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New methods and advanced analytics at the Bank of England

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Advanced Analytics Division

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*Disclaimer: Our views do not necessarily reflect those of the Bank of England (BoE) or any of its committees.

Outline

1. The Bank of England and Advanced Analytics (I)
2. Machine learning in a central banking context (I)
3. Sending firm messages: Text mining PSM letters (II)
4. Enhancing central bank communications with behavioural insights (III)

Every session (I - III) is 20min + 10min Q&A.



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Bank of England (BoE)

“Promoting the good of the people of the United Kingdom by maintaining monetary and financial stability.”

- **Banknotes** (e.g. new polymer notes)
- **Monetary policy** (e.g. interest rates, QE)
- **Financial Stability** (e.g. stress testing)
- **Gold storage** (“the vault”)
- **Markets** (MP implementation)
- **Payment & Settlement** (e.g. CHAPS)
- **Prudential regulation** (e.g. banking supervision)
- **Research** (e.g. SWPs, conferences, Bank Underground)
- **Statistics**

Advanced Analytics (AA) connects to most of these tasks.



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The “AA Team’s” interlocking tasks

- Analytics
- Research
- Outreach
- Technology

AA is kind of an “internal consultancy”
mostly collaborating with other parts of the institution.



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Machine learning in a central banking context*

Chiranjit Chakraborty & Andreas Joseph

* SWP 674: “[Machine learning at central banks](#)” (2017), BU post “[New machines for the old lady](#)” (2017).

Introduction to machine learning (ML) *

- “Econometrics from computer scientists”
- Models as universal approximators (non-parametric non-linearities)
- Focus on prediction (correlation, not causation)
- Few asymptotic results (research needed!) **
- General policy problem includes a prediction component ***

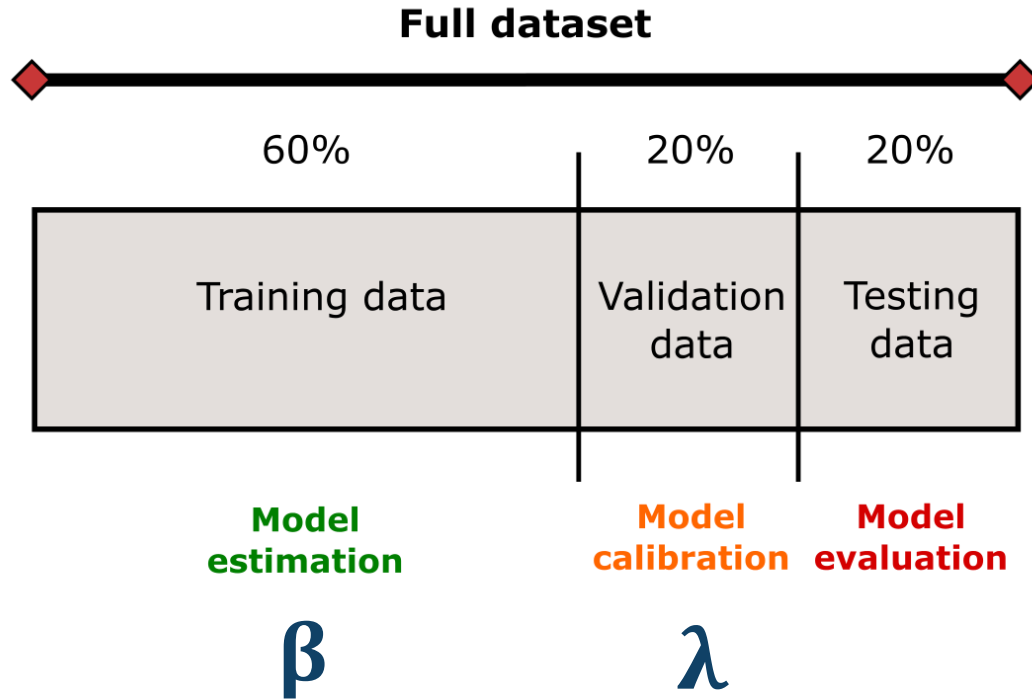
* [“Economists are prone to fads, and the latest is machine learning”](#), The Economist, 26. Nov 2016

** [“Why does deep and cheap learning work so well?”](#), Lin and Tegmark, arXiv:1608.08225, 2016

*** [“Prediction policy problems”](#), Kleinberg et al, AER 105(5):491-95, 2015.



ML modelling protocol (simplified)



1. Fit model on training data.
2. Set hyper-parameters (λ) by testing model on new data (cross-validation)
3. Final model test via out-of-sample testing (no asymptotics)

Gold standard

out-of-sample testing



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General policy problem***

$$\frac{d\pi(X, Y, Z)}{dX} = \left(\underbrace{\frac{\partial \pi}{\partial X}}_{\text{prediction}} \bigg|_Y + \frac{\partial \pi}{\partial Y} \underbrace{\frac{\partial Y}{\partial X}}_{\text{causal inference}} \right) \bigg|_Z$$

π : payoff/welfare, X : policy variable, Y : outcome, Z : controls

Examples:

X : umbrella, Y : weather, π : wellbeing

X : bank capital buffers, Y : growth, π : welfare



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*** "[Prediction policy problems](#)", Kleinberg et al, AER 105(5):491-95, 2015.

Potential central banking applications of ML

1. **Non/semi-structural modelling** (e.g. forecasting)
2. **Operational process optimisation** (e.g. supervision, conduct)
3. **Pattern recognition in large datasets** (e.g. variable extraction)
4. **Policy analysis** (e.g. payoff evaluations, often microeconomic issues)
5. **Dynamic policy simulation** (e.g. dynamically learning agents; similar to DeepMind's [Mastering the game of Go](#) (2016))



SWP case studies

1. **Banking supervision: prudential regulation, financial stability**
2. **Inflation forecasting: monetary policy**
3. **Investigating Fintech funding structures: financial stability**



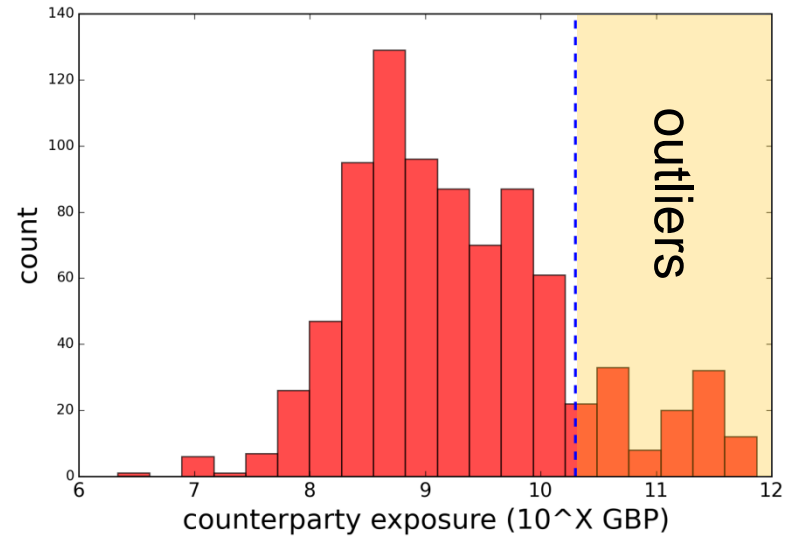
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Case: Banking supervision

- Detect “alerts” which may trigger further action on Banks’ balance sheets
- Stylised setting of incomplete information and non-trivial alert rule
- Data source: regulatory returns (international banks)



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Target (Y): firms with ≥ 3 outliers / quarter out of 6 measures

Inputs (X): 4 measures (CP exp. Removed)

Data Summary

name	has-3-alerts (Y)	leverage	CET1	profitability	assets	CP exp. 1	CP exp. 2
unit	Boolean	ratio	change	log value	change	log value	log value
1-alerts	- -	R	L/R	L/R	L/R	R	R
count	840	840	840	840	840	840	840
mean	0.19	0.54	0.01	2.01	0.02	9.36	9.30
std	0.39	8.34	0.17	6.06	0.12	3.98	3.96
min	0.00	0.00	-0.96	-9.45	-0.49	6.34	6.34
25%	0.00	0.05	-0.01	4.95	-0.02	8.61	8.58
50%	0.00	0.07	0.00	6.00	0.01	9.21	9.14
75%	0.00	0.11	0.01	6.97	0.05	9.94	9.86
max	1.00	238.69	2.90	9.87	1.47	12.03	11.87
var. importance ⁽¹⁾		44	31	46	100	- -	- -
s/n ratio ⁽¹⁾		6.8	6.3	6	∞	- -	- -
var. importance ⁽²⁾		52	47	56	81	95	92
s/n ratio ⁽²⁾		6.4	5.5	5.7	6.5	12.9	10.6



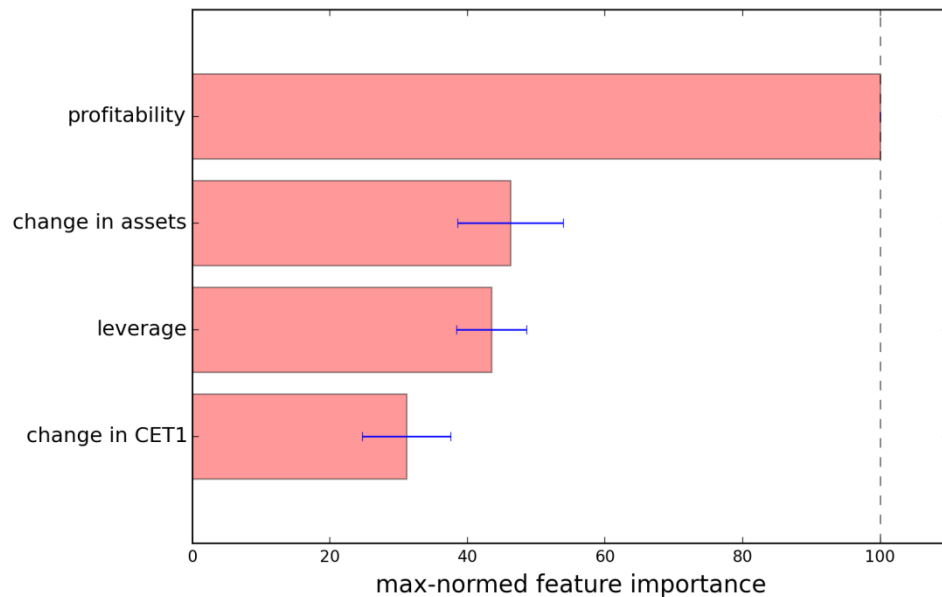
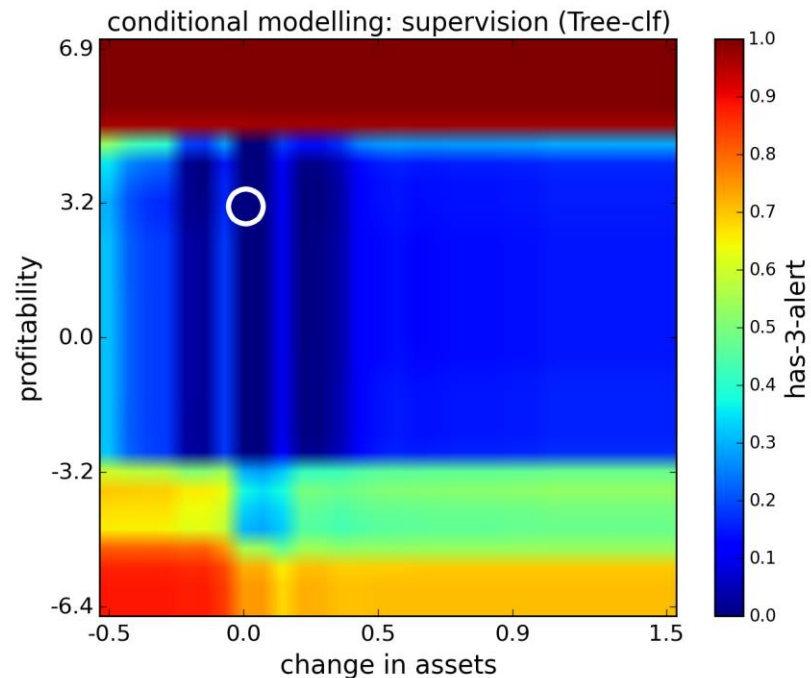
Model Comparison

method	CV	acc_{train}	acc_{test}	$precision$	$recall$	F_1
naïve Bayes	Gaussian kernel	80.3	79.8	46.5	35.4	40.2
k -NN	neighbours/5, $p/1$	93.0	89.7	80.0	61.3	69.4
decision tree	max. depth/6	97.3	89.4	75.6	66.2	70.6
random forest	trees/200, max. depth/9	99.8	91.6	83.3	69.9	76.2
FFANN	$\alpha/10$, hidden/2	90.5	88.9	78.2	58.0	67.0
SVM	C/1000, $\gamma/1$	96.0	88.9	73.6	65.2	69.2
Logit	C/0.01	82.3	81.8	58.5	18.6	28.2



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Conditional predictions & feature importance



Tree models allows to calculate **feature importance**: error reduction across tree branches due to each variable



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Thanks – Q&A



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Sending firm messages: Text mining PSM letters*

David Bholat, James Brookes, Chris Cai, Katy Grundy and Jakob Lund

*SWP 688: “[Sending firm messages: text mining letters from PRA supervisors to banks and building societies they regulate](#)” (2017), BU post “[Open letters: Laying bare linguistic patterns in PRA messages using machine learning](#)” (2018)



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Primary research question and hypotheses

Are PSM letters written differently to firms with different risk profiles?

- *If so, what linguistic features distinguish sub-genres of PSM letters?*

We expected PSM letters to vary depending on firm riskiness

- consistent with the PRA's principle of proportionality

We expected higher risk firms to receive letters that were:

- more complex
- more negative in sentiment
- more directive



'Intrinsic risk' = Potential Impact = Firm Category

Increasing risk ↑

Category 1	Most significant deposit-takers capable of <u>very significant disruption</u>
Category 2	Significant deposit-takers capable of <u>some disruption</u>
Category 3	Deposit-takers capable of <u>minor disruption</u>
Category 4	Deposit-takers capable of <u>very little disruption</u>
Category 5	Deposit-takers capable of <u>almost no disruption</u>



'Imminent risk' = PIF stage = proximity to resolution

Increasing risk



Stage 1	<u>Low risk</u> to viability of firm
Stage 2	<u>Moderate risk</u> to viability of firm
Stage 3	<u>Risk to viability</u> absent action by the firm
Stage 4	<u>Imminent risk</u> to viability of firm
Stage 5	Firms <u>in resolution</u> or being actively wound up



Secondary research question and hypotheses

Has supervisory communication measurably changed post-crisis?

- *If so, how do PRA PSM letters differ from FSA ARROW letters?*

Compared to the ARROW letters, we expected the PSM letters to be:

- more complex
- more directive
- more forward-looking



Linguistic features

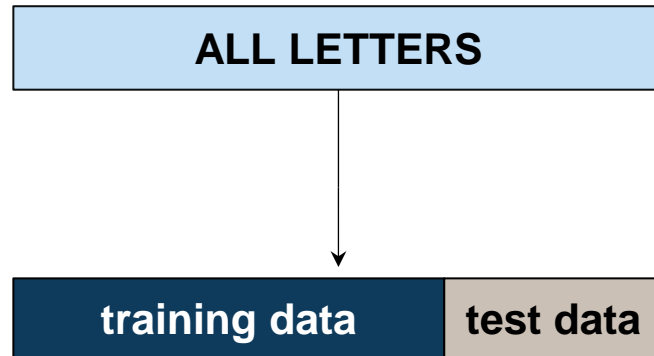
- **Complexity**
 - e.g. length of letter, subordinate clauses
- **Sentiment**
 - e.g. balance of positive versus negative words
- **Directiveness**
 - e.g. obligative phrases such as *should*, *must*, *expect*
- **Formality**
 - e.g. whether the salutation is handwritten or typed
- **Forward-lookingness**
 - e.g. future-oriented verb tenses

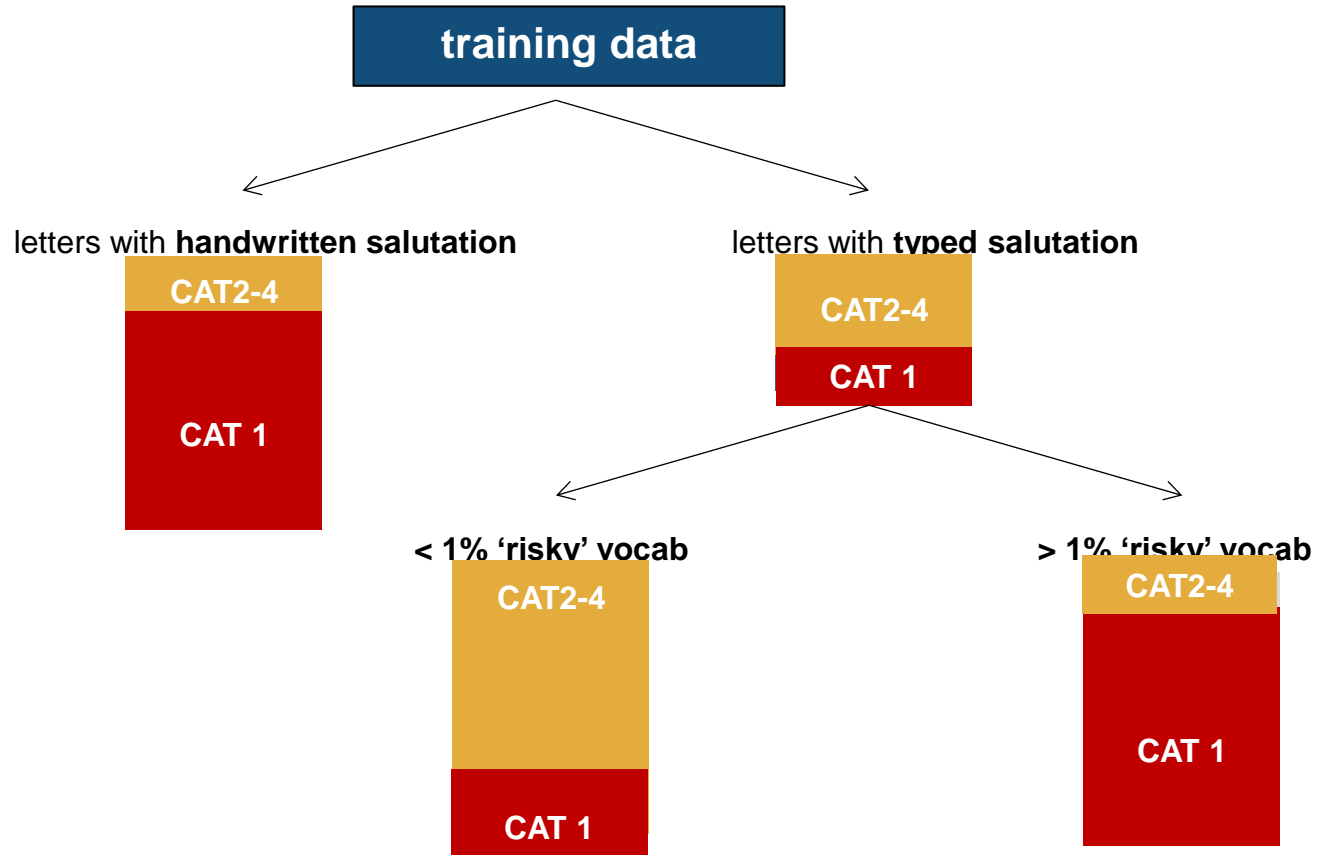


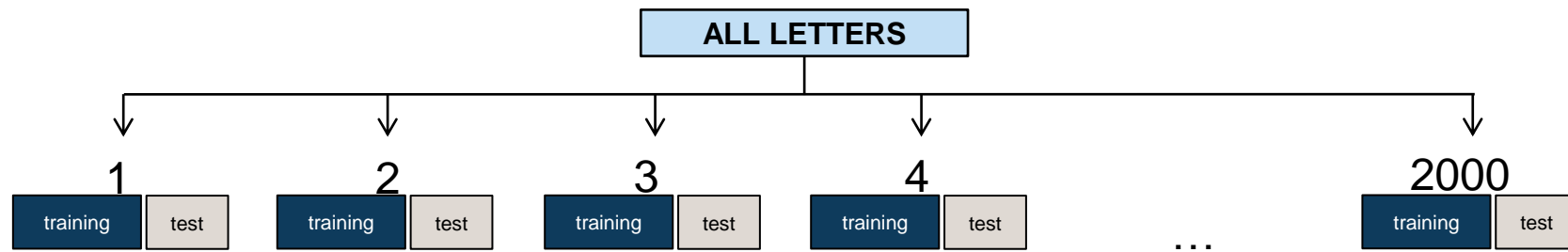
Random Forests

- 1. Category 1 vs. Category 2-4
 - 2. PIF 1-2 vs. PIF 3-4
 - 3. PSM letter vs. ARROW letter
- } ~ 25 linguistic features

Random Forests





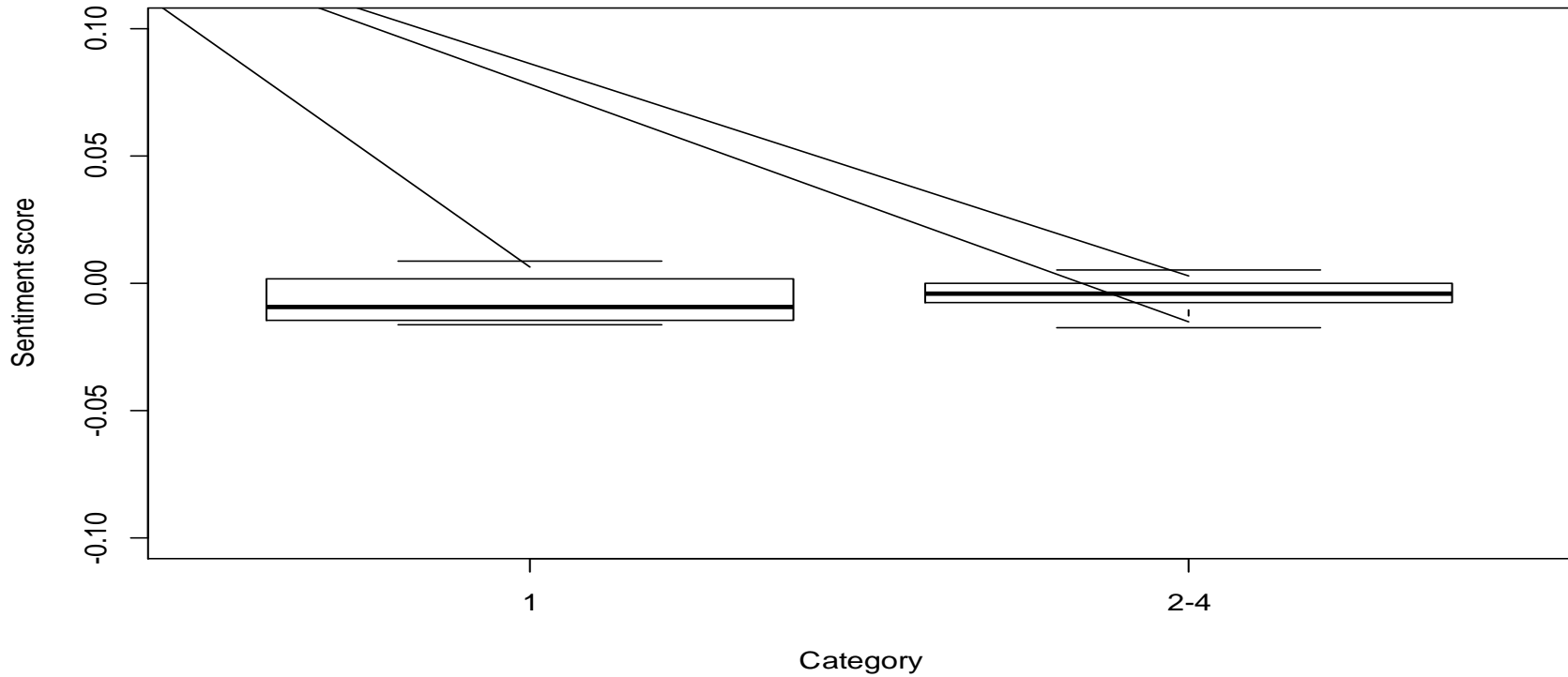


CAT 1 PSM letters different from CAT 2-4 letters

- More complex
- Less directive
- Less formal
- No differences in sentiment



Sentiment with financial context - Year 2015



PIF 3-4 PSM letters different from PIF 1-2 letters

- More complex
- More 'high-risk' vocabulary
- Less directive
- Less formal

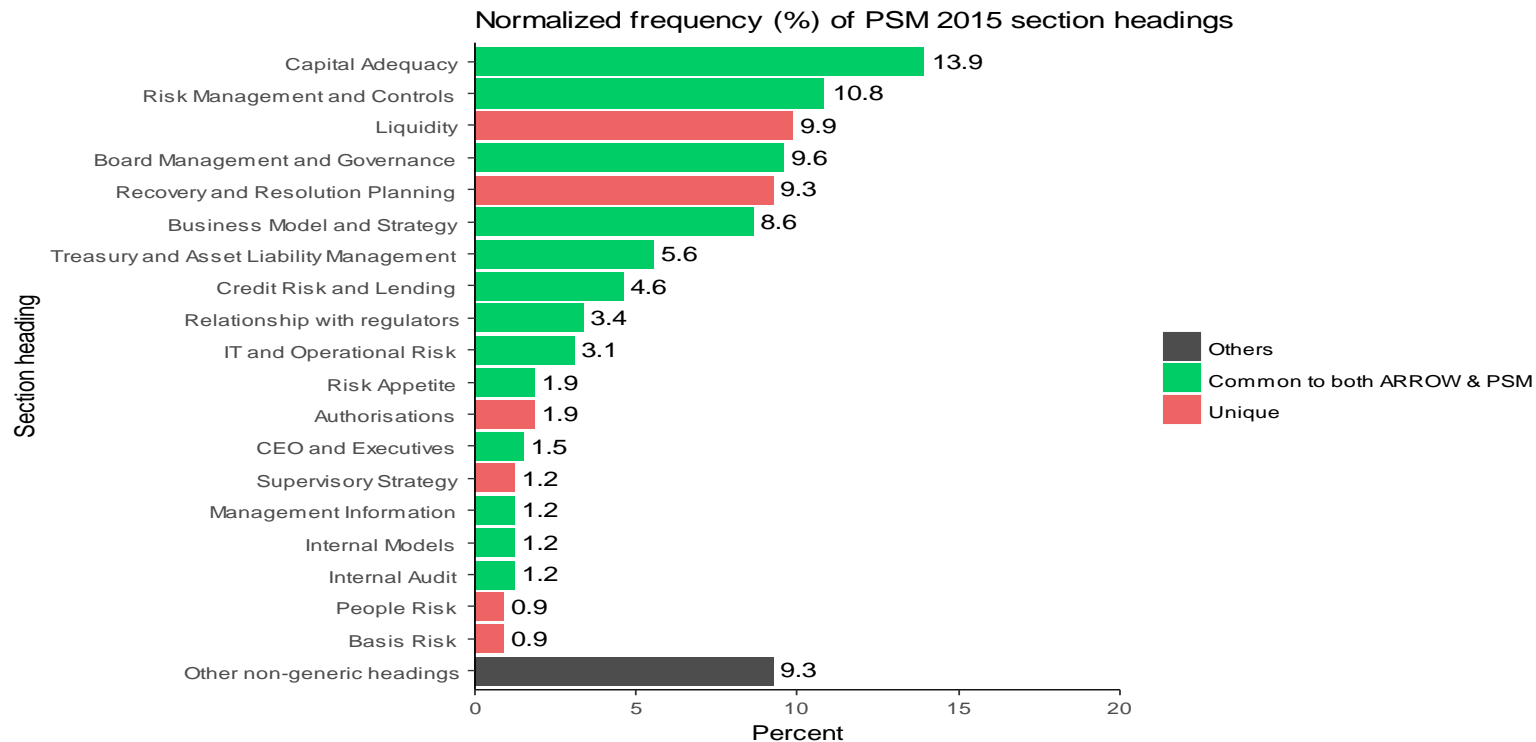


PSM letters different from ARROW letters linguistically

- More complex
- More directive
- More forward-looking



PSM letters different from ARROW letters in content



Summary

- Are PSM letters written differently to firms with different risk profiles?

Yes

- Has supervisory communication measurably changed post-crisis?

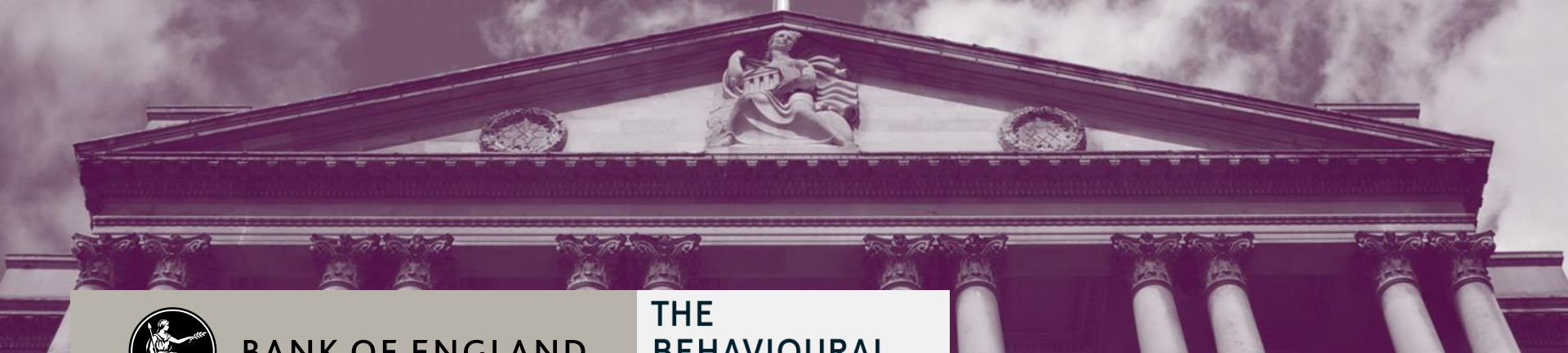
Yes



Thanks – Q&A



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Enhancing central bank communications with behavioural insights*

David Bholat,⁽¹⁾ Nida Broughton,⁽²⁾ Alice Parker,⁽¹⁾ Janna Ter Meer⁽²⁾ and Eryk Walczak⁽¹⁾

⁽¹⁾Bank of England - Advanced Analytics

⁽²⁾Behavioural Insights Team

*forthcoming SWP

Central bank communications matter

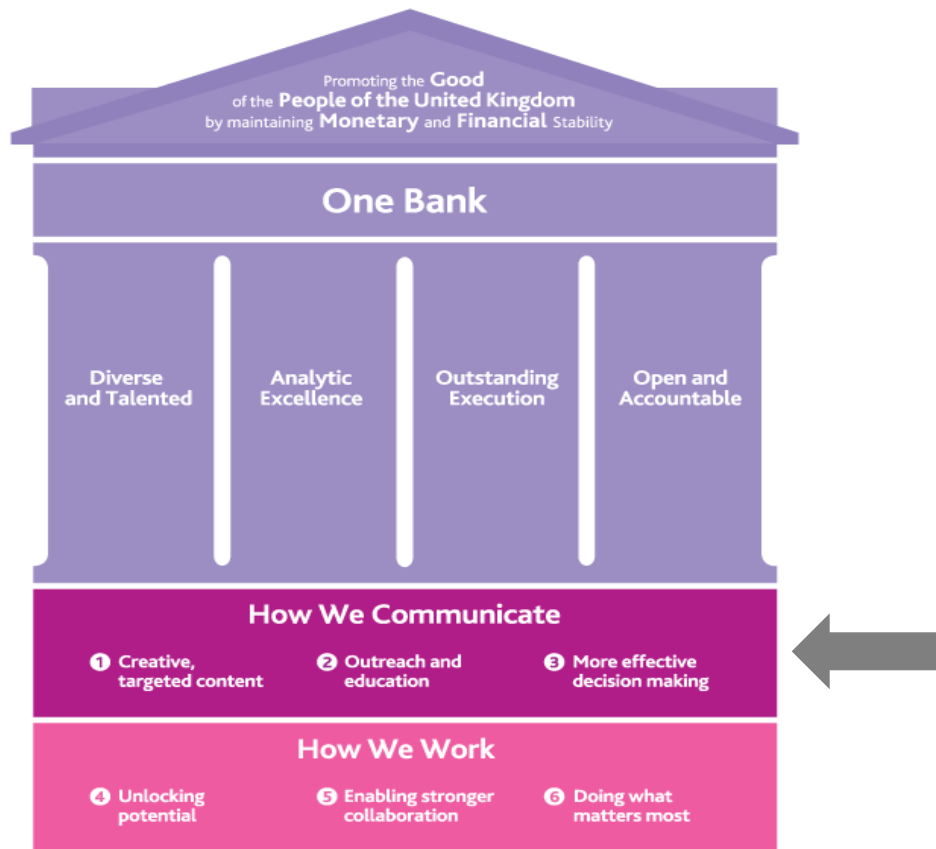
- Good communication is powerful for central banks because it improves the effectiveness of our policies e.g. anchoring inflation expectations
- Good communication could potentially:
 - build awareness of what the Bank of England does and why
 - increase interaction and engagement with the content
 - enhance public trust and understanding



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The Bank of England's Vision 2020 strategy



Research Objectives

- Measure the extent to which the **Visual Summary** improved public comprehension and trust in key messages from the Bank's *Inflation Report* compared to the **Monetary Policy Summary**
- Our experiment also tested two new versions – one version with **Reduced Text** and one that restructures the information and uses **Relatable content**



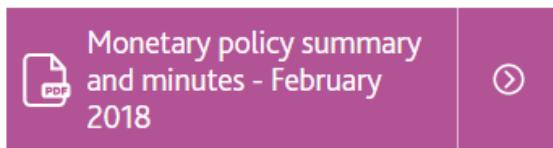
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Monetary Policy Summary

Visual summary	Monetary Policy Summary	Global economic and financial market developments	Demand and output	Supply and the limits to growth	Costs and prices	Prospects for inflation
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Published on 08 February 2018



The Bank of England's Monetary Policy Committee (MPC) sets monetary policy to meet the 2% inflation target, and in a way that helps to sustain growth and employment. At its meeting ending on 7 February 2018, the MPC voted unanimously to maintain Bank Rate at 0.5%. The Committee voted unanimously to maintain the stock of sterling non-financial investment-grade [corporate bond purchases](#), financed by the issuance of central bank reserves, at £10 billion. The Committee also voted unanimously to maintain the stock of [UK government bond purchases](#), financed by the issuance of central bank reserves, at £435 billion.



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Visual Summary

The squeeze on pay is easing

Over the past year, prices have been rising faster than wages. That means people have not been able to afford as much. We think that is changing.

The share of people out of work is now at its lowest level since 1975. And there are a lot of job vacancies. This means that companies are having to compete hard with each other to recruit and retain workers. One way they do that is by offering higher wages – so we expect bigger pay rises over the next few years.

We think that pay will rise faster than prices this year, easing the squeeze on living standards.

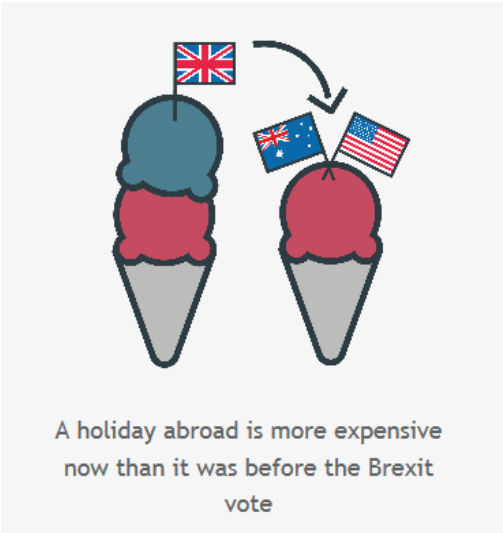
Reduced Text Summary

The squeeze on pay is easing

The share of people out of work is at its lowest level since 1975. And there are a lot of job vacancies. We expect bigger pay rises over the next few years as companies offer higher wages to recruit and retain workers.

We expect that pay will therefore rise faster than prices this year.

Relatable Summary

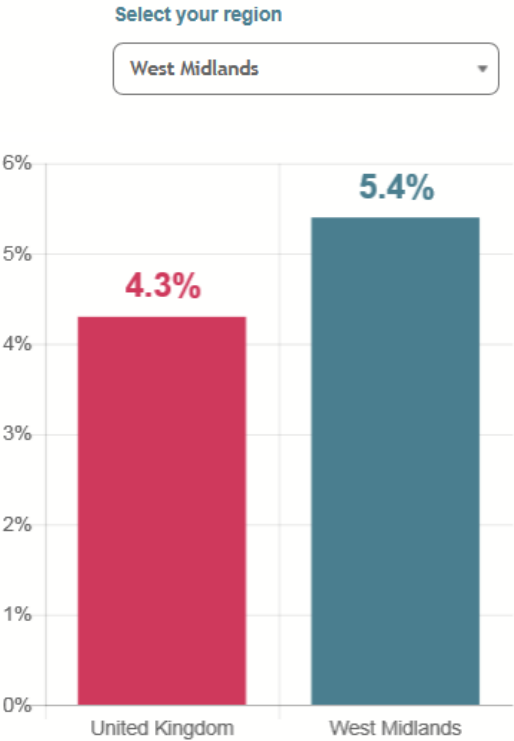


A basket of goods and services that cost you £100 this year...



...should cost you £102 next year

CHART Look at what unemployment is like in your area



Source: ONS data

Treatments

Word count, readability and visual of different arms of the experiment

	Word count	Flesch-Kincaid grade level	Number of Visuals (charts / icons)
Monetary Policy Summary	879	15.26	0
Visual Summary	1069	7.34	14
Reduced Text Summary	535	6.18	14
Relatable Summary	407	4.98	9



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Contributions

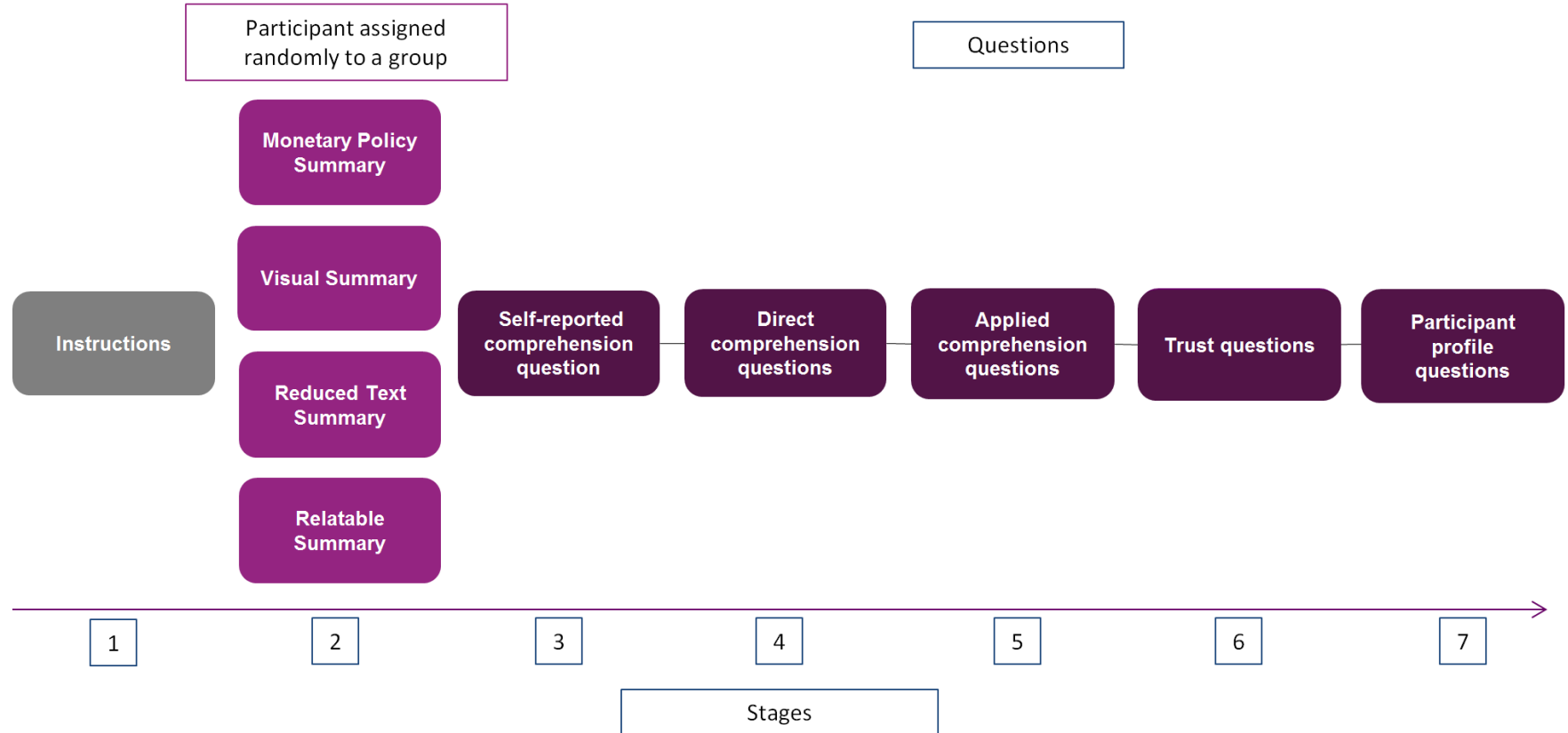
- **Central bank communication literature and Vision 2020**
 - Identify new strategies for external communication
 - Expand literature on central bank communications
 - Expand the Bank's methodological range
- **Behavioural economics literature**
 - From micro to macro decision-making
 - Central banks



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Representative sample (2275 respondents) of UK population based on gender, age, income and regional location, assigned to one of the four groups



Direct Comprehension questions

1. In what way does the Bank of England support the UK economy?
2. Based on what you have read, which of these is true about prices at the moment?
3. Based on what you have read, what has happened to the amount of people that are out of work recently?
4. Based on what you have read, what is likely to happen to how much people can afford to buy this year?
5. What is the Bank of England's current interest rate?



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Model specification

$$Y_i^{comp} = \alpha + \beta_1 T1_i + \beta_2 T2_i + \beta_3 T3_i + \beta_4 \Gamma A_i + \varepsilon_i$$

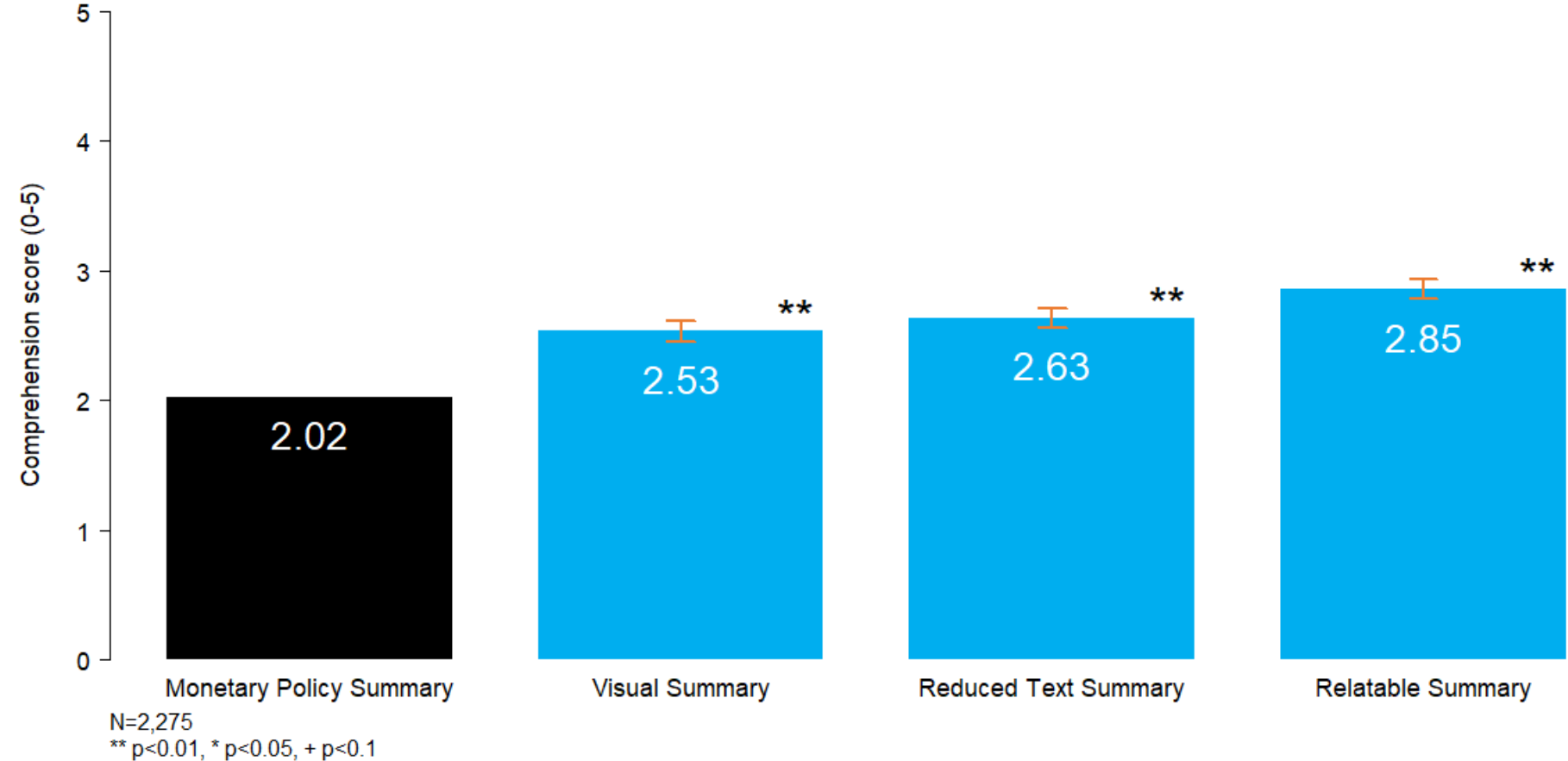
- where Y_i^{comp} is treated as a continuous variable representing the number of correct answers to the comprehension questions for the participant i
- $T1_i$ is a binary variable which indicates the treatment for participant i with a value of 1 if the participant is in the Visual Summary condition and 0 otherwise
- $T2_i$ is a binary variable which indicates the treatment for participant i with a value of 1 if the participant is in the Reduced Text Summary condition and 0 otherwise
- $T3_i$ is a binary variable which indicates the treatment for participant i with a value of 1 if the participant is in the Relatability Summary condition and 0 otherwise
- A_i is a vector of controls indicating the gender, age bracket, income bracket, region, and economics engagement level of participant i
 - α is the regression constant
 - Γ is the coefficient of each control in A_i
 - ε_i is the error term



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Results – Direct Comprehension



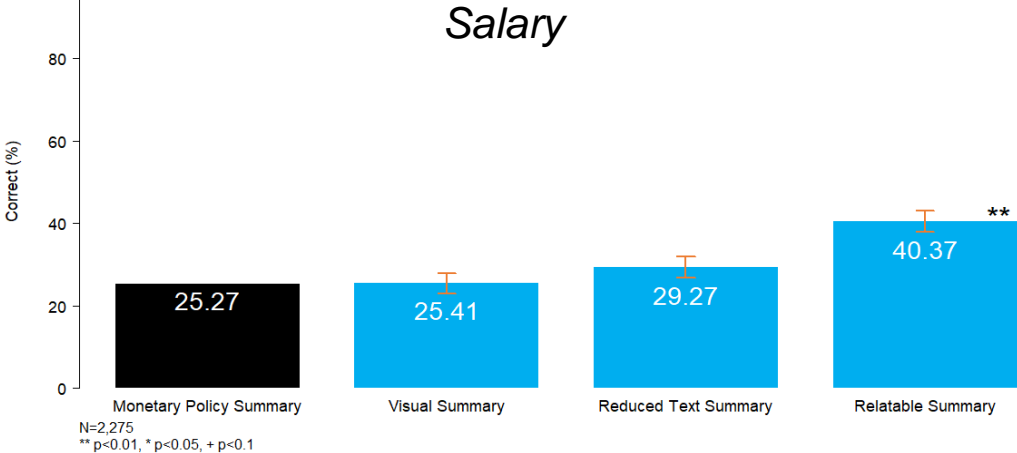
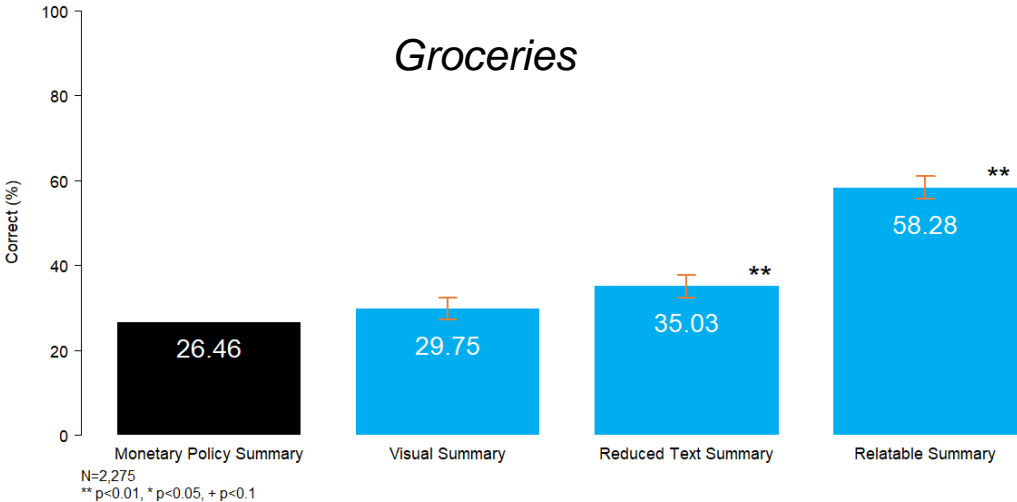
Results – Applied Comprehension

“Your friend spends £100 a week on groceries. They are planning their household finances for next year, and are thinking about how much they need to budget for groceries. They want to keep buying the same things as they are now.

Based on what you have read, what do you think they should budget for their weekly grocery shop next year? What your friend spends each week on groceries now: £ 100”

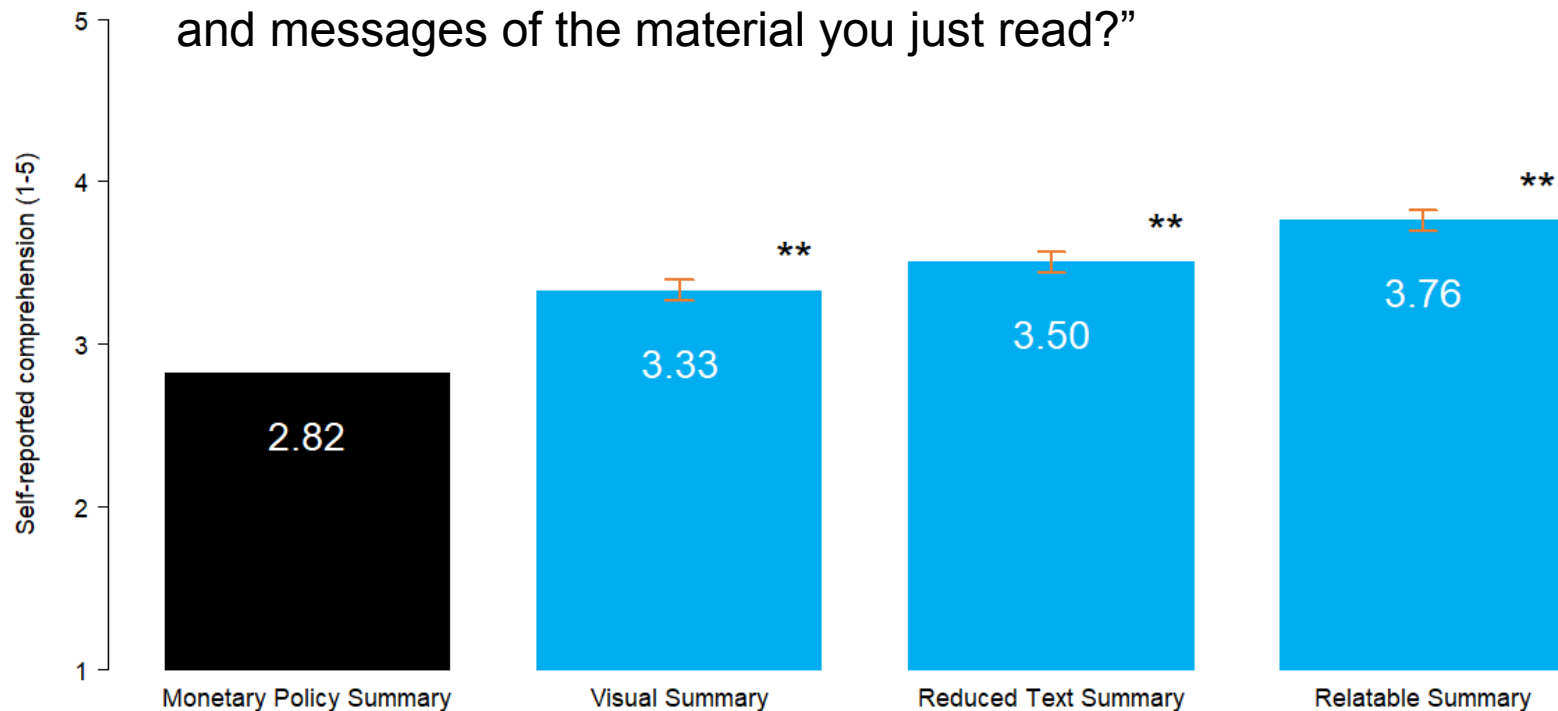
“Your friend earns £100 per day. They will have a chance to ask for a pay rise at the end of this year to cover increases in the cost of living.

Based on what you have read, how much should they ask for, just to cover increases in the cost of living? Your friend’s daily rate (what your friend currently earns): £100 per day”



Results – Self-reported Comprehension (Haldane & McMahon measure)

“To what extent are you able to understand the content and messages of the material you just read?”

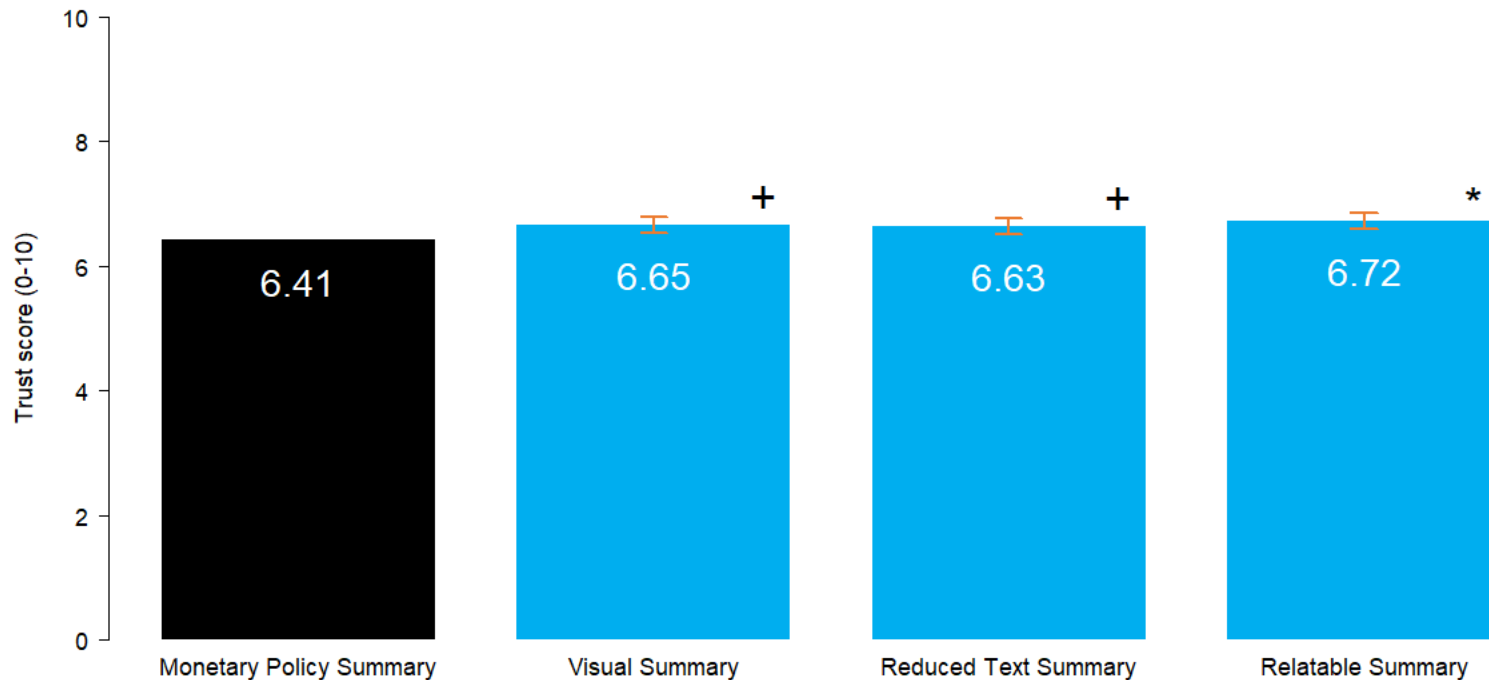


N=2,275

** p<0.01, * p<0.05, + p<0.1

Results – Trust

“Imagine someone is looking for trustworthy information about the economy.
How would you rate the information on the website you have just seen?”
(0-10 point scale)

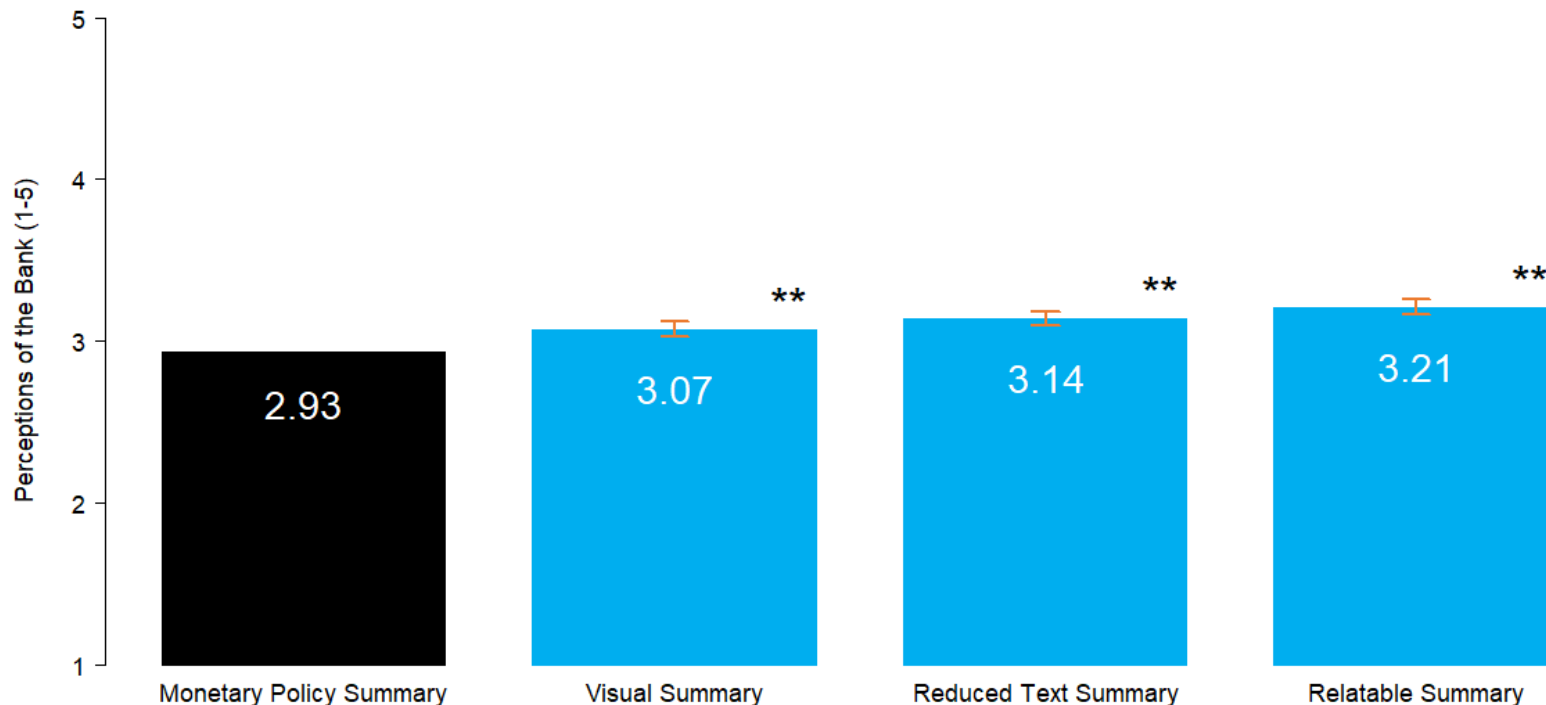


N=2,275

** p<0.01, * p<0.05, + p<0.1

Results – Perceptions (Haldane & McMahon measure)

“Learning that this is typical communication in the Bank of England quarterly *Inflation Report*, how has the *Inflation Report* summary affected your perceptions of the Bank of England, if at all?” (1-5 scale)



N=2,275

** p<0.01, * p<0.05, + p<0.1

Summary findings and implications

- The Visual Summary improves public comprehension relative to the Monetary Policy Summary
- The Visual Summary could be made more relatable to increase public comprehension and trust in the Bank's policy messages.



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Future research

- Relatability
- Trust
- Behavioural biases
- Media sources



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