The Technological Origins of Aggregate Fluctuations and Systematic Risk

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The Technological Origins of Aggregate Fluctuations and Systematic Risk

Where do fluctuations in aggregate economic activity originate?

Shocks to all firms? Oil, credit conditions, monetary and fiscal policy...

- Empirically, leaves some aggregate variance unexplained

Shocks to huge firms? Idiosyncratic shocks, fat-tailed firm size distribution...

- Trouble explaining productivity comovement and firm-level risk

Shocks to networked firms? Idiosyncratic shocks, input-output networks...

- Trouble explaining productivity comovement, maybe also firm-level risk

Where do fluctuations in aggregate economic activity originate? From endogenous co-movement in firm-level productivity

Motivating evidence:

- Three stylized facts on firm-level co-movement using Compustat data
- Based on simple aggregate variance decomposition

Theoretical framework:

- Tractable DSGE production economy with multi-product, multi-technology firms
- Endogenous prob distributions and covariance for firm and aggregate productivity

Regression analysis:

- Plausibility check on key predictions of the model
- Tentative empirical support for TFP comovement hypothesis

My work relates to three strands of literature in macro and finance

Origins of Aggregate Fluctuations:

- Herskovic et al. (2017), Carvalho and Gabaix (2013), Acemoglu et al. (2012), Gabaix (2011)
- Idiosyncratic shocks to large or “hub” firms generate aggregate fluctuations
- Me: Firm-level productivity comovement drives aggregate fluctuations

General Equilibrium Asset Pricing:

- Clementi and Palazzo (2018), Zhang (2017), mrohorolu and Tuzel (2014)
- Idiosyncratic shocks and adjustment costs drive differences in risk
- Me: Differences in exposure to common shocks drive differences in risk

Endogenous Risk:

- Romer (2016), Carvalho and Grassi (2019), Stiglitz (2011), Danielsson and Shin (2003)
- Agents should choose their risks, chosen risks should *become* systemic
- Me: Firms choose their risks, making firm-level uncertainty endogenous

The Technological Origins of Aggregate Fluctuations and Systematic Risk

A simple aggregate variance decomposition

For a firm variable x_ω and an aggregate variable $X = \sum_{\omega \in \Omega} s_\omega x_\omega$:

$$\mathrm{Var}\left(X\right) = \sum_{\Omega} s_\omega^2 \, \mathrm{Var}\left(x_\omega\right) + \sum_{\Omega} \sum_{\Omega \setminus \{\omega\}} s_\omega s_{\omega'} \, \mathrm{Cov}\left(x_\omega, x_{\omega'}\right) = \sum_{\Omega} s_\omega \, \mathrm{Cov}\left(x_\omega, X\right)$$

Stylized facts:

1. Aggregate variance comes mostly from pairwise covariances
2. High-productivity firms contribute more to aggregate variance
3. High-productivity firms contribute less per dollar of market value

TFP Details

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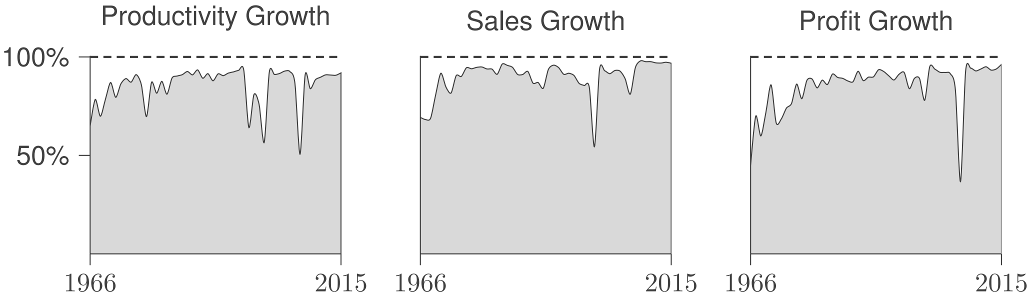
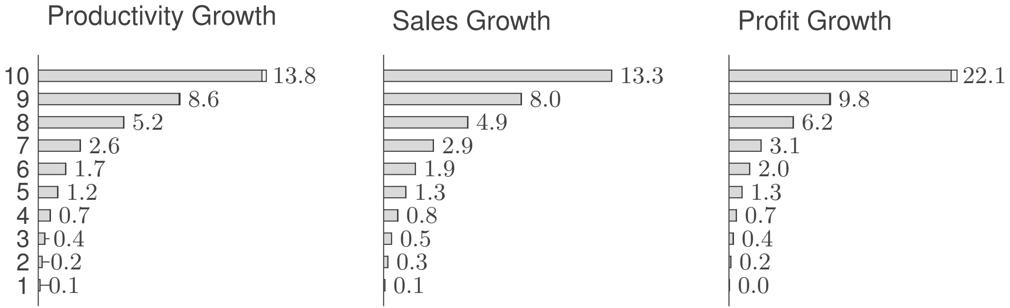
1. Aggregate variance comes mostly from pairwise covariances



Remarks:

- Weighted sum of pairwise covariances divided by aggregate variance
- Variances and covariances in 6-year rolling windows, Compustat 1966–2015

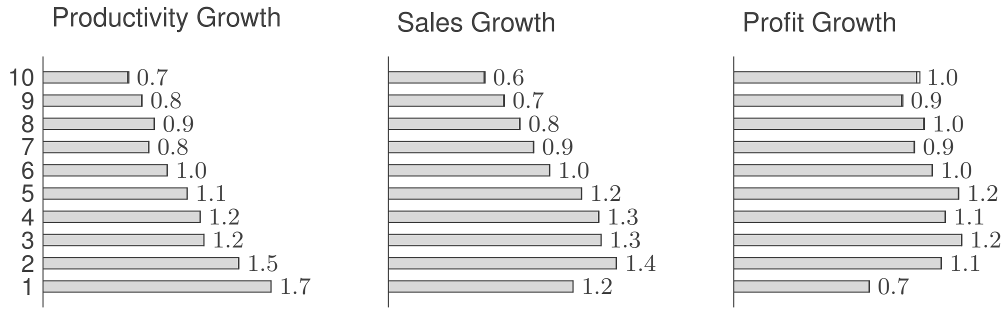
2. High-productivity firms contribute *most* to aggregate variance



Remarks:

- Weighted covariance between firm and aggregate, Compustat 1966–2015
- Decile median relative to cross-sectional median, averaged over 6-year rolling windows

3. High-productivity firms contribute *least* per dollar of market value



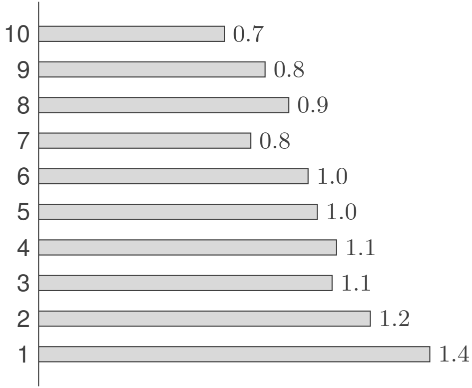
Remarks:

- Weighted covariance between firm and aggregate, relative to firm market value
- Decile median relative to cross-sectional median, averaged over 6-year rolling windows

2PCH

Bottom line: Existing theories don't capture all the evidence

Excess Returns*



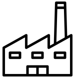
*As reported in mrohorolu and Tuzel (2014)

Remarks:

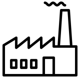
- Aggregate fluctuations come mostly from pairwise covariances, not individual variances
- High-productivity firms contribute *most* to aggregate fluctuations
- High-productivity firms contribute *least* per dollar of market value
- This may help explain high-productivity firms' lower excess returns

The Technological Origins of Aggregate Fluctuations and Systematic Risk

Common technology shocks drive covariance patterns



Low

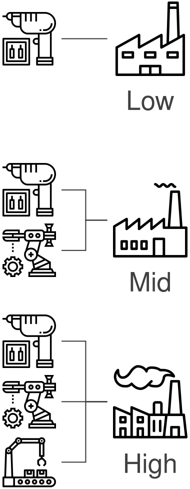


Mid

High

1. Heterogeneous firms
   - Some firms managed well
   - Others managed poorly
2. Heterogeneous technology
   - Some technologies cheap
   - Others expensive
3. Differentiated goods
   - Goods are firm-tech specific
   - Household consumes a basket
4. Common shocks
   - Cheap technologies are systemic
   - Low-prod firms are more exposed

Common technology shocks drive covariance patterns



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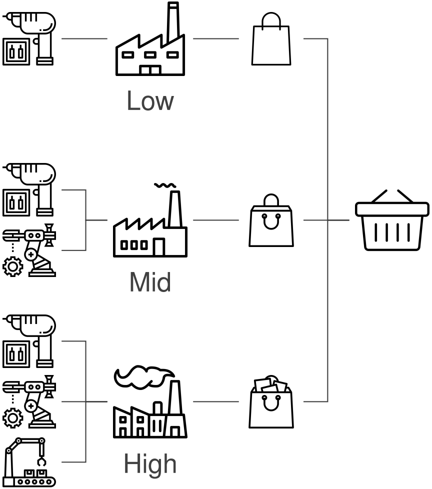

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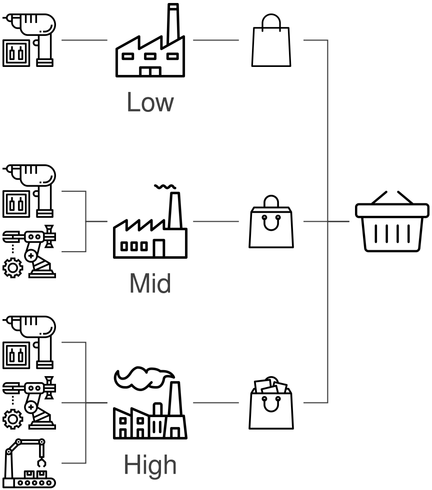

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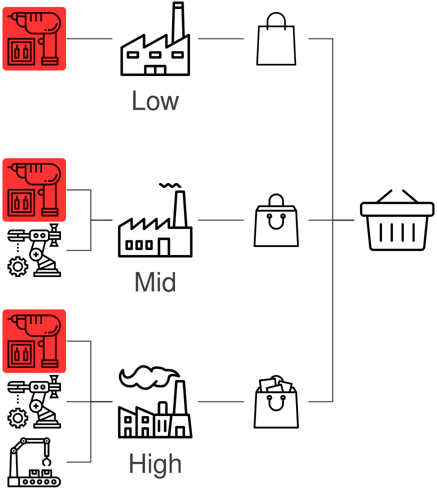

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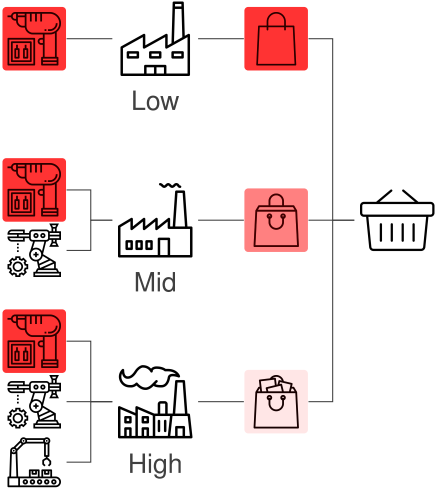

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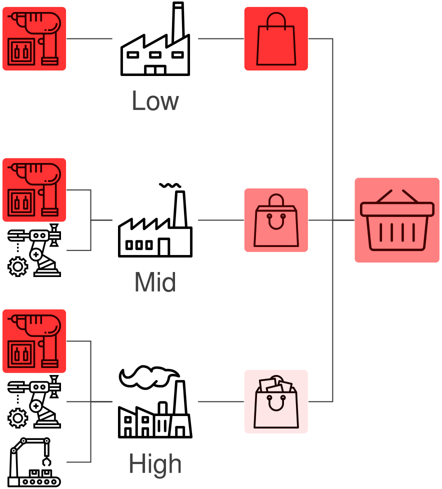

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Firms earn profit using technology to produce differentiated goods

Firms indexed ω produce multiple varieties v, each with a different technology:

$$y_t(v,\omega) = z(\omega) z_t(v) \big[k_t(v,\omega)\big]^{\alpha} \big[l_t(v,\omega)\big]^{1-\alpha}, \tag{1}$$

where $z_t(v)$ is stochastic, and $z(\omega)$ is not. Gross profit from each variety is:

$$\pi_t(v,\omega) = p_t(v,\omega) y_t(v,\omega) - r_t k_t(v,\omega) - w_t l_t(v,\omega). \tag{2}$$

Remarks:

- Two productivities: firm-specific non-random $z(\omega)$, technology-specific random $z_t(v)$
- Firms also pay a period fixed cost $f_t(v)$ for each technology

Firms choose inputs and prices to maximize profit each period I

Firms face downward-sloping demand for each variety:

$$c_t(v,\omega) = \left[p_t(v,\omega)\right]^{-\theta} C_t. \tag{3}$$

Firms choose prices and production factors to maximize profit:

$$\begin{aligned} \max_{\left\{\substack{k_t(v,\omega),\\ l_t(v,\omega),\\ p_t(v,\omega)}\right\}_{v\in\mathcal{V}(\omega)}} \quad & \Pi_t(\omega) = \int_{\mathcal{V}(\omega)} \pi_t(v,\omega)\lambda(dv) \\ \text{s.t.} \quad & \text{(1) and (3)} \quad \forall\, v \in \mathcal{V}(\omega). \end{aligned} \tag{4}$$

Firms must also choose their technology sets $\mathcal{V}(\omega) \subseteq \mathcal{V} = [\underline{v}, \infty)$.

First-Order Conditions

Firms choose next-period technologies to maximize expected profit

Firms operate any technology v with positive expected net present value:

$$\mathrm{E}_t\left[m_{t,t+1}(\pi_{t+1}(v,\omega) - f_{t+1}(v))\right] > 0. \tag{5}$$

Firms pay a fixed cost to operate technology v each period:

$$f_{t+1}(v) = \frac{Y_{t+1}}{\mu} v^{\gamma}. \tag{6}$$

Remarks:

- No sunk cost to adopt or abandon a technology
- Fixed cost assumed to rise and fall with aggregate production

Household buys consumption, capital, and stock with its income

Budget constraint:

$$
\begin{aligned}
w_t L + r_t K_t + \int_\Omega \left[\Pi_t(\omega) - F_t(\omega)\right] S_t(\omega)\lambda(d\omega) \\
= C_t + I_t + \int_\Omega V_t(\omega)\left[S_{t+1}(\omega) - S_t(\omega)\right]\lambda(d\omega).
\end{aligned}
\tag{7}
$$

Capital accumulation:

$$
K_{t+1} = I_t + (1-\delta)K_t. \tag{8}
$$

Remarks:

- Capital is produced in a separate sector to simplify goods market clearing
- I omit the primitives related to capital production here

Household maximizes expected discounted lifetime utility I

The household maximizes utility:

$$\max_{\left\{\substack{C_s,\\ K_{s+1},\\ S_{s+1}(\omega)}\right\}_{\substack{s\in\mathcal{T}_t,\\ \omega\in\Omega}}} \quad U_t = \mathrm{E}\left[\sum_{s=t}^{\infty}\beta^{s-t}\ln(C_s)\right] \tag{9}$$

$$\text{s.t.} \quad \text{(7) and (8)} \quad \forall\, s \geq t,$$

where the consumption basket is

$$C_t = \left[\int_{\Omega}\int_{\mathcal{V}(\omega)} \left[c_t(v,\omega)\right]^{\frac{\theta-1}{\theta}}\lambda(dv d\omega)\right]^{\frac{\theta}{\theta-1}}. \tag{10}$$

First-Order Conditions

Households differentiate goods by producer and technology

The household's second stage problem:

$$\begin{aligned} \max_{\substack{\{c_t(v,\omega)\}_{v\in\mathcal{V},\\ \omega\in\Omega}}} \quad & C_t = \left[\int_{\Omega} \int_{\mathcal{V}(\omega)} [c_t(v,\omega)]^{\frac{\theta-1}{\theta}} \lambda(dv d\omega) \right]^{\frac{\theta}{\theta-1}} \\ \text{s.t.} \quad & 1 = \int_{\Omega} \int_{\mathcal{V}(\omega)} p_t(v,\omega) c_t(v,\omega) \lambda(dv d\omega) \end{aligned} \tag{11}$$

Remarks:

- Household optimally allocates resources among differentiated goods
- Goods are differentiated by producer and by production technology

I've complicated the standard model—now what does it buy me?

What's new here?

- Many technologies exist, each a distinct source of randomness (more uncertainty)
- Some technologies are cheap to operate, others are expensive (more heterogeneity)
- Each technology allows a firm to make a new differentiated good (additional margin)

What does this set-up buy me?

- A microeconomic explanation for aggregate fluctuations
- A microeconomic explanation for firm-level systematic risk
- All fluctuations and risk are endogenous to firm-level decisions!

Can't come cheap, right? Wrong — no loss of tractability b/c model aggregates nicely

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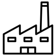
Proposition 1: Aggregation lets us view the model at three levels

Economy-Wide: $$Y_t = Z_t \big[K_t\big]^{\alpha} \big[L\big]^{1-\alpha}$$

Firm-Level: $$Y_t(\omega) = Z_t(\omega) \big[K_t(\omega)\big]^{\alpha} \big[L_t(\omega)\big]^{1-\alpha}$$



Product-Level: $$y_t(v,\omega) = z(\omega) z_t(v) \big[k_t(v,\omega)\big]^{\alpha} \big[l_t(v,\omega)\big]^{1-\alpha}$$

Remarks:

- Outputs Y_t and $Y_t(\omega)$ are each Dixit-Stiglitz aggregates of lower-level aggregates
- Aggregate factor demands and profit are also written in terms of Z_t and $Z_t(\omega)$

Proposition 1 (Aggregation)

A productivity aggregate over technologies summarizes all of the technological heterogeneity within an individual firm ω:

$$Z_t(\omega) = \left[\int_{\mathcal{V}(\omega)} \left[z(\omega) z_t(v) \right]^{\theta-1} \lambda(dv) \right]^{\frac{1}{\theta-1}}. \tag{12}$$

A productivity aggregate over firms summarizes all of the firm-specific and technological heterogeneity within the consumption goods sector:

$$Z_t = \left[\int_{\Omega} Z_t(\omega)^{\theta-1} \lambda(d\omega) \right]^{\frac{1}{\theta-1}}. \tag{13}$$

Aggregate factor demands, production, and profit can be written in terms of aggregate productivities and variables that either do not vary across firms, in the case of firm aggregates, or do not vary across firms or technologies, in the case of economy-wide aggregates.

Derivation

Integral sums of random variables? How is uncertainty preserved?

A simple construction inspired by Al-Najjar (1995) preserves risk in the continuum:

$$z_t(v)^{\theta-1} := \epsilon_{t,\lceil v \rceil} \quad \forall\, v \in \mathcal{V},$$

with $\mathcal{E} = \{\epsilon_{t,1}, \epsilon_{t,2}, \dots\}$ a *countable* set of random variables, and with:

$$\mathrm{E}\left[\epsilon_{t,n}\right] = \mu_\epsilon \quad \forall\, n \in \mathbb{N},$$

$$\mathrm{Var}\left(\epsilon_{t,n}\right) = \sigma_\epsilon^2 \quad \forall\, n \in \mathbb{N},$$

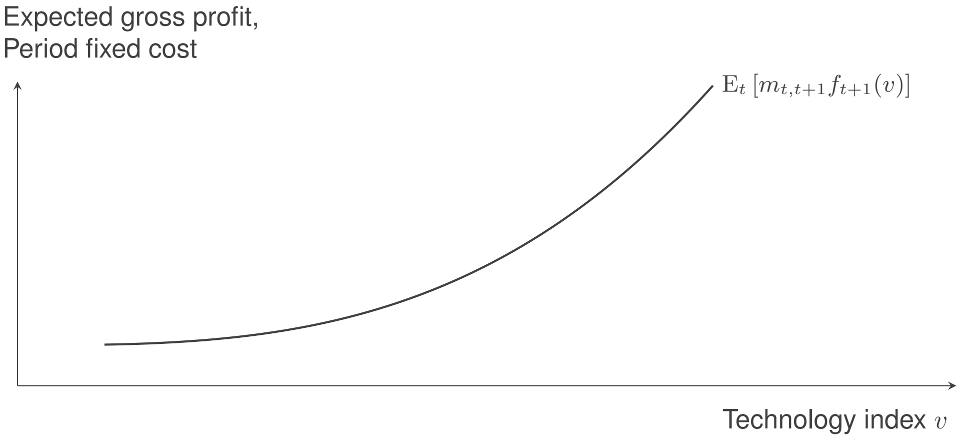
$$\mathrm{Cov}\left(\epsilon_{t,n}, \epsilon_{t,m}\right) = 0 \quad \forall\, n \neq m, \quad n, m \in \mathbb{N},$$

$$\mathrm{Cov}\left(\epsilon_{s,n}, \epsilon_{t,n}\right) = 0 \quad \forall\, n \in \mathbb{N}, \quad s \neq t \in \mathbb{Z}.$$

Remarks:

- Each ϵ_n is associated with a unit interval of $z_t(v)$'s, hence $z_t(v)$'s are not independent
- Interpret ϵ_n's as fundamental technologies, $z_t(v)$'s as commercial applications

Proposition 2: Technology sets are chosen by firms



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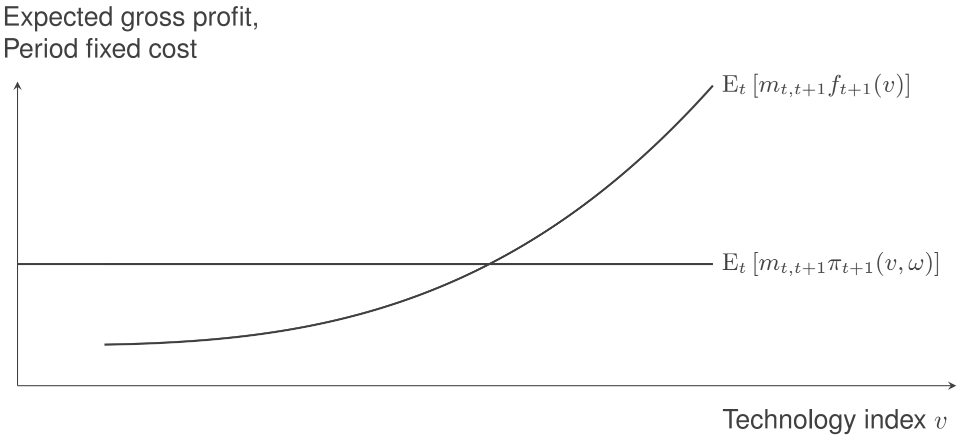

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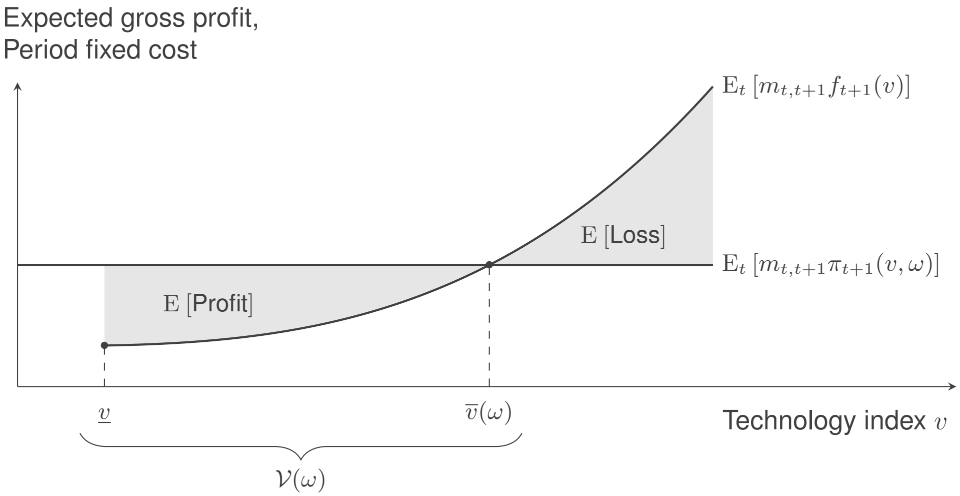


Proposition 2 (Technology Sets)

In non-stochastic steady state, any firm ω with productivity $z(\omega) \geq \underline{z}$ chooses technology set $\mathcal{V}(\omega) = \left\{ v \in \mathcal{V} : \underline{v} \leq v \leq \overline{v}(\omega) \right\}$, where the endogenous cut-offs $\underline{z}$ and $\overline{v}(\omega)$ are given by:

$$\underline{z} = \left(\frac{\theta}{\mu_\epsilon} \right)^{\frac{1}{\theta - 1}} \tag{14}$$

$$\overline{v}(\omega) = \left(\frac{\mu_\epsilon}{\theta} \right)^{\frac{1}{\gamma}} z(\omega)^{\frac{\theta - 1}{\gamma}}. \tag{15}$$

Firms with $z(\omega) < \underline{z}$ do not produce. Under parameter restrictions, firms ω_1 and ω_2 with productivities $\underline{z} < z(\omega_1) < z(\omega_2)$ choose technology sets such that $\mathcal{V}_t(\omega_1) \subset \mathcal{V}_t(\omega_2)$. The above cut-offs are also first-order approximate to those that obtain in a stochastic environment.

Derivation

Proposition 3 (Endogenous First and Second Moments)

Let technology sets be those that firms choose in non-stochastic steady state. Then the first and second moments of firm-level productivity are given by $\mu(\omega)$ and $\sigma^2(\omega)$, respectively:

$$\mu(\omega) = \mu_\epsilon z(\omega)^{\zeta_{\mu\omega 1}} \left[\left(\frac{z(\omega)}{\underline{z}} \right)^{\zeta_{\mu\omega 2}} - 1 \right], \tag{16}$$

$$\sigma^2(\omega) = \sigma_\epsilon^2 z(\omega)^{\zeta_{\sigma\omega 1}} \left[\left(\frac{z(\omega)}{\underline{z}} \right)^{\zeta_{\sigma\omega 2}} - 1 \right]. \tag{17}$$

The first and second moments of aggregate productivity are given by μ and σ^2, respectively:

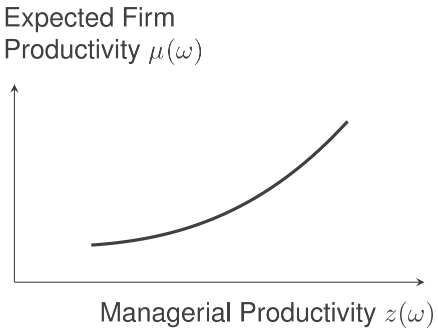
$$\mu = \mu_\epsilon \zeta_{\mu 1} \underline{z}^{\zeta_{\mu 2}}, \tag{18}$$

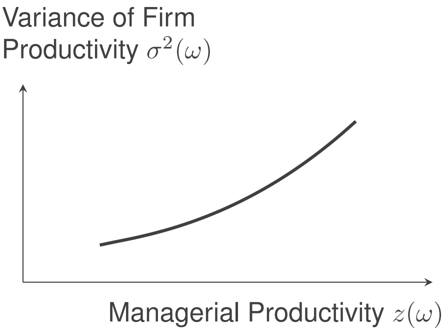
$$\sigma^2 = \sigma_\epsilon^2 \zeta_{\sigma 1} \underline{z}^{\zeta_{\sigma 2}}. \tag{19}$$

Under parameter restrictions, the first and second moments of all productivity aggregates are positive and finite. For firms ω_1 and ω_2 with $z(\omega_1) < z(\omega_2)$, we have $\mu_t(\omega_1) < \mu_t(\omega_2)$ and $\sigma_t^2(\omega_1) < \sigma_t^2(\omega_2)$.

FNZSM Intuition | Derivation

Well-managed firms have higher and more volatile productivity

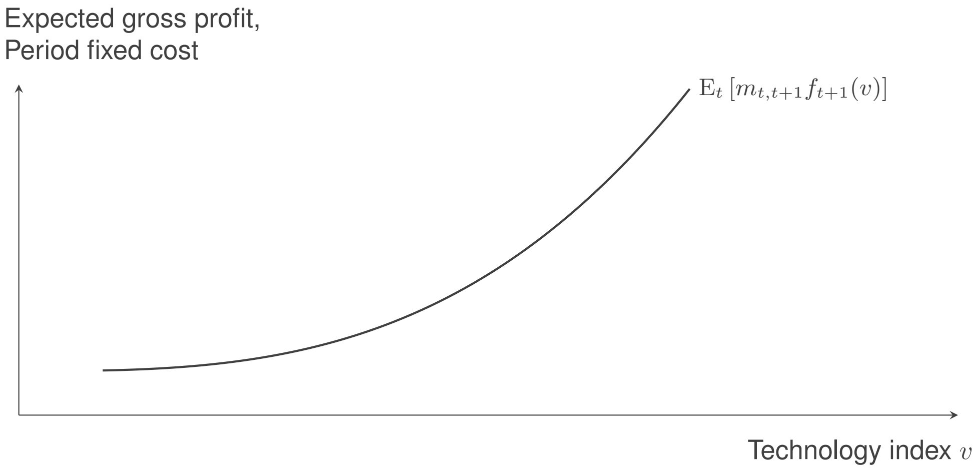




Remarks:

- Ad-hoc parameterization $\beta = 0.99$, $\delta = 0.1$, $\alpha = 0.25$, $\theta = 3.8$, $\kappa = 3.4$, $\gamma = 6$
- "Managerial productivity" is shorthand for firm-specific, non-technological productivity

Proposition 4: Covariance driven by overlapping technology



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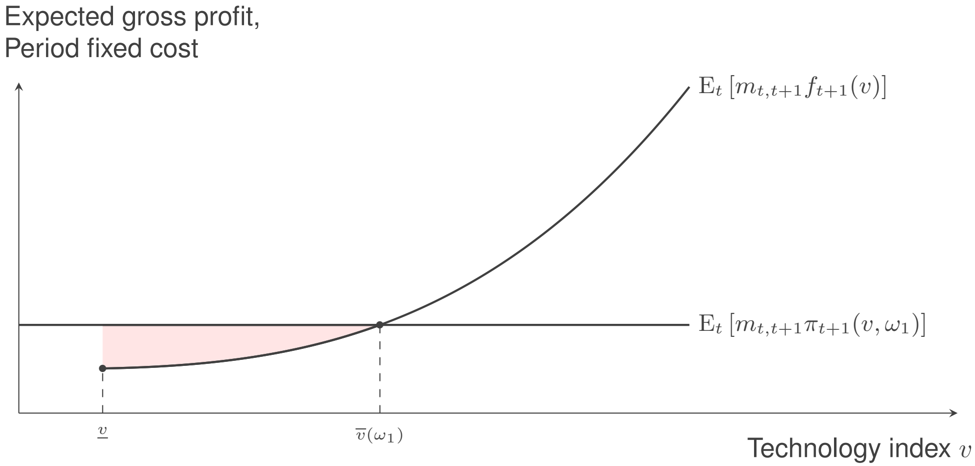

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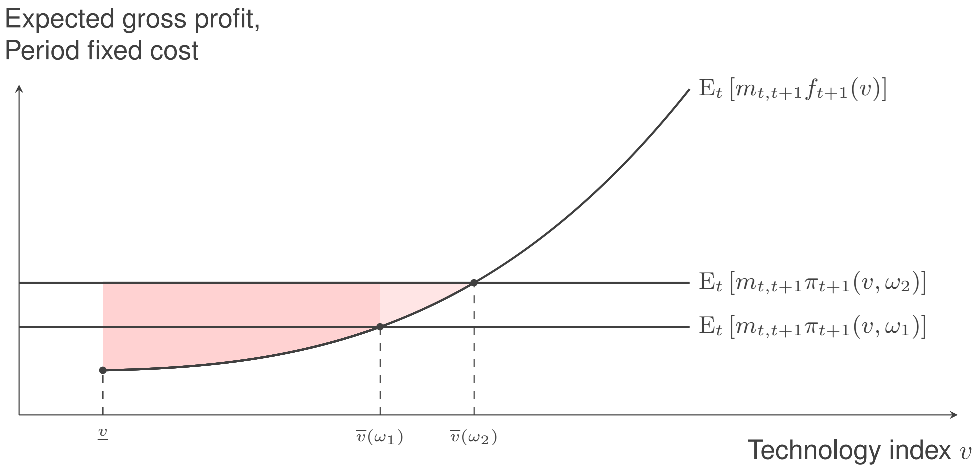

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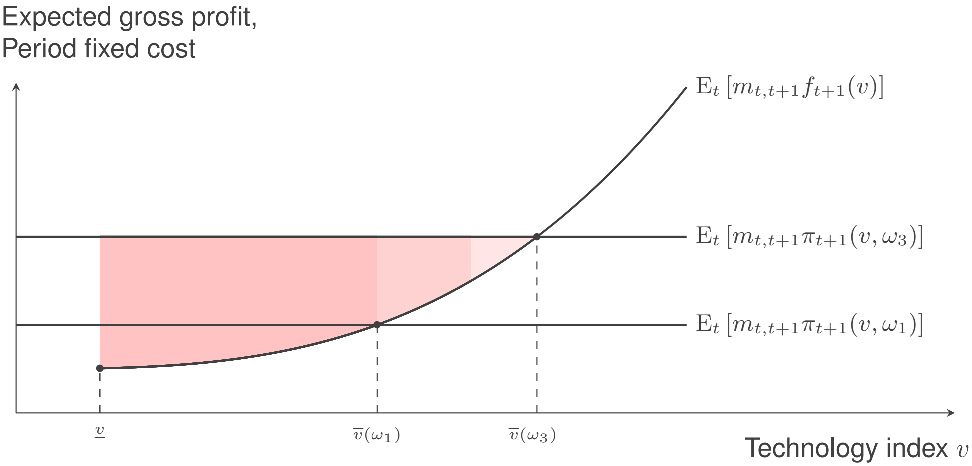

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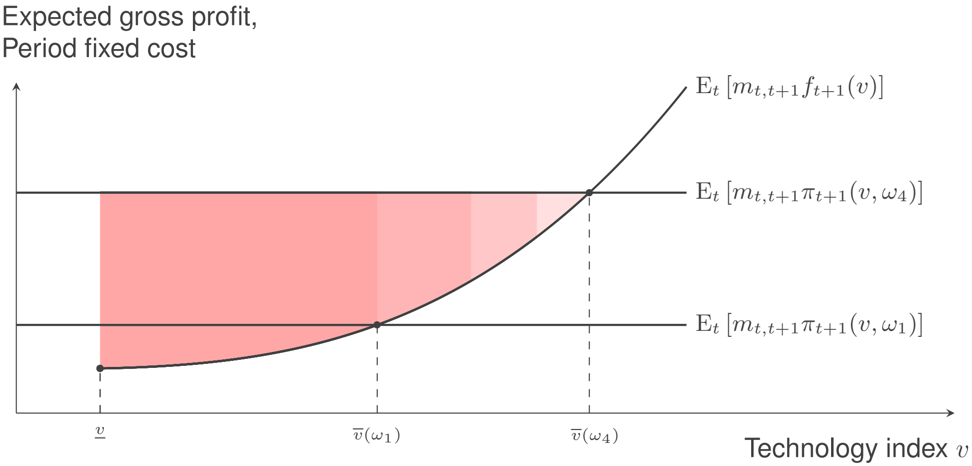

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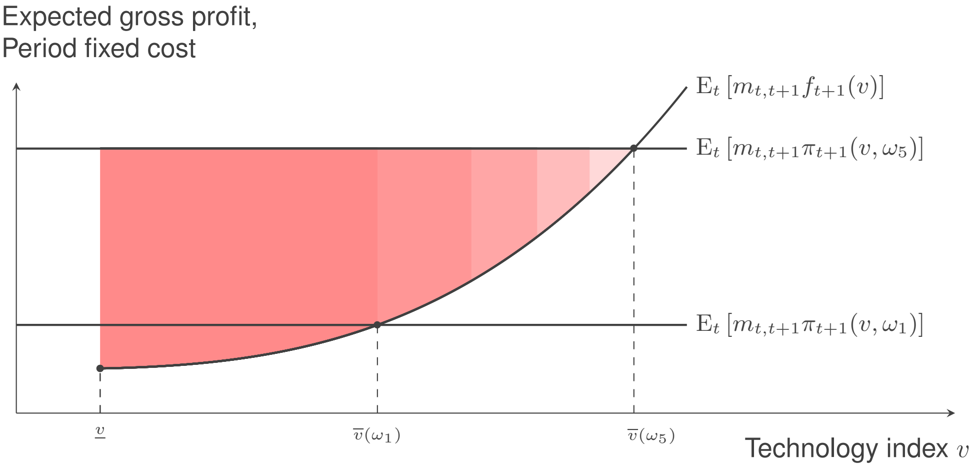


Proposition 4 (Firm-Aggregate Covariance)

Let technology sets be those that firms choose in the non-stochastic steady state. Then the covariance between firm and aggregate productivity, denoted by $\sigma_{\omega\Omega}(\omega) = \mathrm{Cov}\left(Z_t(\omega)^{\theta-1}, Z_t^{\theta-1}\right)$, is given by

$$\sigma_{\omega\Omega}(\omega) = z(\omega)^{\theta-1}\zeta_{\omega\Omega 1}\left[1 - \left(\frac{\underline{z}}{z(\omega)}\right)^{\zeta_{\omega\Omega 2}}\right] \tag{20}$$

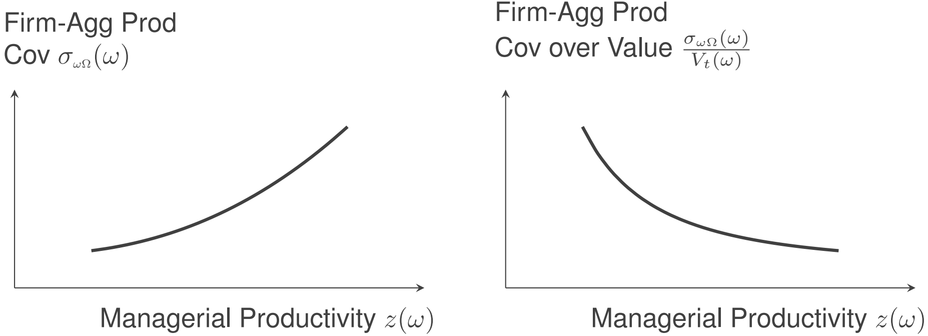
The covariance between firm and aggregate productivity, expressed as a fraction of firm market value, is approximated to a first order by

$$\frac{\sigma_{\omega\Omega}(\omega)}{V_t(\omega)} \approx \frac{1}{Y_t}\left(\frac{\zeta_{\omega\Omega 1}\left[1 - \left(\frac{\underline{z}}{z(\omega)}\right)^{\zeta_{\omega\Omega 2}}\right]}{\zeta_{V1}\left(\frac{z(\omega)}{\underline{z}}\right)^{\zeta_{V2}} + \zeta_{V3}\left(\frac{1}{z(\omega)}\right)^{\zeta_{V4}} - \left(\frac{1}{\underline{z}}\right)^{\zeta_{V4}}}\right). \tag{21}$$

Under parameter restrictions, covariance-over-value falls for all $z(\omega)$ above a threshold. The ratio also falls in the level of aggregate output.

Derivation

Well-managed firms covary more w/ aggregate productivity, but less per dollar of market value



Remarks:

- Firm-aggregate productivity covariance is higher for high-productivity firms
- Covariance-over-value lower for high-productivity firms, as in Compustat data

Proposition 5 (Stock Returns)

Let technology sets be those that firms choose in the non-stochastic steady state. Then firm ω's expected excess return is approximated to a second order by

$$\mathrm{E}_t\left[r_{t+1}(\omega) - r_{f,t+1}\right] \approx \zeta_{r1}\frac{\mu(\omega)}{V_t(\omega)} + \zeta_{r2}\frac{\sigma_{\omega\Omega}(\omega)}{V_t(\omega)}, \tag{22}$$

where I define firm ω's return as $r_t(\omega) = \left[V_{t+1}(\omega) + \Pi_{t+1}(\omega) - F_{t+1}(\omega)\right]/V_t(\omega)$, and the risk-free rate as $r_{f,t} = m_{t,t+1}^{-1}$. Under parameter restrictions, expected excess returns decrease in firm productivity $z(\omega)$ for all $z(\omega)$ above a threshold.

Derivation

The Technological Origins of Aggregate Fluctuations and Systematic Risk

Does TFP help explain patterns in firm-level covariance?

Testable predictions:

1. Ceteris paribus, covariance between firm and aggregate growth rates increases in firm-level total factor productivity.
2. Ceteris paribus, covariance between firm and aggregate growth rates over market value decreases in firm-level total factor productivity.

Compustat: Standard & Poor's data on U.S. public firms I

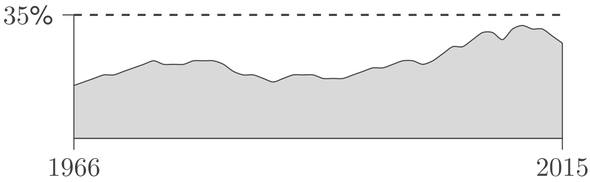
Basic description:

- 50 years: 1966–2015
- about 7,500 firms
- about 20% of yearly GDP
- all industries covered

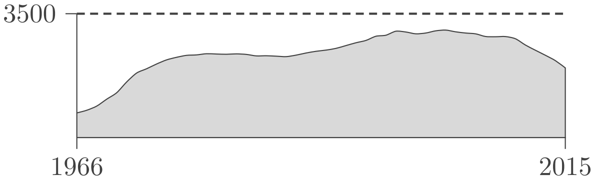
(Dis)advantages:

- Easy to access / replicate
- Not just manufacturing
- No small firms
- No private firms

Compustat Value Added over Real GDP



Yearly Number of Firms in Compustat



Details

Does TFP help explain patterns in firm-level covariance?

$$\frac{s_\omega \,\mathrm{Cov}\left(x_\omega, X\right)}{\mathrm{Base}} = \beta_0 + \beta_1 \left(\begin{smallmatrix} \text{Total Factor-} \\ \text{Productivity}_\omega \end{smallmatrix} \right) + \beta_2 \left(\begin{smallmatrix} \text{Financial} \\ \text{Strength}_\omega \end{smallmatrix} \right) + \beta_3 \left(\begin{smallmatrix} \text{Other} \\ \text{Controls}_{\omega,\Omega} \end{smallmatrix} \right) + \epsilon_\omega,$$

Remarks:

- Base is either aggregate variance $\mathrm{Var}\left(X\right)$, or firm market value $V_t(\omega)$
- Variables x_ω and X are productivity, sales, and profit growth
- Estimated dependent variable, so robust standard errors (Lewis & Linzer, 2005)
- Compustat diversification measures don't work (Villalonga, 2004); Census data needed

Regression: $s_\omega \, \mathrm{Cov}\left(x_\omega, X\right) / \mathrm{Var}\left(X\right)$ on explanatory variables

	Growth Rates		
	x, X = TFP	Sales	Profit
Olley-Pakes Total Factor Productivity	0.053^{*}	0.052^{*}	0.171^{***}
	(0.028)	(0.026)	(0.037)
Debt-to-Book Equity	0.006	0.002	0.004
	(0.005)	(0.004)	(0.004)
Quick Ratio	-0.000	-0.001	0.001
	(0.000)	(0.001)	(0.001)
Years in Compustat	0.022^{***}	-0.005	-0.001
	(0.007)	(0.007)	(0.008)
Employment Share	0.124^{***}	0.358^{***}	0.253^{***}
	(0.026)	(0.034)	(0.029)
R-squared	0.576	0.502	0.551

Regression: $s_\omega \, \mathrm{Cov}\left(x_\omega, X\right) / V_t(\omega)$ on explanatory variables

	Growth Rates		
	x, X = TFP	Sales	Profit
Olley-Pakes Total Factor Productivity	-0.059^{***}	-0.015^{**}	-0.033^{***}
	(0.013)	(0.008)	(0.012)
Debt-to-Book Equity	-0.018	0.005	0.003
	(0.027)	(0.013)	(0.010)
Quick Ratio	-0.008^{***}	-0.015^{***}	-0.011^{***}
	(0.002)	(0.004)	(0.002)
Years in Compustat	-0.103^{***}	-0.268^{***}	-0.144^{***}
	(0.007)	(0.008)	(0.007)
Employment Share	-0.000	0.012	0.035^{***}
	(0.006)	(0.010)	(0.008)
R-squared	0.443	0.420	0.368

Robust standard errors in parentheses; * p<0.10, ** p<0.05, *** p<0.01

The Technological Origins of Aggregate Fluctuations and Systematic Risk

Summing up: what's novel, what's useful, what's next?

Novelty: endogenous productivity comovement

1. firms choose their risks, and the chosen risks become systemic
2. firm-level productivity comovement as driver of aggregate fluctuations

Usefulness: highly tractable model

1. model aggregates, despite technology heterogeneity and choice problem
2. model preserves aggregate risk despite continuum of shocks (Al-Najjar, 1995)

Next Steps:

- Use new data on firm-level technology sets to improve empirics
- Extend framework to allow for dynamic adoption and abandonment

The Technological Origins of Aggregate Fluctuations and Systematic Risk

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