

# Real-time price discovery via verbal communication: Method and application to Fedspeak

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# 1. Introduction

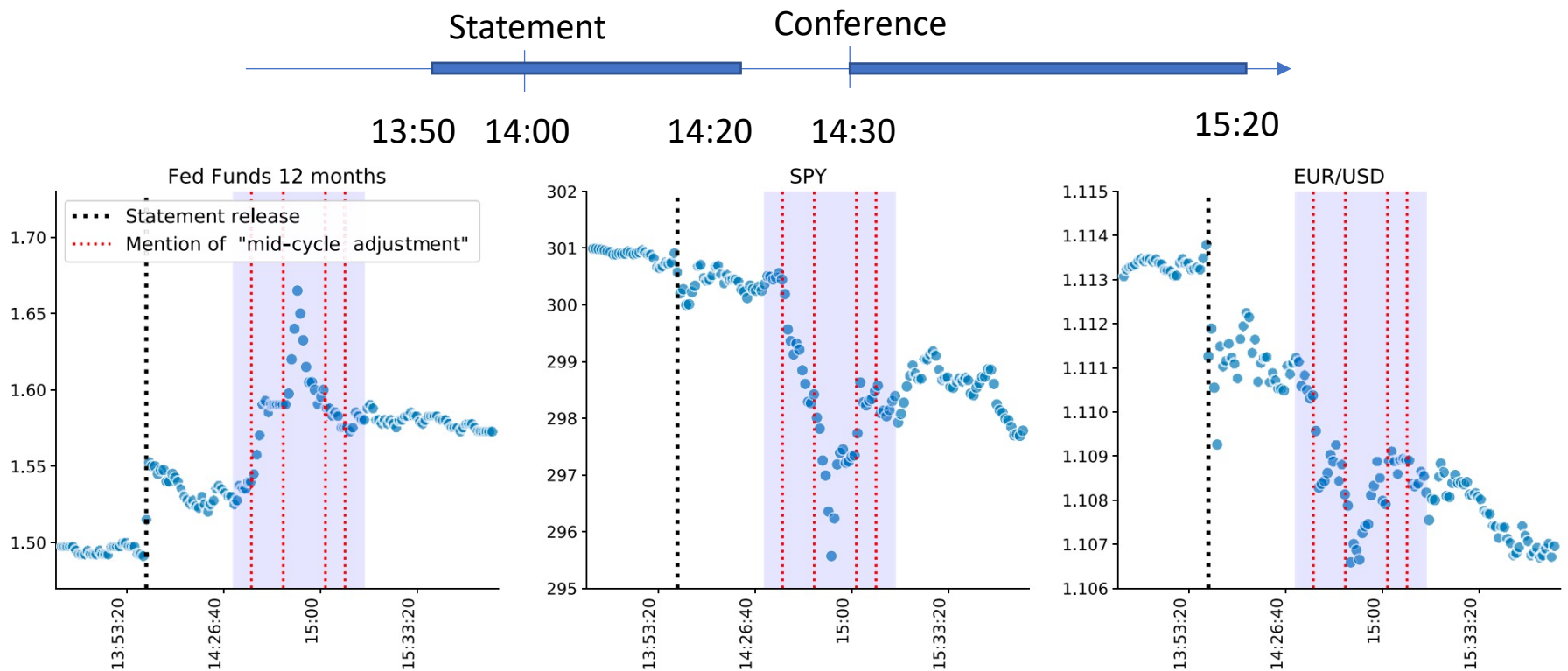
## Background & Motivation

- When policy analysis ignores the role of investor expectations and how investor expectations evolve over time, policy conclusions can be misleading.
- As a result, today's central bankers place a high priority on communications with financial markets in an attempt to manage the public's expectations.
- It is often argued that communication has to be clear and credible to be effective, which has historically led to a difficult trade-off between clarity and time consistency.
- Yet, little is known about **how investors form their expectations in response to central bank communications.**

# 1. Introduction

## Question

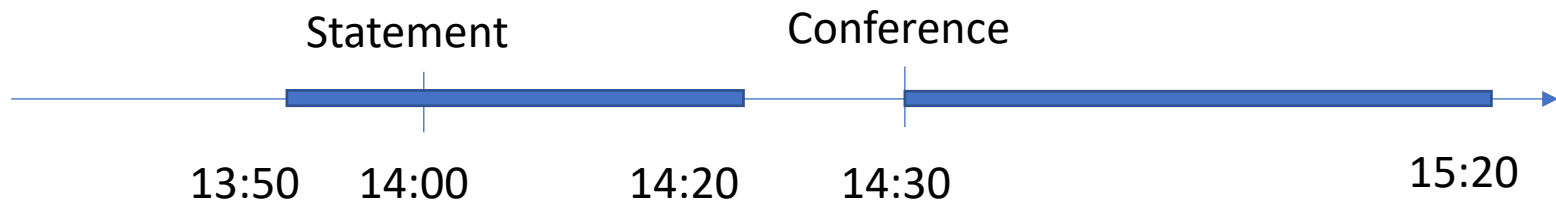
- How investors form their expectations in response to central bank communications?



# 1. Introduction

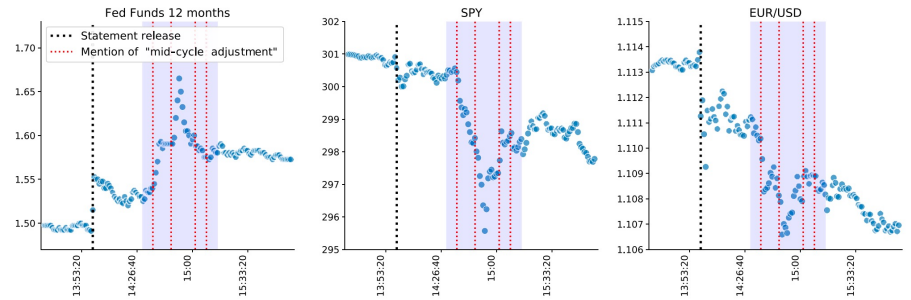
## Research contents

- We separate two specific time periods during statement release and subsequent press conference, then test the relationship of price changes in these time intervals.
- We introduce time-stamped text and use our new method to understand which moments the autocorrelation of price changes described above are realized in.
- In light of our results, we will discuss eight of these mechanisms and assess their plausibility as potential explanations.



# 1. Introduction

Time-stamped FOMC press conferences  
Extracting news from the FOMC meeting statement



1.Persistence

2.Robustness

3.Economic significance

4.Informational content

1.Variable construction

2.How the chairman's message induces variation in investors' beliefs?

3.Linguistic analysis of the press conference

4.Uncertainty reduction about forward guidance

1.Differences in higher-order beliefs

2.Alternative explanations

# 1.Introduction

## Related researches

- Textual analysis methods across different fields of economics (*Tetlock, 2007; Lucca and Trebbi, 2009; Gentzkow and Shapiro, 2010; Loughran and Mc Donald, 2011; Born et al., 2014; Hansen and Mc Mahon, 2016; Hansen et al., 2017; Gentzkow et al., 2019a; Gentzkow et al., 2019b; Hassan et al., 2019; Handlan, 2020; Gardner et al., 2021*)
- Intersection of monetary policy, information transmission, and asset pricing (*Gürkaynak et al., 2005; Swanson, 2017; Mueller et al., 2017; Neuhierl and Weber, 2019; Jarocinski ´ and Karadi, 2020; Cieslak and Schrimpf, 2019; Swanson, 2020*)
- Signaling effects of monetary policy (*Cukierman and Meltzer ,1986; Ellingsen and Soderstrom, 2001; Berkelmans, 2011; Melosi, 2016; Nakamura and Steinsson, 2018*)

# 1.Introduction

## Contribution

- This paper makes two contributions to the literature. The first is empirical and the second methodological.
- Our manuscript makes a methodological contribution to the economics literature by combining video analysis with time-stamped high-frequency financial asset prices.
- The recipe can find applications in numerous settings in which someone wants to bridge linguistics with economics using market prices.
- We contribute to this literature by showing the link between statement and press conference news to financial investors and the relation between messages sent and signals received



# 2. Data & Variable

## 2.1 Time-stamped FOMC press conferences

- We (a) convert the audio into an interpretable text and (b) record the exact time at which each word was pronounced.

**Table 1**  
Example of Time-Stamped Transcription.

Start	End	Text
14:36:34.096	14:36:37.906	In terms of the rest of your question,
14:36:38.356	14:36:42.416	the Committee is really thinking of this as a way
14:36:42.416	14:36:43.526	of adjusting policy
14:36:43.526	14:36:45.576	to a somewhat more accommodative stance
14:36:46.046	14:36:48.596	to further the three objectives that I mentioned:
14:36:49.296	14:36:53.786	to insure against downside risks, to provide support
14:36:53.786	14:36:59.726	to the economy, that those factors are-where factors are
14:36:59.726	14:37:02.756	pushing down on economic growth, and then to support inflation.
14:37:02.756	14:37:05.586	So we do think it will serve all of those goals, but again,
14:37:05.586	14:37:07.696	we're thinking of it as essentially in the nature
14:37:07.696	14:37:09.526	of a mid-cycle adjustment to policy.

## 2. Data & Variable

### 2.1 Time-stamped FOMC press conferences

- We convert a sequence of audio,  $X$ , into a sequence of words,  $W$ . Let  $p(W|X)$  denote the probability of a word sequence given the audio. We obtain  $W^*$  by maximizing  $p(W|X)$  over the set of all possible word sequences  $V$ , that is,

$$W^* = \arg \max_{W \in V} p(W|X).$$

- First, we split the audio into smaller frames of around three seconds each and preprocess the audio clips into spectrograms.
  - Second, we use the end-to-end deep learning algorithm developed by Hannun et al. (2014) to optimize  $p(W|X)$  directly.
- Let  $W_j$  be a matrix summarizing the press conference on date  $j$ . The columns correspond to the words contained in the text of the press conference, while the rows are the three-second time windows.

## 2. Data & Variable

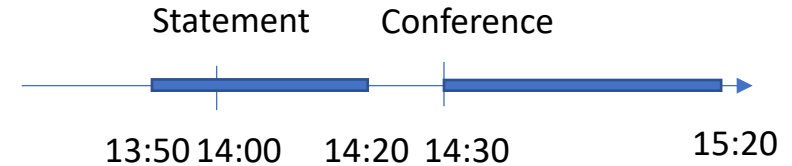
### 2.2 Extracting news from the FOMC meeting statement

- We identify this news by tracking the sentences and/or words added or removed relative to the previous statement.
- For each press conference,  $j$ , we append the changes and build a vector,  $s_j$ .

### 2.3 High-frequency asset prices

- First, we use best of book (BBO) trade and quote data for federal funds futures and Eurodollar futures from the Chicago Board of Trade and the Chicago Mercantile Exchange, respectively
- Second, we use the trades and quote (TAQ) database for the intraday behavior of the S&P 500 index
- Third, and finally, we use spot exchange rate quotes on seven currencies against the U.S. dollar

# 3. Empirical results



## 1) Statement and press conference news (persistent)

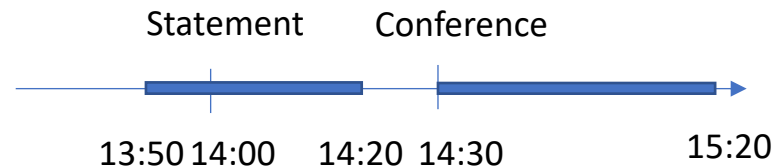
$$\underbrace{\Delta p_{it,PC}}_{\Delta p \text{ at press conference: e.g., 14:30-15:30}} = a_k + b_k \underbrace{\Delta p_{it,ST}}_{\Delta p \text{ around statement: 13:50-14:20}} + \epsilon_{it},$$

	Fed funds futures		Eurodollar futures		Stocks	Forex
	1m-6m	9m-15m	6m-12m	24m-70m		
$a$	0.05 [0.41]	-0.16 [-0.54]	0.03 [0.11]	-0.14 [-0.28]	-4.30 [-0.51]	-5.18 [-1.51]
$b$	0.17 [1.99]	0.17 [1.47]	0.19 [3.87]	0.33 [2.77]	0.41 [2.59]	0.25 [3.10]
$R^2$	8.53	5.50	8.43	20.21	14.10	11.20

FOMC Days without a Press Conference.

	Federal funds futures		Eurodollar futures		SPY	Forex
	1m-6m	9m-15m	6m-12m	24m-70m		
$a$	-0.16 [-2.17]	-0.15 [-2.15]	0.04 [0.16]	0.18 [0.70]	-4.28 [-0.47]	-1.59 [-0.87]
$b$	0.08 [1.49]	0.05 [1.19]	0.01 [0.16]	0.04 [0.33]	-0.21 [-1.11]	-0.01 [-0.05]
$R^2$	0.35	1.30	0.01	0.55	0.51	0.30

# 3. Empirical results



## 1) Statement and press conference news (robustness)

$$\Delta p_{it,PC} = a_k + b_k \Delta p_{it,ST} + c_k \Delta p_{it,ST} \cdot I_{j,t} + \epsilon_{it},$$

**Table D.1**

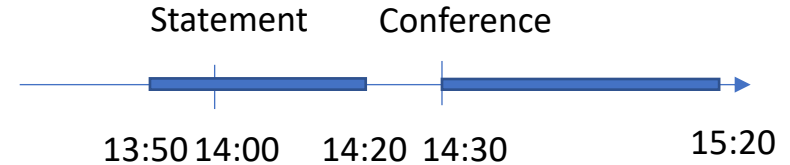
Press conference shocks against statement shocks.

Coef.	Dispersion in analyst forecast				Changes between							
	about FOMC rate decision				Macro uncertainty				consecutive statements			
	Fed funds		Eurodollar		Fed funds		Eurodollar		Fed funds		Eurodollar	
	1-6 (1)	9-15 (2)	6-12 (3)	24-70 (4)	1-6 (5)	9-15 (6)	6-12 (7)	24-70 (8)	1-6 (9)	9-15 (10)	6-12 (11)	24-70 (12)
<i>a</i>	0.06 [0.44]	-0.17 [-0.57]	0.04 [0.13]	-0.22 [-0.45]	0.04 [0.25]	-0.21 [-0.66]	0.00 [0.01]	-0.21 [-0.43]	0.11 [0.81]	-0.13 [-0.39]	0.04 [0.14]	-0.30 [-0.50]
<i>b</i>	-0.01 [-0.10]	-0.04 [-0.21]	0.03 [0.42]	0.26 [2.00]	0.05 [0.43]	0.07 [0.47]	0.10 [3.14]	0.27 [2.49]	0.07 [0.49]	0.14 [0.87]	0.18 [2.65]	0.42 [2.83]
<i>c</i>	0.28 [1.52]	0.37 [1.43]	0.28 [3.59]	0.06 [0.38]	0.47 [1.81]	0.44 [2.57]	0.32 [5.26]	0.19 [0.72]	0.20 [1.14]	0.05 [0.20]	0.02 [0.21]	-0.23 [-0.92]
<i>R</i> <sup>2</sup>	14.81	11.73	12.93	17.06	24.70	12.40	13.64	17.31	11.19	5.63	8.45	22.30

For each asset bucket *k*, the table reports the regression estimates for the following equation:

$$\Delta p_{it,PC} = a_k + b_k \Delta p_{it,ST} + c_k \Delta p_{it,ST} \cdot I_{j,t} + \epsilon_{it},$$

# 3. Empirical results



## 1) Statement and press conference news (portfolios)

- we use the half-hour returns around the FOMC statement release as a trading signal
- P1: We take a long position at the beginning of the press conference if its price went up when the statement was released and a short position otherwise.

$$r_{it,MT} = \alpha_k + \beta_k r_{it,B} + \epsilon_{it},$$

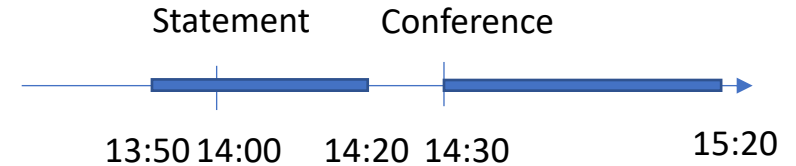
- P2: buy-and-hold strategy

$$\frac{E(r_j) - r_f}{\sigma_j} = \frac{\alpha_j}{\sigma_j} + \rho_{j,B} \frac{E(r_B) - r_f}{\sigma_B}$$

**Table 5**  
Economic Significance.

	Fed funds futures		Eurodollar futures		Stocks	Forex
	1m-6m	9m-15m	6m-12m	24m-70m		
$\alpha$	0.37 [1.27]	0.40 [1.65]	1.16 [2.80]	1.02 [2.11]	12.66 [2.30]	8.14 [2.57]
$\beta$	0.54 [2.40]	0.33 [2.53]	0.32 [2.68]	0.08 [0.42]	-0.13 [-0.61]	0.18 [1.12]
$R^2$	9.84	17.79	4.38	0.89	1.69	3.39

# 3. Empirical results



## 1) Statement and press conference news (information)

Coef.	Variable	Time to maturity (in months)		
		0m-2m (1)	2m-6m (2)	6m-12m (3)
Time period: January 2011 to December 2018				
$b_k^{ST}$	$I_{ST}$	0.164 [0.402]	-1.218 [-3.974]	0.369 [0.780]
$b_k^{ST-PC}$	$I_{ST-PC}$	-1.698 [-2.441]	-1.407 [-1.852]	-1.506 [-1.722]
Time period: January 2008 to December 2010				
$b_k^{ST}$	$I_{ST}$	-4.421 [-1.906]	-7.308 [-3.209]	-10.985 [-4.155]

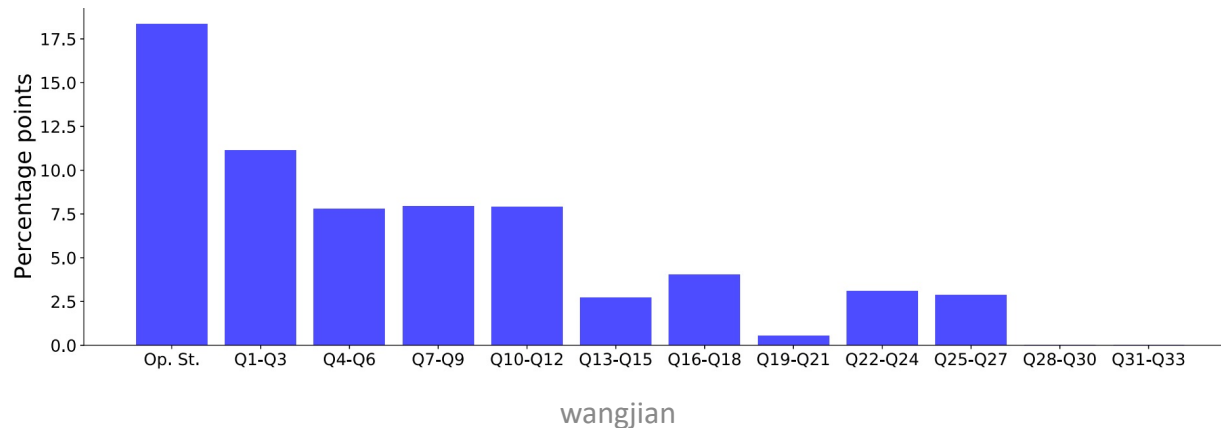
$$|\Delta FE(ff)_{it}| = b_k^{ST} \cdot I_{ST} + b_k^{ST-PC} \cdot I_{ST-PC} + \epsilon_{it},$$

We test whether market participants are better at predicting future monetary policy decisions with or without the press conference. And  $FE(ff)$  it denotes the daily difference in the ex post forecast error implied by federal funds futures

# 3. Empirical results

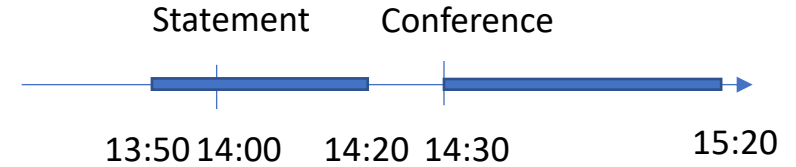
## 1) Within-press-conference analysis (variables)

- We link the statement news  $s_j$  with the press conference word matrix,  $W_j$ . Our approach proceeds in four steps:
  - First, we aggregate the text in  $W_j$  to a one-minute frequency.
  - Second, we run a part-of-speech analysis of the sentences identified in  $s_j$
  - Third, within the press conference text, we search for all combinations that include those nouns and verbs from  $s_j$
  - Fourth, and finally, we create a minute-level **dummy variable**,  $D_t$ , equal to one when that combination is identified in a given minute of the press conference.





# 3. Empirical results



## 1) Within-press-conference analysis ( $D_t$ )

$$|r_{it}| = a_k + b_k D_{t-1} + \epsilon_{it}$$

$$\frac{\text{Vol}_{ijt}}{\sum_{t \in T_i} \text{Vol}_{ijt}} = a_k + b_k D_t + \epsilon_{it}$$

	Fed funds futures		Eurodollar futures		Stocks	Forex
	1m-6m	9m-15m	6m-12m	24m-70m		
$a$	0.08 [4.54]	0.15 [19.61]	0.17 [12.08]	0.26 [35.99]	3.73 [17.36]	2.58 [13.82]
$b$	-0.01 [-1.30]	0.01 [0.35]	0.00 [0.02]	0.04 [2.10]	0.49 [1.94]	0.36 [2.12]

	Fed funds futures		Eurodollar futures	
	1m-6m	9m-15m	6m-12m	24m-70m
$a$	1.77 [42.46]	1.75 [39.75]	1.80 [54.84]	1.78 [64.45]
$b$	0.48 [1.31]	0.86 [4.96]	0.04 [0.31]	0.30 [2.57]

$$r_{it} = \begin{cases} a_k^- + b_k^- D_{t-1} + \epsilon_{it}, & \text{if } \Delta p_{ij,ST} < 0; \\ a_k^+ + b_k^+ D_{t-1} + \epsilon_{it}, & \text{if } \Delta p_{ij,ST} > 0, \end{cases}$$

	Fed funds futures		Eurodollar futures		Stocks	Forex
	1m–6m	9m–15m	6m–12m	24m–70m		
<i>Days when statement shock was negative</i>						
$a^-$	−0.01 [−2.24]	−0.01 [−0.98]	−0.01 [−1.37]	−0.02 [−2.52]	−0.27 [−1.54]	−0.17 [−1.89]
$b^-$	0.00 [0.22]	−0.03 [−1.31]	−0.02 [−0.52]	−0.08 [−2.17]	−1.82 [−2.80]	−0.55 [−1.86]
<i>Days when statement shock was positive</i>						
$a^+$	0.00 [0.43]	0.00 [0.80]	0.00 [0.15]	0.02 [1.84]	0.27 [3.31]	0.08 [0.94]
$b^+$	−0.00 [−0.12]	0.01 [0.53]	0.05 [2.26]	0.04 [1.04]	0.58 [1.92]	0.22 [0.56]

# 3. Empirical results

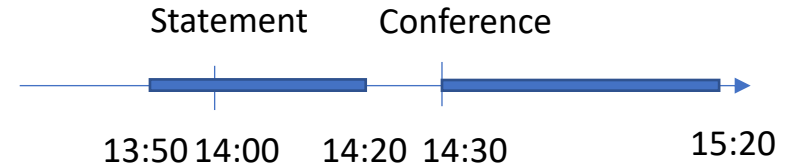
## 1) Within-press-conference analysis (Linguistic analysis)

- For each minute, we compute the percentage of words that falls into one of the following three categories, defined by LIWC2015: focuspast, focuspresent, or focusfuture.

$$|r_{it}| = a_k + b_{S,k} \cdot I_{S,t-1} + b_{D,k} \cdot D_{t-1} + b_{S-D,k} \cdot I_{S,t-1} \cdot D_{t-1} + \epsilon_{it}$$

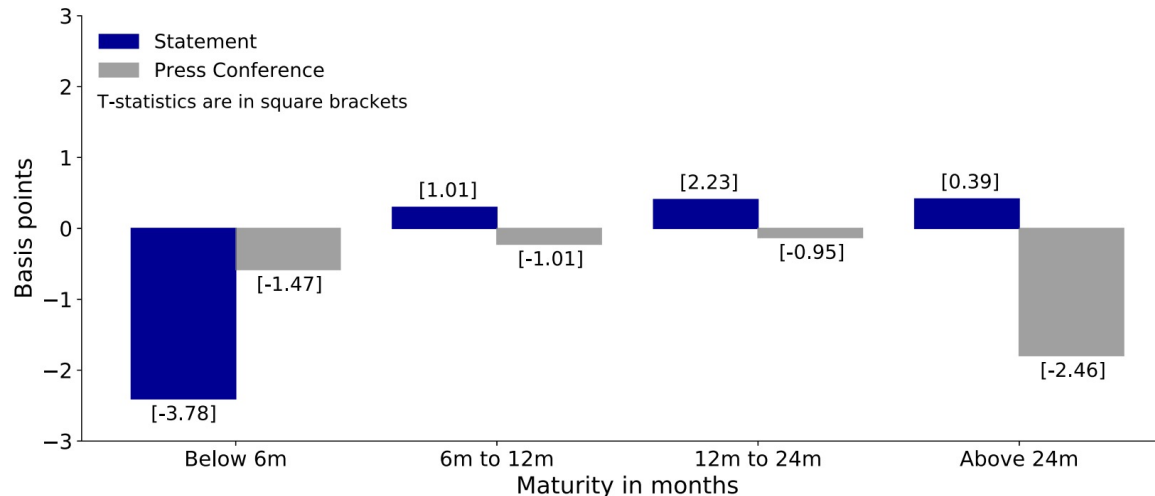
	Fed funds futures				Eurodollar futures				Stocks		Forex	
	1m-6m		9m-15m		9m-15m		24m-70m					
Coef.	Language Category: Future											
$a$	0.06 [3.85]	0.06 [3.92]	0.15 [10.40]	0.16 [10.85]	0.17 [36.85]	0.18 [99.50]	0.27 [27.32]	0.27 [31.10]	4.25 [13.93]	4.21 [14.29]	2.70 [14.73]	2.68 [15.33]
$b_S$	0.00 [0.44]	0.00 [0.47]	0.04 [2.31]	0.03 [5.36]	0.04 [2.27]	0.02 [9.06]	0.04 [1.66]	0.02 [2.17]	0.52 [1.97]	0.42 [12.48]	0.43 [2.35]	0.36 [5.41]
$b_D$	-	-0.02	-	-0.01	-	-0.02	-	0.00	-	0.40	-	0.23
	-	[-7.05]	-	[-1.86]	-	[-1.05]	-	[0.08]	-	[5.20]	-	[3.00]
$b_{S-D}$	-	0.01	-	0.03	-	0.22	-	0.12	-	0.72	-	0.51
	-	[2.23]	-	[1.99]	-	[3.25]	-	[3.68]	-	[3.85]	-	[2.73]
Language Category: Present												
$a$	0.06 3.72 [3.72]	0.06 3.79 [3.79]	0.16 10.91 [10.91]	0.16 11.52 [11.52]	0.18 40.44 [40.44]	0.18 589.49 [589.49]	0.28 30.29 [30.29]	0.28 34.03 [34.03]	4.33 13.90 [13.90]	4.30 14.35 [14.35]	2.78 14.43 [14.43]	2.76 14.99 [14.99]
$b_S$	-0.01 [-1.29]	-0.00 [-1.04]	-0.02 [-2.18]	-0.02 [-5.25]	-0.01 [-0.65]	-0.01 [-0.47]	-0.03 [-2.40]	-0.03 [-16.78]	-0.31 [-1.40]	-0.40 [-7.08]	-0.37 [-2.78]	-0.43 [-5.50]
$b_D$	-	-0.01	-	-0.00	-	0.02	-	0.02	-	0.38	-	0.24
	-	[-5.89]	-	[-0.54]	-	[0.53]	-	[2.10]	-	[6.39]	-	[3.75]
$b_{S-D}$	-	-0.03	-	-0.03	-	-0.03	-	0.01	-	1.59	-	0.91
	-	[-17.74]	-	[-8.51]	-	[-0.44]	-	[1.79]	-	[9.28]	-	[4.25]

# 3. Empirical results



## 1) Within-press-conference analysis (Uncertainty reduction)

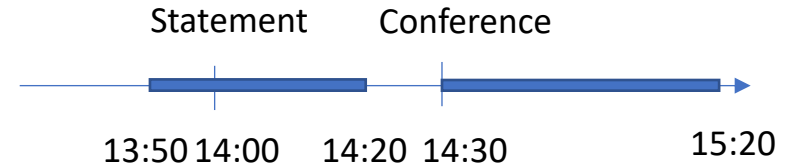
- The next question asks to what extent this information indeed reduces investor uncertainty about future monetary policies



Panel A. Implied Volatility Using [Black \(1976\)](#)

	Maturity in months			
	Below 6m	6m to 12m	12m to 24m	Above 24m
Statement-related minutes	-0.105 [-2.341]	-0.008 [-0.313]	-0.113 [-2.267]	-0.061 [-2.354]
Other minutes	-0.013 [-1.185]	-0.001 [-0.166]	-0.012 [-1.001]	-0.003 [-0.319]

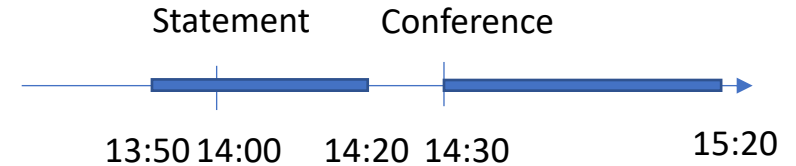
# 3. Empirical results



## 1) Potential explanations (Differences in higher-order beliefs, )

- Banerjee et al. (2009): Standard DO models assume common knowledge of agents' opinions—each agent knows what others believe about the fundamental value of the asset, and agents “agree to disagree.”
- We relax this common knowledge assumption and assume that agents are uncertain about the beliefs of others.
- We show that in a dynamic framework (REE), price drift is not robust in a setting with only first-order disagreement, and we need differences in opinions about higher-order beliefs.

# 3. Empirical results



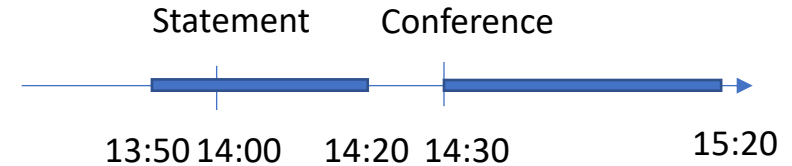
1) Potential explanations (Differences in higher-order beliefs, )

- The Banerjee et al. (2009) model makes the additional prediction that stronger price drifts should coincide with higher uncertainty.
- $I_t$  is an indicator variable (implied volatility)

$$\Delta p_{it,PC} = a_k + b_k \Delta p_{it,ST} + c_k \Delta p_{it,ST} \cdot I_t + \epsilon_{it}$$

	Fed funds futures		Eurodollar futures		Stocks	Forex
	1m-6m	9m-15m	6m-12m	24m-70m		
$a$	0.02 [0.22]	0.20 [0.90]	0.12 [0.40]	0.22 [0.71]	-2.42 [-0.55]	-5.31 [-1.87]
$b$	-0.29 [-1.28]	-0.25 [-1.63]	-0.14 [-2.69]	0.17 [1.33]	0.17 [6.52]	0.04 [0.51]
$c$	0.69 [2.14]	0.73 [3.57]	0.56 [12.62]	0.35 [4.71]	0.45 [2.15]	0.36 [3.60]
$R^2$	32.63	30.70	26.20	25.60	18.37	16.83

# 3. Empirical results



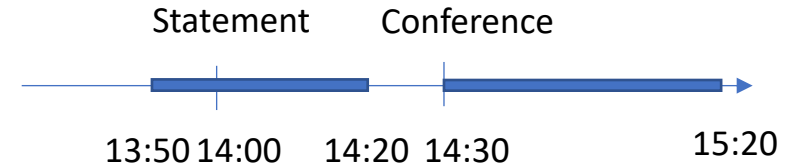
## 1) Potential explanations (Differences in higher-order beliefs, )

- Banerjee (2010) extend these ideas and show how a dynamic model in which **investors disagree about the interpretations of public information also generates a positive relation between disagreement, return volatility, and trading volume.**
- The model's first prediction is about the relation of disagreement and realized volatility
- The second key prediction: whether periods of high uncertainty are also associated with high trading volume
- Moreover, these models also predict that the volume should exhibit a larger positive autocorrelation around larger uncertainty periods

$$\sigma_{i,t} = a_k + b_k \cdot I_t + \epsilon_{it}, \quad V_{it} = a_k + b_k \cdot I_t + \epsilon_{it}$$

$$V_{it,PC} = (a_k + b_k \cdot I_t) \cdot V_{it,ST} + \epsilon_{it}$$

# 3. Empirical results



## 1) Potential explanations (Differences in higher-order beliefs, )

**Table 13**  
Volatility during FOMC Days.

	Fed funds futures		Eurodollar futures		Stocks	Forex
	1m-6m	9m-15m	6m-12m	24m-70m		
<i>a</i>	0.0296 [6.4614]	0.0798 [7.9110]	0.1419 [11.471]	0.1627 [9.6253]	2.7392 [11.081]	1.6377 [12.312]
<i>b</i>	0.0170 [1.8637]	0.0204 [1.1661]	0.0531 [2.2174]	0.0244 [4.6862]	0.8125 [2.1728]	0.2618 [2.1896]

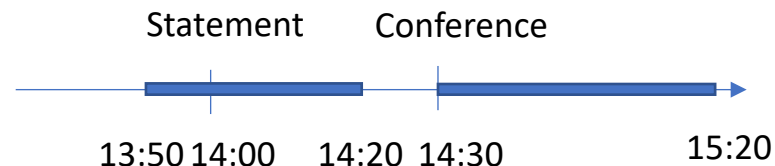
**Table 14**  
Trading Volume during FOMC Days.

	Fed funds futures		Eurodollar futures	
	1m-6m	9m-15m	6m-12m	24m-70m
<i>a</i>	5.4423 [7.4578]	2.8518 [8.4383]	2.0039 [8.6530]	2.4371 [8.8983]
<i>b</i>	1.1541 [0.7922]	0.3180 [0.4963]	1.2837 [2.6802]	0.5865 [1.8292]

**Table 15**  
Trading Volume around the Statement and Press Conference.

	Fed funds futures		Eurodollar futures	
	1m-6m	9m-15m	6m-12m	24m-70m
<i>a</i>	0.519 [5.371]	0.6464 [5.2059]	0.8767 [9.4302]	0.8701 [10.104]
<i>b</i>	0.026 [0.186]	1.3061 [7.3632]	0.2359 [2.1118]	0.2090 [3.3044]
<i>R</i> <sup>2</sup>	59.06	76.94	82.06	82.11

## 4. Conclusion



- We show that at the moment the **chairman discusses the changes** between the current and the previous policy statements, price volatility and trading volume spike dramatically and prices move on average in the same direction as they did around the statement release before the press conference.
- This movement generates a strong positive correlation between price changes around the statement release and the subsequent press conference
- We have argued the difficulty in squaring these explanations with all of the empirical evidence. And the models most directly consistent with our results are those that explicitly feature traders' differential interpretation of public signals.



## 4. Appendix

- We use recurrent neural networks to convert the spectrograms into a sequence of characters,  $c$ , and all corresponding probabilities.
- Conditional on  $c$ , we use the Connectionist Temporal Classification (CTC) algorithm of Graves et al. (2006) to draw a sequence of readable text transcriptions,  $W$ .
- Third, once we are able to evaluate  $p(W|X)$ , we follow Hannun et al. (2014) and use a beam-search algorithm to estimate  $W^*$ .
- Fourth, we leverage the specific structure of our application and align our estimate of  $W^*$  with the text in the press conference transcripts, published by the FOMC.
- Next, we time-stamp the text of each three-second audio frame