This figure shows the variations in implied volatility (VIX) index, market uncertainty (UC) and risk aversion (RA) for the period from December 2004 to May 2018. Following Bekaert et al. (2013), we decompose the implied variance into uncertainty and risk aversion components using the difference between risk-adjusted and risk-free variance of equity market index

Table 3 Impact of Fed's communication tone

Model	(1)	(2)	(3)	(4)	(5)
Panel A: implied volatility (VIX)					
Constant	0.0000	0.0000	0.0000	0.0000	0.0000
	(−0.000)	(−0.000)	(−0.000)	(−0.000)	(−0.000)
Net optimistic tone	−0.4597*	−0.4607*	−0.4132**	−0.4391**	−0.4474**
	(−1.937)	(−1.930)	(−2.179)	(−2.096)	(−2.091)
Policy rate		−0.0561	0.0065	−0.058	−0.1743
		(−0.617)	(0.090)	(−0.528)	(−0.667)
Industrial production			−0.3771***	−0.3887***	−0.5589
			(−3.477)	(−3.102)	(−1.558)
GDP forecasts				−0.0382	−0.006
				(−0.449)	(−0.081)
INF forecasts				0.1252	0.1352
				(0.794)	(0.802)
Unemployment rate					−0.2361
					(−0.634)
Adj. R^2	0.204	0.199	0.332	0.331	0.335
Panel B: uncertainty (S&P500)					
Constant	0.0000	0.0000	0.0000	0.0000	0.0000
	(0.000)	(0.000)	(−0.000)	(−0.000)	(−0.000)
Net optimistic tone	−0.4949*	−0.4967*	−0.4357**	−0.4114**	−0.42**
	(−1.953)	(−1.949)	(−2.392)	(−2.107)	(−2.129)
Policy rate		−0.0944	−0.0142	0.0543	−0.0676
		(−0.978)	(−0.206)	(0.647)	(−0.373)
Industrial production			−0.4835***	−0.4643***	−0.6425**
			(−3.562)	(−3.528)	(−2.113)
GDP forecasts				−0.0661	−0.0324
				(−1.455)	(−0.584)
INF forecasts				−0.1074	−0.0969
				(−1.350)	(−1.176)
Unemployment rate					−0.2474
					(−0.829)
Adj. R^2	0.238	0.24	0.462	0.462	0.468
Panel C: risk aversion (S&P500)					
Constant	0.0000	0.0000	0.0000	0.0000	0.0000
	(0.000)	(0.000)	(−0.000)	(−0.000)	(−0.000)
Net optimistic tone	−0.327*	−0.3273*	−0.3048*	−0.3699*	−0.3773*
	(−1.685)	(−1.679)	(−1.736)	(−1.879)	(−1.856)
Policy rate		−0.0152	0.0144	−0.1548	−0.2579
		(−0.216)	(0.230)	(−1.262)	(−0.880)
Industrial production			−0.1787*	−0.2154*	−0.3663
			(−1.946)	(−1.957)	(−1.013)
GDP forecasts				−0.0031	0.0255
				(−0.028)	(0.265)
INF forecasts				0.3053	0.3142

Table 3 (continued)

Model	(1)	(2)	(3)	(4)	(5)
				(1.483)	(1.429)
Unemployment rate					−0.2093
					(−0.538)
Adj. R^2	0.098	0.09	0.113	0.155	0.154

This table reports the estimation results of Eq. (11). The results for the impact of Fed's net optimistic tone on implied volatility, uncertainty, and risk aversion are provided in panel A, B and C, respectively. Following Bekaert et al. (2013), we use the difference between risk-adjusted and risk-free volatility to decompose the VIX into uncertainty and risk aversion components. To estimate the Fed's tone, we apply a bag of word method of Apel and Grimaldi (2014) to categorise the discussion in FOMC meetings into an optimistic and pessimistic tone. In particular, following Apergis and Pragidis (2019), we measure the frequency of optimistic and pessimistic phrases in each FOMC minutes from January 2005 to May 2018. Estimates on the net optimistic tone are obtained by dividing the difference between the frequency of optimistic and pessimistic phrases with a total number of phrases in each FOMC minutes. We control for the effect of other Fed's announcements using policy rate decisions and projections for Gross Domestic Production (GDP) and inflation (INF) variables. We also include industrial production and unemployment rate to control for business cycle and economic variations. All the series are standardized to have zero mean and unit standard deviation. The t-statistics reported in parentheses are corrected for autocorrelation and heteroscedasticity using the Newey-West (1987) procedure. Superscripts ***, **, * indicate the statistical significance at 1%, 5% and 10% level respectively

information about future economic and financial outlook embedded in the central bank's tone appears to be the primary reason for the effect of communications on equity markets (Romer and Romer 2000). The notion of "Narrative Economics" highlights the importance of popular narratives in formatting and spreading expectations in an economy (Shiller 2017). We provide evidence that central bank communication is a powerful instrument of monetary policy, which can shape investor's expectations and influence the degree of risk aversion in the market.

4.2.2 Is the impact of Fed's tone state-dependent?

Consider next the results for Eq. (12) which allows the impact of central bank communication tone to vary across business cycles. We find that, as one might expect, investors are more sensitive to the Fed's communications tone during recessions than in the normal economic times. Indeed, a closer inspection of Table 4 reveals that both the magnitude and the significance of coefficient on Fed's net optimistic tone is higher in recession (β_i) than in normal economy state (ω_i). This is the case for the implied volatility, uncertainty, and risk aversion. This finding is consistent with the evidence of Basistha and Kurov (2008) who documents a higher impact of policy rate during recessions compared to good economic times. In another closely related study, Apergis and Pragidis (2019) also finds a higher impact of ECB's tone on equity returns and volatility during the global financial crisis period.

Table 4 Impact of Fed's tone during recessions

Model	(1)	(2)	(3)	(4)	(5)
Panel A: implied volatility (VIX)					
Constant	−0.1914**	−0.1949**	−0.1725***	−0.1744***	−0.1725***
	(−2.465)	(−2.613)	(−2.822)	(−2.862)	(−2.672)
Net Opt Tone × D^{Rec}	−1.3144***	−1.3321***	−1.2011***	−1.2281***	−1.223***
	(−4.765)	(−4.954)	(−4.523)	(−4.305)	(−4.496)
Net Opt Tone × $(1 - D^{Rec})$	−0.0708	−0.0657	−0.0801	−0.0945*	−0.1019*
	(−1.213)	(−1.172)	(−1.561)	(−1.664)	(−1.662)
Policy rate		−0.1075*	−0.0608	−0.1021	−0.1517
		(−1.894)	(−1.299)	(−1.505)	(−0.990)
Industrial production			−0.2457***	−0.2475***	−0.3224
			(−4.526)	(−3.599)	(−1.608)
GDP forecasts				−0.0868	−0.0724
				(−0.566)	(−0.495)
INF forecasts				0.0939	0.0985
				(1.175)	(1.138)
Unemployment rate					−0.1017
					(−0.414)
Adj. R^2	0.498	0.504	0.556	0.562	0.559
Panel B: uncertainty (S&P500)					
Constant	−0.2007**	−0.2056**	−0.1736***	−0.1790***	−0.1769***
	(−2.389)	(−2.609)	(−3.046)	(−3.249)	(−3.071)
Net Opt Tone × D^{Rec}	−1.3915***	−1.416***	−1.2286***	−1.2209***	−1.2155***
	(−5.126)	(−5.533)	(−6.140)	(−5.082)	(−5.322)
Net Opt Tone × $(1 - D^{Rec})$	−0.087	−0.0799	−0.1005**	−0.0578	−0.0657
	(−1.453)	(−1.458)	(−2.286)	(−1.200)	(−1.350)
Policy rate		−0.1486**	−0.0819*	0.009	−0.0444
		(−2.431)	(−1.832)	(0.175)	(−0.465)
Industrial production			−0.3513***	−0.3194***	−0.4**
			(−5.166)	(−4.929)	(−2.437)
GDP forecasts				−0.116	−0.1005
				(−1.095)	(−0.947)
INF forecasts				−0.1395**	−0.1345**
				(−2.305)	(−2.326)
Unemployment rate					−0.1095
					(−0.573)
Adj. R^2	0.562	0.58	0.691	0.707	0.706
Panel C: risk aversion (S&P500)					
Constant	−0.1402**	−0.1419**	−0.1350**	−0.1334**	−0.1314*
	(−2.164)	(−2.222)	(−2.170)	(−2.110)	(−1.947)
Net Opt Tone × D^{Rec}	−0.9532***	−0.9618***	−0.9214**	−0.9732***	−0.9678***
	(−2.685)	(−2.700)	(−2.562)	(−2.797)	(−2.897)
Net Opt Tone × $(1 - D^{Rec})$	−0.0421	−0.0396	−0.0441	−0.1065*	−0.1142
	(−0.870)	(−0.826)	(−0.920)	(−1.717)	(−1.577)
Policy rate		−0.0526	−0.0382	−0.1885*	−0.2407

Table 4 (continued)

Model	(1)	(2)	(3)	(4)	(5)
		(−1.087)	(−0.882)	(−1.923)	(−1.143)
Industrial production			−0.0758	−0.1075	−0.1862
			(−1.065)	(−1.427)	(−0.811)
GDP forecasts				−0.0403	−0.0251
				(−0.243)	(−0.164)
INF forecasts				0.2813*	0.2862*
				(1.929)	(1.824)
Unemployment rate					−0.107
					(−0.375)
Adj. R^2	0.252	0.247	0.245	0.285	0.28

This table reports the estimation results of Eq. (12). The results for the state-dependent impact of Fed's net optimistic tone on implied volatility, uncertainty, and risk aversion are provided in panel A, B and C respectively. Following Bekaert et al. (2013), we use the difference between risk-adjusted and risk-free volatility to decompose the VIX into uncertainty and risk aversion components. We follow Apergis and Pragidis (2019) and measure the frequency of optimistic and pessimistic phrases in each FOMC minutes from January 2005 to May 2018. This study estimates an interaction dummy which takes the value of unity for the NBER designated recessionary months and zeroes otherwise. We control for the effect of other Fed's announcements using policy rate decisions and projections for Gross Domestic Production (GDP) and inflation (INF) variables. We also include industrial production and unemployment rate to control for business cycle and economic variations. All the series are standardized to have zero mean and unit standard deviation. The t-statistics reported in parentheses are corrected for autocorrelation and heteroscedasticity using the Newey-West (1987) procedure. Superscripts ***, **, * indicate the statistical significance at 1%, 5% and 10% level respectively

Next, we also analyze the impact of Fed's tone over the periods of high and low policy uncertainty. The results for the effect of Fed's communication tone at the times when economic or monetary policy uncertainty is elevated are provided in Tables 5 and 6, respectively. Similar to the recession analysis, we interact Fed's tone with a dummy variable which takes the value of unity for periods with high policy uncertainty. Our results show that the Fed's tone has a much stronger impact on uncertainty and risk aversion during the period with a high policy uncertainty. During the episodes of high EPU and MPU, market participants are unsure about future economic conditions resulting in stronger response to the new information in central bank communications (Hubert and Labondance 2017).

4.2.3 Does the Fed's communication tone have spillover effect?

The results reported in Tables 7 and 8 show that the effects of Fed's communication indeed spillover to other developed economies such as the U.K. and Eurozone. A closer inspection reveals that the impact of Fed's tone is stronger in the Eurozone than in the U.K. These results confirm the findings of Nave and Ruiz (2015) about the potential impact of the unexpected reduction in Federal fund rate on the uncertainty and risk aversion in European equity markets. Additionally, Hayo et al. (2010) finds that the Fed's tone extracted from speeches significantly affect the changes in European and Pacific equity markets. In this paper we show that apart from policy rate decisions

Fed's communication also affects the changes in investor's perception and pricing of risk in other developed nations. The Fed's communication is a vital source of information for investors not only in the U.S. but also in the global financial markets.

4.2.4 Asymmetric effect of optimistic and pessimistic tone

The results of our investigation into the potential asymmetric effects of Fed's optimism and pessimism are presented in Table 9. As expected, the implied volatility, uncertainty and risk aversion decrease (increase) in response to the Fed's optimistic (pessimistic) tone. Comparative analysis suggests that the Fed's pessimistic tone has a relatively stronger effect on risk aversion compared to an optimistic tone. In particular, one percentage point increase in the Fed's pessimistic tone increases investor's risk aversion by 0.30 percentage point. However, one percentage point increase in optimistic tone decreases the risk aversion by only 0.15 percentage point. This confirms that there is a "Negativity bias" and investors overreact to bad news compared to good news (Akhtar et al. 2011). Our results are also in line with those of White (2018) who finds that in equity markets, the negative communication by the Fed has a higher impact than its positive communication.

4.2.5 Heterogeneous impact of topic's tone

To further understand the information that drive investor's risk perception and appetite, we examine the impact of communication tone of certain topics on uncertainty and risk aversion. The results in Table 10 show that Fed's optimism about financial markets, investment and exchange rate are primarily responsible for the changes in investor's risk attitude. Specifically, our results show that the Fed's optimistic discussions about financial market and investment have significantly reduced the level of uncertainty in the U.S market.

The results of Table 11 show that an optimistic tone for financial market outlook and credit conditions decreases uncertainty. In addition, pessimism related to the economic outlook, growth indicators and investment scenario increases market uncertainty. Surprisingly, the Fed's optimism about the future path of policy rate increases investor fear and risk aversion. These findings imply that market participants view FOMC meeting discussion as an indication of the future short-term rate. Fed's optimistic tone about monetary policy indicates future contractionary monetary policy and thus increases investor's aversion to risk in the market. Jegadeesh and Wu (2017) also find that the Fed's positive tone about financial market, investments outlook, and economic situations reduce the unexpected volatility in the S&P500 index, but a positive tone about policy stance increases the unexpected volatility. Picault and Renault (2017) documents that both ECB's dovishness about monetary policy stance and positivism about economic conditions decreases the volatility in European stock markets. In this study, we find that the Fed's optimistic tone about the economic outlook and financial market conditions decreases the uncertainty and risk aversion. However, the optimistic tone about policy stance increases the market-wide fear and investor's aversion to risk.

5 Robustness tests and additional results

5.1 Robustness

In this section we conduct a series of robustness checks to test the validity our results by changing (i) weighting scheme, (ii) scaling method, (iii) directional dictionary, (iv) measures for uncertainty and risk aversion, and (v) the number of topics in LDA analysis.[24],[25]

5.1.1 Term weighting scheme

In the analysis presented in the previous sections, we assign equal weight to each term appearing in the FOMC meeting minutes. However, the terms appearing more frequently may add less to the conceptual information. As a robustness check, we use an alternative weighting scheme that penalizes the most frequent terms in the text to extract central bank tone. The term frequency-inverse document frequency (tf-idf) is the most commonly known weighting scheme which inversely related to the frequency of terms (Jegadeesh and Wu 2017). The results reported in Table B3 of appendix B confirms our earlier findings that the Fed's optimism decreases both uncertainty and risk aversion, with the former effect being stronger.

5.1.2 Net optimistic index

Next, we estimate Fed's net optimistic index by dividing the number of net optimistic phrases with a sum of optimistic and pessimistic phrases in each minute document. This exercise addresses the concern that using the ratio of net optimistic phrases out of total phrases in FOMC minutes may cause a bias in the estimation of Fed's tone. For example, a lengthy meeting may have a comparatively lower ratio which results in extremely low values for net optimistic tone. Thus, we calculate another index of net optimistic tone which does not penalize the tone measure for the length of the document. The results presented in Table B4 of appendix B are qualitatively similar to that reported previously in Table 3 suggesting that Fed's optimistic (pessimistic) tone decreases (increases) investor's risk aversion.

5.1.3 Fed's positive tone

Consideration is also given to the potential influence of using an alternative dictionary to extract the Fed's tone. Different from the main analysis, here we extract the Fed's tone

[24] In the interest of brevity, the results for our robustness checks and additional analyses are given in appendix B.

[25] It is possible that the observed link between Fed's communication and market expectations is caused by the Fed's reaction to the state of the economy and periods of heighten uncertainty. We are grateful to the referee for pointing out this possibility. As the robustness check, we conduct a series of additional tests considering (i) orthogonal Fed tone, (ii) lagged independent variable, and (iii) the Fed's tone 'surprise'. The results of these tests show that our conclusions remain unchanged after addressing the endogeneity concern. In the interest of brevity, the results of these checks are not reported here but are available upon request.

Table 5 Impact of Fed's tone during high economic policy uncertainty

Model	(1)	(2)	(3)	(4)	(5)
Panel A: implied volatility (VIX)					
Constant	−0.0149	−0.0148	−0.0143	−0.0138	−0.0146
	(−0.116)	(−0.114)	(−0.136)	(−0.131)	(−0.141)
Net Opt Tone × D^{EPU}	−0.6557**	−0.6536**	−0.6014**	−0.6159**	−0.6364**
	(−2.179)	(−2.147)	(−2.403)	(−2.383)	(−2.425)
Net Opt Tone × $(1 - D^{EPU})$	−0.1455	−0.1501	−0.1116	−0.1446	−0.138
	(−1.137)	(−1.197)	(−1.225)	(−1.331)	(−1.191)
Policy rate		−0.0282	0.0329	−0.0232	−0.1666
		(−0.339)	(0.487)	(−0.232)	(−0.699)
Industrial production			−0.3727***	−0.3841***	−0.5964*
			(−4.216)	(−3.767)	(−1.762)
GDP forecasts				−0.0141	0.0275
				(−0.140)	(0.316)
INF forecasts				0.1026	0.1138
				(0.649)	(0.685)
Unemployment rate					−0.295
					(−0.793)
Adj. R^2	0.259	0.252	0.383	0.378	0.388
Panel B: uncertainty (S&P500)					
Constant	−0.0151	−0.0147	−0.0142	−0.0144	−0.0153
	(−0.112)	(−0.108)	(−0.148)	(−0.150)	(−0.163)
Net Opt Tone × D^{EPU}	−0.6934**	−0.6886**	−0.6215***	−0.5964**	−0.6179**
	(−2.224)	(−2.180)	(−2.627)	(−2.390)	(−2.497)
Net Opt Tone × $(1 - D^{EPU})$	−0.1768	−0.1877	−0.1381	−0.1032	−0.0962
	(−1.082)	(−1.169)	(−1.486)	(−1.149)	(−0.933)
Policy rate		−0.0667	0.0119	0.0907	−0.0595
		(−0.754)	(0.185)	(1.073)	(−0.383)
Industrial production			−0.4792***	−0.4594***	−0.6818**
			(−3.914)	(−4.167)	(−2.382)
GDP forecasts				−0.0409	0.0027
				(−0.761)	(0.049)
INF forecasts				−0.131	−0.1193
				(−1.411)	(−1.299)
Unemployment rate					−0.309
					(−1.025)
Adj. R^2	0.295	0.292	0.514	0.515	0.529
Panel C: risk aversion (S&P500)					
Constant	−0.0121	−0.0122	−0.0120	−0.0108	−0.0115
	(−0.110)	(−0.110)	(−0.113)	(−0.108)	(−0.116)
Net Opt Tone × D^{EPU}	−0.4859*	−0.4865*	−0.462*	−0.5088**	−0.5265**
	(−1.907)	(−1.892)	(−1.959)	(−2.094)	(−2.082)
Net Opt Tone × $(1 - D^{EPU})$	−0.0723	−0.071	−0.0529	−0.1387	−0.133
	(−0.765)	(−0.758)	(−0.583)	(−1.204)	(−1.137)
Policy rate		0.0078	0.0365	−0.1275	−0.2518

Table 5 (continued)

Model	(1)	(2)	(3)	(4)	(5)
		(0.119)	(0.608)	(−1.162)	(−0.912)
Industrial production			−0.175**	−0.2118**	−0.3959
			(−2.358)	(−2.286)	(−1.140)
GDP forecasts				0.0158	0.0519
				(0.124)	(0.460)
INF forecasts				0.2875	0.2973
				(1.428)	(1.391)
Unemployment rate					−0.2558
					(−0.657)
Adj. R^2	0.131	0.122	0.144	0.179	0.183

This table reports the estimation results of Eq. (13). The results for the state-dependent impact of Fed's net optimistic tone on implied volatility, uncertainty, and risk aversion are provided in panel A, B and C respectively. Following Bekaert et al. (2013), we use the difference between risk-adjusted and risk-free volatility to decompose the VIX into uncertainty and risk aversion components. We follow Apergis and Pragidis (2019) and measure the frequency of optimistic and pessimistic phrases in each FOMC minutes from January 2005 to May 2018. This study estimates an interaction dummy which takes the value of unity for the months with higher-than-average EPU and zero otherwise. We control for the effect of other Fed's announcements using policy rate decisions and projections for Gross Domestic Production (GDP) and inflation (INF) variables. We also include industrial production and unemployment rate to control for business cycle and economic variations. All the series are standardized to have zero mean and unit standard deviation. The t-statistics reported in parentheses are corrected for autocorrelation and heteroscedasticity using the Newey-West (1987) procedure. Superscripts ***, **, * indicate the statistical significance at 1%, 5% and 10% level respectively

using a list of negative words from Loughran and McDonald (2011) financial dictionary. Next, we compute the frequency of negative words in each FOMC minute. As Jegadeesh and Wu (2017) points out the positive words are more frequently negated, we only use a list of negative words. Then, we estimate the ratio of negative terms out of total unique terms in each document.

$$Ratio\ of\ Negative\ Terms_D = \frac{\#\ Negative\ Terms\ (N)_D}{\#\ Total\ Terms\ (T)_D} \tag{21}$$

To capture optimism in the Fed's communication, we subtract the estimated ratio of negative terms from 1 to measure the Fed's positive tone.

$$Fed's\ Positive\ Tone_D = 1 - \ Ratio\ of\ Negative\ terms\ _D \tag{22}$$

Table B1 of appendix B reports descriptive statistics for the Fed's positive and negative tone. As shown in Figure B1 the Fed's positive tone and our 'net optimistic tone' move closely together for the period under study. Similar to the results presented in the previous sections, it is evident that during the 2007–2008 global financial crisis Fed's tone was extremely negative. Interestingly, similar pattern can also be seen in the net optimistic tone measure. The results of Table B5 confirm that the findings in previous sections carry over to this alternative lexicon.

Table 6 Impact of Fed's tone during high monetary policy uncertainty

Model	(1)	(2)	(3)	(4)	(5)
Panel A: implied volatility (VIX)					
Constant	−0.0009	−0.0009	−0.0009	−0.0009	−0.0008
	(−0.007)	(−0.007)	(−0.009)	(−0.008)	(−0.008)
Net Opt Tone × D^{MPU}	−0.6194**	−0.6224**	−0.5819**	−0.5869**	−0.592**
	(−2.050)	(−2.045)	(−2.274)	(−2.257)	(−2.299)
Net Opt Tone × $(1 - D^{MPU})$	−0.2299	−0.2285	−0.1693	−0.1982*	−0.2103
	(−1.299)	(−1.308)	(−1.622)	(−1.714)	(−1.642)
Policy rate		−0.0627	0.0004	−0.0343	−0.1433
		(−0.809)	(0.006)	(−0.358)	(−0.639)
Industrial production			−0.3822***	−0.3867***	−0.5455
			(−3.735)	(−3.481)	(−1.647)
GDP forecasts				−0.0441	−0.014
				(−0.379)	(−0.148)
INF forecasts				0.0738	0.084
				(0.535)	(0.571)
Unemployment rate					−0.2203
					(−0.630)
Adj. R^2	0.234	0.23	0.368	0.361	0.364
Panel B: uncertainty (S&P500)					
Constant	−0.0007	−0.0007	−0.0008	−0.0009	−0.0009
	(−0.005)	(−0.005)	(−0.008)	(−0.009)	(−0.009)
Net Opt Tone × D^{MPU}	−0.6267**	−0.6314**	−0.5797**	−0.5653**	−0.5706**
	(−2.121)	(−2.122)	(−2.554)	(−2.247)	(−2.307)
Net Opt Tone × $(1 - D^{MPU})$	−0.3054	−0.3032	−0.2277*	−0.1606*	−0.1732
	(−1.318)	(−1.324)	(−1.816)	(−1.664)	(−1.638)
Policy rate		−0.0999	−0.0194	0.0789	−0.0353
		(−1.167)	(−0.323)	(0.950)	(−0.243)
Industrial production			−0.4879***	−0.4622***	−0.6287**
			(−3.635)	(−3.921)	(−2.259)
GDP forecasts				−0.0723	−0.0407
				(−1.057)	(−0.727)
INF forecasts				−0.1609*	−0.1501
				(−1.686)	(−1.628)
Unemployment rate					−0.231
					(−0.829)
Adj. R^2	0.256	0.259	0.488	0.497	0.502
Panel C: risk aversion (S&P500)					
Constant	−0.0009	−0.0009	−0.0009	−0.0007	−0.0007
	(−0.008)	(−0.008)	(−0.009)	(−0.007)	(−0.007)
Net Opt Tone × D^{MPU}	−0.4905*	−0.4915*	−0.472*	−0.493**	−0.4975**
	(−1.780)	(−1.774)	(−1.835)	(−2.008)	(−2.030)
Net Opt Tone × $(1 - D^{MPU})$	−0.0919	−0.0915	−0.063	−0.1695	−0.1802
	(−0.996)	(−1.003)	(−0.877)	(−1.478)	(−1.394)
Policy rate		−0.0219	0.0084	−0.1351	−0.2322

Table 6 (continued)

Model	(1)	(2)	(3)	(4)	(5)
		(−0.380)	(0.164)	(−1.283)	(−0.885)
Industrial production			−0.1837**	−0.2138**	−0.3552
			(−2.237)	(−2.151)	(−1.050)
GDP forecasts				−0.008	0.0188
				(−0.058)	(0.159)
INF forecasts				0.2625	0.2716
				(1.468)	(1.403)
Unemployment rate					−0.1962
					(−0.532)
Adj. R^2	0.129	0.121	0.146	0.172	0.171

This table reports the estimation results of Eq. (14). The results for the state-dependent impact of Fed's net optimistic tone on implied volatility, uncertainty, and risk aversion are provided in panel A, B and C respectively. Following Bekaert et al. (2013), we use the difference between risk-adjusted and risk-free volatility to decompose the VIX into uncertainty and risk aversion components. We follow Apergis and Pragidis (2019) and measure the frequency of optimistic and pessimistic phrases in each FOMC minutes from January 2005 to May 2018. This study estimates an interaction dummy which takes the value of unity for the months with higher-than-average MPU and zero otherwise. We control for the effect of other Fed's announcements using policy rate decisions and projections for Gross Domestic Production (GDP) and inflation (INF) variables. We also include industrial production and unemployment rate to control for business cycle and economic variations. All the series are standardized to have zero mean and unit standard deviation. The t-statistics reported in parentheses are corrected for autocorrelation and heteroscedasticity using the Newey-West (1987) procedure. Superscripts ***, **, * indicate the statistical significance at 1%, 5% and 10% level respectively

5.1.4 FOMC minutes release day

For completeness, we also examine the impact of Fed's tone on investor's risk perception and risk appetite on the day Fed releases the FOMC meeting minutes. The results are reported in Table B6 of appendix B. Interestingly, whilst there is a decrease in uncertainty and risk aversion even on the day FOMC minutes published, it turns out that the coefficient capturing the impact of Fed's optimism on minutes release day (βi) becomes generally smaller and less significant than that reported in Table 3. The differences allow us to corroborate the recent evidence of Cieslak et al. (2019) that FOMC announcements have a strong effect on stock returns even weeks after a meeting.

5.1.5 Number of topics

In our main analysis, we analyze 10 distinct topics under discussion in FOMC meetings. As a robustness test, we follow Jegadeesh and Wu (2017) and examine only eight topics in this section. Figure B3 of appendix B provides a graphical description of the topic along with each term's beta weights and Table B2 includes the most frequent twenty terms in each topic. We assigned names to each topic based on the most frequent terms in each topic. A total of 8 topics were extracted: financial market, consumption, inflation, policy,

Table 7 Spillover effect of Fed's tone in the United Kingdom (UK)

Model	(1)	(2)	(3)	(4)	(5)
Panel A: implied volatility (VFTSE)					
Constant	0.0000	0.0049	0.0049	0.0069	0.0069
	(0.000)	(0.036)	(0.036)	(0.078)	(0.081)
Net optimistic tone (Fed)	−0.481**	−0.4807**	−0.4805**	−0.2437**	−0.2928**
	(−2.146)	(−2.138)	(−2.118)	(−2.244)	(−2.497)
Policy rate (Fed)		−0.0163	−0.0032	−0.6089**	−0.4581*
		(−0.173)	(−0.012)	(−2.058)	(−1.741)
Industrial production (UK)			−0.0144	0.7378**	0.5496*
			(−0.056)	(2.234)	(1.938)
Gross domestic production (UK)				−0.6585***	−0.5532***
				(−3.276)	(−3.093)
Consumer price index (UK)					0.1746**
					(2.243)
Adj. R^2	0.224	0.217	0.209	0.479	0.498
Panel B: uncertainty (FTSE-100)					
Constant	0.0000	0.0056	0.0050	0.0072	0.0072
	(0.000)	(0.040)	(0.035)	(0.087)	(0.089)
Net optimistic tone (Fed)	−0.5205**	−0.5209**	−0.515**	−0.2579**	−0.2933**
	(−2.187)	(−2.179)	(−2.268)	(−2.388)	(−2.585)
Policy rate (Fed)		−0.0591	0.2469	−0.4105**	−0.3021*
		(−0.594)	(0.799)	(−2.500)	(−1.816)
Industrial production (UK)			−0.3354	0.4811***	0.3458**
			(−1.056)	(2.955)	(2.134)
Gross domestic production (UK)				−0.7148***	−0.6391***
				(−4.557)	(−4.300)
Consumer price index (UK)					0.1256*
					(1.920)
Adj. R^2	0.264	0.261	0.274	0.594	0.603
Panel C: risk aversion (FTSE-100)					
Constant	0.0000	0.0047	0.0047	0.0067	0.0067
	(−0.000)	(0.035)	(0.035)	(0.076)	(0.079)
Net optimistic tone (Fed)	−0.4653**	−0.4649**	−0.4654**	−0.2364**	−0.2862**
	(−2.127)	(−2.119)	(−2.089)	(−2.212)	(−2.470)
Policy rate (Fed)		−0.0106	−0.0345	−0.6201*	−0.4675*
		(−0.115)	(−0.130)	(−1.972)	(−1.680)
Industrial production (UK)			0.0262	0.7535**	0.5629*
			(0.102)	(2.129)	(1.854)
Gross domestic production (UK)				−0.6367***	−0.5301***
				(−3.097)	(−2.911)
Consumer price index (UK)					0.1769**
					(2.226)
Adj. R^2	0.209	0.201	0.194	0.445	0.464

This table reports the estimation results of Eq. (15). The results for the spillover effect of Fed's net optimistic tone on implied volatility, uncertainty, and investor's risk aversion in the United Kingdom (UK) are pro-

Table 7 (continued)

vided in panel A, B and C respectively. Following Bekaert et al. (2013), we use the difference between risk-adjusted and risk-free volatility to decompose the VFTSE into uncertainty and risk aversion components. To estimate the Fed's tone, we apply a bag of word method of Apel and Grimaldi (2014) to categorise the discussion in FOMC meetings into an optimistic and pessimistic tone. In particular, following Apergis and Pragidis (2019), we measure the frequency of optimistic and pessimistic phrases in each FOMC minutes from January 2005 to May 2018. We control for the effect of other Fed's announcements using policy rate decisions. We also include the growth of industrial production, GDP, and CPI in the UK to control for domestic macroeconomic variations. All the series are standardized to have zero mean and unit standard deviation. The t-statistics reported in parentheses are corrected for autocorrelation and heteroscedasticity using the Newey-West (1987) procedure. Superscripts ***, **, * indicate the statistical significance at 1%, 5% and 10% level respectively

employment, growth, exchange rate, and investments. The evidence reported in Table B7 of appendix B shows that the Fed's optimism about financial markets, consumption, economic growth, and employment are primarily responsible for the impact of Fed's tone on risk perception and risk appetite.

Finally, Table B8 of appendix B also provides the results of asymmetric impact of optimistic and pessimistic tone in each of eight topics. The evidence presented suggests that optimism about financial market, consumption, employment, and exchange rate decrease uncertainty and risk aversion. On the other hand, pessimism about the financial market, inflation and consumption increase uncertainty and risk aversion. These findings are consistent with the evidence of Jegadeesh and Wu (2017) who shows that the Fed's positive tone about inflation, policy, and employment determines the unexpected volatility in the U.S. stock market.

5.2 Additional analysis

There is a number of communication tools the central bank can use to shape market expectations and to influence the behaviour in financial markets. For instance, Boukus and Rosenberg (2006) estimates the Fed's tone using FOMC meeting minutes. On the other hand, Hubert and Labondance (2017) focus on FOMC policy statements to extract information from the Fed's communication. While FOMC minutes provide a more detailed view of members about economic outlook and credit conditions, the FOMC minutes published after 3 weeks of meeting and investor may respond to contents of policy statement that released on the day of FOMC meeting. Previous studies also suggest that ECB's press conferences after the Governing Council meetings may affect the changes in equity prices. Hence, in this section we re-examine the impact of Fed's tone considering these alternative communication tools.

5.2.1 FOMC policy statements

We extract the Fed's tone from FOMC policy statements to understand the investor response to the new information revealed in these statements. To measure the optimism and pessimism in the policy statement, we use the directional dictionary of Apel and

Table 8 Spillover effect of Fed's tone in the Euro area (EA)

Model	(1)	(2)	(3)	(4)	(5)
Panel A: implied volatility (VSTOXX)					
Constant	0.0000	0.0061	0.0040	0.0056	0.0037
	(0.000)	(0.046)	(0.031)	(0.049)	(0.036)
Net optimistic tone (Fed)	−0.4735**	−0.4757**	−0.4642**	−0.3567***	−0.3961***
	(−2.291)	(−2.296)	(−2.403)	(−2.859)	(−3.090)
Policy rate (Fed)		−0.1589	−0.0463	−0.078	−0.1299
		(−1.641)	(−0.372)	(−0.790)	(−1.336)
Industrial production (EA)			−0.1902**	0.1939	0.0504
			(−2.048)	(0.986)	(0.306)
Gross domestic production (EA)				−0.4929**	−0.4025**
				(−2.161)	(−2.156)
Consumer price index (EA)					0.2557**
					(2.040)
Adj. R^2	0.217	0.235	0.251	0.342	0.386
Panel B: uncertainty (STOXX-50)					
Constant	0.0000	0.0069	0.0033	0.0050	0.0036
	(0.000)	(0.051)	(0.026)	(0.046)	(0.036)
Net optimistic tone (Fed)	−0.4824**	−0.4852**	−0.4652**	−0.3518***	−0.3809***
	(−2.238)	(−2.250)	(−2.542)	(−2.932)	(−3.180)
Policy rate (Fed)		−0.1915*	0.0036	−0.0298	−0.068
		(−1.894)	(0.027)	(−0.312)	(−0.708)
Industrial production (EA)			−0.3298***	0.0754	−0.0303
			(−2.642)	(0.593)	(−0.239)
Gross domestic production (EA)				−0.52***	−0.4534***
				(−2.785)	(−2.731)
Consumer price index (EA)					0.1884
					(1.622)
Adj. R^2	0.225	0.256	0.32	0.423	0.445
Panel C: risk aversion (STOXX-50)					
Constant	0.0000	0.0058	0.0040	0.0056	0.0037
	(−0.000)	(0.045)	(0.032)	(0.049)	(0.035)
Net optimistic tone (Fed)	−0.4609**	−0.463**	−0.4531**	−0.349***	−0.389***
	(−2.286)	(−2.290)	(−2.373)	(−2.832)	(−3.056)
Policy rate (Fed)		−0.1502	−0.0527	−0.0833	−0.1361
		(−1.593)	(−0.435)	(−0.850)	(−1.403)
Industrial production (EA)			−0.1649*	0.2069	0.0612
			(−1.863)	(1.007)	(0.361)
Gross domestic production (EA)				−0.4771**	−0.3854**
				(−2.065)	(−2.056)
Consumer price index (EA)					0.2597**
					(2.057)
Adj. R^2	0.205	0.22	0.23	0.315	0.36

This table reports the estimation results of Eq. (16). The results for the spillover effect of Fed's net optimistic tone on implied volatility, uncertainty, and investor's risk aversion in the Euro Area (EA) are provided in

Table 8 (continued)

panel A, B and C respectively. Following Bekaert et al. (2013), we use the difference between risk-adjusted and risk-free volatility to decompose the VSTOXX-50 into uncertainty and risk aversion components. To estimate the Fed's tone, we apply a bag of word method of Apel and Grimaldi (2014) to categorise the discussion in FOMC meetings into an optimistic and pessimistic tone. In particular, following Apergis and Pragidis (2019), we measure the frequency of optimistic and pessimistic phrases in each FOMC minutes from January 2005 to May 2018. We control for the effect of other Fed's announcements using policy rate decisions. We also include the growth of industrial production, GDP, and CPI in the EA to control for domestic macroeconomic variations. All the series are standardized to have zero mean and unit standard deviation. The t-statistics reported in parentheses are corrected for autocorrelation and heteroscedasticity using the Newey-West (1987) procedure. Superscripts ***, **, * indicate the statistical significance at 1%, 5% and 10% level respectively

Grimaldi (2014). The results reported in Table B9 of appendix B are largely consistent with our findings obtained from FOMC minutes, indicating that the Fed's optimism revealed in both policy statements and meeting minutes helps to reduce the level of uncertainty and investor's aversion to risk.

5.2.2 FOMC press conferences

Compared to minutes of FOMC meetings which are published with a lag of 3 weeks, a press conference provides information to market participants on the same day of the meeting. The press conferences are quite detailed compared to policy statements and they are similar to FOMC minutes containing the views of committee members about current and future economic conditions. However, the Fed only started press conferences in April 2011 and there were relatively few observations for a rigorous empirical analysis. Nonetheless, we create a dummy variable which takes a value of unity for observations after April 2011 and zeros otherwise in order to test whether the impact of Fed's tone (extracted from FOMC minutes) varies before and after April 2011. The results reported in Table B10 show that the response of investors to FOMC minutes is highly significant before the Fed started press conferences and remained muted for the period after April 2011. The differences allow us to suggest that after the Fed started press conferences the effect of FOMC minutes on investor's risk perception and appetite decreased.

Table 9 Asymmetric impact of Fed's optimistic and pessimistic tone

Model	(1)	(2)	(3)	(4)	(5)
Panel A: implied volatility (VIX)					
Constant	0.0000	0.0000	0.0000	0.0000	0.0000
	(−0.000)	(−0.000)	(−0.000)	(−0.000)	(−0.000)
Optimistic tone	−0.3517**	−0.3297**	−0.2594**	−0.2027***	−0.2042***
	(−2.143)	(−2.065)	(−2.540)	(−2.787)	(−2.742)
Pessimistic tone	0.4314*	0.4518*	0.3876**	0.2807**	0.2814**
	(1.770)	(1.801)	(2.001)	(2.160)	(2.155)
Policy rate		−0.1074	−0.0387	0.2903*	0.2292
		(−1.133)	(−0.529)	(1.903)	(1.313)
Industrial production			−0.4461***	−0.4132***	−0.4929**
			(−2.957)	(−3.648)	(−2.091)
GDP forecasts				0.1029	0.0991
				(0.846)	(0.817)
INF forecasts				−0.5402**	−0.5199***
				(−2.439)	(−2.647)
Unemployment rate					−0.1082
					(−0.446)
Adj. R^2	0.226	0.229	0.414	0.515	0.512
Panel B: uncertainty (S&P500)					
Constant	0.0000	0.0000	0.0000	0.0000	0.0000
	(−0.000)	(−0.000)	(−0.000)	(−0.000)	(−0.000)
Optimistic tone	−0.3167	−0.309	−0.2401	−0.1762*	−0.1818*
	(−1.472)	(−1.435)	(−1.655)	(−1.832)	(−1.909)
Pessimistic tone	0.3237	0.3308	0.2679	0.1452	0.148*
	(1.382)	(1.396)	(1.544)	(1.594)	(1.712)
Policy rate		−0.0373	0.0301	0.4077**	0.1851
		(−0.566)	(0.520)	(1.992)	(1.061)
Industrial production			−0.4371**	−0.4012**	−0.6917**
			(−2.083)	(−2.582)	(−2.569)
GDP forecasts				0.1301	0.1161
				(1.060)	(0.892)
INF forecasts				−0.6293**	−0.5553**
				(−2.067)	(−2.067)
Unemployment rate					−0.3941
					(−1.617)
Adj. R^2	0.145	0.138	0.315	0.452	0.472
Panel C: risk aversion (S&P500)					
Constant	0.0000	0.0000	0.0000	0.0000	0.0000
	(−0.000)	(−0.000)	(−0.000)	(−0.000)	(−0.000)
Optimistic tone	−0.2278**	−0.2112**	−0.1783***	−0.1543***	−0.1542***
	(−2.280)	(−2.313)	(−2.628)	(−2.854)	(−2.778)
Pessimistic tone	0.3923*	0.4076*	0.3776*	0.3061*	0.3061*
	(1.669)	(1.662)	(1.722)	(1.824)	(1.806)
Policy rate		−0.0806	−0.0484	0.1726	0.1777

Table 9 (continued)

Model	(1)	(2)	(3)	(4)	(5)
		(−0.926)	(−0.649)	(1.298)	(1.089)
Industrial production			−0.209*	−0.21**	−0.2034
			(−1.944)	(−2.571)	(−1.012)
GDP forecasts				0.2198	0.2201*
				(1.651)	(1.685)
INF forecasts				−0.4792**	−0.4809***
				(−2.503)	(−2.801)
Unemployment rate					0.009
					(0.039)
Adj. R^2	0.153	0.15	0.184	0.254	0.247

This table reports the estimation results of Eq. (17). The results for the asymmetric impact of Fed's optimistic and pessimistic tone on implied volatility, uncertainty, and risk aversion are provided in panel A, B and C respectively. Following Bekaert et al. (2013), we use the difference between risk-adjusted and risk-free volatility to decompose the VIX into uncertainty and risk aversion components. To estimate the Fed's tone, we apply a bag of word method of Apel and Grimaldi (2014) to categorise the discussion in FOMC meetings into an optimistic and pessimistic tone. In particular, following Apergis and Pragidis (2019), we measure the frequency of optimistic and pessimistic phrases in each FOMC minutes from January 2005 to May 2018. We control for the effect of other Fed's announcements using policy rate decisions and projections for Gross Domestic Production (GDP) and inflation (INF) variables. We also include industrial production and unemployment rate to control for business cycle and economic variations. All the series are standardized to have zero mean and unit standard deviation. The t-statistics reported in parentheses are corrected for autocorrelation and heteroscedasticity using the Newey-West (1987) procedure. Superscripts ***, **, * indicate the statistical significance at 1%, 5% and 10% level respectively

Table 10 Heterogeneous impact of topic's tone

Model	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Topic	Panel A: implied volatility (VIX)			Panel B: uncertainty (S&P500)			Panel C: risk aversion (S&P500)		
Constant	0.022	0.0217	0.018	0.0828	0.082	0.075	−0.0353	−0.0347	−0.0344
	(0.190)	(0.187)	(0.154)	(0.581)	(0.572)	(0.526)	(−0.438)	(−0.426)	(−0.418)
Economy	−0.1057	−0.1057	−0.1126	−0.1285	−0.1285	−0.1414	−0.0695	−0.0695	−0.0688
	(−1.470)	(−1.457)	(−1.502)	(−1.405)	(−1.386)	(−1.492)	(−1.477)	(−1.468)	(−1.412)
Financial market	−0.1326*	−0.1328*	−0.1225*	−0.1486	−0.1492	−0.13	−0.0814	−0.0809	−0.0819
	(−1.842)	(−1.829)	(−1.709)	(−1.656)	(−1.638)	(−1.463)	(−1.431)	(−1.416)	(−1.427)
Credit conditions	−0.0929	−0.093	−0.0983	−0.0873	−0.0878	−0.0976	−0.0775	−0.0771	−0.0766
	(−1.068)	(−1.065)	(−1.132)	(−0.798)	(−0.799)	(−0.884)	(−1.267)	(−1.260)	(−1.269)
Consumption	−0.1069	−0.1082	−0.0998	−0.1292	−0.1332	−0.1176	−0.0945	−0.0915	−0.0923
	(−0.964)	(−0.990)	(−0.907)	(−0.879)	(−0.929)	(−0.831)	(−1.213)	(−1.183)	(−1.164)
Growth	−0.0932	−0.0931	−0.0611	−0.1964	−0.196	−0.1362	0.0216	0.0213	0.0183
	(−1.079)	(−1.076)	(−0.703)	(−1.513)	(−1.514)	(−1.129)	(0.353)	(0.344)	(0.278)
Employment	−0.1251	−0.1221	−0.1467	−0.12	−0.1105	−0.1564	−0.1182	−0.1253	−0.123
	(−0.949)	(−0.918)	(−1.121)	(−0.948)	(−0.777)	(−1.098)	(−0.930)	(−1.076)	(−1.090)
Investments	−0.1815*	−0.1808*	−0.166*	−0.2577**	−0.2553**	−0.2277*	−0.0669	−0.0687	−0.0701
	(−1.770)	(−1.809)	(−1.691)	(−2.107)	(−2.116)	(−1.955)	(−1.046)	(−1.090)	(−1.084)
Inflation	0.0803	0.0791	0.0778	0.0805	0.0766	0.0742	0.0811	0.084	0.0842
	(0.745)	(0.726)	(0.696)	(0.691)	(0.644)	(0.598)	(0.856)	(0.886)	(0.877)
Monetary policy	0.0645	0.0656	0.056	0.0472	0.0507	0.0328	0.0563	0.0537	0.0546
	(1.067)	(0.998)	(0.814)	(0.805)	(0.806)	(0.480)	(0.966)	(0.852)	(0.874)
Exchange rate	0.1197*	0.1205*	0.1211*	0.1647*	0.1673*	0.1685*	0.0379	0.036	0.0359
	(1.893)	(1.791)	(1.806)	(1.836)	(1.791)	(1.820)	(0.961)	(0.878)	(0.867)
Control variables									
GDP forecast		−0.007	−0.006		−0.0225	−0.0206		0.0169	0.0168
		(−0.070)	(−0.066)		(−0.209)	(−0.217)		(0.212)	(0.207)
INF forecast			−0.0832			−0.1551			0.0077

Table 10 (continued)

Model	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Topic	Panel A: implied volatility (VIX)			Panel B: uncertainty (S&P500)			Panel C: risk aversion (S&P500)		
			(−0.941)			(−1.507)			(0.111)
Adj. R^2	0.246	0.236	0.233	0.292	0.283	0.291	0.108	0.097	0.085

This table reports the estimation results of Eq. (18). The results for the heterogeneous impact of topic's net optimistic tone on implied volatility, uncertainty, and risk aversion are provided in panel A, B and C respectively. Following Bekaert et al. (2013), we use the difference between risk-adjusted and risk-free volatility to decompose the VIX into uncertainty and risk aversion components. To estimate the Fed's tone, we apply a bag of word method of Apel and Grimaldi (2014) to categorise the discussion in FOMC meetings into an optimistic and pessimistic tone. In particular, following Apergis and Pragidis (2019), we measure the frequency of optimistic and pessimistic phrases in each FOMC minutes from January 2005 to May 2018. This study applies the Latent Dirichlet allocation (LDA) method to identify unique topics from the discussion in FOMC meetings. More specifically, we first employ the coherence score to find the optimal number of topics and use LDA to estimate term's weights and topic proportions to identify distinct topics and portion of each topic in FOMC minutes. We control for the effect of other Fed's announcements using projections for Gross Domestic Production (GDP) and inflation (INF) variables. All the series are standardized to have zero mean and unit standard deviation. The t-statistics reported in parentheses are corrected for autocorrelation and heteroscedasticity using the Newey-West (1987) procedure. Superscripts ***, **, * indicate the statistical significance at 1%, 5% and 10% level respectively

Table 11 Asymmetric impact of topic's optimistic and pessimistic tone

Model		(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Topics	Tone	Panel A: implied volatility (VIX)			Panel B: uncertainty (S&P500)			Panel C: risk aversion (S&P500)		
	Constant	0.0048	0.0056	0.000	0.0635	0.0639	0.054	−0.048	−0.047	−0.048
		(0.049)	(0.056)	(−0.005)	(0.530)	(0.536)	(0.469)	(−0.631)	(−0.614)	(−0.608)
Economy	Optimistic	−0.074	−0.074	−0.097	−0.049	−0.049	−0.086	−0.087	−0.088	−0.09
		(−0.957)	(−0.953)	(−1.262)	(−0.500)	(−0.497)	(−0.916)	(−1.662)	(−1.654)	(−1.634)
	Pessimistic	0.1438*	0.1444*	0.141**	0.1882**	0.1886**	0.1831**	0.077	0.0779	0.0776
		(1.979)	(1.996)	(2.034)	(2.069)	(2.068)	(2.105)	(1.437)	(1.453)	(1.461)
Financial market	Optimistic	−0.186**	−0.187**	−0.171**	−0.238***	−0.239***	−0.212**	−0.1	−0.102	−0.1
		(−2.263)	(−2.297)	(−2.181)	(−2.694)	(−2.722)	(−2.631)	(−1.376)	(−1.398)	(−1.380)
	Pessimistic	−0.021	−0.022	−0.027	−0.058	−0.058	−0.066	−0.002	−0.003	−0.003
		(−0.341)	(−0.348)	(−0.453)	(−0.831)	(−0.824)	(−1.078)	(−0.028)	(−0.048)	(−0.056)
Credit conditions	Optimistic	−0.172*	−0.171*	−0.197**	−0.194*	−0.193*	−0.236**	−0.107	−0.105	−0.108
		(−1.926)	(−1.869)	(−2.341)	(−1.760)	(−1.715)	(−2.259)	(−1.551)	(−1.512)	(−1.644)
	Pessimistic	−0.027	−0.027	−0.043	−0.015	−0.015	−0.041	−0.019	−0.02	−0.021
		(−0.295)	(−0.299)	(−0.454)	(−0.127)	(−0.129)	(−0.329)	(−0.269)	(−0.276)	(−0.288)
Consumption	Optimistic	0.0139	0.0166	0.0223	0.0175	0.0192	0.0285	−0.02	−0.016	−0.015
		(0.174)	(0.226)	(0.329)	(0.191)	(0.224)	(0.373)	(−0.287)	(−0.240)	(−0.233)
	Pessimistic	0.1328	0.1315	0.111	0.1578	0.157	0.1234	0.1056	0.1038	0.1016
		(0.825)	(0.812)	(0.655)	(0.796)	(0.791)	(0.599)	(0.854)	(0.829)	(0.775)
Growth	Optimistic	−0.055	−0.056	−0.023	−0.084	−0.084	−0.03	−0.022	−0.022	−0.018
		(−0.879)	(−0.873)	(−0.337)	(−0.964)	(−0.960)	(−0.366)	(−0.444)	(−0.446)	(−0.318)
	Pessimistic	0.1403	0.1413	0.1121	0.2876**	0.2883**	0.2405**	−0.039	−0.038	−0.041
		(1.448)	(1.475)	(1.268)	(2.348)	(2.368)	(2.231)	(−0.500)	(−0.479)	(−0.547)
Employment	Optimistic	−0.081	−0.087	−0.116	−0.097	−0.1	−0.149**	−0.054	−0.062	−0.065
		(−0.759)	(−0.979)	(−1.513)	(−1.033)	(−1.297)	(−2.058)	(−0.542)	(−0.709)	(−0.826)
	Pessimistic	0.0935	0.0942	0.1254	0.0449	0.0454	0.0964	0.1393	0.1404	0.1437
		(0.623)	(0.615)	(0.869)	(0.257)	(0.256)	(0.597)	(1.260)	(1.250)	(1.247)

Table 11 (continued)

Model		(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Topics	Tone	Panel A: implied volatility (VIX)			Panel B: uncertainty (S&P500)			Panel C: risk aversion (S&P500)		
Investment	Optimistic	−0.025	−0.028	−0.006	−0.043	−0.045	−0.009	0.007	0.0034	0.0057
		(−0.274)	(−0.300)	(−0.063)	(−0.431)	(−0.432)	(−0.084)	(0.092)	(0.045)	(0.073)
	Pessimistic	0.1808*	0.182*	0.1805*	0.2239**	0.2247**	0.2221**	0.1028	0.1045	0.1043
		(1.907)	(1.934)	(1.947)	(2.097)	(2.098)	(2.174)	(1.521)	(1.556)	(1.535)
Inflation	Optimistic	−0.018	−0.017	−0.029	−0.056	−0.055	−0.075	0.0353	0.0361	0.0348
		(−0.209)	(−0.200)	(−0.322)	(−0.772)	(−0.755)	(−0.979)	(0.381)	(0.386)	(0.352)
	Pessimistic	−0.09	−0.093	−0.105	−0.094	−0.096	−0.117	−0.078	−0.081	−0.083
		(−0.849)	(−0.852)	(−0.950)	(−0.739)	(−0.731)	(−0.852)	(−0.953)	(−0.986)	(−0.997)
Monetary policy	Optimistic	0.1607*	0.1617**	0.1444*	0.1395*	0.1401*	0.1117	0.1242*	0.1257*	0.1239*
		(1.981)	(2.019)	(1.846)	(1.823)	(1.848)	(1.499)	(1.704)	(1.732)	(1.719)
	Pessimistic	−0.062	−0.058	−0.054	−0.091	−0.088	−0.082	−0.019	−0.013	−0.013
		(−0.658)	(−0.591)	(−0.566)	(−0.774)	(−0.724)	(−0.712)	(−0.281)	(−0.194)	(−0.185)
Exchange rate	Optimistic	0.0928	0.0904	0.0941	0.1683*	0.1667*	0.1728*	−0.002	−0.005	−0.005
		(1.425)	(1.269)	(1.385)	(1.826)	(1.709)	(1.917)	(−0.046)	(−0.127)	(−0.117)
	Pessimistic	−0.026	−0.026	−0.025	−0.012	−0.012	−0.01	−0.025	−0.024	−0.024
		(−0.423)	(−0.412)	(−0.364)	(−0.144)	(−0.138)	(−0.105)	(−0.554)	(−0.534)	(−0.527)
Control variables										
GDP forecast			0.0157	0.0131		0.0102	0.0059		0.0223	0.022
			(0.174)	(0.161)		(0.112)	(0.074)		(0.287)	(0.285)
INF forecast				−0.114			−0.187*			−0.012
				(−1.281)			(−1.800)			(−0.168)
Adj. R^2		0.257	0.246	0.248	0.331	0.32	0.335	0.075	0.062	0.048

Table 11 (continued)

This table reports the estimation results of Eq. (19). The results for the asymmetric impact of topic's optimistic and pessimistic tone on implied volatility, uncertainty, and risk aversion are provided in panel A, B and C respectively. Following Bekaert et al. (2013), we use the difference between risk-adjusted and risk-free volatility to decompose the VIX into uncertainty and risk aversion components. To estimate the Fed's tone, we apply a bag of word method of Apel and Grimaldi (2014) to categorise the discussion in FOMC meetings into an optimistic and pessimistic tone. In particular, following Apergis and Pragidis (2019), we measure the frequency of optimistic and pessimistic phrases in each FOMC minutes from January 2005 to May 2018. This study applies the Latent Dirichlet allocation (LDA) method to identify unique topics from the discussion in FOMC meetings. More specifically, we first employ the coherence score to find the optimal number of topics and use LDA to estimate term's weights and topic proportions to identify distinct topics and portion of each topic in FOMC minutes. We control for the effect of other Fed's announcements using projections for Gross Domestic Production (GDP) and inflation (INF) variables. All the series are standardized to have zero mean and unit standard deviation. The t-statistics reported in parentheses are corrected for autocorrelation and heteroscedasticity using the Newey-West (1987) procedure. Superscripts ***, **, * indicate the statistical significance at 1%, 5% and 10% level respectively

6 Conclusions

Recent studies show that apart from policy decisions (*actions*) central bank communications (*words*) also play a significant role in determining asset prices and economic outcomes. Yet, with the growing importance of central bank communications, there remain an imperative question regarding the channels through which communications affect prices. This paper addresses empirically this question and investigates for first time the effects of Federal Reserve (Fed) communication on the level of uncertainty and risk aversion in global equity markets. First, we apply the computational linguistic analysis on the minutes of 108 FOMC meetings to compute a quantitative measure of Fed's confidence about the economic and financial outlook. Then, we decompose the option-implied volatility into proxies for uncertainty and risk aversion to examine the impact of Fed's optimism on investors' risk expectation and risk appetite. Furthermore, following the 'Topic-to-Tone' modelling approach, we study the heterogeneous impact of FOMC's discussions on various topics. Finally, we also analyze the spillover effect of Fed's communications on uncertainty and risk aversion in the U.K. and the Eurozone.

Overall, our findings provide novel evidence that monetary policy in the form of central bank communication can impact both uncertainty and risk aversion in global equity markets, with the former effect being stronger. It uncovers an important 'signalling' channel through which information embedded in central bank communications (*words*) transmits to financial markets i.e., by altering investors' perception and pricing of risk and return in the marketplace. In addition, we find that investors' response to pessimistic tone is stronger compared to the optimistic tone and there is also a stronger response of market participants to the Fed communication during recessions and at the times when policy uncertainty is elevated. Further analysis reveals that, in formulating their risk preferences, investors pay particular attention to FOMC's discussion about financial market, credit condition, employment, and growth.

We deem our results very important in contributing to the current debate on the role of central bank communication in asset pricing and investment behaviour, and are of great significance to the market regulators and finance practitioners. Market participants need to consider the information embedded in the communications of central banks while evaluating their investment decisions and may treat this as a 'signal' or predictor for future market movement. Another policy implication behind our empirical results is that when communicating to the public the authorities need to be mindful of using pessimistic language as financial markets tend to overreact to negative news, especially during recessions and economic downturns. More broadly, as central bank communications are closely followed by financial markets, policymakers should carefully design a transparent communication strategy to ensure market stabilization and effective implementation of monetary policy.

In this paper we provide evidence that the Fed communication tone conveys important information relevant for market participants in shaping their risk expectation and risk tolerance. However, as with any empirical investigation, the results of this study must be taken in context. We investigate a modest number of FOMC minutes that are available at a relatively low frequency with a 3-weeks publication lag. Also, we focus our attention on the impact of Fed communication on global equity markets, whilst it may be more informative to conduct a comparative analysis of the communication strategies of the Fed, the Bank of England, and the ECB. Further research which seeks to address these issues may provide additional insights into the link between central bank communication tone and the changes in market expectation. Likewise, exploration of the impact of central bank communication

on investor trading behaviour (e.g., portfolio rebalancing and arbitrage decisions) would also be an interesting area for future research.

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Declarations

Conflict of interest The authors are not aware of any conflict-of-interest issues in relation to this study.

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