From Man vs. Machine to Man + Machine: The art and AI of stock analyses

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Motivation

- “Man vs. Machine” or “Man + Machine”
  - Existing literature: how human **passively adapt** to disruption by AI revolution.
  - But primary goal to develop AI is to enhance human **productivity**.
- Motivated by the history experience in chess games.
  - IBM’s Deep Blue beat grand master.
  - The centaur (a chess player equipped with AI assistance) kept an **upper hand** against machines.

Research Questions

- (1) How far is the performance gap between human, AI, and human + AI?
- (2) Do human analysts have comparative advantages over AI?
- (3) What is incremental contribution of analysts to man–machine synergy?

Contribution

- Contribute to literature on threat to human workers posed by new technology.
  - Prior literature: how AI **replace** intermediate-skill jobs and **disrupt** high-skill jobs.
  - Extend: explore humans **relative advantage** against AI.
- Contribute to literature on the impact of big data and AI in finance.
  - Prior literature: use market-level **proxies** (Grennan and Michaely, 2020).
  - Extend: construct AI process; identify **the synergy between human and machine**.

Contribution

- Contribute to literature that build and assess the performance of ML in finance.
  - Prior literature: predict asset prices (Gu et al., 2020), manage portfolios (Chen et al., 2023), forecast earnings (Cao and You, 2024), etc.
  - Extend: explore the **complementary value** of humans' analysis over ML.
- Contribute to literature of applying ML to analyst forecasts.
  - Prior literature: calibrate analyst biases focusing on the **term structure** (de Silva, 2024) and the link with **corporate actions** (van Binsbergen et al., 2023).
  - Extend: compare debiased analyst forecast with AI; focus on **innate limitation** in human to acquire and process information.

What object to predict?

- Corporate earnings
  - Earnings are more susceptible to management discretion.
  - Managed earnings often meet or slightly beat analyst forecasts (Doyle et al., 2013).
- Target stock price
  - Valuation targets receive more attention with investors.
  - Market reacts strongly to target price revisions (Asquith et al., 2005).
  - Analysts adjust price target more frequently than earnings forecast.
- Cash flow
  - Difficult to manipulate (Abarbanell and Lehavy, 2003).
  - Few forecasted separately in analyst reports.

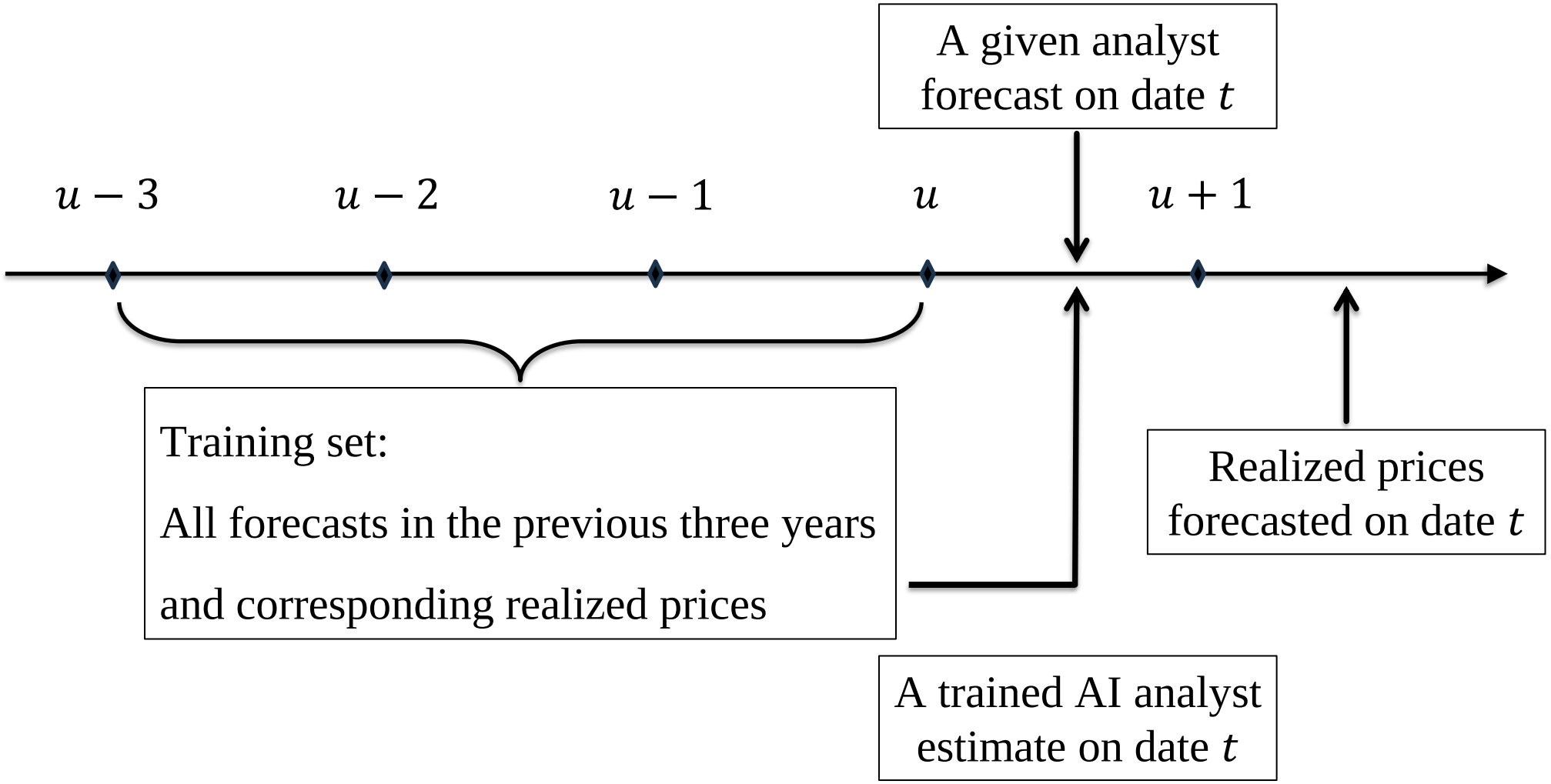
Data

- Analyst forecasts
  - Thomson Reuters I/B/E/S analyst database from 1996 to 2018
  - 12-month target price forecasts (99%)
- Information set fed into AI
  - Firm characteristics
  - Industry variables
  - Macro variables
  - Textual information: corporate disclosure, news, social media, patents

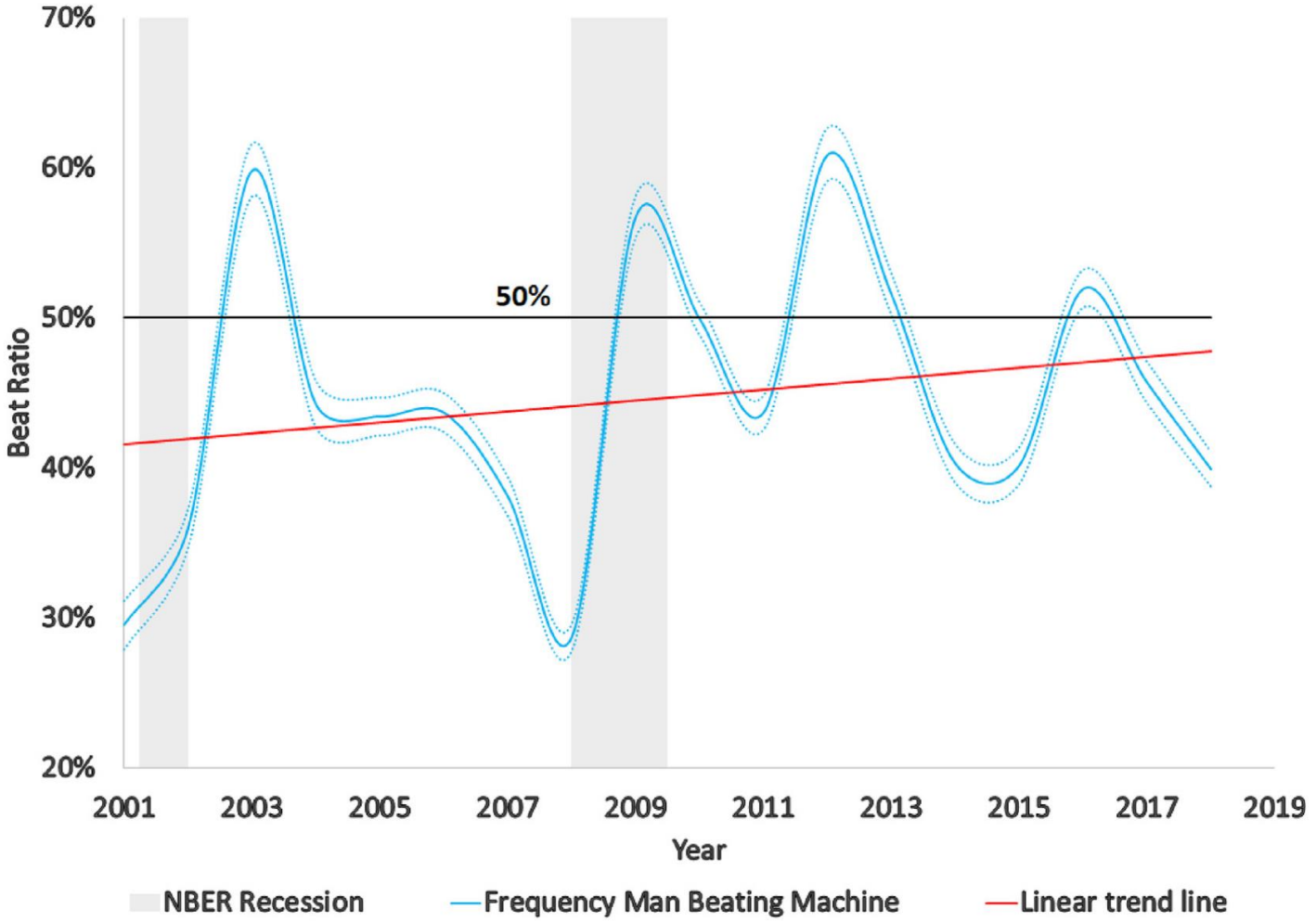
Construction of AI analyst

- ML algorithm
  - LSTM, RF, GB
  - Adopt **median** prediction of these three models
- Prediction model
  - $R_{i,t,T} = R_{i,t}^{AI} + \varepsilon_{i,t},\ R_{i,t}^{AI} = f_{t-}(X_{i,t-})$
  - Unified form for every stock at a given time
  - Allow the model to be time-varying
- Input
  - All publicly available information up to the date of forecasts
  - Three-year rolling window (Narasimhan et al., 2019; Elton et al., 1996)

Three-year rolling window

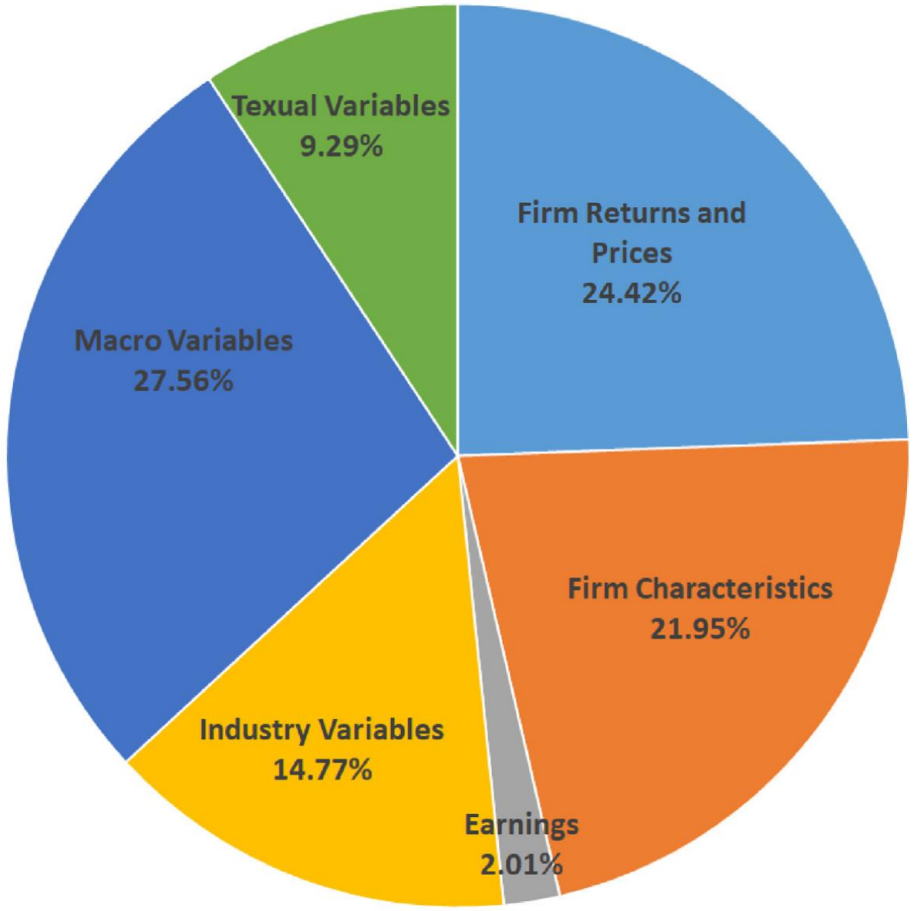


- The performance of analyst vs. AI
  - **Beat**: human analyst win against AI $\left(\left|R_{i,t}^{Man} - R_{i,t,T}\right| < \left|R_{i,j,t}^{AI} - R_{i,t,T}\right|\right)$

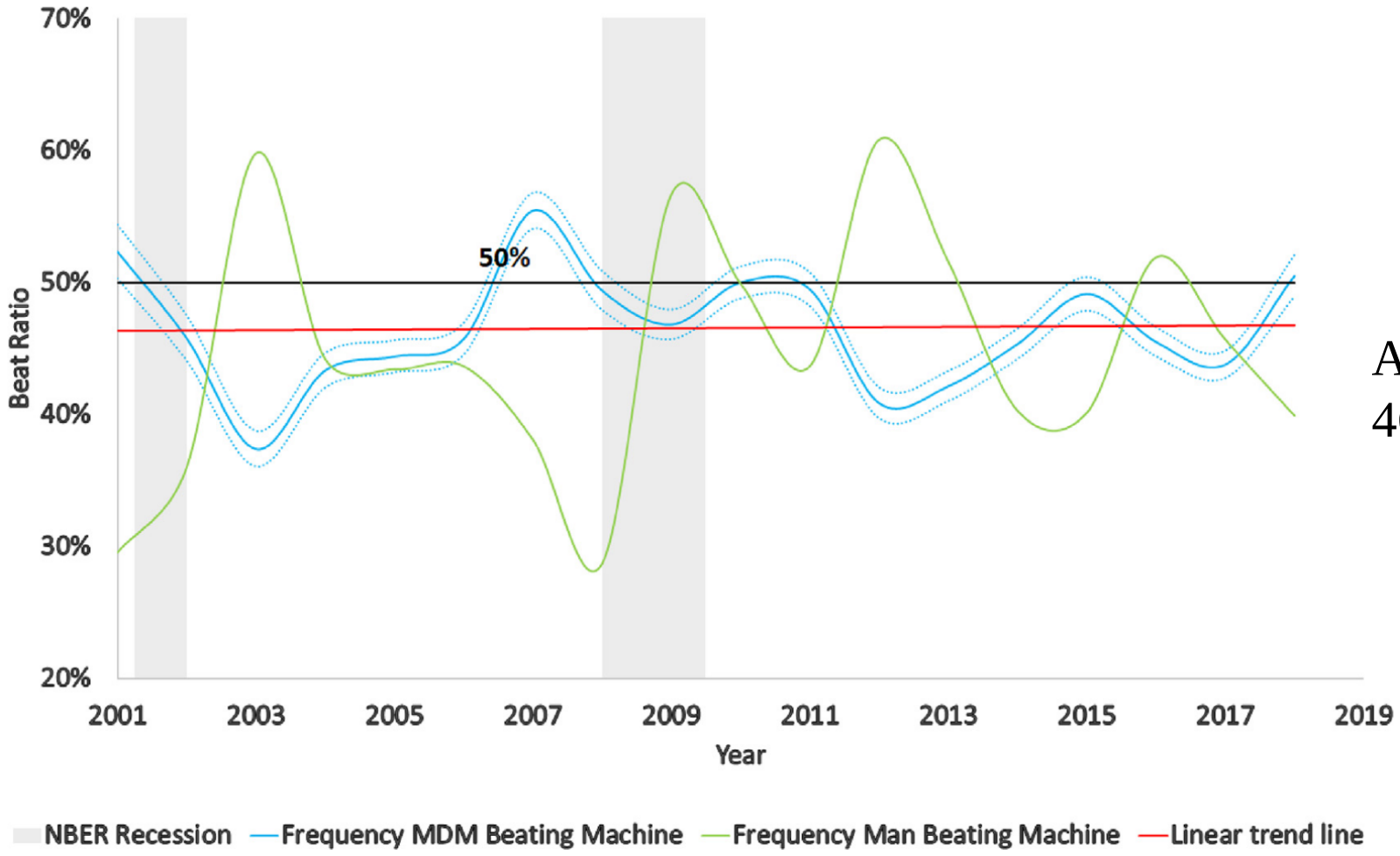


Average: 45.5%

- Contribution of variables to the AI prediction
  - Drop-one-set AI model: set a given group of variables to their **past average values**.
  - Difference between the **squared forecast error** of the full AI model and the drop-one-set AI model.



- The performance of debiased analyst vs. AI
  - **Debiased**: $\log\left(1+R_{i,j,t}^{Man}\right)-\log\left(1+R_{i,t,T(t)}\right)=g\left(X_{i,t-},Z_{i,j,t-}\right)+\varepsilon_{i,t}$



Average: 46.5%

- AI vs. Analysts with persistent performance
  - Sort analysts into the **top** and **bottom** halves based on their average prediction error.

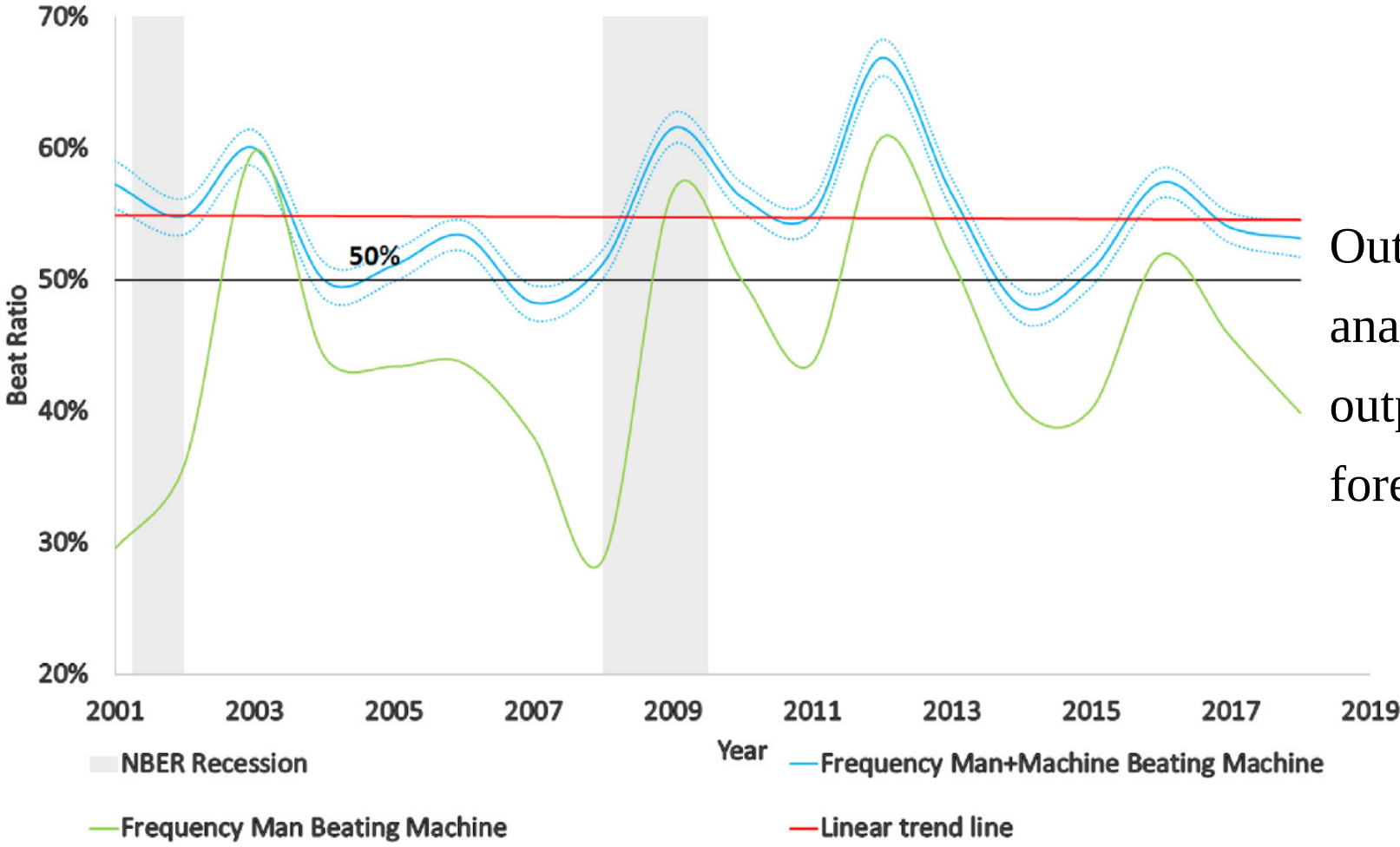
Panel A: Analyst beat ratio sorted by analysts who are above/below median					
	1 year	2 years	3 years	4 years	5 years
Analyst top	49.25%	49.26%	49.11%	49.10%	49.08%
Analyst bottom	43.01%	42.95%	43.04%	43.04%	43.05%

Panel B: Analyst beat ratio sorted by analysts who are above median each of the past years					
	1 years	2 years	3 years	4 years	5 years
Analyst Persistent top	49.25%	50.33%	49.87%	49.63%	49.40%
Analyst Persistent bottom	43.01%	42.34%	41.39%	40.95%	40.79%

- Performance of portfolio following AI recommendations
  - For each pair of predictions: past 30, 60, 90, 180, and 360 days
  - **Buy** signal: (1)Machine's prediction greater than the median in the prior month
    (2)Human's prediction less than the median in the prior month
  - **Sell** signal: both conditions are negated
  - Position: long the stock if more buy than sell signals and short the stock otherwise
  - Strategy: hold the position for at least six months or until the signals reverse
  - Value-weighted & semi-annually rebalanced

Long-Short		30 day inform	60 day inform	90 day inform	180 day inform	360 day inform
Monthly returns	Ret	0.64***	0.65***	0.58***	0.60***	0.53***
		(3.06)	(3.67)	(3.33)	(3.79)	(3.66)
	FF3	0.69***	0.72***	0.64***	0.65***	0.61***
		(3.40)	(4.19)	(3.80)	(4.24)	(4.45)
	FFC4	0.62***	0.65***	0.58***	0.58***	0.52***
		(3.16)	(3.97)	(3.57)	(4.03)	(4.21)
	FF5	0.51**	0.62***	0.55***	0.55***	0.51***
		(2.54)	(3.73)	(3.37)	(3.72)	(3.74)
	FF6	0.51***	0.63***	0.56***	0.56***	0.50***
		(2.62)	(3.92)	(3.54)	(4.02)	(4.09)
Long-Leg		30 day inform	60 day inform	90 day inform	180 day inform	360 day inform
Monthly returns	Ret	0.92***	0.97***	0.93***	0.97***	0.98***
		(2.69)	(2.96)	(2.83)	(3.07)	(3.32)
	FF3	0.42***	0.48***	0.44***	0.44***	0.42***
		(3.12)	(4.12)	(3.99)	(4.53)	(5.09)
	FFC4	0.39***	0.47***	0.42***	0.41***	0.38***
		(2.93)	(3.98)	(3.84)	(4.34)	(4.84)
	FF5	0.37***	0.46***	0.42***	0.40***	0.37***
		(2.76)	(3.90)	(3.91)	(4.28)	(4.43)
	FF6	0.37***	0.46***	0.42***	0.40***	0.36***
		(2.81)	(3.92)	(3.94)	(4.40)	(4.59)
Short-Leg		30 day inform	60 day inform	90 day inform	180 day inform	360 day inform
Monthly returns	Ret	−0.28	−0.32	−0.35	−0.37	−0.44
		(−0.78)	(−0.89)	(−0.99)	(−1.09)	(−1.33)
	FF3	0.27**	0.23***	0.20	0.21***	0.19***
		(2.49)	(2.82)	(2.44)	(2.83)	(2.63)
	FFC4	0.23**	0.18**	0.16**	0.17**	0.13**
		(2.22)	(2.51)	(2.10)	(2.52)	(2.18)
	FF5	0.14	0.16**	0.13	0.15**	0.14**
		(1.27)	(2.02)	(1.58)	(2.01)	(1.98)
	FF6	0.14	0.16**	0.13*	0.15**	0.14**
		(1.30)	(2.29)	(1.74)	(2.27)	(2.17)

- The performance of Man + Machine hybrid analyst vs. AI
  - Combine wisdom of man and machine: feed AI with the **analyst predicted values** in previous 90 days.



Outperform human analysts 57.8% and outperform AI-alone forecasts 54.8%

Comparative advantages of man vs. machine

- Heterogeneity
  - **Firm**-level: illiquidity, market cap, information availability, text complexity, intangible assets, default risk
  - **Analyst**-level: star analyst, brokerage power, institutional holdings
  - **Industry**-level: recession, competition
- Relative performance
  - **Analyst Beats AI** (absolute forecast error of analyst smaller than AI)
  - **Forecast Error Difference** (difference between absolute prediction error)
  - $Relative\ performance_{i,j,t} = H_{i,j,t}\beta + \alpha_i + \alpha_j + \alpha_{year} + \varepsilon_{i,j,t}$

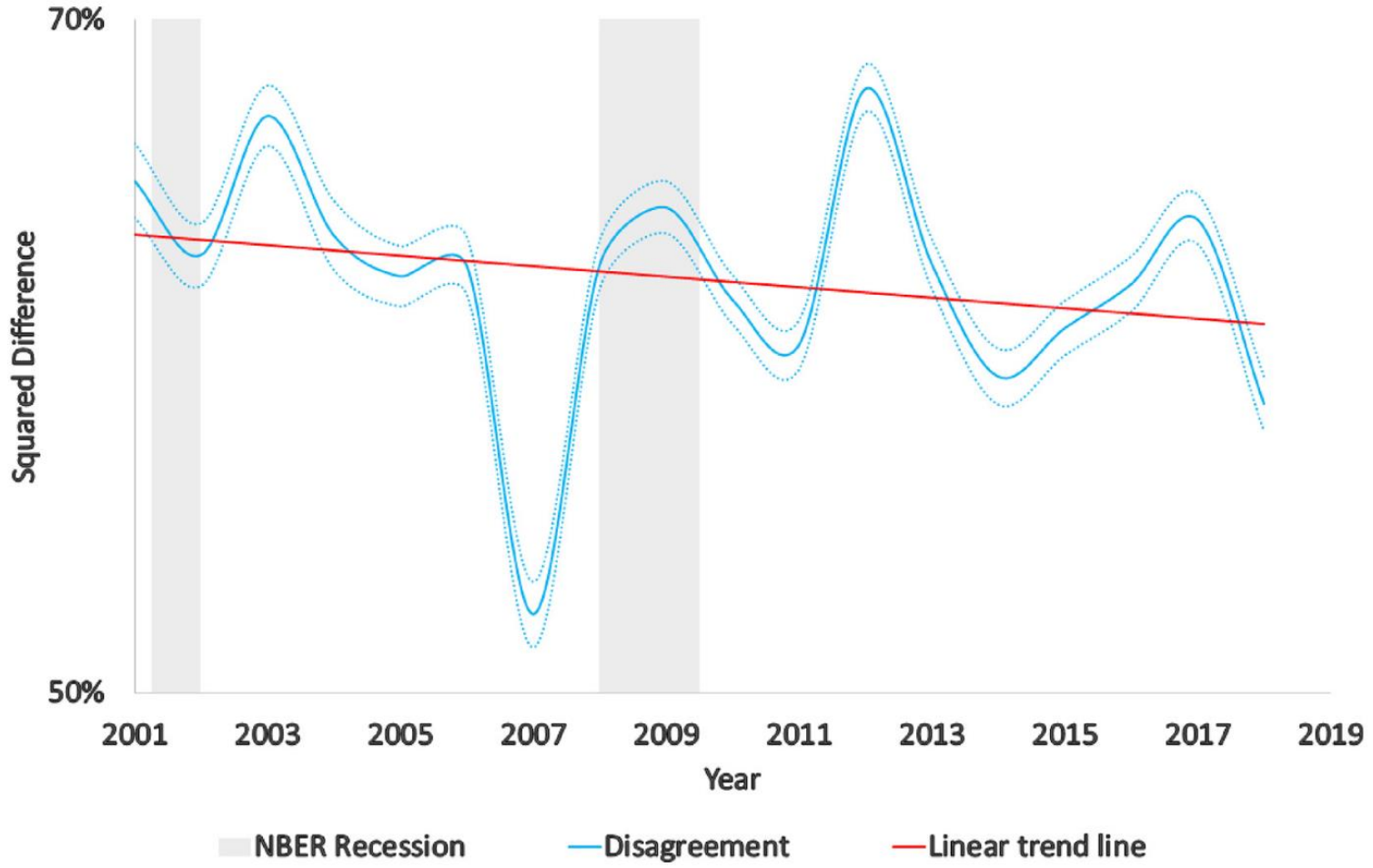
Panel A: Analyst Beats AI

Variables				
Amihud Illiquidity	0.252***	0.218***	0.200***	0.119**
	(11.51)	(6.06)	(6.39)	(2.24)
Intangible Assets	0.027***	0.026***	0.021**	0.023***
	(4.09)	(4.57)	(2.49)	(2.88)
# Analysts in Brokerage Firm	0.700***	0.931***	0.109	0.501
	(5.28)	(7.14)	(0.29)	(1.34)
Star Analyst	−0.106	−0.290	0.373	0.207
	(−0.17)	(−0.48)	(0.51)	(0.29)
# Information Events	−0.026***	−0.012***	−0.025***	−0.010**
	(−5.81)	(−2.68)	(−5.47)	(−2.16)
Distance to Default	−0.009***	−0.005***	−0.014***	−0.011***
	(−8.16)	(−3.75)	(−12.55)	(−8.41)
Market Cap	−0.071***	−0.049***	−0.085***	−0.055***
	(−15.18)	(−10.84)	(−16.79)	(−10.79)
% Institutional Holdings	−0.033**	−0.011	−0.012	−0.004
	(−1.99)	(−0.58)	(−0.70)	(−0.43)
Fluidity	0.243*	−0.273**	0.529***	0.032
	(1.89)	(−2.02)	(4.13)	(0.24)
Text Complexity	−0.001	0.001	−0.003	0.000
	(−0.67)	(0.65)	(−1.25)	(0.09)
Industry Recession	0.012**	0.030***	0.027***	0.044***
	(2.07)	(5.06)	(4.28)	(6.84)
Time Trend	0.010***		0.009***	
	(11.90)		(8.60)	
Year Fixed Effect	No	Yes	No	Yes
Firm Fixed Effect	Yes	Yes	Yes	Yes
Analyst Fixed Effect	No	No	Yes	Yes
Observations	352,358	352,358	352,358	352,358
Adjusted R-squared	0.07	0.09	0.13	0.15

Panel B: Forecast Error Difference: Analyst vs. AI

Variables				
Amihud Illiquidity	0.292***	0.263***	0.205***	0.129***
	(8.60)	(11.03)	(5.52)	(3.71)
Intangible Assets	0.027***	0.026***	0.024***	0.025***
	(3.92)	(4.04)	(3.03)	(3.31)
# Analysts in Brokerage Firm	0.762***	0.990***	0.435	0.787*
	(5.47)	(7.14)	(1.07)	(1.95)
Star Analyst	0.105	−0.082	0.436	0.262
	(0.16)	(−0.13)	(0.57)	(0.35)
# Information Events	−0.022***	−0.013**	−0.023***	−0.011**
	(−4.30)	(−2.35)	(−4.37)	(−2.04)
Distance to Default	−0.008***	−0.004***	−0.013***	−0.010***
	(−6.41)	(−2.82)	(−10.09)	(−6.91)
Market Cap	−0.068***	−0.047***	−0.077***	−0.049***
	(−13.76)	(−9.23)	(−14.62)	(−8.71)
% Institutional Holdings	0.031***	0.050*	0.056***	0.061***
	(2.77)	(1.83)	(5.71)	(3.81)
Fluidity	0.117	−0.383**	0.418***	−0.080
	(0.76)	(−2.32)	(2.81)	(−0.50)
Text Complexity	−0.000	0.002	−0.001	0.001
	(−0.16)	(0.67)	(−0.45)	(0.54)
Industry Recession	0.014**	0.030***	0.027***	0.042***
	(2.00)	(4.33)	(3.53)	(5.56)
Time Trend	0.009***		0.008***	
	(9.35)		(7.02)	
Year Fixed Effect	No	Yes	No	Yes
Firm Fixed Effect	Yes	Yes	Yes	Yes
Analyst Fixed Effect	No	No	Yes	Yes
Observations	352,358	352,358	352,358	352,358
Adjusted R-squared	0.10	0.12	0.16	0.17

- Disagreement between man and machine
  - **Disagreement**: average squared differences in prediction between analysts and AI.



Dependent variable	Full sample		Disagreement sample	
	Disagreement		*Human wins*	
	(1)	(2)	(3)	(4)
Amihud Illiquidity	0.034***	0.034***	0.445***	0.383***
	(2.78)	(2.74)	(12.08)	(8.02)
Intangible Assets	0.005***	0.005***	0.029**	0.028**
	(3.07)	(2.87)	(2.05)	(2.18)
# Analysts in Brokerage Firm	−0.605***	−0.626***	1.055***	1.209***
	(−9.15)	(−9.39)	(3.32)	(3.86)
Star Analyst	−0.332	−0.284	4.129	5.603*
	(−0.93)	(−0.79)	(1.36)	(1.87)
# Information Events	−0.007***	−0.003	−0.020**	−0.011
	(−3.94)	(−1.51)	(−2.07)	(−1.09)
Distance to Default	−0.005***	−0.004***	−0.002	−0.002
	(−12.96)	(−8.55)	(−0.94)	(−0.90)
Market Cap	−0.003**	−0.005***	−0.062***	−0.041***
	(−2.04)	(−3.74)	(−8.26)	(−5.16)
% Institutional Holdings	−0.083***	−0.080***	−0.618	2.335
	(−5.50)	(−5.50)	(−0.30)	(0.80)
Fluidity	0.138***	0.062	0.251	−0.217
	(3.56)	(1.59)	(1.10)	(−0.93)
Text Complexity	0.000	0.001	−0.003	−0.000
	(0.43)	(1.01)	(−0.56)	(−0.09)
Industry Recession	0.018***	0.018***	−0.006	0.014
	(7.03)	(6.75)	(−0.50)	(1.09)
Time Trend	−0.000		0.007***	
	(−0.18)		(5.34)	
Year Fixed Effect	No	Yes	No	Yes
Firm Fixed Effect	Yes	Yes	Yes	Yes
Observations	352,358	352,358	42,023	42,023
Adjusted R-squared	0.01	0.01	0.10	0.13

- Synergy between human and machine.
  - $Squared\ forecast\ error_{i,j,t}^{Man+Machine} = \alpha + \beta_1 Squared\ forecast\ error_{i,j,t}^{Man}$
    $+\beta_2 Squared\ forecast\ error_{i,j,t}^{Machine} + Residual_{i.j.t}$
  - **Synergy**: $Residual_{i,j,t} = H_{i,j,t}\beta + \alpha_i + \alpha_j + \alpha_{year} + \varepsilon_{i,j,t}$

	M+M squared error residual				M+M forecast error residual			
Amihud Illiquidity	0.375***	0.371***	0.398***	0.398***	0.218***	0.215***	0.248***	0.250***
	(5.11)	(5.22)	(3.96)	(4.24)	(3.34)	(3.70)	(2.80)	(3.29)
Intangible Assets	0.001*	0.001	0.000	−0.000	−0.000	−0.001	0.000	−0.000
	(1.71)	(0.96)	(0.02)	(−0.36)	(−0.16)	(−0.88)	(0.23)	(−0.23)
# Analysts in Brokerage Firm	−0.060***	−0.072***	0.011	−0.004	−0.061***	−0.074***	0.036	0.026
	(−3.69)	(−4.48)	(0.24)	(−0.08)	(−3.28)	(−4.08)	(0.74)	(0.57)
Star Analyst	−0.054	−0.048	0.005	0.009	−0.076	−0.071	−0.036	−0.034
	(−0.86)	(−0.78)	(0.07)	(0.12)	(−1.05)	(−1.00)	(−0.40)	(−0.39)
# Information Events	0.001**	0.001**	0.001**	0.001**	0.002***	0.002**	0.002***	0.002**
	(2.25)	(2.57)	(2.07)	(2.41)	(3.14)	(2.54)	(2.80)	(2.46)
Distance to Default	−0.001***	0.000	−0.001***	0.000	−0.001***	−0.000**	−0.001***	−0.000
	(−7.77)	(0.26)	(−5.90)	(1.42)	(−8.22)	(−2.01)	(−5.90)	(−0.21)
Market Cap	0.006***	0.004***	0.005***	0.004***	0.005***	0.003***	0.005***	0.003***
	(7.81)	(5.55)	(6.48)	(4.65)	(7.83)	(4.79)	(6.78)	(4.19)
% Institutional Holdings	−0.010***	−0.010**	−0.015***	−0.014***	−0.009**	−0.009*	−0.011***	−0.011***
	(−2.75)	(−2.16)	(−6.82)	(−4.77)	(−2.12)	(−1.67)	(−5.31)	(−3.30)
Fluidity	0.010	0.026	0.008	0.020	0.007	0.040**	−0.007	0.025
	(0.67)	(1.52)	(0.50)	(1.01)	(0.46)	(2.24)	(−0.38)	(1.20)
Text Complexity	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.03)	(0.37)	(0.06)	(0.44)	(0.53)	(0.90)	(0.84)	(1.12)
Industry Recession	0.004***	0.003***	0.004***	0.002***	0.004***	0.002***	0.003***	0.001
	(4.68)	(3.23)	(3.95)	(2.59)	(4.43)	(2.60)	(3.16)	(1.54)
Time Trend	−0.001***		−0.000***		−0.001***		−0.001***	
	(−6.32)		(−3.85)		(−6.23)		(−4.47)	
Year Fixed Effect	No	Yes	No	Yes	No	Yes	No	Yes
Firm Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Analyst Fixed Effect	No	No	Yes	Yes	No	No	Yes	Yes
Observations	346,301	346,301	346,301	346,301	346,301	346,301	346,301	346,301
Adjusted R-squared	0.13	0.14	0.23	0.24	0.08	0.09	0.15	0.16

- Man + Machine can avoid extreme error.
  - **Extreme error**: the forecast error of each man or machine forecast larger than **90th** percentile of squared errors from all analysts on the same firm in the same year.
  - Four outcomes: (1) both analyst and AI; (2) analyst; (3) AI; (4) neither

	Both	Analyst	AI	Neither
Uncond. Prob.	3.46%	9.34%	7.84%	79.36%
	M+M Avoids Both	M+M Avoids Analyst	M+M Avoids AI	M+M Creates EE
Uncond. Prob.	0.16%	8.47%	3.41%	0.11%
	M+M Avoids Both/ Both EE	M+M Avoids Analyst/ Analyst EE	M+M Avoids AI/ AI Only	M+M Creates EE/ Neither EE
Conditional Prob.	4.57%	90.72%	43.56%	0.13%

- Impact of man + machine: An event study
  - **Alternative data** have to be processed by ML.
  - Analysts cover firms served by the alternative data are potentially in Man + Machine.
  - **AI Hiring**: AI resources that analysts have access to.

Variables	Analyst Beats AI		
Treat × AI Hiring	0.533**	0.503**	0.627***
	(2.16)	(2.04)	(2.71)
Treat: Alt Data Cover × Post	0.002	0.028	0.029
	(0.05)	(0.61)	(0.64)
AI Hiring	0.032	0.069	0.018
	(0.90)	(1.52)	(0.52)
Alt Data Cover	0.029	−0.007	
	(0.69)	(−0.17)	
Year Fixed Effect	Yes	Yes	Yes
Firm Fixed Effect	No	No	Yes
Analyst Fixed Effect	No	Yes	No
Observations	56,697	56,697	56,697
Adjusted R-squared	0.03	0.07	0.14

Conclusion

- AI analyst we built can beat the majority of human analysts.
  - Even with superior excellent human analysts.
- Human and machine have their own comparative advantages.
  - AI win when information is more transparent but voluminous.
  - Human win when critical information requires institutional knowledge.
- Combining wisdom of man and machine can play a synergistic role.
  - Man + Machine produce highest potential in generating accurate forecasts.
  - Human provide significant incremental value in Man + Machine.

New ideas

- In this paper, machine just learn from human analysts.
  - Can we consider a process of mutual learning and continuous improvement?
  - (1) Input analyst forecasts to AI model.
  - (2) Generate AI forecasts including human wisdom.
  - (3) Human analysts modify their forecasts based on AI results.
  - (4) Modified forecasts are then again fed into AI model.
- Other predictive object
  - Interest rate, Exchange rate, GDP growth