Incomplete Information and Investment Inaction

Kansas City Fed Research Dept. Brown Bag: August 27, 2025

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- Both frictions are important, but studied individually. Do they interact?

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- Several lines of active research trying to resolve this tension, e.g. production networks (Winberry and vom Lehn 2025)

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3. **Empirical Analysis:**
    - Test predictions using Japanese administrative data
    - Firms with worse information behave as predicted by model

Theory

Firms' Problem

- Atomistic firms face simple investment problem
- Produce using capital K and stochastic productivity A by

$$F(A, K) = A^{1-\alpha} K^{\alpha}$$

- Log productivity a follows a random walk:

$$da = \sigma_a dW^a$$

- Investment I is irreversible. Conditional on investing, profits are

$$\pi = A^{1-\alpha} K^{\alpha} - \psi I$$

- The law of motion for capital is

$$dK = I - \delta K dt$$

Firms' Behavior: Investment Inaction Region

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- Effect of incomplete information? *It determines the inaction region*

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- $\hat{a}$ follows a random walk with the same properties as a

▸ Nowcast Behavior

Solving the Firm's Problem: Inaction Boundary

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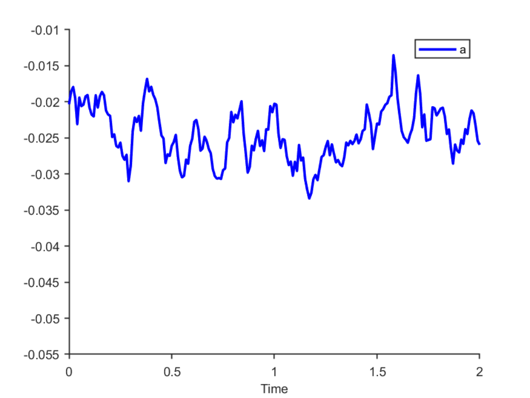
- Firm maximizes *expected value function* $\hat{V}(e^{\hat{x}}) = \mathbb{E}[V(e^x)|e^{\hat{x}}]$
- We show that the optimum is characterized by usual value-matching and super contact conditions, except applied to $\hat{V}$:

$$\hat{V}'(e^{\hat{b}}) = \psi \qquad \lim_{e^{\hat{x}} \to \infty} \hat{V}'(e^{\hat{x}}) = 0$$

$$\hat{V}''(e^{\hat{b}}) = 0 \qquad \lim_{e^{\hat{x}} \to \infty} \hat{V}''(e^{\hat{x}}) = 0$$

▸ Exact Expression ▸ Normalized HJB

Example of a Typical Firm's Behavior



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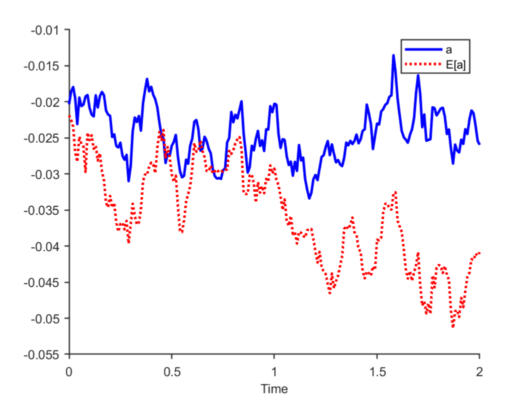

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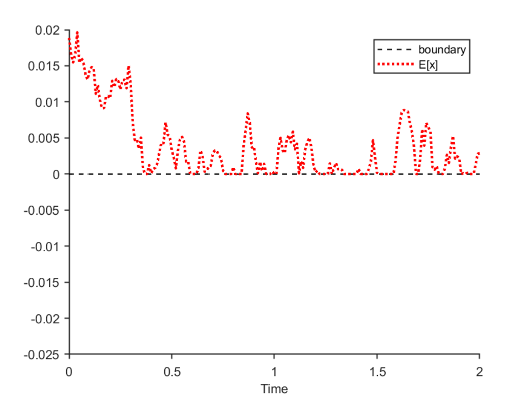

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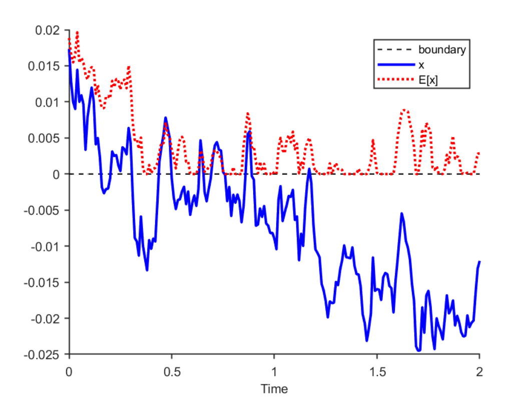

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- Actual norm. capital x follows $x = k - a = \hat{x} + \hat{a} - a$

Micro-Level Implications 1: Reduced Inaction

1. Information friction **increases** the incentive to invest

$$\hat{b} = \underbrace{b^{FI}}_{\text{Full Info.}} + \frac{\alpha^2}{2(1-\alpha)} \underbrace{\frac{\tau \sigma_a^2 \sigma_n^2}{\sigma_a^2 + \sigma_n^2}}_{Var[u]}$$

- Greater noise ($\sigma_n \uparrow$) or delay ($\tau \uparrow$) raise boundary $\hat{b}$
- Contrasts with traditional uncertainty channel: $\sigma_a \uparrow \implies b^{FI} \downarrow$
- Why? An Oi-Hartman-Abel effect:
  - MPK is convex in log productivity. Firms: risk-loving on normalized capital x
  - Friction acts as a mean preserving spread on x

▸ Boundary Properties ▸ Partial Irreversibility

Micro-Level Implications 2: Attenuated Shocks

2. Information friction **reduces** elasticity of forecasts to productivity shocks

$$\frac{d}{da_{t-h}}\mathbb{E}[a_t|\Omega_t] = \begin{cases} \gamma & 0 \leq h < \tau \\ 1 & h \geq \tau \end{cases}$$

where

$$\gamma \equiv \frac{\sigma_a^2}{\sigma_a^2 + \sigma_n^2} < 1$$

Testable predictions for later: worse information associated with

- **Lower inaction rate**, conditional on firm size
- **Lower sensitivity of investment to productivity shocks**

Micro-to-Macro: The Distribution of Firms

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- ODE solution:

$$h(\hat{x}) = \rho e^{-\rho(\hat{x}-\hat{b})}, \quad \text{where} \quad \rho \equiv \frac{\delta}{\sigma_a^2} + \sqrt{\frac{\delta^2}{\sigma_a^4} + 2\frac{\eta}{\sigma_a^2}}$$

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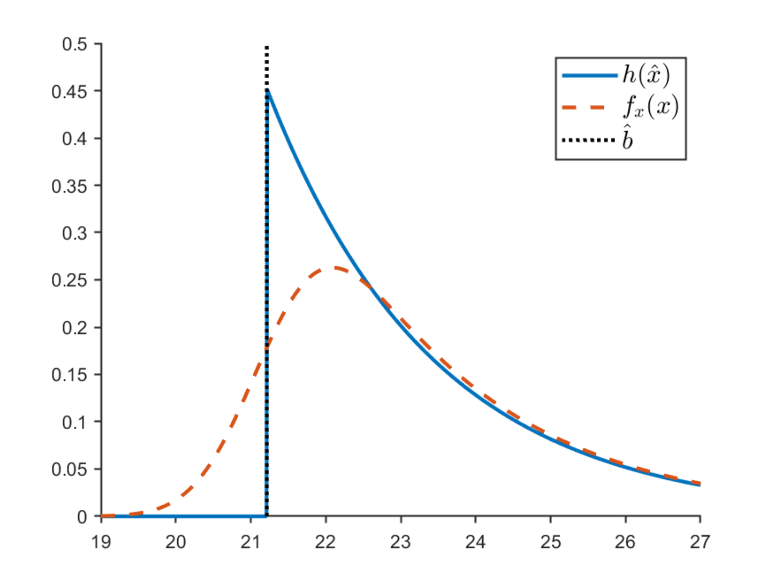
- Actual $x = \hat{x} + u$ is more dispersed

Stationary Distributions: Expected & Actual Normalized Capital



Micro-to-Macro: The Joint Distribution of Firms

- Joint distribution $f_{k,\hat{x}}(k,\hat{x})$ satisfies (+ boundary conditions)

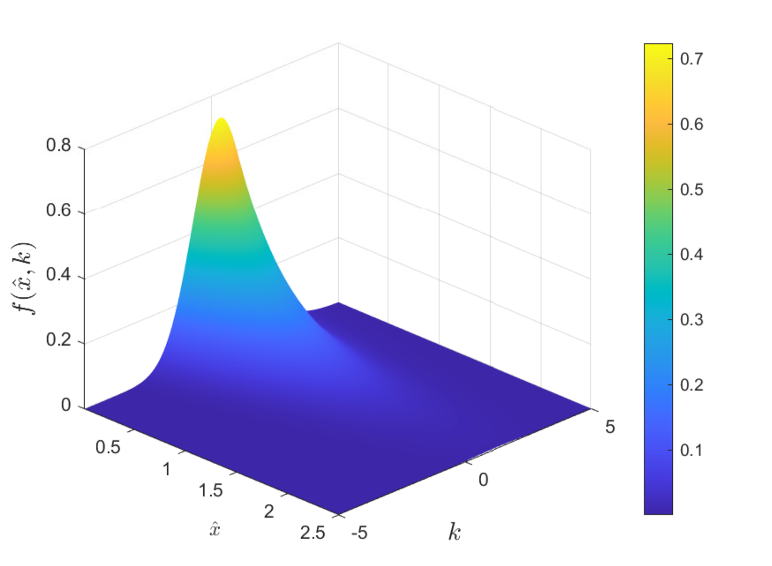
$$0 = \frac{\sigma_a^2}{2}\partial_{\hat{x}}^2 f_{k,\hat{x}} + \delta\left(\partial_{\hat{x}} f_{k,\hat{x}} + \partial_k f_{k,\hat{x}}\right) - \eta\, f_{k,\hat{x}}$$

- PDE solution:

$$f_{k,\hat{x}}(k,\hat{x}) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \frac{-\mathcal{N}(\xi)}{\frac{\sigma_a^2}{2}\lambda_-(\xi)+\delta} e^{i\xi k + \lambda_-(\xi)(\hat{x}-\hat{b})} d\xi$$

where $\mathcal{N}(\xi)$ denotes the Fourier transform of $\eta\phi\left(\frac{k}{\varsigma}\right)$ and
$\lambda_-(\xi) \equiv \frac{-\delta-\sqrt{\delta^2+2\sigma_a^2(i\delta\xi+\eta)}}{\sigma_a^2}$

Stationary Distribution: Capital & Expected Norm. Capital



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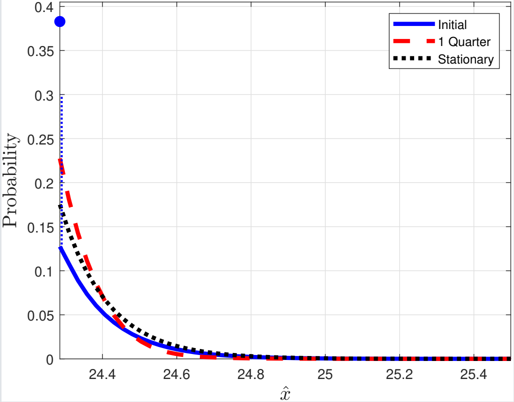
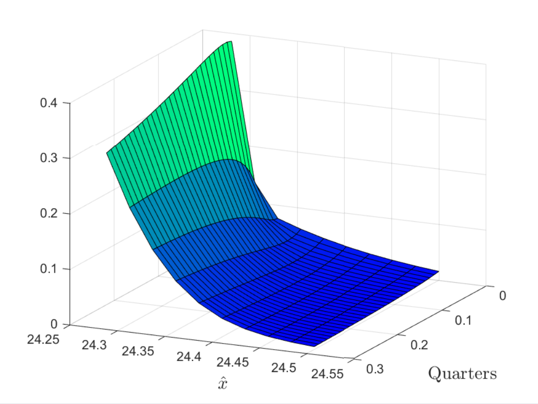
3. Information friction **increases** average firm volatility
4. Information friction **attenuates** aggregate responses to productivity shocks:

$$\widehat{IRF}_k(t) = \gamma \widehat{IRF}_k^{FI}(t) \qquad \gamma = \frac{\sigma_a^2}{\sigma_a^2 + \sigma_n^2}$$

Aggregate Response of $\hat{x} = k - \hat{a}$ to a Productivity Shock

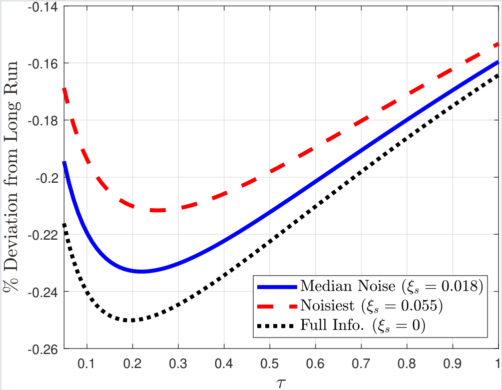


Distribution After Shock

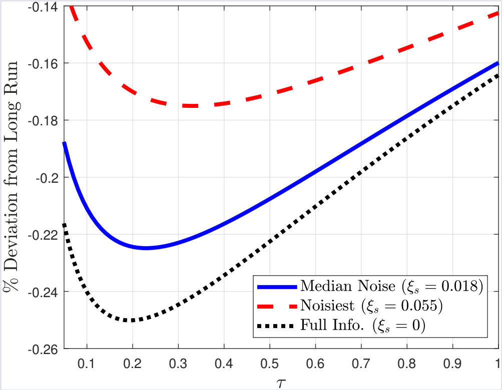


Distribution Over Time

Info. Friction Attenuates Aggregate Response to Shocks



Quick Revelation $\tau = 1$



Slow Revelation $\tau = 4$

Validation with Firm-level Data

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  - Merged dataset contains firms with at least 1 billion JPY in registered capital

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- Estimate industry-specific attenuation coefficient ξ_s:

$$e_{it+1} = \xi_s w_{it} + \Gamma z_{it} + \gamma_{st} + \gamma_{rt} + \gamma_{gt} + \epsilon_{it+1}$$

Heterogeneity in Attenuation Coefficients

- Information friction: forecast error response to productivity shocks
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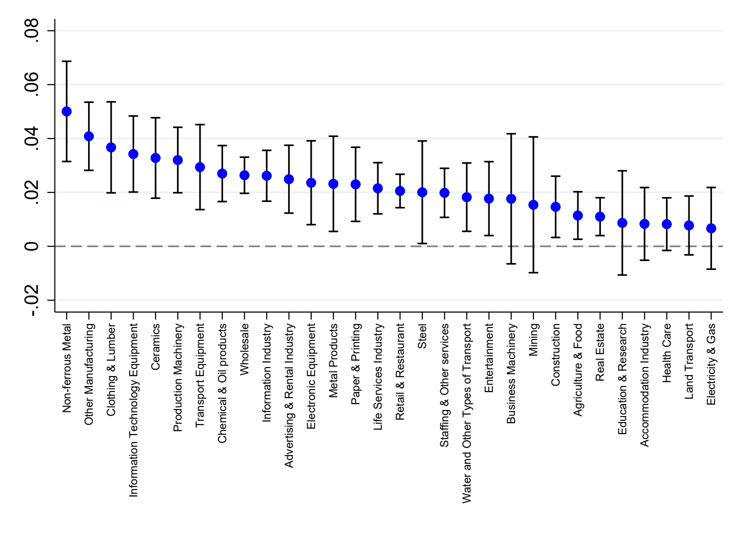
  - Industry-time, region-time, size-time fixed effects

- Positive $\xi_s \implies$ forecast *underreaction*

Attenuation Coefficients across Industries



Empirical Exercise 1: Information Frictions & Inv. Inaction

- Do we observe more investment inaction for firms in industries with more severe information frictions?

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  - ζ_s: industry-level controls
  - γ_t: time fixed effects
  - Standardize ξ_s

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  - z_{it}: firm-level controls
  - ζ_s: industry-level controls
  - γ_t: time fixed effects
  - Standardize ξ_s
- α is the coefficient of interest
- We calibrate & simulate our model (& match ξ_s distrib.) for comparison.

▸ Calibration

Empirical Exercise 1: Information Frictions & Inv. Inaction

	inaction = 1							
	Data						Model	
ξ_s	**-0.076****	**-0.079*****	**-0.054****	**-0.069****	**-0.039***	**-0.051****	-0.013	-0.011
	(0.028)	(0.026)	(0.025)	(0.026)	(0.020)	(0.021)	(——)	(——)
$a_{i,t}$	0.039	0.059*	0.104***	0.113***	0.091**	0.099***	-0.206	-0.298
	(0.034)	(0.031)	(0.038)	(0.033)	(0.033)	(0.032)	(——)	(——)
$k_{i,t-1}$		-0.050***	-0.049***	-0.044***	-0.041***	-0.039***		-0.458
		(0.009)	(0.009)	(0.007)	(0.008)	(0.007)		(——)
$m_{i,t}$			-0.026	-0.045***	-0.015	-0.030**		
			(0.021)	(0.016)	(0.019)	(0.014)		
cap share$_s$				-0.549*		-0.366		
				(0.314)		(0.304)		
growth vol$_s$					1.016***	0.870***		
					(0.279)	(0.278)		
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	99027	99027	86294	86294	86294	86294	14291997	14291997
adj. R^2	0.038	0.069	0.063	0.089	0.078	0.095	0.116	0.180

Empirical Exercise 1: Information Frictions & Inv. Inaction

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	Data						Model	
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More severe information frictions $\Rightarrow$ less inaction

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	Data						Model	
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1 SD in $\xi_s \Rightarrow$ 5.1 p.p. (14%) less inaction

Empirical Exercise 2: Information Frictions & Inv. Sensitivity

- Do we see lower investment sensitivity to productivity shocks in industries with stronger information frictions?
- We estimate

$$\text{inaction}_{it} = \beta(w_{it} \times \xi_s) + \gamma w_{it} + \Gamma z_{it} + \gamma_i + \gamma_{st} + \epsilon_{it}$$

  - w_{it} : productivity shock (random walk or AR(1))
  - z_{it}: firm-level controls
  - γ_i: firm fixed effects
  - γ_{st}: industry-time fixed effects
  - Standardize ξ_s

Empirical Exercise 2: Information Frictions & Inv. Sensitivity

	inaction = 1					
	Data				Model	
$\xi_s \times w_{i,t}$	**0.010****	**0.011****	**0.011****	**0.010****	0.012	0.013
	(0.005)	(0.005)	(0.005)	(0.005)	(——)	(——)
w_{it}	-0.036	-0.030	-0.036	-0.029	-0.188	-0.188
	(0.031)	(0.031)	(0.032)	(0.032)	(——)	(——)
a_{it-1}	-0.028**	-0.015	-0.029**	-0.016	-0.670	-0.670
	(0.012)	(0.012)	(0.011)	(0.011)	(——)	(——)
Productivity	Rand. Walk	Rand. Walk	Auto. Reg(1)	Auto. Reg(1)	Rand. Walk	Rand. Walk
Firm FE	Y	Y	Y	Y	Y	Y
Time FE	Y	Y	Y	Y	Y	Y
Industry-Time FE	N	Y	N	Y	N	Y
N	84656	84656	84313	84313	14274640	14274640
adj. R^2	0.446	0.451	0.446	0.451	0.450	0.450

Empirical Exercise 2: Information Frictions & Inv. Sensitivity

	inaction = 1					
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$\xi_s \times w_{i,t}$	**0.010****	**0.011****	**0.011****	**0.010****	0.012	0.013
	(0.005)	(0.005)	(0.005)	(0.005)	(——)	(——)
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a_{it-1}	-0.028**	-0.015	-0.029**	-0.016	-0.670	-0.670
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Productivity	Rand. Walk	Rand. Walk	Auto. Reg(1)	Auto. Reg(1)	Rand. Walk	Rand. Walk
Firm FE	Y	Y	Y	Y	Y	Y
Time FE	Y	Y	Y	Y	Y	Y
Industry-Time FE	N	Y	N	Y	N	Y
N	84656	84656	84313	84313	14274640	14274640
adj. R^2	0.446	0.451	0.446	0.451	0.450	0.450

Dampened inaction responses to prod. shocks in industries with higher ξ

Empirical Exercise 2: Information Frictions & Inv. Sensitivity

	inaction = 1					
	Data				Model	
$\xi_s \times w_{i,t}$	**0.010****	**0.011****	**0.011****	**0.010****	0.012	0.013
	(0.005)	(0.005)	(0.005)	(0.005)	(——)	(——)
w_{it}	-0.036	-0.030	-0.036	-0.029	-0.188	-0.188
	(0.031)	(0.031)	(0.032)	(0.032)	(——)	(——)
a_{it-1}	-0.028**	-0.015	-0.029**	-0.016	-0.670	-0.670
	(0.012)	(0.012)	(0.011)	(0.011)	(——)	(——)
Productivity	Rand. Walk	Rand. Walk	Auto. Reg(1)	Auto. Reg(1)	Rand. Walk	Rand. Walk
Firm FE	Y	Y	Y	Y	Y	Y
Time FE	Y	Y	Y	Y	Y	Y
Industry-Time FE	N	Y	N	Y	N	Y
N	84656	84656	84313	84313	14274640	14274640
adj. R^2	0.446	0.451	0.446	0.451	0.450	0.450

1 SD in $\xi_s \Rightarrow$ reduces prod shock response by $\sim 1/3$

Conclusions

- Information and investment frictions interact in rich ways
- Parsimonious model delivers testable predictions, consistent with the data
- Information frictions are easily incorporated into continuous time inaction models (there are many applications beyond investment)
- An alternative structure for investment frictions:
  - Old paradigm: fixed costs to get inaction, + large or convex adjustment costs to get attenuation
  - New paradigm: *irreversibility* to get inaction, + *information frictions* to get attenuation
- Strong empirical evidence, and robust to many alternative specifications

Appendix

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Koby, Yann and Christian Wolf, "Aggregation in heterogeneous-firm models: Theory and measurement," *Manuscript, July*, 2020.

How Do Firms Nowcast?

Lemma (1.a)

For a firm with information set $\Omega(t)$, productivity is conditionally distributed

$$a(t)|\Omega(t) \sim N\left(a(t-\tau) + \gamma\left(s(t) - s(t-\tau)\right), \nu\right)$$

where

$$\gamma \equiv \frac{\sigma_a^2}{\sigma_a^2 + \sigma_n^2} \qquad \nu \equiv \frac{\tau\sigma_a^2\sigma_n^2}{\sigma_a^2 + \sigma_n^2}$$

How Do Nowcasts Behave?

Lemma (1.b)

A firm's expected productivity $\hat{a} \equiv \mathbb{E}[a|\Omega]$ *and nowcast error* u *follow the diffusions*

$$d\hat{a} = \sigma_a dW^{\hat{a}} \qquad du = \sigma_u dW^u$$

where

$$dW_t^{\hat{a}} = (1-\gamma)dW_{t-\tau}^A + \gamma dW_t^A + \gamma\frac{\sigma_n}{\sigma_a}(dW_t^n - dW_{t-\tau}^n)$$

$$dW_t^u = (1-\gamma)\frac{\sigma_a}{\sigma_u}(dW_t^A - dW_{t-\tau}^A) + \gamma\frac{\sigma_n}{\sigma_u}(dW_t^n - dW_{t-\tau}^n)$$

$$\sigma_u^2 = 2\frac{\sigma_n^2\sigma_a^2}{\sigma_a^2 + \sigma_n^2}$$

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Boundary Solution

The critical value $\hat{b}$ depends on: the variance of nowcast errors ν, the capital share α, the cost of investment ψ, as well as ϱ and m defined as:

$$\varrho \equiv \frac{\mu - \sqrt{\mu^2 + 2\sigma_a^2 r}}{\sigma_a^2} \qquad m \equiv \frac{1}{r + \mu\alpha - \frac{\sigma_a^2}{2}\alpha^2}$$

Lemma (3)

The critical value of expected normalized capital is

$$\hat{b} = \underbrace{\frac{1}{(1-\alpha)} \log\left(\frac{m\alpha(\alpha-\varrho)}{\psi(1-\varrho)}\right)}_{b^{FI} \text{ full info. boundary}} + \frac{\alpha^2\nu}{2(1-\alpha)}$$

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Solving the Firm's Problem: Normalization

- Standard approach: define normalized capital

$$X \equiv \frac{K}{A} \qquad x \equiv k - a$$

- HJB is simpler in one dimension:

$$rV(X) = X^{\alpha} - \delta X V'(X) + \frac{\sigma_a^2 X^2}{2} V''(X)$$

or in logs

$$rv(x) = e^{\alpha x} - \mu v'(x) + \frac{\sigma_a^2}{2} v''(x)$$

where $\mu \equiv \delta + \frac{\sigma_a^2}{2}$

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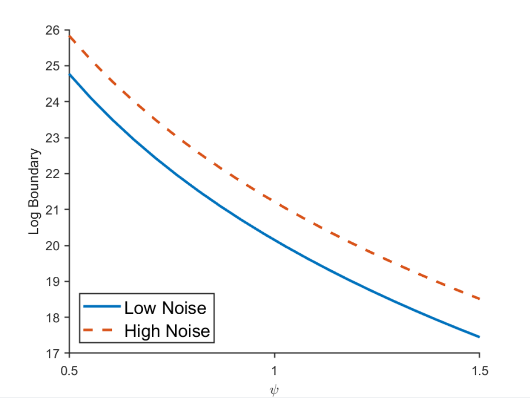
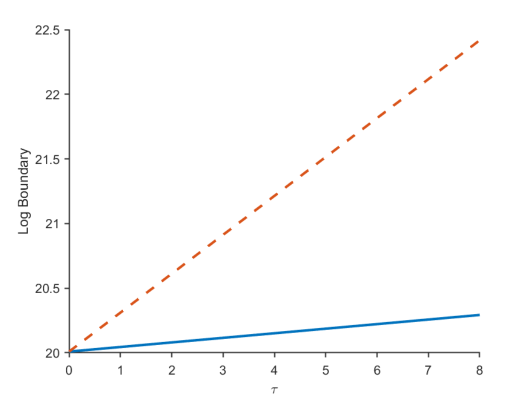
How the Boundary $\hat{b}$ Depends on the Information Friction

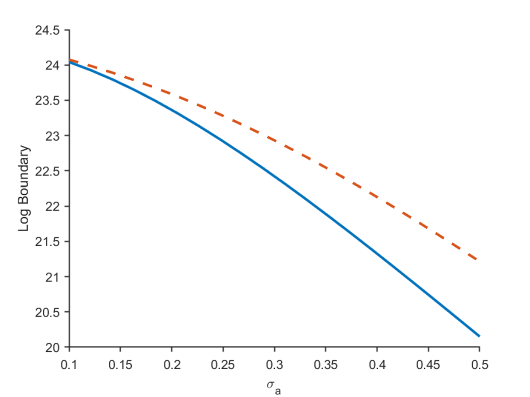


Investment Cost ψ



Revelation Delay τ

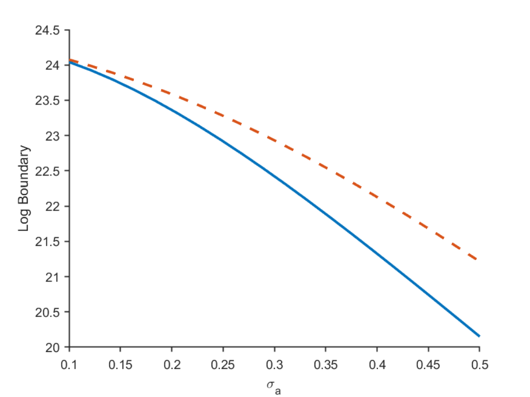
How the Boundary $\hat{b}$ Depends on "Uncertainty"



- Full info option-value effect of uncertainty over *future* productivity: higher volatility $\implies$ lower capital threshold

▸ Back

How the Boundary $\hat{b}$ Depends on "Uncertainty"



- Full info option-value effect of uncertainty over *future* productivity: higher volatility $\implies$ lower capital threshold
- ... but uncertainty over *current* productivity has opposite effect: more noise ($\sigma_n \uparrow$) $\implies$ *higher* capital threshold

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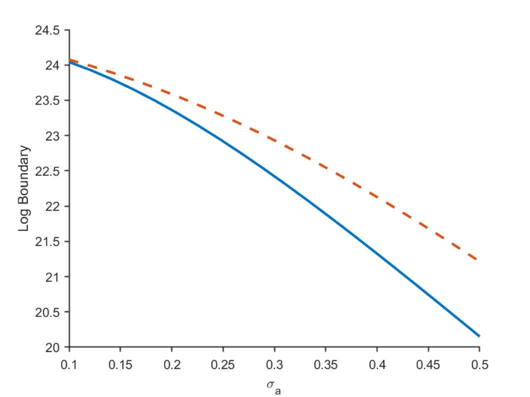

- Full info option-value effect of uncertainty over *future* productivity: higher volatility $\implies$ lower capital threshold
- ... but uncertainty over *current* productivity has opposite effect: more noise ($\sigma_n \uparrow$) $\implies$ *higher* capital threshold
- Noise interacts nonlinearly with the original effect!

▸ Back

Firm Entry and Exit

- Firm entry/exit keeps the size distribution non-degenerate

▸ Back

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- Firm entry/exit keeps the size distribution non-degenerate
- Firms exit randomly at rate η, with value returned to owners. Measure η of firms enter at every moment

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  - Enter with distribution $\hat{a} \sim N(0, \varsigma)$

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  - Enter with distribution $\hat{a} \sim N(0, \varsigma)$
  - Entering firms are as uncertain about productivity as existing firms: $a \sim N(\hat{a}, \nu)$

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- Firms exit randomly at rate η, with value returned to owners. Measure η of firms enter at every moment
- Measure η of firms enter at every moment
  - Enter with distribution $\hat{a} \sim N(0, \varsigma)$
  - Entering firms are as uncertain about productivity as existing firms: $a \sim N(\hat{a}, \nu)$
  - Their expected normalized capital $\hat{x}$ enters at the critical value $\hat{b}$

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Summary of the Japanese Firm-level Data

Table 1: Sample Comparison (Quarterly)

Moments	Merged Dataset	Entire Sample (FSS)
Number of obs. (Non-missing sales)	392,158	1,260,836
Average employment	1040.582	491.6123
Average sales (million JPY)	19991.75	8541.767
Average fixed capital stock	59919.34	24842.79

Table 2: Investment Moments Using Fixed Capital at Both Frequencies

Frequency	Exit Rate	Agg. Inv. Rate	Inv. Rate Mean	Inv. Rate S.D.	Inaction Rate	Spike Rate
Quarterly	2.00%	1.23%	2.27%	6.10%	60.00%	0.90%
Semiannual	3.96%	2.64%	4.00%	8.3%	36.6%	2.45%

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Model Calibration

Table 3: Parametrization of the Stylized Model

Parameter	r	α	τ	ψ	η	ς	δ	σ_a	σ_n^0	σ_n^{30}	$\Delta\sigma_n$
Value	1%	0.85	1	1	2%	0	1.23%	0.15	0.00	$0.75\sigma_a$	$0.025\sigma_a$

Table 4: Information Incompleteness and Investment Moments

Industry	σ_n	ξ_s	Inv. Rate Mean	Inv. Rate S.D.	Inaction Rate	Spike Rate
Full Information	0.000	0.000	2.37%	6.7%	81.0%	3.9%
Median Noise	$0.375\sigma_a$	0.018	2.29%	6.1%	79.8%	3.3%
Highest Noise	$0.75\sigma_a$	0.055	2.20%	5.53%	77.7%	2.4%

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Partial Irreversibility

- If firms invest, they do so at cost $\Psi(I)$:

$$\Psi(I) = \begin{cases} \psi_+ I & I \geq 0 \\ \psi_- I & I < 0 \end{cases}$$

  with $\psi_+ > \psi_- > 0$

- Instantaneous profit is $\pi = A^{1-\alpha} K^{\alpha} - \Psi(I)$
- Optimal firm behavior: for a range of capital values, firms choose to neither invest nor divest. Usual HJB in the inaction region.
- Solving the firm's problem comes down to finding the optimal choice of $\hat{B}_L$ and $\hat{B}_U$

Partial Irreversibility

Lemma

Under incomplete information, the boundary conditions consist of two value-matching conditions:

$$\hat{V}'(\hat{B}_L) = \psi_+ \qquad \hat{V}'(\hat{B}_U) = \psi_-$$

and two super contact conditions:

$$\hat{V}''(\hat{B}_L) = 0 \qquad \hat{V}''(\hat{B}_U) = 0$$

Partial Irreversibility

Proposition (7)

The critical values of expected normalized capital are

$$\hat{b}_L = b_L^{FI} + \frac{\alpha^2 \nu}{2(1-\alpha)} \qquad \hat{b}_H = b_H^{FI} + \frac{\alpha^2 \nu}{2(1-\alpha)}$$

where b_L^{FI} and b_H^{FI} denote the full information solutions such that $\nu = 0$.

▸ Back