The Coherence Side of Rationality

Rules of Thumb, Narrow Bracketing, and Managerial Incoherence in Corporate Forecasts

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[**Coherence**:] "consistency of the elements of the person's judgment"
Hammond (2007), p. xvi

- A **pillar of rationality** of judgement and decision (e.g., Tversky and Kahneman (1974, 1981), Sen (1993), Becker (1996), Posner (2014)).
- Together with accuracy, one of the **two standards of rationality** of judgment – expectations, forecasts (e.g., Hammond (1990, 1996), Gigerenzer et al. (1999), Arkes et al. (2016)).
- **Large literature on forecast accuracy**, centering on predictability of forecast errors given info at time of forecast (e.g., Tversky and Kahneman (1974) and Benjamin (2019)'s review). **Forecast coherence has received less attention**.

Forecast Coherence in Production: Essential Background

- Top financial executives (CFOs) regularly make **internal forecasts of multiple firm variables** (balance-sheet items) at the same time, aka **'firm plans'**.
- They **start** from Y by making a **sales revenue forecast** ('top line forecast'), and **then proceed to** forecast **other items** such as K and L expenditures.
- This is a challenging **multidimensional forecasting problem**, requiring CFOs to draw on their knowledge of the **firm's prod possibility and budget constraint**.
  - This paper's 'coherence benchmark'.
  - Ignoring technology and/or budget relationships may imply use of a suboptimal mix of K and L, and may be costly to the firm.
- MBA textbooks/case studies provide **rules of thumb (RoT)** to help CFOs make such forecasts (e.g., Ruback (2004), Welch (2017), Koller et al. (2020)).
  - These rules differ in their concern for coherence across forecasts of related vars, ranging from forecasting each variable independently (**'narrow bracketing'**), to anchoring individual items' forecasts to the sales forecast (**'sales anchoring'**), to more sophisticated multivariate rules.
  - These RoT have *not* been assessed theoretically or empirically so far.

The Paper Provides:

- Theory and evidence...
  - On the prevalence with and extent to which CFOs of mid and large US corporations make (in)coherent forecasts of own firm's output and inputs growth.
  - On a specific mechanism by which incoherent forecasts are made, that is, the use of suboptimal rules of thumb (RoT).
  - On the relationship between forecast incoherence, RoT use, and firm performance (and policies).
- An evaluation of the managerial RoT taught by MBA textbooks/case studies.
- A series of restrictions and of formal statistical tests (regression-based and individual-level) of coherence, some of which also enable us to disentangle forecast (in)coherence and (in)accuracy.

We Build On and Contribute to Multiple Strands of Lit

1. Coherence and Accuracy Sides of Rationality
   * Tversky and Kahneman (multi), Hammond (multi), Osherson, Shafir, & Smith (94), Wrightetal (94), Gigerenzer et al. (99), Rabin (02), Mandel (05), Newell (05), Reyna & Lloyd (06), Gigerenzer & Gaissmaier (11), Baron (12), Lee & Zhang (12), Wallin (13), Arkes et al. (16), Benjamin, Rabin, & Raymond (16), Zhuetal (20, 22), Bergetal (22).
   - **By disentangling coherence and accuracy theoretically and empirically**.

2. Bracketing
   * *Applied Theory*: Barberis et al. (06) (stock market participation), Rabin & Weizsacker (09) (gambling), **Lian (21) (consumption)**.
   * *Mental Accounting*: Thaler (85), Kahneman & Lovallo (93), Read et al. (99), Rabin & Weizsacker (09), Hastings & Shapiro (13, 18), Farhi & Gabaix (20), Ellis and Freeman (20).
   * *Inattention and Sparsity*: Sims (03), Mackowiak & Wiederholt (09), Matejka & McKay (15), Mackowiak et al. (18), Koszegi & Matejka (20), Gabaix (14, 19).
   - **By providing first theory and evidence of (narrow) bracketing in production**.

3. Survey Expectations of Firms
   * **Top executives: Ben-David et al. (13), Boutros et al. (20), Campello et al. (10), Campello et al. (11, 12), Gennaioli et al. (16), Graham (22)**.
   * *Firm expectations*: Bachmann & Bayer (13, 14), Bachmann et al. (20), Bloom et al. (21), Altig et al. (22), Barrero (22), Born et al. (23), D'Acunto et al. (23), Candia et al. (23).
   - **By studying forecast heterogeneity, coherence, accuracy for multiple balance-sheet vars**.

4. Behavioral Firms * DellaVigna (18), DellaVigna & Gentzkow (19), Strulov-Shlain (22).
   - **By studying relationship of incoherence / RoT use and firm performance and policies**.

Outline

1. Theory
   - Normative benchmark of *ex ante* optimal coherent forecast (full info)
   - Positive model of narrow thinking in corporate forecast (imperfect info)

2. Data
   - Expectations from Duke Survey of mid and large US corporations
   - Realizations from Compustat

3. Evidence
   - RoT indicators and theory-based measure of *ex ante* incoherence
   - *Ex ante* incoherence, RoT use, and corporate performance (and policies)

4. More Theory + Evidence on *ex post* Coherence Conditions and Tests Based on Forecast Errors (FEs)
   - Intuitive restrictions
   - Regression tests
   - Individual-level tests

RoT Taxonomy by Welch (2017)

(R1) A **plain growth** forecast: each item (say, CapEx) forecasted individually by projecting into the future the item's past growth rates $\Longrightarrow$ 'narrow bracketing'.

- Welch (2017) takes average of two most recent annual growth rates.

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(R3) An **economies-of-scale** forecast: each item's forecast has a fixed component and a variable component, the latter a proportion of the sales forecast.

- Welch (2017) estimates BLPs under square loss of each balance-sheet item's growth on contemporaneous sales' growth using Compustat data to obtain:
  - fixed component = intercept estimate;
  - variable component = slope estimate $\times$ sales forecast.

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(R4) An **industry-based** forecast: an industry-specific economies-of-scale forecast.

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(R5) A **disaggregated** forecast: accounting for the fact that an item may comove with other items (beyond sales) $\Longrightarrow$ 'sophisticated'.

- Welch (2017) conditions on additional contemporaneous items (relative to (R3)-(R4)).

Setup: Environment and Some Assumptions

- Consider a profit-max firm, with CES prod fn and budget constraint:

$$y = f(x_1, x_2) = \left(\frac{a}{a+b} x_1^{\xi} + \frac{b}{a+b} x_2^{\xi} \right)^{\frac{a+b}{\xi}}$$
$$p_1 x_1 + p_2 x_2 = Z,$$

where:

- y is output, x_1, x_2 input quantities (say, K, L), and p_1, p_2 their prices;
- denote $\log p_i = \pi_i$, with $i = 1, 2$;
- Z is a real-valued budget constraint;
- returns to scale are constant for $a + b = 1$, decreasing for $a + b < 1$;
- elasticity of substitution between x_1 and x_2 is $\chi = \frac{1}{1-\xi}$;
- factor-augmenting productivities constant and normalized to 1.

(A1) Technology stable over time and no aggregate shocks.

(A2) Prices i.i.d., $\{\pi_{i,t}\}_{t \geq 1} \sim \mathcal{N}(0, \sigma_i^2)$, with $corr(\pi_1, \pi_2) = \rho_{1,2}$.

Setup: Forecast Problem

- Forecaster issues $\mathbf{F}_t$ of $\mathbf{x}_{t+1} = (y_{t+1}, x_{1,t+1}, x_{2,t+1})$ by minimizing an expected square loss (*inaccuracy*),

$$\min_{\mathbf{F}_t} \mathbb{E}\left[(\mathbf{x}_{t+1} - \mathbf{F}_t)^2 \,|\Omega_t\right],$$

  where the info set at t, Ω_t, embeds the firm's production technology and budget constraint (*coherence constraint*).

  - At solution, $\mathbf{F}_t^* = \mathbb{E}\left[\mathbf{x}_{t+1}|\Omega_t\right] \equiv \mathbb{E}_t\left[\mathbf{x}_{t+1}\right]$.
  - Square loss enables us to nest the RoT, (R1)-(R5), as forecasts under those rules are (conditional) means.

Normative Theory I: Main Results

Proposition 1 (Inequality). *When $\xi \leq 1$ and $a + b \leq 1$, the CES function is concave; then forecast coherence requires that $\mathbb{E}_t [y_{t+1}]$, $\mathbb{E}_t [x_{1,t+1}]$, and $\mathbb{E}_t [x_{2,t+1}]$, satisfy*

$$\mathbb{E}_t [y_{t+1}] \leq \left(\frac{a}{a+b} \mathbb{E}_t [x_{1,t+1}]^{\xi} + \frac{b}{a+b} \mathbb{E}_t [x_{2,t+1}]^{\xi} \right)^{\frac{a+b}{\xi}}.$$

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- Prop 1 gives a first condition coherent forecasts should satisfy.
  - The inequality can be implemented empirically. (We do so in the paper.)
  - The CES is not linear, whereas the RoT are (think of as 1st-order linear approx). To see if we can rationalize (some of) them, we consider the Cobb-Douglas case.

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Corollary 1 (Cobb-Douglas). *In the limit for $\xi \to 0$,*

$$\mathbb{E}_t \log [y_{t+1}] = a \cdot \mathbb{E}_t \log [x_{1,t+1}] + b \cdot \mathbb{E}_t \log [x_{2,t+1}].$$

Similarly,

$$\mathbb{E}_t \log \left[\frac{y_{t+1}}{y_t} \right] = a \cdot \mathbb{E}_t \log \left[\frac{x_{1,t+1}}{x_{1,t}} \right] + b \cdot \mathbb{E}_t \log \left[\frac{x_{2,t+1}}{x_{2,t}} \right].$$

- Cobb-Douglas is linear in log, so Prop 1 holds with equality both for forecasts in levels and growth rates.

Normative Theory II: Additional Results

- Prop 1 does not consider uncertainty.
  - Later, we derive additional conditions (statistical tests) of coherence under an AR(1) process for log-prices.
- We also provide corollaries for the case in which technology parameters, a and b, are unknown to the forecaster and s/he estimates them via linear projections.
  - A **multivariate rule** akin to (R5) is rationalized as **1st-best optimal**.
  - The **univariate rules** ((R3) and its special case (R2)) – **and the narrow bracketing rule** (R1) – are **generally suboptimal** and can be rationalized only in very special cases.

Positive Theory I: Narrow Thinking in Firm Forecasts

- In reality, CFO may be better informed about K than L, or vice versa; about physical than intangible assets, or vice versa; etc.
  - Forecasts maybe in between broad bracketing and narrow bracketing.
  - Narrow bracketing could be 2nd-best optimal under imperfect info.

- To capture these possibilities, we introduce noisy signals following Lian (2021), and recast the forecasting problem as multiple selves playing an incomplete info, common interest game.
  - "CFO K-self" forecasts K growth by observing imprecise signals on Y and L growth.
  - "CFO L-self" forecasts L growth by observing imprecise signals on Y and K growth.

- In equilibrium, each self's forecast is made with imperfect knowledge of other selves' forecasts (signals, states of mind).
  - **Narrow thinking in forecasting of multiple related variables as intra-personal frictions in coordinating multiple forecasts**.

Positive Theory II: Noisy Signals and Optimal Forecast

- Consider a CFO forecasting input 1 ($i = 1$), $\log x_1$, by $\min_{F \log x_1} \mathbb{E} (\log x_1 - F \log x_1)^2$,

  where t dropped (by stationarity), $y = x_1^a x_2^b$, and $p_1 x_1 + p_2 x_2 = Z$.

- Assume the CFO observes noisy signals for y and x_2 (i.e., $\neg i = 2$), $\eta_y = \log y + \epsilon_y$ and $\eta_2 = \log x_2 + \epsilon_2$, where $\epsilon_y \sim \mathcal{N}(\mu_y, s_y^2)$ and $\epsilon_2 \sim \mathcal{N}(\mu_2, s_2^2)$.

Proposition 3. *The optimal forecast of* $\log x_1$ *given* η_y *and* η_2 *is*

$$\mathbb{E}[\log x_1 | \eta_y, \eta_2] = \mu_1 + \beta_y (\eta_y - \mu_y) + \beta_2 (\eta_2 - \mu_2),$$

where

$$\beta_y = \frac{a\sigma_1^2}{a^2\sigma_1^2 + b^2\sigma_2^2 + s_y^2 - \frac{b^2\sigma_2^4}{\sigma_2^2 + s_2^2}}; \beta_2 = \frac{ab\sigma_1^2\sigma_2^2}{b^2\sigma_2^4 - (\sigma_2^2 + s_2^2)(a^2\sigma_1^2 + b^2\sigma_2^2 + s_y^2)}.$$

- Optimal forecast for "x_1" is a linear projection of (deviations of signals from prior means of) "y" and "x_2", where intercept is prior mean for "x_1" and slopes are fns of fundamental uncertainty and precision of signals $\Longrightarrow$ rationalizes (R5).

Positive Theory III: Rationalizing (R1) and (R3)-(R4)

Corollary 6 (Narrow Bracketing). *When* $s_y^2, s_2^2 \to +\infty$, *the optimal forecast is*

$$\mathbb{E}\left[\log x_1 | \eta_y, \eta_2\right] = \mu_1.$$

$\Longrightarrow$ (R1) 2nd-best optimal when both signals are infinitely noisy.

Corollary 7 (Univariate Projections). *When* $s_2^2 \to +\infty$ *and* $0 < s_y^2 < +\infty$, *the optimal forecast is*

$$\mathbb{E}\left[\log x_1 | \eta_y, \eta_2\right] = \mu_1 + \beta_y \left(\eta_y - \mu_y\right),$$

where

$$\beta_y = \frac{a\sigma_1^2}{a^2\sigma_1^2 + b^2\sigma_2^2 + s_y^2}.$$

$\Longrightarrow$ (R3)-(R4) 2nd-best optimal when other input's signal is infinitely noisy and output's signal is noisy but informative.

Taking Stock of Theory

- RoT Ranking: Model yields a partial ranking of RoT,

$$\text{(R5)} \succeq \text{(R4)-(R3)} \succeq \text{(R2)-(R1)},$$

where:

(R5) is the ex ante optimal multivariate rule;

(R1) is the narrow bracketing rule, most distant from (R5);

(R2) is the sales anchoring rule, using info on output but suboptimally;

(R3) and (R4) are the univariate rules, lying between (R1) and (R5).

- (R3) *VS* (R4):
  - Parameters may be industry-specific $(a_j, b_j) \Longrightarrow$ (R4).
  - Using industry-specific subsamples may reduce precision $\Longrightarrow$ (R3).

- Prediction: If incoherence implies a suboptimal mix of inputs in production, firm's profits will decrease with extent of deviation from optimal forecast.

- Mechanism: Narrow thinking may generate incoherence via use of suboptimal rules of thumb.

CFO Expectations Come from Duke Survey

- **Duke Survey** was co-launched by Michael Bradley and Campbell Harvey in 1996 and is currently run by John Graham and Campbell Harvey at Duke University.
  - Surveys 2-3K CFOs/quarter, asking their views about the US economy and corporate policies, and expectations of future firm performance and operational plans.
  - Usual response rate/quarter is 5-8% within a couple of days.
  - Since late 1990s, has been asking Rs' expectations of future 12-month growth rates of key corporate variables, including sale revenues (Y), capital expenditures (K), and wages (L).

- **Our data** comprises CFOs' point forecasts of multiple firm's variables for the period 2001q1-2018q4, elicited as follows:

4. Relative to the previous 12 months, what will be your company's PERCENTAGE CHANGE during the next 12 months? (e.g., +3%, -2%, etc.) [Leave blank if not applicable]

% Prices of your products	% Technology spending
% Overtime	% Earnings
% Advertising/Marketing spending	% Revenues
% Number of employees	% Inventory
% Productivity (output per hour worked)	% M&A activity
% Wages/Salaries	% Capital spending
% Health care costs	% Dividends

Firm Realizations Come from Compustat

- **Compustat** extracts the data from the Security and Exchange Commission (SEC)-required public filing of financial statements.
  - It covers all publicly traded firms across all sectors of the US economy since 1955.

- **Compustat VS Duke** – Relative to Compustat firms, Duke Study firms are on average:
  - larger in sales and assets, more profitable, and hoarding more cash;
  - similar in market-to-book ratio (avg. Tobin's q), investment (capital expenditures), and leverage (LT debt/assets)

  (e.g., Ben-David et al. (2013)).

- **Duke-Compustat Matching** – Subject to various sources of attrition, including:
  - Compustat's poor coverage of wages (about 90% missing) $\Longrightarrow$ $\sim$**no realizations and, hence, forecast errors for labor input**;
  - matches concentrated in early period (until 2011q4) $\Longrightarrow$ **focus on pre-financial crisis period**, consistent with stability assumption of model.

▸ Details

We Use Compustat to Implement (R1)-(R5) As in Welch

- We focus on forecasts of Y (Sale Revs) and K input (CapEx), as they have a clear mapping with theory and high coverage in Compustat.

(R1) **Plain growth**: Avg. of two most recent annual growth rates of *CapEx Growth*.

(R2) **Proportion of sales**: BLP under square loss of *CapEx Growth* given *Sales Growth*, with zero const and unit slope.

(R3) **Economies-of-scale**: BLP under square loss of *CapEx Growth* given *Sales Growth*, estimated with all Compustat firms.

(R4) **Industry-based**: Like (R3), but by industry. We do it for 10 sectors, based on SIC 1-digit codes.

(R5) **Disaggregated**: Would like BLP under square loss of *CapEx Growth* given *Sales Growth* & *Labor Cost Growth*. In practice:

- Main version: *CapEx Growth* on *Sales Growth* & *Earnings Growth*.
- Appendix version: *CapEx Growth* on *Sales Growth* & *Advertising Expend Growth*.

Min Dist of CFO Forecasts from RoT $\Rightarrow$ CFO 'Type'

- For each CFO, we determine a 'type' in two steps:
  1. Compute orthogonal dist between CFO's actual forecast and that implied by each RoT.
  2. Compute *min* dist among the 5 $\Longrightarrow$ CFO's 'type' is RoT to which CFO's forecast is closest.

	All	R1	R2	R3	R4	R5
Mean	0.033	0.058	0.030	0.019	0.031	0.043
Std Dev	0.059	0.100	0.064	0.017	0.035	0.069
Frac Zeros	0.106	0.000	**0.268**	0.000	0.000	0.000
P10	0.000	0.008	0.000	0.005	0.002	0.003
P25	0.007	0.015	0.000	0.006	0.007	0.008
P50	0.019	0.028	0.014	0.010	0.023	0.023
P75	0.036	0.064	0.035	0.028	0.048	0.043
P90	0.071	0.114	0.071	0.048	0.072	0.089
P95	0.106	0.143	0.106	0.048	0.100	0.140
N Obs	396	30	157	43	107	59
Fraction	1.000	**0.076**	**0.396**	**0.109**	**0.270**	**0.149**

$\Longrightarrow$ $\sim$**40%** of CFOs give a forecast closest to that implied by (R2) – **'sales anchorers'**

$\Longrightarrow$ $\sim$27% of whom ($\sim$10% in tot) do **exactly** (R2) Why Bad

$\Longrightarrow$ $\sim$**8%** of CFOs give a forecast closest to that implied by (R1) – **'narrow bracketers'** Bad

$\Longrightarrow$ $\sim$15% of CFOs give a forecast closest to that implied by (R5) – 'sophisticated'

Ex Ante Incoherence

- Ex Ante Incoherence: Orthogonal distance between actual forecast and that implied by (R5),

$$\text{Incoherence}_{i,t} = \frac{\left| F_{i,t}\left[y_{i,t+1}\right] - \widehat{\beta}_1 F_{i,t}\left[x_{1i,t+1}\right] - \widehat{\beta}_2 F_{i,t}\left[x_{2i,t+1}\right] - \widehat{\alpha} \right|}{\sqrt{1^2 + \widehat{\beta}_1^{\,2} + \widehat{\beta}_2^{\,2}}},$$

where $\widehat{\alpha}$, $\widehat{\beta}_1$, $\widehat{\beta}_2$ are the estimated coefficients of (R5), using Compustat data and alternative measures for $x_{2i,t}$:

  - Earnings Growth (here);
  - Advertisement Growth (appendix);
  - Wages Growth (too few obs).

- Note: This incoherence measure is predetermined relative to firm outcomes and can be used to assess the model's predictions.

RoT Indicators and Ex Ante Incoherence – Main

▸ Robust , ▸ Heterog

- The model predicts (R5) $\succeq$ (R3)-(R4) $\succeq$ (R1)-(R2).
- We regress *ex ante incoherence* on *RoT dummies*, where (R5) is used as a reference group.

	(1)	(2)	(3)	(4)	(5)
Rule 1	0.081				0.104
	(0.014)				(0.016)
Rule 2		0.039			0.053
		(0.008)			(0.011)
Rule 3			-0.055		-0.020
			(0.012)		(0.014)
Rule 4				-0.027	0.010
				(0.009)	(0.012)
Const	0.066	0.057	0.079	0.080	0.043
	(0.004)	(0.005)	(0.004)	(0.005)	(0.009)
N Obs	396	396	396	396	396

$\Longrightarrow$ (R1) & (R2) CFOs have on avg. **largest incoherence** relative to (R5) CFOs.

CFO Incoherence – or RoT – and Firm Outcomes

- We investigate relationship between firm's outcomes and CFO's incoherence by:

$$\text{Outcome}_{ijt} = \alpha + \lambda_j + \delta_t + \beta \cdot \text{Incoherence}_{ijt} \left[\text{or RoT}_{ijt}\right] + \theta \cdot X_{ijt} + \varepsilon_{ijt},$$

  where i is CFO-firm pair, j is industry, and t is time.

- Outcome_{ijt} is alternatively:
  i. **ROA = percent return on firm's assets**.
     - If incoherence implies suboptimal inputs mix, expect $\beta < 0$ for incoherence, and also for types (R1), (R2), (R3) relative to (R5).
  ii. I/A = capital expenditures divided by assets.
     - If incoherent CFOs invest less than required to achieve planned output growth, expect $\beta < 0$ for incoherence / suboptimal RoT.
  iii. D/A = LT book debt divided by assets.

- X_{ijt} includes:
  - CFO-level variables: Short-term and long-term miscalibration and optimism from Ben-David et al. (2013).
  - Firm-level variables: Firm size, market-to-book, dividends.

Ex Ante Incoherence and Firm Performance (ROA)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Incoherence	-0.377	-0.378	-0.360	-0.396	-0.399	-0.386	-0.317	-0.307
	(0.157)	(0.179)	(0.162)	(0.162)	(0.186)	(0.169)	(0.192)	(0.181)
Misc ST		0.003			0.001		-0.001	
		(0.005)			(0.005)		(0.004)	
Optm ST		0.000			0.000		0.001	
		(0.006)			(0.006)		(0.005)	
Misc LT			0.004			0.002		0.001
			(0.005)			(0.005)		(0.005)
Optm LT			0.008			0.007		0.009
			(0.006)			(0.006)		(0.006)
Firm size							0.009	0.009
							(0.003)	(0.003)
Mkt-to-Book							0.028	0.027
							(0.014)	(0.015)
Dividends							0.022	0.023
							(0.012)	(0.013)
Const	0.069	0.069	0.068	0.054	0.056	0.057	-0.131	-0.123
	(0.011)	(0.011)	(0.011)	(0.014)	(0.020)	(0.019)	(0.047)	(0.0471)
Industry FE	N	N	N	Y	Y	Y	Y	Y
Survey FE	N	N	N	Y	Y	Y	Y	Y
N Obs	468	423	428	468	423	428	396	401

RoT Indicators and Firm Performance (ROA)

Pols

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rule 1	-0.057	-0.061	-0.059	-0.051	-0.059	-0.055	-0.053	-0.051
	(0.022)	(0.025)	(0.024)	(0.023)	(0.025)	(0.025)	(0.026)	(0.025)
Rule 2	-0.026	-0.027	-0.023	-0.023	-0.028	-0.024	-0.034	-0.031
	(0.014)	(0.015)	(0.015)	(0.015)	(0.017)	(0.016)	(0.021)	(0.019)
Rule 3	-0.031	-0.036	-0.034	-0.027	-0.037	-0.034	-0.047	-0.045
	(0.017)	(0.019)	(0.019)	(0.019)	(0.020)	(0.021)	(0.023)	(0.022)
Rule 4	-0.012	-0.010	-0.010	-0.008	-0.008	-0.007	-0.012	-0.011
	(0.012)	(0.014)	(0.014)	(0.013)	(0.014)	(0.015)	(0.015)	(0.015)
Misc ST		0.001			-0.001		-0.002	
		(0.005)			(0.005)		(0.004)	
Optm ST		0.001			0.000		0.001	
		(0.006)			(0.005)		(0.005)	
Misc LT			0.003			0.002		0.001
			(0.006)			(0.005)		(0.004)
Optm LT			0.007			0.006		0.008
			(0.006)			(0.006)		(0.005)
Const	0.065	0.066	0.064	0.040	0.045	0.046	-0.147	-0.137
	(0.011)	(0.012)	(0.013)	(0.015)	(0.019)	(0.028)	(0.046)	(0.050)
Firm characts	N	N	N	N	N	N	Y	Y
Industry FE	N	N	N	Y	Y	Y	Y	Y
Survey FE	N	N	N	Y	Y	Y	Y	Y
N Obs	468	423	428	468	423	428	396	401

- Robustness: Similar results with (R1)-(R6). (R6) has -0.04 lower ROA than (R5).

Next: Tests of Forecast Coherence – And Disentangling Forecast (In)Coherence and (In)Accuracy

- So Far
  - ∼50% of CFOs seem to be using incoherent RoT, (R1) and (R2).
  - *Ex ante* incoherence is negatively associated with firm performance.
  - Same for use of incoherent RoT with firm performance (and investment).
    - Intuition: (R1) and (R2) imply associations between forecasts of CapEx growth and of Sales growth that are much lower than in realizations, resulting in systematic underprediction of CapEx growth given a targeted Sales growth. R2 Detail, R1 Detail
    - Note: These empirical results do not depend on the theoretical assumptions underlying the optimality conditions for the RoT.
- Next
  - We combine forecasts and realizations, and show how to disentangle (in)coherence and (in)accuracy using forecast errors (FEs).
    - We derive a number of conditions and statistical tests based on FEs.
    - For the latter, we introduce more structure and assumptions.

Why Forecast Errors?

- Consider a general empirical formulation of a production function,

$$y_{t+1}^f = \alpha + \alpha^f + \sum_{i=1}^{n} \beta_i^f x_{i,t+1}^f + \sum_{i=1}^{n} \sum_{s=0}^{t} \delta_{i,t-s}^f x_{i,t-s}^f + \sum_{j=1}^{m} \sum_{s=0}^{t} \gamma_{j,t-s}^f z_{j,t-s}^f + \varepsilon_{t+1}^f,$$

where f is firm, i input, and z any relevant state (e.g., inventory, cash, etc.). Inputs and state vars can affect output with lags, and vars could be in levels, growth rates, or logs.

- Coherent forecasts should be cross-sectionally linked in a similar way:

$$\mathbb{E}_t\left[y_{t+1}^f\right] = \alpha + \alpha^f + \sum_{i=1}^{n} \beta_i^f \mathbb{E}_t\left[x_{i,t+1}^f\right] + \sum_{i=1}^{n} \sum_{s=0}^{t} \delta_{i,t-s}^f x_{i,t-s}^f + \sum_{j=1}^{m} \sum_{s=0}^{t} \gamma_{j,t-s}^f z_{j,t-s}^f.$$

- Computing FEs at the firm level gives:

$$FE_t\left[y_{t+1}^f\right] = \sum_{i=1}^{n} \beta_i^f FE_t\left[x_{i,t+1}^f\right] + \varepsilon_{t+1}^f$$

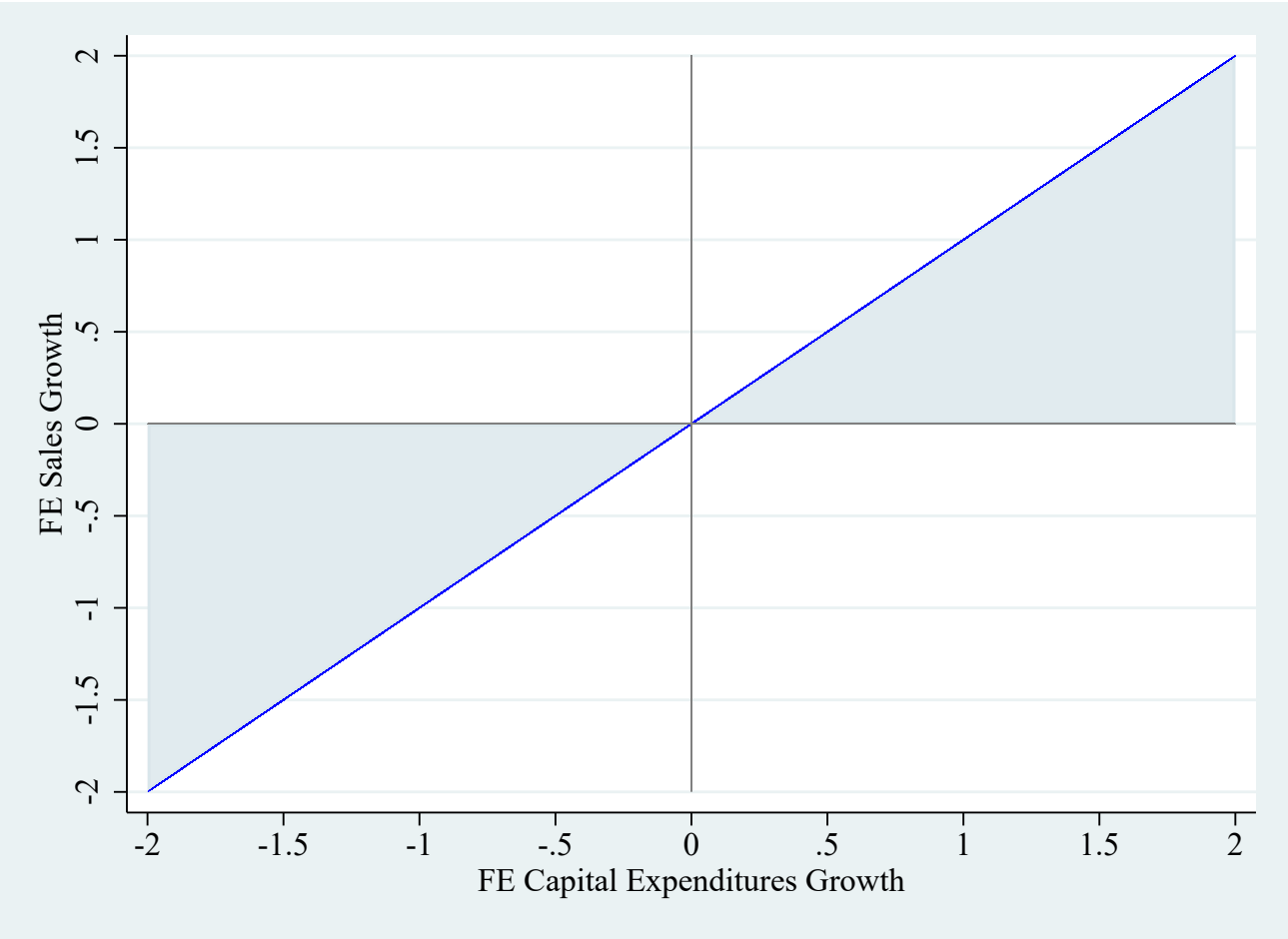
$\Longrightarrow$ **FEs associated to coherent forecasts of output and inputs should also be cross sectionally linked by parameters of prod fn** (loadings on contemporaneous inputs only).

- Note: Any additive firm-level (f) component known or predictable at the time of forecast (t) should get differenced away in FEs.

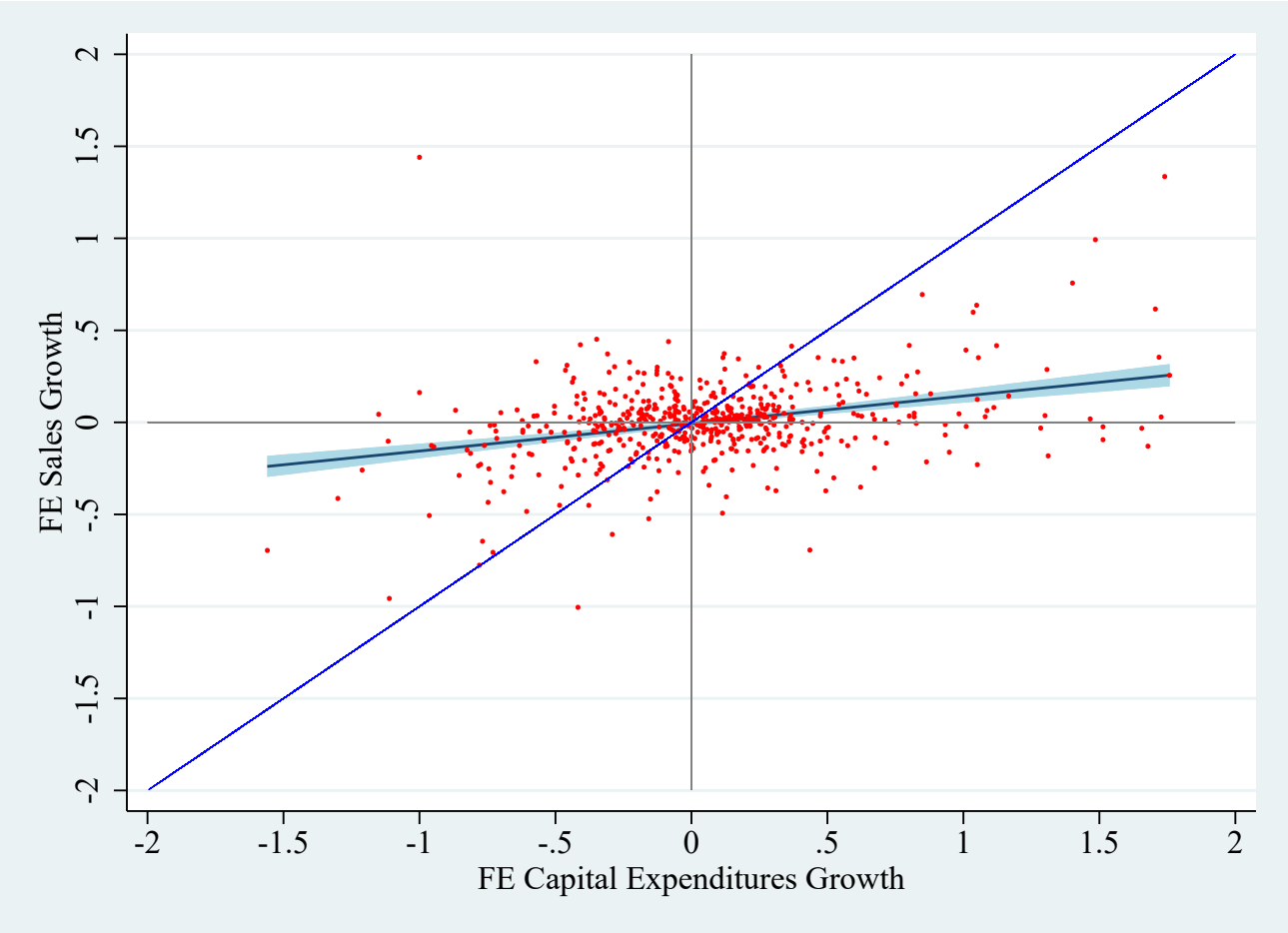
Intuitive Restrictions on FEs of Output and Inputs

(1) Free disposal: FEs of output and each input positively associated ($\beta_i^f \geq 0$).

(2) No increasing returns: FEs lie between horizontal axis and 45d line ($\beta_i^f \leq 1$).



FEs of Output and *K*-Input in the Data



- Reassuringly positive BLP's slope = 0.149.
- *But* ∼**42% obs** in UL-LR quadrants $\Longrightarrow$ **output-input FEs with opposite sign**.
- *Plus* ∼**10% obs** between 45d line and vertical axis $\Longrightarrow$ **K-input loading** > 1.

  $\Longrightarrow$ ∼**52% CFOs violate restriction (1) or (2)**. (Similar for other pairs.)

Regression Tests of Coherence and of Accuracy

- Coherence: slope of each input's FE (in a reg of output FE on inputs' FEs) should equal the corresponding loading in the production function equation.
- *VS* Accuracy: mean of FEs is zero for each variable.

	FE of Log CapEx Gr		**FE of Log SaleRev Gr**		
	(1)	(2)	(3)	(4)	(5)
FE of Log CapEx Gr			**0.113**	**0.135**	
			(0.063)	(0.032)	
FE of Log Wages Gr			0.023		0.019
			(0.309)		(0.321)
Constant	**-0.042**	-0.009	**0.046**	-0.004	0.033
	(0.025)	(0.009)	(0.023)	(0.009)	(0.022)
N obs	359	359	51	359	52

$\Longrightarrow$ Col (1): Reject forecast accuracy for capital expenditures (CapEx).

$\Longrightarrow$ Col (2): Cannot reject forecast accuracy for sales revenue (SaleRev).

$\Longrightarrow$ Cols (3)-(4): Reject forecast coherence (against any capital share > 0.3).

Individual-Level Tests in Theory

- Assume AR(1) log-prices for inputs: $\pi_{i,t+1} = \gamma_i \pi_{i,t} + \epsilon_{i,t+1}$,

  with $0 < \gamma_i < 1$, $\{\epsilon_{i,t}\}_{t \geq 1} \sim \mathcal{N}(0, \sigma_i^2)$ for $i = 1, 2$, and $\{\epsilon_{1,t}\}_{t \geq 1} \perp \{\epsilon_{2,t}\}_{t \geq 1}$.

Proposition 4 (C-Stat). *If $\xi \to 0$, under the null of coherence:*

$$\text{C2-stat} \equiv \frac{FE_t \log y_{t+1} - aFE_t \log x_{1,t+1}}{b\sigma_2} \sim \mathcal{N}(0,1).$$

- Intuition: Under the null, FEs of output and input "not far" from each other.
  - Should hold beyond Cobb-Douglas, for FEs on all n inputs; under Cobb-Douglas, requires FEs for only $(n-1)$ inputs.
- *VS* Accuracy: $FE_t \log x_{t+1}/\sigma_x \sim \mathcal{N}(0,1)$ (for generic x).
- (In)Coherence-(In)Accuracy Conceptual Figure: Go To

Individual-Level Tests in the Data

▸ Implementation ▸ Bootstrap ▸ Inequality ▸ C2-InCo Validation ▸ (In)Coh-(In)Acc Fig

*Panel A. Separate Assessment of Coherence and Accuracy (***% Rejections of Null***)*

Confidence $(1-\alpha)$	Coherence Sales-CapEx	Accuracy Sales	Accuracy CapEx	Accuracy Both
	(1)	(2)	(3)	(4)
95%	55.7%	27.2%	47.9%	57.0%
99%	7.7%	1.8%	6.4%	7.1%

*Panel B. Joint Assessment of Coherence and Accuracy (***% C-A Combinations***)*

Confidence $(1-\alpha)$	Coherent & Accurate	Coherent & Inaccurate	Incoherent & Accurate	Incoherent & Inaccurate
	(1)	(2)	(3)	(4)
95%	31.1%	13.2%	12.0%	43.7%
99%	89.4%	2.9%	3.4%	4.3%

To Sum Up

- We develop a theory of forecast coherence in firm production, yielding a benchmark of 1st-best coherent forecasts.
- In a positive version, incoherence arises from 'narrow thinking' (intrapersonal frictions in coordinating forecasts across firm variables), and operates via use of rules of thumb (RoT).
- The model rationalizes some (but not all) managerial RoT as 2nd-best optimal responses to noisy signals about firm's inputs and output, and provides a partial ranking of RoT.
- Using the Duke Survey of chief financial officers (CFOs), we document substantial heterogeneity in RoT use across CFOs.
- Firm performance correlates negatively with incoherence, and is lowest for firms whose CFOs use suboptimal RoT such as 'narrow bracketing' (R1) and 'sales anchoring' (R2).
- Albeit consistent with theory, these results reflect CFOs' RoT use (not assumptions).

Takeaways

- While relying on different setups and assumptions, all empirical results point to ∼50% of CFOs providing incoherent forecasts of output and input growth.
- These results reflect a lack of consensus in managerial textbooks and case studies, and a lack of theory and evidence to distinguish among different RoT.
- Takeaway: simple, intuitive, and much advertised RoT such as (R1) and (R2) perform poorly, and should not be part of future managers' toolkit.

Conclusion

Thank You!

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Duke-Compustat Matching

Bck

- **Duke-Compustat matching** is done via firm ID and has 4 main sources of **attrition**:

  (1) Due to privacy restrictions, not all Duke Rs report their firm ID needed for matching.

  (2) Not all Duke Rs give forecasts on all variables.

  $\Longrightarrow$ **Likely selection, potentially positive**.

  (3) Some variables forecasted in Duke do not have precise counterparts in Compustat: technology spending, outsourced employees, health spending, productivity, product prices, and share repurchases.

  (4) Among variables with precise counterparts, a few important ones don't have full coverage in Compustat: wages (about 90% missing), R&D expenditures, and advertising expenditures.

  $\Longrightarrow$ **(-) Analysis involving forecast errors (FE) limited to variables with full coverage in both datasets**.

  $\Longrightarrow$ **(+) Main coherence restriction (statistic) will not require FEs on all variables**.

- Matched sample mostly refers to early period (until 2011q4).

  $\Longrightarrow$ Empirical analysis will focus on **pre-financial crisis period**, consistent with stability assumption of model.

Discuss I: 'Sales Anchoring' (R2) ▸ Bck1, ▸ Bck2

- Popular in our data is the "proportion of sales" rule (R2), assigning to each item (say, CapEx) the same growth rate as Sales ('sales anchoring').
  - Consistent with teachings of managerial and consulting textbooks and case studies (e.g., Koller et al. (20), Luehrman and Heilprin (09), Stafford and Heilprin (11)).
  - Simple, intuitive, and seemingly incorporating coherence concerns.

- Can express this rule as a mean regression,

$$\text{CapEx Growth} = \alpha + \beta \cdot \text{Sales Growth} + \varepsilon,$$

  with $\alpha = 0$ and $\beta = 1$.

- Compare to "economies of scale" rule (R3), *actually estimating* the above reg by LS.
  - Doing so in Compustat yields $\hat{\alpha} = 0.217$ and $\hat{\beta} = 1.055$.

- Consider a firm aiming at a 5% Sales growth:
  - under "proportion of sales" (R2) $\Longrightarrow$ CapEx growth forecast = **5%**;
  - under "economies of scales" (R3) $\Longrightarrow$ CapEx growth forecast = **27%**.

- **Bottom line: (R2) under-predicts** CapEx, as it ignores the fixed component ($\alpha > 0$ in the data).

Discussion II: 'Narrow Bracketing' (R1) Bck1, Bck2

- Also "narrow bracketing" rule (R1) **under-predicts** CapEx, as it ignores its relation to Sales.
  - In time series regs, CapEx growth is mean reverting:
    - under (R1) $\Longrightarrow$ after high CapEx, forecast low CapEx;
    - under **other rules**, tying CapEx to Sales $\Longrightarrow$ if want to grow, after high CapEx, forecast high CapEx.
- Cross-sectional regs in Compustat for all RoT: Go to.

RoT Regressions in Compustat

Bck

	Const	Slope 1	Slope 2	R^2	N Obs
Rule 1 ('narrow bracketing')	0.316	-0.089		0.004	74,413
	(0.041)	(0.016)			
Rule 3 ('economies of scale')	0.217	1.055		0.081	100,441
	(0.025)	(0.036)			
Rule 4 ('industry based')					
SIC 0	0.330	2.050		0.097	358
	(0.156)	(0.344)			
SIC 1	0.243	0.950		0.115	8,983
	(0.045)	(0.072)			
SIC 2	0.243	0.859		0.050	14,777
	(0.026)	(0.054)			
SIC 3	0.186	1.188		0.104	24,852
	(0.024)	(0.058)			
SIC 4	0.180	0.925		0.064	14,398
	(0.022)	(0.091)			
SIC 5	0.163	1.281		0.081	10,266
	(0.027)	(0.121)			
SIC 6	0.402	0.963		0.036	7,477
	(0.041)	(0.062)			
SIC 7	0.202	1.162		0.105	14,673
	(0.039)	(0.090)			
SIC 8	0.198	1.216		0.088	3,911
	(0.023)	(0.128)			
SIC 9	0.222	1.288		0.123	746
	(0.058)	(0.182)			
Rule 5 ('broad bracketing')	0.217	1.042	0.018	0.082	100,040
	(0.025)	(0.036)	(0.004)		

RoT Indicators and Ex Ante Incoherence – Robust

Bck

- Distance between actual forecast and that implied by the attributed rule is relatively small, but strictly positive on avg (mean = 0.033), and heterogeneous (sd = 0.059).
- Small discrepancies may be simply due to rounding/truncation or small differences in implementation. Larger discrepancies could mean that the CFO is using a different rule.
- We construct a **"residual group" (R6)**, considering alternative thresholds +/-0.050 (+/-0.025 and +/-0.005), and perform robustness checks.

	(1)	(2)	(3)	(4)	(5)	(6)
Rule 1	0.037					0.088
	(.018)					(0.017)
Rule 2		0.010				0.060
		(0.008)				(0.011)
Rule 3			-0.058			0.001
			(0.013)			(0.014)
Rule 4				-0.043		0.019
				(0.009)		(0.012)
Rule 6					0.097	**0.132**
					(0.009)	(0.012)
Const	0.071	0.069	0.079	0.082	0.054	0.020
	(0.004)	(0.005)	(0.004)	(0.004)	(0.004)	(0.009)
N Obs	396	396	396	396	396	396

$\Longrightarrow$ As expected, (R6) forecasts (18.7%) are the most distant from (R5). Relative ranking of (R1)-(R4) is unchanged.

CFO + Firm Characteristics and Ex Ante Incoherence

Bck

	(1)	(2)	(3)	(4)	(5)	(6)
CFO has MBA	0.005					0.007
	(0.009)					(0.011)
Tenure > Median	0.008					0.006
	(0.008)					(0.011)
Age 40-		-0.011				-0.025
		(0.022)				(0.029)
Age 41-50		**-0.027**				**-0.038**
		(0.016)				(0.019)
Age 51-60		-0.024				**-0.030**
		(0.017)				(0.017)
Gender		0.002				0.005
		(0.010)				(0.012)
Miscalibration ST			-0.012			-0.014
			(0.008)			(0.010)
Optimism ST			-0.012			-0.010
			(0.007)			(0.009)
Miscalibration LT				-0.005		-0.002
				(0.004)		(0.006)
Optimism LT				0.001		0.005
				(0.004)		(0.007)
Firm size					**-0.006**	**-0.005**
					(0.003)	(0.003)
Market-to-Book					0.011	0.014
					(0.013)	(0.014)
Dividends					-0.015	-0.020
					(0.012)	(0.013)
Constant	0.043	0.078	0.052	0.046	0.137	0.159
	(0.022)	(0.025)	(0.027)	(0.021)	(0.036)	(0.049)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Survey FE	Yes	Yes	Yes	Yes	Yes	Yes
N of Obs	396	396	360	362	364	332

CFO characteristics: 45% with MBA; mean age 50.4; 9% female; on the job 4.3 years.
Firm characteristics: Avg firm size 2.5 billion USD sales; avg market-to-book ratio 1.685; 64% pay a dividend.

RoT Indicators and Corporate Policies

Bck

	Investment			Leverage		
	(1)	(2)	(3)	(4)	(5)	(6)
Rule 1	-0.016	-0.014	-0.015	0.055	0.041	0.047
	(0.011)	(0.011)	(0.012)	(0.092)	(0.101)	(0.092)
Rule 2	-0.013	-0.015	-0.012	0.093	0.098	0.092
	(0.006)	(0.007)	(0.008)	(0.053)	(0.060)	(0.053)
Rule 3	-0.007	-0.011	-0.010	-0.023	-0.015	-0.027
	(0.008)	(0.010)	(0.010)	(0.073)	(0.091)	(0.084)
Rule 4	-0.003	-0.003	-0.003	-0.004	0.005	0.001
	(0.007)	(0.008)	(0.008)	(0.045)	(0.050)	(0.046)
Misc ST		0.001			0.012	
		(0.003)			(0.024)	
Optm ST		0.002			-0.006	
		(0.003)			(0.019)	
Misc LT			0.002			0.013
			(0.002)			(0.018)
Optm LT			0.004			-0.010
			(0.002)			(0.017)
Const	0.044	0.043	0.050	0.568	0.666	0.620
	(0.025)	(0.023)	(0.023)	(0.249)	(0.228)	(0.249)
Firm characts	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y
Survey FE	Y	Y	Y	Y	Y	Y
N Obs	437	397	402	437	397	402

▶ Event Study: Go to

Direction of Causality? Bck

- Results so far are descriptive, correlational.
  - Higher CFO incoherence $\Longrightarrow$ lower investment and performance?
  - Lower investment $\Longrightarrow$ CFO more incoherent, thus forecasting too high a revenue growth?
  - Incoherent CFOs self-select (or are selected) into firms with low investment spending and poor performance?

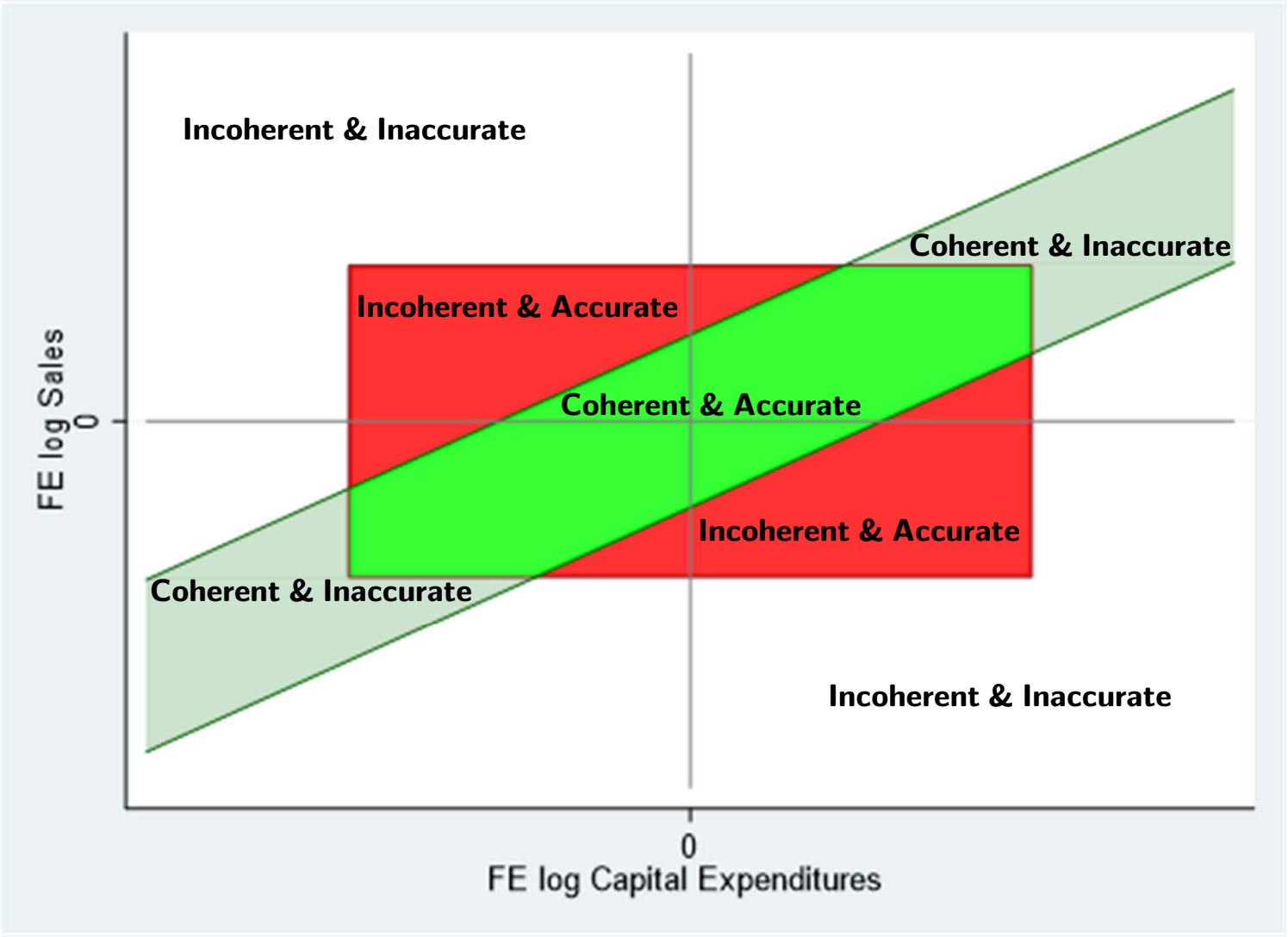
- We investigate how corporate performance, investment, and leverage evolve in the years surrounding a CFO's hiring.
  - We extract the dates when CFOs join firms from Execucomp and Boardex data, and hand-collect data from 10-K filings.
  - CFOs considered to take office when they first sign the firm's 10-K.
  - We match corporate performance, investment, leverage, and characteristics from Compustat for the year of taking office.

Change in Firm Performance and Corporate Policies When New CFO Takes Office

Bck

	Change in ROA		Change in Investment		Change in Leverage	
	(1)	(2)	(3)	(4)	(5)	(6)
Incoherence	**-1.633**		-0.049		-0.047	
	(0.989)		(0.045)		(1.115)	
Rule 1		-0.274		**-0.022**		-0.011
		(0.213)		(0.012)		(0.231)
Rule 2		-0.000		-0.003		-0.201
		(0.036)		(0.008)		(0.199)
Rule 3		-0.057		-0.008		-0.110
		(0.051)		(0.012)		(0.153)
Rule 4		0.019		0.001		-0.070
		(0.048)		(0.009)		(0.118)
Firm characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N Obs	142	142	140	140	146	146

(In)Coherence and (In)Accuracy ▸ Bck1, ▸ Bck2



Implementing Coherence and Accuracy Stats of Prop 4

Bck

- We proceed with the coherence statistic based on FEs:

$$\text{C2-stat} \equiv \frac{FE_t \log y_{t+1} - aFE_t \log x_{1,t+1}}{\sigma_2 b} \sim \mathcal{N}(0,1),$$

and the accuracy statistics for output (i.e., Sales Rev) and input 1 (i.e., CapEx):

$$\text{Accu-Y} \equiv \frac{FE_t \log y_{t+1}}{\sigma_y} \sim \mathcal{N}(0,1)$$

and

$$\text{Accu-X}_1 \equiv \frac{FE_t \log x_{1,t+1}}{\sigma_1} \sim \mathcal{N}(0,1).$$

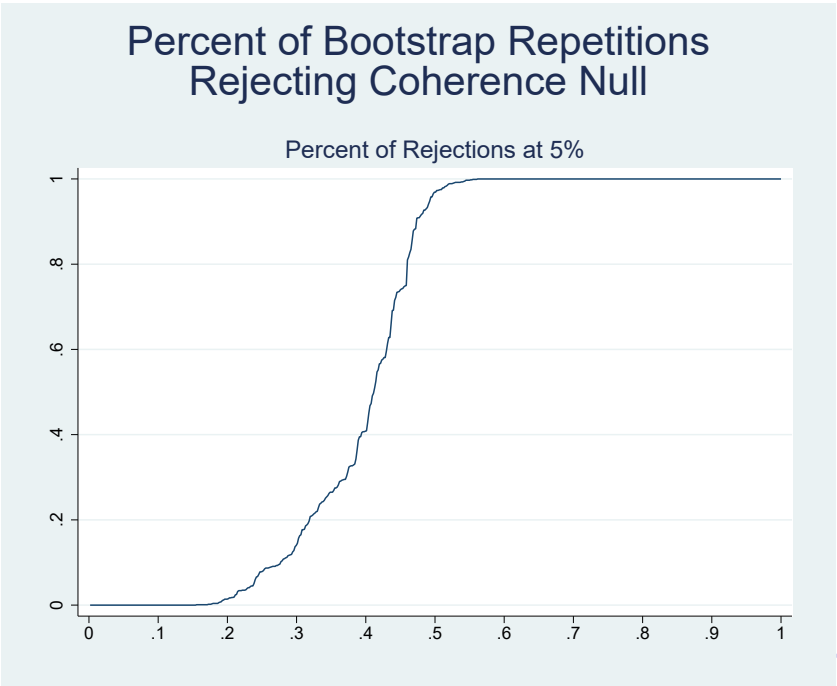
- They cannot be implemented directly using survey forecasts (not about log-variables). So, we use $\mathbb{E}_t \log x_{t+1} = \log \mathbb{E}_t x_{t+1} - \frac{1}{2} V_t \log x_{t+1}$ (for generic x) and relationships between cond and uncond variance for capital input and output (recall AR(1) log-prices for inputs).

- With estimated parameters (a, b, σ's), $\sim$ Student t (with 1 dof).

Bootstrapped C2

Bck

- To account for estimation uncertainty, we obtain bootstrap estimates of C2 (1,000 repetitions per CFO).
- For each CFO, we compute the fraction of bootstrap repetitions for which the coherence null is rejected at 95% and 99% CL. This stat ranges between 0 and 1.
- We plot this stat (on the y-axis) against its empirical cdf (on the x-axis). Here shown for the 95% CL case.
- For $\sim$15% of CFOs, the null is never rejected. For $\sim$40% of CFOs, the null is always rejected. For $\sim$45% of CFOs, the fraction of rejections across bootstrap reps is strictly between 0 and 1.
- The null is rejected more than 1/2 of the times for $\sim$55% of CFOs.



Inequality Restriction of Prop 1 ($\leq$ Case)

▸ Bck, ▸ Implementation

	$\chi = 0.5$	$\chi = 0.7$	$\chi = 0.9$
Inequality in Levels			
% Incoherent	100.00	100.00	99.07
% Coherent	0.00	0.00	0.93
% Total	100.00	100.00	100.00
N Obs	107	107	107
Inequality in Growth Rates			
% Incoherent	73.31	73.14	72.96
% Coherent	26.69	26.86	27.04
% Total	100.00	100.00	100.00
N Obs	577	577	577

- Most CFOs violate the inequality, as they forecast higher sales growth than implied by feeding into the CES their capital and labor growth forecasts.
- Extent of violations is heterogeneous. (Different conditions? Uncertainty?)
- $\chi \to 1$ gives CFOs a better chance to coherence? (MBA teaching examples are about Cobb-Douglas.)

Implementing Inequality of Prop 1

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- We begin with the relevant inequality from Proposition 1 (concave case):

$$\begin{aligned}\mathbb{E}_t\left[y_{t+1}\right] &\leq f\left(\mathbb{E}_t\left[x_{1,t+1}\right], \mathbb{E}_t\left[x_{2,t+1}\right]\right) \\ &\leq \left(\frac{a}{a+b}\mathbb{E}_t\left[x_{1,t+1}\right]^{\xi} + \frac{b}{a+b}\mathbb{E}_t\left[x_{2,t+1}\right]^{\xi}\right)^{\frac{a+b}{\xi}}.\end{aligned}$$

- We implement it both in levels and in growth rates.
  - We observe CFO forecasts of growth rates, not of levels. We back out the latter as $\mathbb{E}_t\left[x_{i,t+1}\right] = x_{i,t} \cdot \mathbb{E}_t\left[\frac{x_{i,t+1}}{x_{i,t}}\right]$ for $i = 1, 2$.
  - As most realizations on labor expenditures (i.e., $x_{2,t}$) are missing in Compustat, we end with fewer observations in levels than in growth rates.

- We compute industry-level a_j and b_j, using data on the universe of industries from the Bureau of Economic Analysis.

- We present results for $\chi = 0.5, 0.7, 0.9$, informed by the macro/IO literature (e.g., Berndt (1976), Oberfield and Raval (2021), and others).

Ex Ante *VS* Ex Post Incoherence

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- Validation: *Ex ante* incoherence measure predicts *ex post* C2-stat:

$$\widehat{|\text{C2}|} = \underset{(0.022)}{0.229} + \underset{(0.197)}{0.629} \cdot \text{Incoherence},$$

where SEs are in parentheses under the point estimates.