The Coherence Side of Rationality

Theory and evidence from firm plans

Pamela Giustinelli
Bocconi, IGIER, and LEAP

Stefano Rossi
Bocconi, ECGI, and CEPR

European Winter Meeting of the Econometric Society
December 17, 2024

The Coherence Side of Rationality

[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), Thagard (2000), Posner (2014)).
- One of the **two standards of rationality** of judgment, together with accuracy (e.g., Hammond (1990, 1996), Gigerenzer et al. (1999), Arkes et al. (2016)).
- In the context of **multidimensional forecasting**:
  1. **Coherence** ('consistency') requires forecasts of individual variables to incorporate the connections among those variables $\Longrightarrow$ *ex ante*.
  2. **Accuracy** ('correspondence') requires forecasts of individual variables to be not systematically different from realizations $\Longrightarrow$ *ex post*.
- Large literature on forecast accuracy (e.g., Tversky and Kahneman (1974) and Benjamin (2019)'s review). **Forecast coherence has received less attention**.

We Study Forecast Coherence in Firm Plans

Essential Background & Motivation

- Firm Internal Plans: To allocate resources within the firm, top financial executives (CFOs) make **internal forecasts over balance-sheet variables**.
- Pro Forma Statements: CFOs **start with a sale revenues' forecast** ('top line'), **then proceed to other items** (e.g., K and L expenditures) to achieve Y-target.
- Multidimensional Forecasting Problem: High-stake and challenging, requiring CFOs to draw on their knowledge of the **firm's production possibility**.
  - Natural 'coherence benchmark.'
  - 'Forecast incoherence' (by failing to account for technology relationships) may be costly to the firm (by implying use of a suboptimal mix of inputs).

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  - Natural 'coherence benchmark.'
  - 'Forecast incoherence' (by failing to account for technology relationships) may be costly to the firm (by implying use of a suboptimal mix of inputs).
- MBA textbooks/case studies provide **rules of thumb (RoT)** to help CFOs make internal forecasts (e.g., Ruback (2004), Welch (2017), Koller et al. (2020)).
  - These RoTs produce very different forecasts and differ in their concern for coherence – from forecasting each variable in isolation (**'narrow bracketing'**), to anchoring each forecast to the sale revenues' forecast (**'sales anchoring'**), to using multivariate regression (**'sophisticated'**).
  - RoTs 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 firms make (in)coherent forecasts of own output and inputs growth.
  - The empirical relevance of forecast incoherence: negatively associated with firm performance.
  - A specific mechanism underlying forecast incoherence: use of suboptimal RoTs.
- First evaluation of the managerial RoTs taught by MBA textbooks/case studies.
- Theory-based restrictions and formal statistical tests, some based on forecasts ('ex ante' approaches) and others on forecast errors ('ex post' approaches).
  - Two ex post approaches – a regression test and an individual-level test – enable us to disentangle (in)coherence from (in)accuracy.

We Build On and Contribute to Multiple Strands of Lit

1. 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 forecasts of multiple simultaneous vars and heterogeneity in forecasting rules.**
2. Behavioral Research on Bracketing
   * *Applied Theory*: Barberis et al (06), Rabin & Weizsacker (09), Lian (21), Wang (24).
   * *Mental Accounting*: Thaler (85), Kahneman & Lovallo (93), Read et al (99), Rabin & Weizsacker (09), Hastings & Shapiro (13, 18), Farhi & Gabaix (20), Ellis & 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 the firm context.**
3. Coherence and Accuracy Requirements of Rationality
   * Tversky & Kahneman (multi), Hammond (multi), Osherson et al (94), Gigerenzer et al (99), Lee & Zhang (12), Arkes et al (16), Benjamin et al (16), Zhu et al (20, 22).
   - **By disentangling coherence and accuracy theoretically and empirically.**
4. Behavioral Corporate Finance
   * Baker et al (07), Malmendier and Tate (05, 08), Landier and Thesmar (09), Gervais at al (11), Schneider and Spalt (14), DellaVigna (18), Guenzel and Malmendier (20).
   - **By studying a novel managerial trait and its relationship to firm outcomes.**

Roadmap

1. RoTs and Theoretical Framework
2. Data Sources
3. Descriptive Evidence (largely theory-free)
4. More Theory-Based Evidence

We Consider Five RoTs from Welch (2017)'s Taxonomy

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(R3) **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 realizations data from Compustat to obtain:
  - fixed component = intercept estimate;
  - variable component = slope estimate × sales forecast.

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(R5) **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.

Setup I: Environment and Main Assumptions

- Consider a profit-max firm, with CES production fn,

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

  and cost fn $Z^*(p_1, p_2, y^*)$, where:
  - y is output, and x_1, x_2 input quantities (say, K, L);
  - returns to scale are constant for $\nu \equiv a + b = 1$, decreasing for $\nu < 1$;
  - elasticity of substitution between x_1 and x_2 is $\chi = \frac{1}{1-\xi}$;
  - p_1, p_2 are input prices and $\log p_i = \pi_i$, with $i = 1, 2$;
  - factor-augmenting productivities are time constant and normalized to 1.

- Further assume:

  (A1) No technological innovation or unanticipated aggregate shocks.

  [-] *No dynamics / disruptions* $\Longrightarrow$ Cannot study in-coherence as (optimal?) adaptation to changing circumstances.

  [+] *No wedge between ex ante and ex post coherence* $\Longrightarrow$ Can nest coherence and accuracy within a single framework and clarify their distinction. Can learn from cross-sectional variation in coherence and relate it to firm outcomes.

  (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 II: Forecast Problem

- The forecaster issues $\mathbf{F}_t = (Fy_{t+1}, Fx_{1,t+1}, Fx_{2,t+1})$ by minimizing *expected inaccuracy* for each item $x \in (y, x_1, x_2)$, which takes the form of an expected square loss,

$$\min_{Fx_t} \mathbb{E}\left[(x_{t+1} - Fx_t)^2 \,|\Omega_t\right],$$

  under a *coherence constraint*, which is embedded in Ω_t and takes $y = f(x_1, x_2)$ into account.

- At solution, $Fx_t^* = \mathbb{E}[x_{t+1}|\Omega_t] \equiv \mathbb{E}_t[x_{t+1}]$, for each x in (y, x_1, x_2).

- Assuming:
  - Square loss, as a natural way to nest the five RoTs (R1-R5), as forecasts under those rules are (conditional) means;
  - CFOs know their firm's $f(\cdot)$.

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*

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

When $\xi \geq 1$ and $a+b \geq 1$, the CES function is convex and the inequality flipped.

- Implementable empirically, but not sufficiently credibly in our data.
- The CES is non-linear, differently from the RoTs (1st-order linear approx). To see if we can rationalize (some of) them, we consider the Cobb-Douglas case.

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,

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

- C-D is linear in log, so Prop 1 holds with equality in levels and growth rates.

Normative Theory II: Corollaries

- We provide corollaries for the case in which technology parameters, a and b, are unknown and the forecaster estimates them via linear projections.
  - A version of the **multivariate rule** (R5) is rationalized as **1st-best optimal** (for variables in log and growth rates).
  - 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.
    - Details

Positive Theory I: Narrow Thinking in Firm Forecasts

- Could narrow bracketing be a 2nd-best optimal response to imperfect info?
  - E.g., CFOs may issue forecasts in between broad and narrow bracketing, as they may be better informed about certain inputs than others.
- 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 (i.e., signals, or states of mind).
  - **Narrow thinking reflects intra-personal frictions in coordinating forecasts of different variables**.

Positive Theory II: Noisy Signals and Optimal Forecast

- Consider a CFO forecasting (log of) input $i = 1$ by min square loss.

- CFO observes noisy signals for (log of) y and input $\neg i = 2$:

$\eta_y = \log y + \epsilon_y$ and $\eta_2 = \log x_2 + \epsilon_2$, where $\epsilon_y \sim \mathcal{N}\left(\mu_y, s_y^2\right)$, $\epsilon_2 \sim \mathcal{N}\left(\mu_2, s_2^2\right)$.

Proposition 3. *Assume $y = x_1^a x_2^b$. The optimal forecast of $\log x_1$ given η_y and η_2 is*

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

where

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

  - Linear projection of (signal-prior mean deviations for) "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).

- To rationalize (R1), need $s_y^2 \to +\infty$ & $s_2^2 \to +\infty$. Details

- To rationalize (R3)-(R4), need $s_2^2 \to +\infty$ & $0 < s_y^2 < +\infty$. (R2) hard to rationalize.

Taking Stock

- RoT Ranking: Theory yields a partial ranking of RoTs,

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

  where:

  (R5) is the sophisticated multivariate rule;

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

  (R2) is the sales anchoring rule, using info on output 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: Insofar as incoherence in internal planning induces suboptimal allocation of resources to inputs, profits will decrease with deviation of actual forecasts from ex ante optimal ones.

- Mechanism: Narrow thinking, via use of suboptimal RoTs such as R1-R2.

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CFO Expectations Come from Duke Survey

- **Duke Survey** 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 90s, has been asking Rs' expectations of future 12-month growth rates of key corporate variables: sale revenues (Y), capital expenditures (K), 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.
  - Covers all publicly traded firms across all sectors of the US economy since 1955.

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

  Details

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We Implement R1-R5 As in Welch: Here for *CapEx*

Det

	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 ('sophisticated')	0.217	1.042	0.018	0.082	100,040
	(0.025)	(0.036)	(0.004)		

Inferring RoT Use

- We assign a 'type' to each CFO by computing:
  1. Orthogonal dist of CFO's actual forecast to each of those implied by the 5 RoTs.
  2. *Min* dist among the 5 $\Longrightarrow$ CFO's 'type' is the 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)

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

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

A Continuous Measure of Ex Ante InCoherence

- Orthogonal distance between CFO-given and (R5)-implied forecasts,

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

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).

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

RoT Indicators and Ex Ante Incoherence – Main Version

Robust Version | Heterogeneity

- Theory predicts (R5) $\succeq$ (R3)-(R4) $\succeq$ (R1)-(R2).
- We regress *ex ante incoherence* on *RoT dummies*, with (R5) reference.

	(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 (R1)-(R2) and (R3)-(R4) 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 RoTs.
  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)

	(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

- Robust to (R1)-(R6); R6 has 0.04 lower ROA.
- Event Study: To s1, To s2

Roadmap

1. RoTs and Theoretical Framework
2. Data Sources
3. Descriptive Evidence (largely theory-free)
4. More Theory-Based Evidence

Next: Tests of Coherence Based on Forecast Errors

And Disentangling Forecast (In)Coherence and (In)Accuracy

- So Far
  - $\sim$48% of CFOs appear to use incoherent RoTs, (R1)-(R2).
  - *Ex ante* incoherence is negatively associated with firm performance.
  - Same for use of incoherent RoTs with firm performance (and investment).
    - Intuition: (R1) and (R2) imply a much lower CapEx Gr-Sales Gr association than realizations imply, 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.
- Next
  - We ask what we can learn by relying more directly on the assumptions about firm's environment and technology, and show the usefulness of combining forecasts and realizations into forecast errors (FEs).
    - We derive restrictions and tests based on output-input FEs.
    - We show how to disentangle coherence and accuracy with FEs.

Why Forecast Errors?

- Consider a general empirical formulation of a production function,

$$y^f_{t+1} = \alpha + \alpha^f + \sum_{i=1}^{n} \beta^f_i x^f_{i,t+1} + \sum_{i=1}^{n} \sum_{s=0}^{t} \delta^f_{i,t-s} x^f_{i,t-s} + \sum_{j=1}^{m} \sum_{s=0}^{t} \gamma^f_{j,t-s} z^f_{j,t-s} + \varepsilon^f_{t+1},$$

where f indexes firms, i inputs, and j relevant states (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:

$$\mathbb{E}_t \left[y^f_{t+1} \right] = \alpha + \alpha^f + \sum_{i=1}^{n} \beta^f_i \mathbb{E}_t \left[x^f_{i,t+1} \right] + \sum_{i=1}^{n} \sum_{s=0}^{t} \delta^f_{i,t-s} x^f_{i,t-s} + \sum_{j=1}^{m} \sum_{s=0}^{t} \gamma^f_{j,t-s} z^f_{j,t-s}.$$

- Computing FEs at the firm level gives:

$$FE_t \left[y^f_{t+1} \right] = \sum_{i=1}^{n} \beta^f_i FE_t \left[x^f_{i,t+1} \right] + \varepsilon^f_{t+1}$$

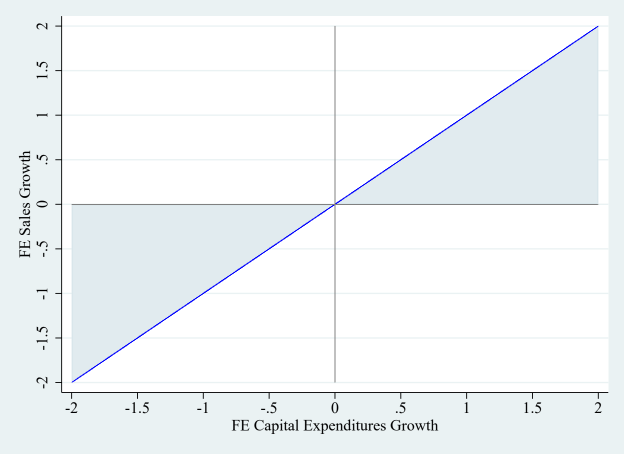
$\Longrightarrow$ **FEs associated to coherent forecasts of output and inputs should also be cross sectionally linked by parameters of prod fn** (loadings on contemporaneous inputs only).

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

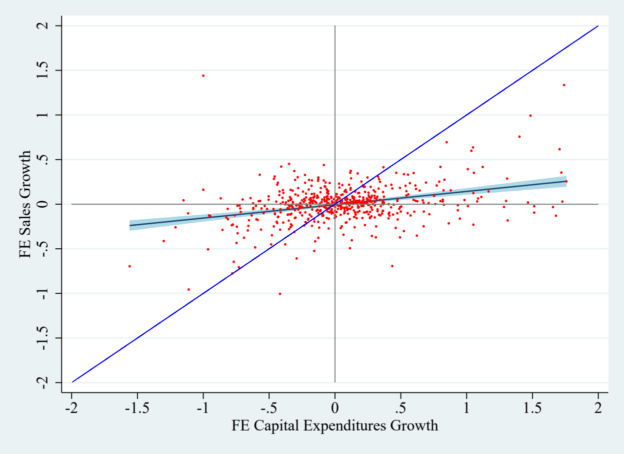
Intuitive Restrictions on FEs of Output and Input Growths

(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 Growths in the Data



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

⟹ ∼**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 log CapEx Growth	FE log SaleRev Growth			
	(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 sale revenues (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 $0 < \gamma_i < 1$, $\{\epsilon_{i,t}\}_{t\geq 1} \sim \mathcal{N}\left(0, \sigma_i^2\right)$ 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:*

$$\text{C1-stat} \equiv \frac{\frac{\mathbb{E}_t \log y_{t+1} - a\mathbb{E}_t \log x_{1,t+1}}{b} - \log \frac{b}{a+b} Z}{\gamma_2 \sigma_2} \sim \mathcal{N}(0,1)$$

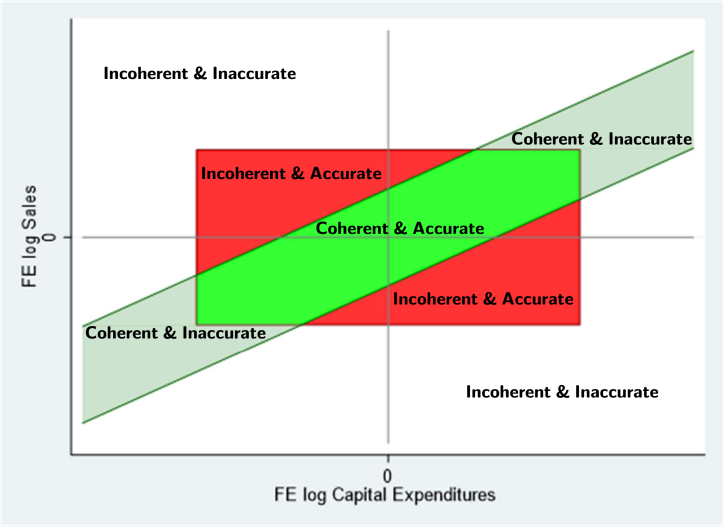
and

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

- 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: $FE_t \log x_{t+1}/\sigma_x \sim \mathcal{N}\left(0,1\right)$ (for generic x).

(In)Coherence *VS* (In)Accuracy

Graphical Illustration



Individual-Level Tests in the Data

▸ C2 Implementation ▸ Bootstrap ▸ Inequality ▸ C2-Incoherence Validation

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%

Takeaways

- While relying on assumptions of varying number and strength, all empirical results point to ∼50% of CFOs providing incoherent forecasts of simultaneous variables.
- Likely reflecting a lack of consensus in managerial textbooks and case studies, and a lack of theory and evidence to distinguish among different RoTs.
- Much research in psychology and elsewhere has been cast in terms of whether the use of heuristics is good or bad. But heuristics are not all the same; some may be helpful, some harmful. Heuristics should be evaluated with respect to their proposed goals – and typically this requires both theory and data.
- Simple, intuitive, and much advertised RoTs such as (R1)-(R2) perform poorly, and should not be part of future managers' toolkit.

Thank You!

<pamela.giustinelli@unibocconi.it>

Normative Theory II: More on Corollaries

Back

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.

(R3): Need $\rho_{1,2} = 1$ and $\sigma_1^2 = \sigma_2^2 = \sigma_{1,2} = \sigma^2$. Under $\nu < 1$, get linear projection's intercept $\alpha > 0$ and slope $0 < \beta < 1$.

(R2): Further need $\nu = 1$, so $\alpha = 0$ and $\beta = 1$.

(R1): Need info on past growth rates for $k \to \infty$ periods and random-walk prices.

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

Back

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.

$\Longrightarrow$ (R2) hard to rationalize even in 2nd-best sense, as would need $\mu_1 = 0$ and $\beta_y = 1$.

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 positive selection**.
  (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.

We Use Compustat to Implement (R1)-(R5)...

Bck

- 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*.

Discuss I: 'Sales Anchoring' (R2) Bck

- 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) Bck

- 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.

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).
$\Longrightarrow$ Importantly, 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.

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 revenues 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

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

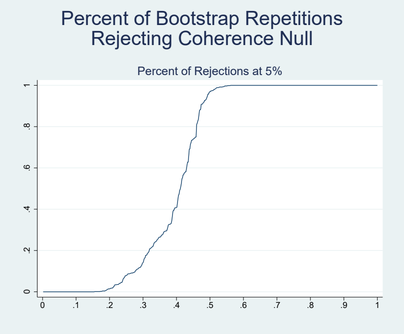
$$\text{Accu-X}_1 \equiv \frac{FE_t \log x_{1,t+1}}{\sigma_1} \sim \mathcal{N}(0,1).$$

- 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 ∼15% of CFOs, the null is never rejected. For ∼40% of CFOs, the null is always rejected. For ∼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 ∼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 Bck

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

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

- 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 $\mathbb{E}_t[x_{i,t+1}] = x_{i,t} \cdot \mathbb{E}_t\left[\frac{x_{i,t+1}}{x_{i,t}}\right]$ 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

Bck

- 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.