Ownership Structure and Economic Growth

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Ownership Structure $\Longrightarrow$ Economic Growth?

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Share

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  - BlackRock, Vanguard, and State Street exercise 30% of the votes at S&P 500
- Firms maximize shareholder value $\Longrightarrow$
  partially internalize externalities across commonly owned firms
- Ownership structure (common ownership, cross-ownership, M&A, ...) $\Longrightarrow$ Economic growth?
  - – Business-stealing effect
  - \+ Technology spillover effect

Quantitative Schumpeterian Growth Model with Ownership Structure

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  - Monopolistic competition
  - Very few firms in Markov perfect equilibrium

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  - Many oligopolists engage in a dynamic R&D game
  - Three inter-firm networks:
    1. Ownership structure
    2. Product-market rivalry
    3. Technology spillovers

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    1. Ownership structure
    2. Product-market rivalry
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- Commonly owned firms that are close in ...
  - product space $\Longrightarrow$ internalize the business-stealing effect $\Longrightarrow$ R&D $\downarrow$
  - technology space $\Longrightarrow$ internalize technology spillovers $\Longrightarrow$ R&D $\uparrow$

Identification and Findings

- Identify networks for publicly listed patenting firms in the U.S. ($>$ 700 firms)

Network	Measurement
Ownership structure	Investor holdings from 13F filings (Backus et al., 2021)
Product-market rivalry	Product proximity (Hoberg and Phillips, 2016): Based on business descriptions in 10-K filings
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- The rise of common ownership from 1999 to 2017 $\Longrightarrow g \downarrow$ by 0.11 p.p., CE welfare $\downarrow$ by 0.54%
- Internalization of business-stealing $>$ Internalization of technology spillover

Related Literature

- Competition & Innovation:
  d'Aspremont and Jacquemin (1988); Kamien et al. (1992); Aghion et al. (2001, 2005); Acemoglu and Akcigit (2012); Aghion et al. (2013); Bloom et al. (2013); Lopez and Vives (2019); Peters (2020); Akcigit and Ates (2021, 2023); Liu et al. (2022); Cavenaile et al. (2023), **Hopenhayn and Okumura (2024)**
  Quantitative Schumpeterian growth model with ownership structure
- Hedonic Demand / Empirical IO:
  Lancaster (1966); Rosen (1974); Berry et al. (1995); Nevo (2001), **Pellegrino (2024); Ederer and Pellegrino (2024)**
  Dynamic general equilibrium / R&D
- Oligopoly / Common Ownership / Market Power:
  Rubinstein and Yaari (1983); Rotemberg (1984); Neary (2003); Atkeson and Burstein (2008); Gutierrez and Philippon (2017); He and Huang (2017); Azar et al. (2018, 2022); Autor et al. (2020); Baqaee and Farhi (2020); De Loecker et al. (2020); Azar and Vives (2021); Edmond et al. (2023), **Anton et al. (2023, 2025); Kini et al. (2024)**

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- Firm $i \in \{1, \ldots, n\}$ has knowledge capital $z_{i,t}$ and produces a single differentiated product

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  - $\boldsymbol{\Sigma} = \left[\sigma_{ij}\right]$: product-market rivalry matrix (network) $(\sigma_{ii} = 1)$

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- Each firm allocates knowledge capital to improve labor productivity and product quality:

$$\zeta a_{i,t} + b_{i,t} = z_{i,t}$$

Common Ownership Weights (Networks)

- $\boldsymbol{K} = [\kappa_{ij}]$: common ownership weights that firm i places on the value of firm j $\quad (\kappa_{ii} = 1)$
- More overlapping ownership between firms i and $j \implies$ higher κ_{ij}

Proportional Influence

- $\boldsymbol{K} = \boldsymbol{I}$: dispersed ownership (each firm maximizes its own value)
- $\boldsymbol{K} = \mathbf{1}_{n\times n}$: monopoly (maximizes total producer surplus)

Law of Motion of Knowledge Capital

$$\dot{z}_t = \underbrace{\boldsymbol{\Omega} z_t}_{\text{Tech Spillover}} + \underbrace{\mu x_t}_{\text{R\&D}} - \underbrace{\delta z_t}_{\text{Depreciation}}$$

- $\boldsymbol{\Omega} = [\omega_{ij}]$: technology spillover matrix (network)
- $x_{i,t} = \sqrt{d_{i,t}}$
  - $d_{i,t}$: R&D input in terms of final good
  - Innovation elasticity is 0.5
- μ, δ: positive scalars
- Can incorporate idiosyncratic & aggregate shocks (not today)

Market Clearing and Preference

- Inelastic labor supply:

$$L = \sum_i l_{i,t}$$

- Linear-quadratic aggregator:

$$Y_t = \boldsymbol{q}_t^T \boldsymbol{b}_t - \frac{1}{2} \boldsymbol{q}_t^T \boldsymbol{\Sigma} \boldsymbol{q}_t$$

- Final good market clearing:

$$C_t + \underbrace{\sum_i d_{i,t}}_{\text{R\&D input}} = Y_t$$

- Risk-neutral representative household:

$$U_t = \int_t^\infty \exp\left(-\rho s\right) C_s ds$$

Static Cournot Game

- Firm i's static objective is given by:

$$\phi_{i,t} = \sum_j \kappa_{ij} \pi_{j,t}$$

where the profit (before R&D cost) of firm i is given by:

$$\pi_{i,t} = p_{i,t} q_{i,t} - w_t l_{i,t} = q_{i,t} \left(b_{i,t} - \sum_{j \neq i} \sigma_{ij} q_{j,t} - q_{i,t} - \frac{w_t}{a_{i,t}} \right)$$

- Given w_t, $z_{i,t}$, and $\{a_{j,t}, b_{j,t}, q_{j,t}\}_{j \neq i}$ and $\zeta a_{i,t} + b_{i,t} = z_{i,t}$, firm i chooses $a_{i,t}$, $b_{i,t}$, and $q_{i,t}$ to maximize $\phi_{i,t}$

Static Equilibrium

Linear-Quadratic Differential Game

- Given other firms' R&D $\{x_{j,t}\}_{j\neq i,\, t\geq 0}$, firm i chooses R&D $\{x_{i,t}\}_{t\geq 0}$ to maximize

$$\max_{\{x_{i,t}\}_{t\geq 0}} \quad V^i(\boldsymbol{z}_0) \equiv \int_0^{\infty} \exp(-\rho t) \left\{ \sum_j \kappa_{ij} \left(\pi_{j,t} - d_{j,t}\right) \right\} dt$$

subject to $\dot{\boldsymbol{z}}_t = \boldsymbol{\Omega} \boldsymbol{z}_t + \mu \boldsymbol{x}_t - \delta \boldsymbol{z}_t$

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- Gross profit: $\sum_j \kappa_{ij} \pi_{j,t} = \boldsymbol{z}_t^T \boldsymbol{Q}^i \boldsymbol{z}_t$ Q

- R&D cost: $d_{i,t} = x_{i,t}^2$

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- Gross profit: $\sum_j \kappa_{ij} \pi_{j,t} = \boldsymbol{z}_t^T \boldsymbol{Q}^i \boldsymbol{z}_t$ Q
- R&D cost: $d_{i,t} = x_{i,t}^2$
- Firm i's HJB equation:

$$\rho V^i(\boldsymbol{z}) = \max_{x_i} \left\{ \boldsymbol{z}^T \boldsymbol{Q}^i \boldsymbol{z} - \sum_j \kappa_{ij} x_j^2 + V_{\boldsymbol{z}}^i(\boldsymbol{z}) \left[\boldsymbol{\Omega} \boldsymbol{z} + \mu \boldsymbol{x} - \delta \boldsymbol{z} \right] \right\}$$

HJB Equations $\Longrightarrow$ Riccati Equations

- Guess and verify $V^i(z) = z^T X^i z$ (for any z)
- X^i is the solution of stacked algebraic Riccati equations

Riccati Equations

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  Riccati Equations
- Public & patenting firms in the U.S. in our dataset > 700 firms $\Longrightarrow$
  $\underbrace{700 \times 700}_{\text{size of } X^i} \times \underbrace{700}_{n} = 343$ million undetermined coefficients (< 1 min on my laptop)

Oligopolistic Schumpeterian	Computation time	# of firms	Productivity space
Cavenaile et al. (2023)	$O(2^n)$	4	6 grid
Our model	$O(n^4)$	>700	Continuous

Transition

BGP

- Linear R&D strategy: $x_t = \mu \widetilde{\boldsymbol{X}} z_t$ where $\widetilde{\boldsymbol{X}} = \begin{bmatrix} \boldsymbol{X}_1^1 & \cdots & \boldsymbol{X}_n^n \end{bmatrix}^T$ and $\boldsymbol{X}_i^i$ is the ith column of $\boldsymbol{X}^i$
- The law of motion is rewritten as $\dot{z}_t = \boldsymbol{\Phi} z_t$ where

$$\boldsymbol{\Phi} \equiv \underbrace{\boldsymbol{\Omega}}_{\text{Tech Spillover}} + \underbrace{\mu^2 \widetilde{\boldsymbol{X}}}_{\text{R\&D}} - \underbrace{\delta \boldsymbol{I}}_{\text{Depreciation}}$$

BGP

- Linear R&D strategy: $x_t = \mu \widetilde{X} z_t$ where $\widetilde{X} = \left[X_1^1 \ \cdots \ X_n^n\right]^T$ and X_i^i is the ith column of X^i
- The law of motion is rewritten as $\dot{z}_t = \Phi z_t$ where

$$\Phi \equiv \underbrace{\Omega}_{\text{Tech Spillover}} + \underbrace{\mu^2 \widetilde{X}}_{\text{R\&D}} - \underbrace{\delta I}_{\text{Depreciation}}$$

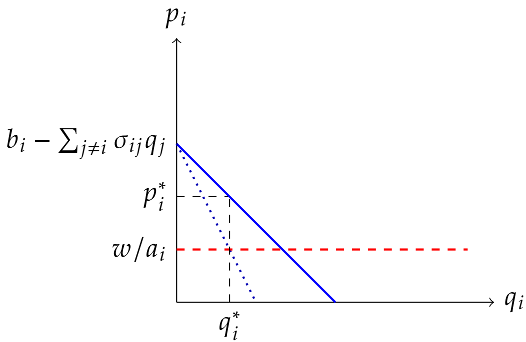
Theorem

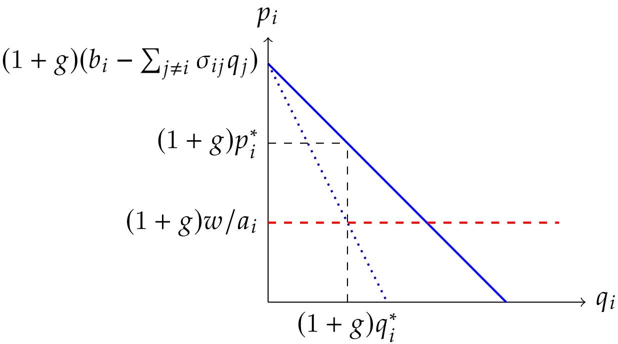
If Φ is irreducible, then:
(i) There exists a largest positive eigenvalue of Φ, g, and an associated positive eigenvector, z^*.
(ii) There exists a globally stable BGP such that the knowledge capital growth rate of all firms is g, and the knowledge capital distribution is a scalar multiple of z^*.

- Proof: Perron–Frobenius Theorem
- "Φ is irreducible" $\Longleftrightarrow$ "All firms are directly or indirectly connected technologically"

Symmetric Example

CES on BGP despite Non-CES Demand





- a_i, b_i, $q_i (= a_i l_i)$, p_i, and w/a_i grow at the same rate g
- (i) (consumer surplus / producer surplus) and (ii) (cost / revenue) stay the same
- Demand elasticity is constant on BGP despite linear demand

Lifetime Utility

- Lifetime utility is expressed in quadratic form:

$$\int_t^{\infty} \exp\left(-\rho s\right) C_s ds = \boldsymbol{z}_t^T X \boldsymbol{z}_t$$

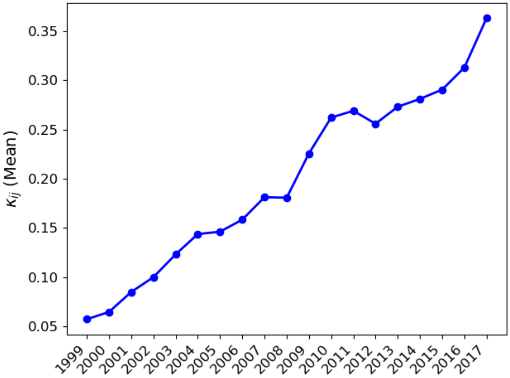
X

- Solve the equilibrium once $\Longrightarrow$ we can compute lifetime utility for any initial z_t
- This property holds even if we introduce idiosyncratic / aggregate shocks
- In the exercise, we focus on the transition dynamics starting from the observed initial z_t

Common Ownership Weights K

- Backus et al. (2021) construct a dataset on investors' holdings based on Form 13F
- Baseline: Rotemberg (1984) proportional influence

Proportional Influence



Product-Market Rivalry Σ

- Hoberg and Phillips (2016) estimates product proximity using business descriptions in 10-K
- Pellegrino (2024) estimates α to align with the cross-price elasticity of demand

$$\underbrace{\sigma_{ij}}_{\text{substitutability}} = \alpha \times \text{product proximity between } i \text{ and } j \qquad (i \neq j)$$

micro estimates

Technological Proximity $\widetilde{\Omega}$

- Technological profile of firm i
  - The vector of the share of patents held by firm i in each technology class
  - Baseline: group-level patent classifications (≈ 4000), five years window

- Jaffe (1986) technological proximity measure $\tilde{\omega}_{ij}$:
  - Cosine similarity of the technological profiles between firms i and j
  - Impose $\sum_{j \neq i} \tilde{\omega}_{ij} = 1$ for each i

Distribution of Knowledge Capital z_t

Variables	Identification
$\pi_{i,t}$	Gross profit (before R&D cost) = Revenue − Cost of goods sold
$\boldsymbol{q}_t$	$\pi_{i,t} = \sum_j \kappa_{ij}\, \sigma_{ij}\, q_{i,t}\, q_{j,t}$
ζ/L	Matches sample firms' cost share (average markup)
$\boldsymbol{z}_t$	$\boldsymbol{z}_t = \left\{2\frac{\zeta}{L}\mathbf{1}_{n\times n} + \boldsymbol{\Sigma} + \boldsymbol{K} \circ \boldsymbol{\Sigma}\right\} \boldsymbol{q}_t$

Technology Spillover $\Omega = \beta \times$Technological Proximity $\widetilde{\Omega}$ First Stage

$$\log z_{i,t+1} - \log z_{i,t} = \beta \sum_{j \neq i} \tilde{\omega}_{ij,t} \frac{z_{j,t}}{z_{i,t}} + \text{Controls}_{i,t} + \epsilon_{i,t}$$

	(1) $\log z_{i,t+1} - \log z_{i,t}$	(2) $\log z_{i,t+1} - \log z_{i,t}$	(3) $\log z_{i,t+1} - \log z_{i,t}$
$\sum_{j \neq i} \tilde{\omega}_{ij,t} \frac{z_{j,t}}{z_{i,t}}$	0.026**	0.024**	0.073*
	(0.010)	(0.010)	(0.038)
$\frac{x_{i,t}}{z_{i,t}}$		0.514***	
		(0.063)	
Firm & Year FEs	✓	✓	✓
Controls	✓	✓	✓
IV			✓
Observations	14,576	14,576	14,576

SEs clustered by years and 4-digit NAICS industries are reported in parentheses. Control variables include $\log z_{i,t}$, firm fixed effects, and year fixed effects. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

- IV: User cost of R&D, driven by federal and state-specific rules variations (Bloom et al., 2013)

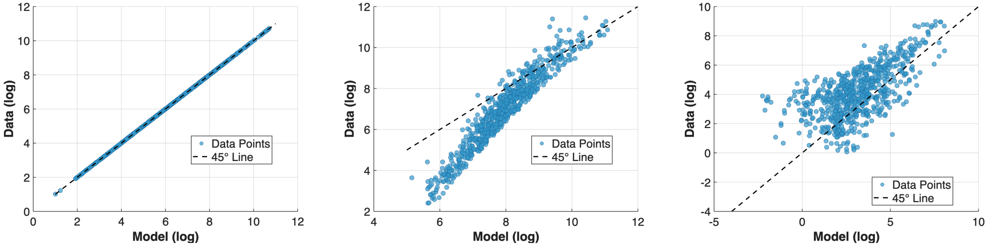
Identification: Summary

- Publicly available data + Compustat

Notation	Description	Value	Source
$\boldsymbol{\Sigma}$	Product proximity		Form 10-K, Hoberg and Phillips (2016)
$\widetilde{\boldsymbol{\Omega}}$	Technological proximity		USPTO, Patent classification
$\boldsymbol{K}$	Common ownership weights		Form 13F, Backus et al. (2021)
α	Product proximity $\rightarrow$ Substitutability	0.120	Pellegrino (2024)
β	Technological proximity $\rightarrow$ Spillovers	0.024	Estimated from the law of motion
ζ/L	Labor-augmenting efficiency	0.004	Compustat, Cost of goods sold
ρ	Discount rate	0.100	
μ	R&D efficiency	0.066	2.6% R&D share (moment match)
δ	Depreciation rate	0.017	1.2% economic growth rate (moment match)

Model vs. Data: Firm-level Profits, Sales, and R&D

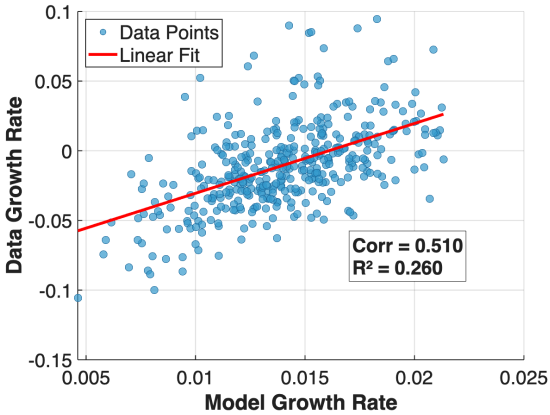
- Comparison of firm-level model-generated values (x-axis) with observed data (y-axis)



(a) Log of Profit (Targeted) (b) Log of Sales (c) Log of R&D Expenditure

Model vs. Data: Firm-level Growth Rates

- Data: Average growth rate of $z_{i,t}$ between 2010 and 2017
- Model: Networks and initial knowledge capital in 2010



Counterfactual Ownership Structures

Ownership Structure	Description
Baseline	Observed common ownership structure in 2017
Dispersed	$\boldsymbol{K}^D = \boldsymbol{I}$
Mean=1999	$\kappa_{ij,2017}^{M1999} = \text{const} \times \kappa_{ij,2017}$ and $\boldsymbol{E}\left[\kappa_{ij,2017}^{M1999}\right] = \boldsymbol{E}\left[\kappa_{ij,1999}\right]$ for $j \neq i$
Uniform	$\kappa_{ij,2017}^{U} = \boldsymbol{E}\left[\kappa_{ij,2017}\right]$ for $j \neq i$
Monopoly	$\boldsymbol{K}^M = \mathbf{1}_{n \times n}$

- For the moment, assume:
  - Ownership structure only affects R&D decisions
  - Product-market competition: firms maximize static profits (dispersed ownership)

Total R&D Expenditure (Optimal R&D: 100)

Total R&D in 2017 (Optimal R&D: 100)	Ownership (Baseline: 2017)				
	Dispersed	Mean=1999	Uniform	Baseline	Monopoly
Baseline	40.48	38.68	31.56	28.26	21.39
Only Business Steal $\boldsymbol{\Omega} = [0]$					
Only Tech Spill $\boldsymbol{\Sigma} = \boldsymbol{I}$, $\zeta/L = 0$					

- Internalization of business-stealing > internalization of technology spillovers

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	Dispersed	Mean=1999	Uniform	Baseline	Monopoly
Baseline	40.48	38.68	31.56	28.26	21.39
Only Business Steal $\boldsymbol{\Omega} = [0]$	52.04	49.73	41.51	36.40	30.69
Only Tech Spill $\boldsymbol{\Sigma} = \boldsymbol{I}$, $\zeta/L = 0$					

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Only Business Steal $\boldsymbol{\Omega} = [0]$	52.04	49.73	41.51	36.40	30.69
Only Tech Spill $\boldsymbol{\Sigma} = \boldsymbol{I},\ \zeta/L = 0$	13.61	14.25	18.33	19.33	27.77

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Total R&D, Growth Rate, Social Welfare, Firm Value Share

	Ownership (Baseline: 2017)				
	Dispersed	Mean=1999	Uniform	Baseline	Monopoly
Total R&D (Optimal R&D: 100)	40.48	38.68	31.56	28.26	21.39
Economic Growth Rate (%)					
Welfare (Optimal R&D: 100)					
Firm Value Share (%)					

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	Dispersed	Mean=1999	Uniform	Baseline	Monopoly
Total R&D (Optimal R&D: 100)	40.48	38.68	31.56	28.26	21.39
Economic Growth Rate (%)	1.32	1.31	1.24	1.20	1.11
Welfare (Optimal R&D: 100)					
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Economic Growth Rate (%)	1.32	1.31	1.24	1.20	1.11
Welfare (Optimal R&D: 100)	94.91	94.86	94.52	94.35	93.47
Firm Value Share (%)					

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Welfare (Optimal R&D: 100)	94.91	94.86	94.52	94.35	93.47
Firm Value Share (%)	26.63	26.72	27.20	27.24	27.82

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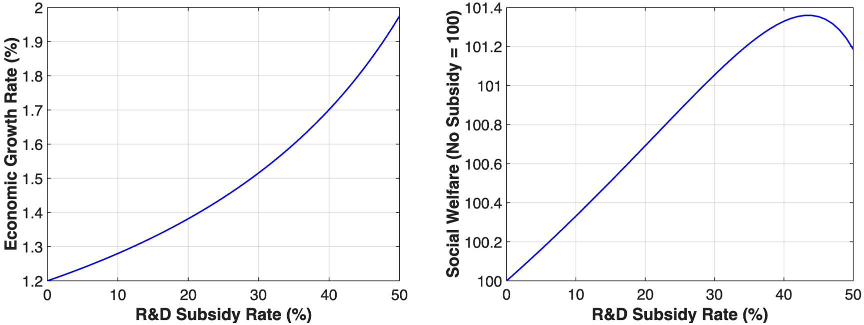
When Common Ownership Affects Both R&D and Production

Production ownership structure	Dispersed	Dispersed	Common
R&D ownership structure	Dispersed	Common	Common
Output (Dispersed: 100)	100.00	100.00	97.26
Total R&D (Dispersed: 100)	100.00	69.81	86.36
Economic Growth Rate (%)	1.323	1.200	1.288
Welfare (Dispersed: 100)	100.00	99.41	97.28
Firm Value Share (%)	26.63	27.24	34.10

- Less product market competition $\Longrightarrow$ Private return on R&D $\uparrow$

Optimal Uniform R&D Subsidy



(a) Economic Growth (b) Social Welfare

- Optimal rate is $s = 43\%$, which increases g by 0.57 pp and CE welfare by 1.36%
- c.f. Welfare gains from optimal R&D allocation: 6.0%

Which Firms' R&D Should be Subsidized?

	Private R&D x	Social / Private value of R&D
Initial knowledge capital z	0.122***	-0.000212
	(0.000848)	(0.000158)
Ownership structure centrality	-7.16***	0.580***
	(0.239)	(0.0446)
Product market centrality	-16.4***	-1.06***
	(0.286)	(0.0532)
Technology spillover centrality	5.45***	1.48***
	(0.423)	(0.0788)
Intercept	-22.4***	0.900***
	(0.255)	(0.0475)
Observations	740	740
R^2	0.976	0.555

Conclusion

- Quantitative Schumpeterian growth model with ownership structure
  - Utilizes micro data and computational capabilities
- Common ownership in the U.S.:
  1. Internalization of business-stealing effect $\Longrightarrow g \downarrow\downarrow$
  2. Internalization of technology spillover effect $\Longrightarrow g \uparrow$
- Potential applications:
  - Conglomerate: e.g., Chaebols (Korea), Zaibatsu / Keiretsu (Japan)
  - FDI and international technology diffusion
  - Technology licensing

Share of Top 5 Shareholders in Largest Market Cap Firms

Back

Microsoft	
Vanguard	9.20%
Blackrock	7.75%
Steven Ballmer	4.48%
State Street	3.97%
Fidelity	2.66%

Nvidia	
Vanguard	8.93%
BlackRock	7.74%
Fidelity	4.12%
State Street	3.97%
Jensen Huang	3.80%

Apple	
Vanguard	9.29%
Blackrock	7.48%
State Street	3.96%
Fidelity	2.27%
Geode Capital	2.26%

Google	
Vanguard	7.36%
Blackrock	6.47%
State Street	3.39%
Fidelity	3.01%
Sergey Brin	2.99%

Amazon	
Jeffrey Bezos	8.58%
Vanguard	7.77%
Blackrock	6.50%
State Street	3.44%
Fidelity	3.10%

Meta	
Vanguard	7.55%
Blackrock	6.50%
Fidelity	5.38%
Accel IX LP	3.88%
State Street	3.40%

Equity Investments by Big Tech in AI Startups

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Shareholding percentage	Microsoft	Google	Amazon
OpenAI (ChatGPT)	49%	—	—
Anthropic (Claude)	—	14%	23%

Technology & Product Proximity: Example

Tesla vs. Ford	
Technology Proximity	0.11
Product Proximity	0.15

Apple vs. Intel	
Technology Proximity	0.57
Product Proximity	0.00

Rotemberg (1984) Proportional Influence

- $o \in \{1, 2, ..., n_o\}$: owners
- s_{io}: the proportion of shares in firm i owned by owner o where $\sum_o s_{io} = 1$
- $\widehat{V}_i$: value of firm i
- $\widetilde{V}_o \equiv \sum_i s_{io} \widehat{V}_i$: value of owner o
- Firm i's objective:

$$\sum_o s_{io} \widetilde{V}_o \propto \sum_j \kappa_{ij} \widehat{V}_j$$

where

$$\kappa_{ij} \equiv \frac{\mathbf{s}_i^T \mathbf{s}_j}{\mathbf{s}_i^T \mathbf{s}_i} = \cos\left(\mathbf{s}_i, \mathbf{s}_j\right) \sqrt{\frac{IHHI_j}{IHHI_i}} \quad \text{where} \quad \mathbf{s}_i \equiv [s_{i1}, ..., s_{io}, ..., s_{in_o}]^T$$

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Empirical Literature: Common Ownership $\implies$ R&D

- Anton et al. (2025):
  - Dependent variables: R&D, citation-weighted patents, market value of patents
    - $+$ Interaction term between common ownership and technology proximity
    - $-$ Interaction term between common ownership and product proximity
- Kini et al. (2024): DiD that exploits mergers between financial institutions
  - Dependent variables: Investments, new product development
    - $+$ Post (merger) $\times$ treatment (common owner) $\times$ technology proximity

R&D Externalities

1. Business-stealing effect
   - Innovators steal the business (profits) of other firms
2. Technology spillover effect
   - Innovation improves the productivity of other firms
3. Appropriability effect (market power)
   - Innovators cannot appropriate the entire consumer surplus

Generalized Hedonic-Linear Demand (Pellegrino, 2024)

- $i \in \{1, 2, \dots, n\}$: firms / products
- 1 unit of product i provides
  - 1 unit of idiosyncratic characteristic $k \in \{1, 2, \dots, n\}$
  - $\psi_{k,i}$ unit of shared characteristic $k \in \{n+1, n+2, \dots, n+n_k\}$ where $\sum_k \psi_{k,i}^2 = 1$
- Aggregate each characteristic:

$$y_{k,t} = \begin{cases} q_{k,t} & k = 1, 2, \dots, n \\ \sum_i \psi_{k,i} q_{i,t} & k = n+1, n+2, \dots, n+n_k \end{cases}$$

- Linear-quadratic aggregator over characteristics:

$$Y_t = (1-\alpha) \sum_{k=1}^{n} \left(\underbrace{\hat{b}_{k,t} y_{k,t} - \frac{1}{2} y_{k,t}^2}_{\text{idiosyncratic characteristic}} \right) + \alpha \sum_{k=n+1}^{n+n_k} \left(\underbrace{\hat{b}_{k,t} y_{k,t} - \frac{1}{2} y_{k,t}^2}_{\text{shared characteristic}} \right)$$

Generalized Hedonic-Linear Demand (Pellegrino, 2024)

- Quality:

$$b_i = (1 - \alpha)\,\hat{b}_i + \alpha \sum_{k=n+1}^{n+n_k} \psi_k \hat{b}_k$$

- Inverse demand:

$$\frac{\boldsymbol{p}}{P} = \boldsymbol{b} - \boldsymbol{\Sigma}\boldsymbol{q}$$

- Inverse cross-price elasticity of demand:

$$\frac{\partial \log p_i}{\partial \log q_j} = -\frac{q_j}{p_i} \cdot \sigma_{ij}$$

- Cross-price elasticity of demand:

$$\frac{\partial \log q_i}{\partial \log p_j} = -\frac{p_j}{q_i} (\boldsymbol{\Sigma}^{-1})_{ij}$$

Characteristics of Static Equilibrium

- Equilibrium quantities:

$$q_i^* = \frac{1}{2} z_i - \sqrt{\zeta w_t} - \frac{1}{2} \sum_{j \neq i} (\sigma_{ij} + \kappa_{ij} \sigma_{ij}) q_j^*$$

- Assume $\{q_j^*\}_{j \neq i}$ are held constant
- By the Envelope Theorem, the marginal value of knowledge capital (R&D incentive) is given by:

$$\frac{\partial \phi_i^*}{\partial z_i} = q_i^*$$

- Greater overlap between ownership and product-market rivalry networks $\Longrightarrow$ R&D $\downarrow$

$$\frac{\partial^2 (\partial \phi_i^* / \partial z_i)}{\partial \kappa_{ij} \partial \sigma_{ij}} = \frac{\partial^2 q_i^*}{\partial \kappa_{ij} \partial \sigma_{ij}} = -\frac{1}{2} q_j^* < 0$$

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Static Profits

- Gross profit: $\pi_{i,t} = \sum_j \kappa_{ij}\sigma_{ij}q_{i,t}q_{j,t}$
- Firms choose labor productivity and product quality: $\zeta a_{i,t} = \sqrt{\zeta w_t}$, $b_{i,t} = z_{i,t} - \sqrt{\zeta w_t}$
- Labor market clearing: $L = \sum_i \frac{q_{i,t}}{a_{i,t}} \Longrightarrow \sqrt{\zeta w_t} = \frac{\zeta}{L}\sum_i q_{i,t}$
- $\boldsymbol{q}_t = \boldsymbol{N}\boldsymbol{z}_t$ where $\boldsymbol{N} \equiv \left\{2\frac{\zeta}{L}\boldsymbol{J} + \boldsymbol{\Sigma} + \boldsymbol{K}\circ\boldsymbol{\Sigma}\right\}^{-1}$
- $\boldsymbol{N}_i$: the ith row of $\boldsymbol{N}$
- Ownership weighted profit:

$$\sum_j \kappa_{ij}\frac{\pi_{j,t}}{P_t} = \sum_j \kappa_{ij}\sum_h \kappa_{jh}\sigma_{jh}q_{j,t}q_{h,t} = \boldsymbol{z}_t^T\boldsymbol{Q}^i\boldsymbol{z}_t$$

where

$$\boldsymbol{Q}^i = \frac{1}{2}\sum_j \kappa_{ij}\sum_h \kappa_{jh}\sigma_{jh}\left(N_j^T N_h + N_h^T N_j\right)$$

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Riccati Equations

- $V^i(z) = z^T X^i z$ where X^i is the solution of the stacked Riccati equation

$$0 = Q^i - \mu^2 \sum_j \kappa_{ij} X_j^j \left(X_j^j\right)^T + \left(\Phi - \frac{1}{2}\left(\rho - \gamma^2\right) I\right)^T X^i + X^i \left(\Phi - \frac{1}{2}\left(\rho - \gamma^2\right) I\right)$$

  - $X_i^i \equiv$ the ith column of X^i
  - $\Phi \equiv \Omega + \mu^2 \begin{bmatrix} X_1^1 & \cdots & X_n^n \end{bmatrix}^T$

- Algorithm: Given $\begin{bmatrix} X_\tau^1 & \cdots & X_\tau^n \end{bmatrix}$, update $\begin{bmatrix} X_{\tau-\Delta}^1 & \cdots & X_{\tau-\Delta}^n \end{bmatrix}$ by

$$-\frac{X_\tau^i - X_{\tau-\Delta}^i}{\Delta} = Q^i - \mu^2 \sum_j \kappa_{ij} X_{j,\tau}^j \left(X_{j,\tau}^j\right)^T + \left(\Phi_\tau - \frac{1}{2}\left(\rho - \gamma^2\right) I\right)^T X_\tau^i + X_\tau^i \left(\Phi_\tau - \frac{1}{2}\left(\rho - \gamma^2\right) I\right)$$

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Summary of Equilibrium

Description	Expression
Production strategy	$\boldsymbol{q}_t = \boldsymbol{N}\boldsymbol{z}_t$
R&D strategy	$\boldsymbol{x}_t = \mu\tilde{\boldsymbol{X}}\boldsymbol{z}_t$
Law of motion	$d\boldsymbol{z}_t = \left(\boldsymbol{\Omega}\boldsymbol{z}_t + \mu\boldsymbol{x}_t\right)dt + \gamma\boldsymbol{z}_t dW_t$
Profit of final producers	$\Pi_t^F/P_t = \boldsymbol{q}_t^T\left(\frac{1}{2}\boldsymbol{\Sigma}\right)\boldsymbol{q}_t$
Total operating profit of firms	$\Pi_t/P_t = \boldsymbol{q}_t^T\left(\frac{1}{2}\boldsymbol{\Sigma}\circ\left(\boldsymbol{K}+\boldsymbol{K}^T\right)\right)\boldsymbol{q}_t$
Labor income	$w_t L/P_t = \boldsymbol{q}_t^T\left(\frac{\zeta}{L}\boldsymbol{J}\right)\boldsymbol{q}_t$
Output	$Y_t = \boldsymbol{q}_t^T\left(\frac{\zeta}{L}\boldsymbol{J} + \frac{1}{2}\boldsymbol{\Sigma} + \frac{1}{2}\boldsymbol{\Sigma}\circ\left(\boldsymbol{K}+\boldsymbol{K}^T\right)\right)\boldsymbol{q}_t$
Consumption	$C_t = Y_t - \boldsymbol{x}_t^T\boldsymbol{x}_t$

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Example: Symmetric Equilibrium

Assumption

- No common ownership, symmetric product substitutability, symmetric technology spillover: $\kappa_{ij} = 0,\ \sigma_{ij} = \sigma, \omega_{ij} = \omega \quad \forall i \neq j$

- R&D strategy: $x^*_{i,t} = \mu \left(\tilde{x}_1 z_{i,t} + \tilde{x}_2 \sum_{j \neq i} z_j \right)$
  - $\tilde{x}_1$: market size effect (> 0)
  - $\tilde{x}_2$: strategic substitutability (< 0) / complementarity (> 0)

- Growth rate: $g = \underbrace{(n-1)\omega}_{\text{Tech Spillover}} + \underbrace{\mu^2 (\tilde{x}_1 + (n-1)\tilde{x}_2)}_{\text{R\&D}}$

- Stability (irreducibility) requires $\omega + \mu^2 \tilde{x}_2 > 0$
  - Tech spillover (ω) must be strong relative to strategic substitutability ($\tilde{x}_2 < 0$)

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Output and Expected Utility

- Output: $Y_t = \boldsymbol{q}_t^T \boldsymbol{Q} \boldsymbol{q}_t$ where

$$\boldsymbol{Q} = \frac{\zeta}{L}\boldsymbol{J} + \frac{1}{2}\boldsymbol{\Sigma} + \frac{1}{2}\boldsymbol{\Sigma} \circ \left(\boldsymbol{K} + \boldsymbol{K}^T\right)$$

- Expected utility:

$$V\left(\boldsymbol{z}_t\right) \equiv \boldsymbol{E}_t\left[\int_t^{\infty} \exp\left(-\rho s\right) C_s ds \middle| \boldsymbol{z}_t\right] = \boldsymbol{z}_t^T \boldsymbol{X} \boldsymbol{z}_t$$

where $\boldsymbol{X}$ is the solution of the Lyapunov equation (obtained from households' HJB equation):

$$0 = \boldsymbol{Q} - \mu^2 \tilde{\boldsymbol{X}}^T \tilde{\boldsymbol{X}} + \boldsymbol{X}\left(\boldsymbol{\Phi} - \frac{1}{2}\left(\rho - \gamma^2\right)\boldsymbol{I}\right) + \left(\boldsymbol{\Phi} - \frac{1}{2}\left(\rho - \gamma^2\right)\boldsymbol{I}\right)^T \boldsymbol{X}$$

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Social Optimum

- Static optimal allocation: $\boldsymbol{q}_t^* = \boldsymbol{N}^* \boldsymbol{z}_t$ where $\boldsymbol{N}^* \equiv \left\{2\frac{\zeta}{L}\boldsymbol{J} + \boldsymbol{\Sigma}\right\}^{-1}$
- Optimal output: $Y_t^* = \boldsymbol{z}_t^T \boldsymbol{Q}^* \boldsymbol{z}_t$ where $\boldsymbol{Q}^* = \frac{1}{2}\boldsymbol{N}^*$
- Optimal expected utility:

$$V^*(\boldsymbol{z}_t) \equiv \boldsymbol{E}_t \left[\int_t^\infty \exp(-\rho s)\, C_s ds \middle| \boldsymbol{z}_t \right] = \boldsymbol{z}_t^T \boldsymbol{X}^* \boldsymbol{z}_t,$$

where $\boldsymbol{X}^*$ is the solution of the Riccati equation (obtained from planner's HJB equation):

$$0 = \boldsymbol{Q}^* - \mu^2 (\boldsymbol{X}^*)^2 + \boldsymbol{X}^* \left(\boldsymbol{\Phi}^* - \frac{1}{2}(\rho - \gamma^2)\boldsymbol{I}\right) + \left(\boldsymbol{\Phi}^* - \frac{1}{2}(\rho - \gamma^2)\boldsymbol{I}\right)\boldsymbol{X}^*$$

- Optimal R&D: $\boldsymbol{x}_t^* = \mu \boldsymbol{X}^* \boldsymbol{z}_t$
- Optimal technology transition matrix: $\boldsymbol{\Phi}^* = \boldsymbol{\Omega} + \mu^2 \boldsymbol{X}^*$

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Property of BGP

- On the BGP, $\boldsymbol{a}_t$, $\boldsymbol{b}_t$, $\boldsymbol{z}_t$, and $\boldsymbol{q}_t$ grow at the same rate

Knowledge Capital:	$\zeta a_{i,t} + b_{i,t} = z_{i,t}$
Linear Production Technology:	$q_{i,t} = a_{i,t} l_{i,t}$
Inelastic Labor Supply:	$L = \sum_i l_{i,t}$

- The linear and quadratic terms in $\boldsymbol{q}_t$ of output grow at the same rate:

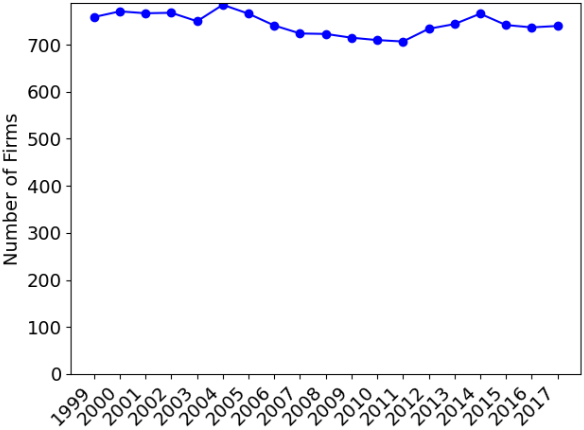
$$Y_t = \boldsymbol{q}_t^T \boldsymbol{b}_t - \frac{1}{2} \boldsymbol{q}_t^T \boldsymbol{\Sigma} \boldsymbol{q}_t$$

Growth Decomposition

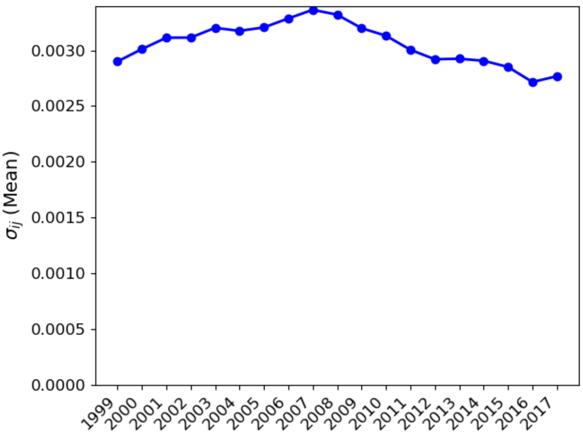
- Aggregate output: $Y_t = z_t^T Q z_t$
- $dz_t/dt = \mathbf{\Phi} z_t$ where $\mathbf{\Phi} = \mathbf{\Omega} + \mu^2 \widetilde{X} - \delta \boldsymbol{I}$

$$\frac{d\log Y_t}{dt} = \underbrace{\frac{z_t^T\left(Q\mathbf{\Omega} + \mathbf{\Omega}Q\right)z_t}{Y_t}}_{\text{Tech Spillover}} + \underbrace{\frac{\mu^2 z_t^T\left(Q\widetilde{X} + \widetilde{X}^T Q\right)z_t}{Y_t}}_{\text{R\&D}} - \underbrace{2\delta}_{\text{Depreciation}}$$

Number of Sample Firms

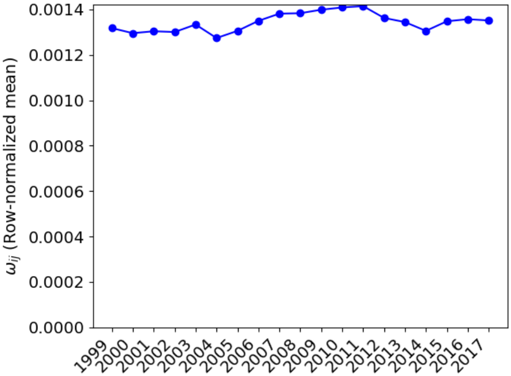


Trend of Product Substitutability



Technological Proximity

- Merge USPTO data with Compustat firms using DISCERN 2 dataset (Arora et al., 2024)
- Jaffe measure, group-level patent classification, stacked over 5 years



Correlation Across Networks

	K	Σ	Ω
K	1.0000	-0.0035	0.0115
Σ	-0.0035	1.0000	0.2542
Ω	0.0115	0.2542	1.0000

- K: Ownership network
- Σ: Product substitutability network
- Ω: Technological proximity network

Microeconometric Estimates vs. GHL (Pellegrino, 2024) (1/2)

Market	Firm i	Firm j	Micro Estimate	GHL
Auto	Ford	Ford	-4.320	-5.197
Auto	Ford	General Motors	0.034	0.056
Auto	Ford	Toyota	0.007	0.017
Auto	General Motors	Ford	0.065	0.052
Auto	General Motors	General Motors	-6.433	-4.685
Auto	General Motors	Toyota	0.008	0.005
Auto	Toyota	Ford	0.018	0.025
Auto	Toyota	General Motors	0.008	0.008
Auto	Toyota	Toyota	-3.085	-4.851

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Microeconometric Estimates vs. GHL (Pellegrino, 2024) (2/2)

Market	Firm i	Firm j	Micro Estimate	GHL
Cereals	Kellogg's	Kellogg's	-3.231	-1.770
Cereals	Kellogg's	Quaker Oats	0.033	0.023
Cereals	Quaker Oats	Kellogg's	0.046	0.031
Cereals	Quaker Oats	Quaker Oats	-3.031	-1.941
Computers	Apple	Apple	-11.979	-8.945
Computers	Apple	Dell	0.018	0.025
Computers	Dell	Apple	0.027	0.047
Computers	Dell	Dell	-5.570	-5.110

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First Stage

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	R&D (1)
State tax credit component of R&D user cost	-1.16^{***} (0.29)
Federal tax credit component of R&D user cost	-34.29^{***} (3.64)
Firm fixed effects	✓
Year fixed effects	✓
No. of observations	16197

SEs clustered by years and 4-digit NAICS industries are reported in parentheses.

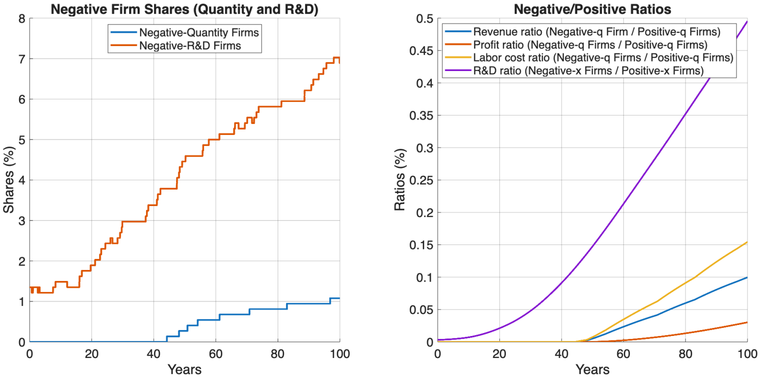
- IV: User cost of R&D, driven by federal and state-specific rules variations (Wilson, 2009; Bloom et al., 2013)

Negative R&D and Output

- Issue with the model: negative output and R&D
  - Inada condition is not satisfied
  - Non-negativity constraint makes model intractable

Negative R&D and Quantity

- Firms with negative values are negligible along the transition path
- The weight on consumption 100 years and beyond is 0.00454% ($\rho = 0.1$)



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Alternative Corporate Governance Models: Ederer and Pellegrino (2024)

1. Super-proportional influence: $\tilde{\kappa}_{ij} = \frac{\sum_o s_{io}\gamma_{io}s_{jo}}{\sum_o s_{io}\gamma_{io}s_{io}}$ where $\gamma_{io} = \sqrt{s_{io}}$
2. Blockholder influence: $\tilde{\kappa}_{ij} = \frac{\sum_o s_{io}b_{io}s_{jo}}{\sum_o s_{io}s_{jo}} \quad (i \neq j)$, where $b_{io} = 1$ if $s_{io} > 5\%$
3. Governance frictions and entrenchment
   - Azar and Ribeiro (2021) estimate an objective function where the manager of firm i discounts other firms' profit by τ_i

Alternative Corporate Governance Models

	Ownership Structure in 2017					
	Dispersed Ownership	Baseline: Proportional Influence	Super Proportional Influence	Blockholder Influence	Governance Frictions (Uniform)	Governance Frictions (Firm-Specific)
Total R&D Expenditure	100.00	69.81	68.97	77.45	90.32	90.41
Expected Growth Rate (%)	1.323	1.200	1.194	1.234	1.287	1.289
Expected Social Welfare	100.00	99.41	99.37	99.59	99.86	99.86
Firm Value Share (%)	26.63	27.24	27.24	27.09	26.82	26.84

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