

Ownership Structure and Economic Growth

Koki Okumura

The Chinese University of Hong Kong

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The Causes and Consequences of Common Ownership

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Ownership Structure $\implies$ Economic Growth?

- Corporate ownership is highly concentrated
 - In 2017, BlackRock, Vanguard, and State Street cast about 25% of the votes at S&P 500 firms (Bebchuk and Hirst, 2019)
- Such concentration has led to extensive policy and academic debate on common ownership
 - Less product-market competition (Azar et al., 2018; Ederer and Pellegrino, 2026)
 - Weaker incentives to innovate (Guideline 11, 2023 Merger Guidelines)
- **This paper examines the macroeconomic effects of common ownership on innovation, growth, and welfare**

Common Ownership and R&D Incentives

- Firms account for the value of other commonly owned firms $\implies$ they internalize inter-firm externalities
- Two inter-firm innovation externalities (Aghion and Howitt, 1992; Bloom et al., 2013):
 - Business stealing
 - + Technology spillovers
- When commonly owned firms are close in (Antón, Ederer, Giné, and Schmalz, 2025):
 - Product space: internalize business stealing $\implies$ R&D $\downarrow$
 - Technology space: internalize technology spillovers $\implies$ R&D $\uparrow$
- **What are the net effects of common ownership on aggregate R&D and economic growth?**

Network Approach

- Common ownership and technology spillovers span across industries
 - A major driver of common ownership is index funds, which hold firms across industries
 - Technology spillovers flow across sectors (Liu and Ma, 2024)
- Common ownership facilitates the internalization of externalities within and across industries
- Canonical growth models:
 - Continuum of industries $\implies$ Strategic interactions occur only within each industry
- I use a **network approach**:
 - Hundreds of granular firms
 - Pair-specific inter-firm relationships
 - Strategic interactions among all firms

Endogenous Growth Model with Three Inter-Firm Networks

- My framework builds on the endogenous growth model of Hopenhayn and Okumura (2026)
 - **Product-market rivalry networks** (Pellegrino, 2025)
 - **Technological spillover networks**
- This paper adds **ownership networks**
- The interaction of these networks determines how the two externalities are internalized
- Tractable despite dynamic oligopoly with many granular firms

Measurement and Findings

- Measure the networks for 638 publicly listed, patenting U.S. firms

Network	Measurement
Ownership	SEC filings of institutions, blockholders, and insiders (Amel-Zadeh, Kasperk, and Schmalz, 2022)
Product-market rivalry	Product-market proximity (Hoberg and Phillips, 2016)
Technological spillovers	Technological proximity (Jaffe, 1986)

- The rise of common ownership in R&D decisions from 2004 to 2019 lowers R&D by 21.2%, the growth rate by 0.087 pp, and welfare by 0.32%, but raises firm value by 1.08%
- **Internalization of business stealing dominates internalization of technology spillovers**

Related Literature

- Competition and Innovation:

d'Aspremont and Jacquemin (1988), Kamien et al. (1992), Ericson and Pakes (1995), Aghion et al. (2001), Aghion et al. (2005), Acemoglu and Akcigit (2012), Aghion et al. (2013), Bloom et al. (2013), Lopez and Vives (2019), Peters (2020), Akcigit and Ates (2021), and Akcigit and Ates (2023), **Cavenaile et al. (2026)**

Endogenous growth model with ownership structure

- Common Ownership:

Rubinstein and Yaari (1983), Rotemberg (1984), Gutiérrez and Philippon (2017), He and Huang (2017), Azar et al. (2018), Azar et al. (2022), Azar and Vives (2021), and Antón et al. (2023), **Kini et al. (2024) and Antón et al. (2025)**

Macroeconomic implications of common ownership for R&D allocation and growth

- Oligopoly / Hedonic Demand:

Lancaster (1966), Rosen (1974), Berry et al. (1995), Nevo (2001), Neary (2003), Atkeson and Burstein (2008), and Autor et al. (2020), **Pellegrino (2025) and Ederer and Pellegrino (2026)**

Dynamic general equilibrium model / R&D / technology spillovers

Model

Preference and Production Technology (1/2)

- Continuous time
- Risk-neutral representative household: $U_t = \int_t^\infty \exp(-\rho(s-t)) C_s ds$
- Production labor is inelastically supplied
- Final goods are used for consumption and R&D
- Firm $i \in \{1, \dots, n\}$ produces a single differentiated intermediate good
- Linear-quadratic aggregator (Pellegrino, 2025):

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

- $\mathbf{b}_t = [b_{1,t}, \dots, b_{n,t}]^T$: product quality vector (endogenous)
- $\Sigma = [\sigma_{ij}]$: **product-market rivalry matrix (exogenous)** ($\sigma_{ii} = 1$)

Preference and Production Technology (2/2)

- Final-good price is normalized to 1
- Linear inverse demand:

$$p_{i,t} = b_{i,t} - \sum_{j \neq i} \sigma_{ij} q_{j,t} - q_{i,t}$$

- CRS intermediate-good production technology:

$$q_{i,t} = a_{i,t} l_{i,t}$$

- Each firm i has knowledge capital $z_{i,t}$
- Firms allocate knowledge capital to improve labor productivity and product quality:

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

Law of Motion of Knowledge Capital

$$\dot{\mathbf{z}}_t = \underbrace{\Omega \mathbf{z}_t}_{\text{Technology spillovers}} + \underbrace{\mu \mathbf{x}_t}_{\text{R\&D}} - \underbrace{\delta \mathbf{z}_t}_{\text{Obsolescence}}$$

- $\Omega = [\omega_{ij}]$: technological spillover network
- $x_{i,t} = \sqrt{d_{i,t}}$
 - $d_{i,t}$: R&D expenditure in terms of final good
 - Innovation elasticity $d \log(\text{Innovation output}) / d \log(\text{R\&D expenditure}) = 0.5$
- μ : R&D efficiency; δ : obsolescence rate

Ownership Weights

- $\mathbf{K} = [\kappa_{ij}]$: ownership weights that firm i places on the value of firm j ($\kappa_{ii} = 1$)
- More overlapping ownership between firms i and $j \implies$ higher κ_{ij}
- $\mathbf{K} = \mathbf{I}$: dispersed ownership (each firm maximizes its own value)
- $\mathbf{K} = \mathbf{1}_{n \times n}$: monopoly (maximizes total producer surplus)

Proportional Influence (Rotemberg, 1984)

- Baseline corporate governance assumption to map shareholding data to κ_{ij}
- $o \in \{1, 2, \dots, n_o\}$: owners
- s_{io}, v_{io} : owner o 's shares of firm i 's cash-flow and voting rights, with $\sum_o s_{io} = \sum_o v_{io} = 1$
- $\widehat{V}_i$: value of firm i
- $\widetilde{V}_o \equiv \sum_i s_{io} \widehat{V}_i$: portfolio value of owner o
- Firm i 's objective:

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

where

$$\kappa_{ij} \equiv \frac{\mathbf{v}_i^T \mathbf{s}_j}{\mathbf{v}_i^T \mathbf{s}_i} \quad \text{where} \quad \mathbf{s}_i \equiv [s_{i1}, \dots, s_{in_o}]^T, \quad \mathbf{v}_i \equiv [v_{i1}, \dots, v_{in_o}]^T$$

Equilibrium

Markov Perfect Equilibrium

- Given other firms' strategies, firm i chooses $\{a_{i,t}, b_{i,t}, q_{i,t}, x_{i,t}\}_{t \geq 0}$ to maximize

$$\max_{\{a_{i,t}, b_{i,t}, q_{i,t}, x_{i,t}\}_{t \geq 0}} V_i(\mathbf{z}_0) \equiv \int_0^\infty \exp(-\rho t) \sum_j \kappa_{ij} \left(\underbrace{\pi_{j,t}}_{\text{Gross Profit}} - \underbrace{d_{j,t}}_{\text{R\&D Cost}} \right) dt$$

- Markov perfect equilibrium can be solved by the following steps:
 - Static Game:** Choose $\{a_{i,t}, b_{i,t}, q_{i,t}\}$ to maximize $\sum_j \kappa_{ij} \pi_{j,t}$.
 - Dynamic Game:** Given the static strategy profile, choose $\{x_{i,t}\}$ to maximize $V_i(\mathbf{z}_t)$

HJB Equations $\implies$ Riccati Equations

- Guess and verify $V_i(\mathbf{z}) = \mathbf{z}^T \mathbf{X}^i \mathbf{z}$ (for any $\mathbf{z}$)
- $\mathbf{X}^i$ is the solution of stacked algebraic Riccati equations
- Public & patenting firms in the U.S. in our dataset: 638 firms $\implies$
 $\underbrace{n \times n}_{\text{size of } \mathbf{X}^i} \times \underbrace{n}_{\text{firms}} \approx 260 \text{ million undetermined coefficients (19 seconds on my laptop)}$

Social Welfare and Firm Value

- Social welfare (the household's lifetime utility) is expressed in quadratic form:

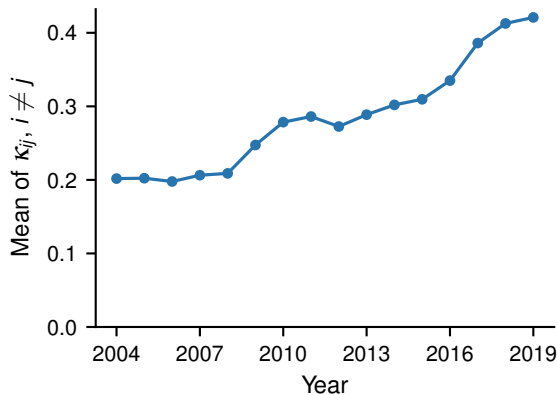
$$\int_t^{\infty} \exp(-\rho(s-t)) C_s ds = \mathbf{z}_t^T \mathbf{X} \mathbf{z}_t$$

- The total value of firms (the discounted sum of profits net of R&D costs) is also quadratic:
 $\mathbf{z}_t^T \mathbf{X}^P \mathbf{z}_t$
- **Solve the equilibrium once $\implies$ we can compute social welfare for any initial $\mathbf{z}_t$**

Data

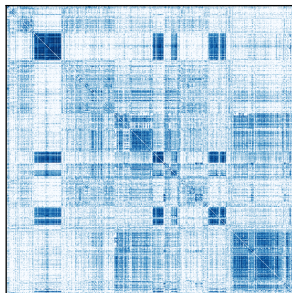
The average ownership weight doubled from 2004 to 2019

- Holdings as of June 30 from Form 13F, Schedules 13D/G, and Forms 3/4/5, compiled by Amel-Zadeh, Kasperk, and Schmalz (2022)
- The mean κ_{ij} rose from 0.20 to 0.42
- The rise comes from BlackRock, Vanguard, and State Street, whose combined stake in the average sample firm grew from 7% to 19%

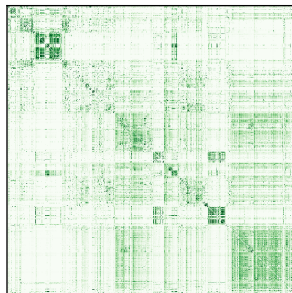


Ownership weights are not concentrated within industries

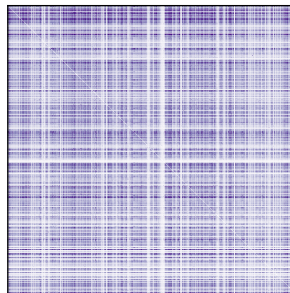
(a) Product-market rivalry σ_{ij}



(b) Technological proximity $\tilde{\omega}_{ij}$



(c) Ownership weight κ_{ij}



- Product-market rivalry and technological proximity are concentrated within industries
- A firm's weights on other firms depend mainly on its own owners, not on the firms' industries

Results

Counterfactual: Common Ownership in R&D Decisions

	R&D ownership (weights in R&D decisions)	Production ownership (weights in production decisions)
Counterfactual	K_{2004}	K
Observed economy (2019)	K	K

- K_{2004} : every off-diagonal weight of K scaled by 0.48 to the 2004 mean intensity, so the placement of ownership links is unchanged
- Changes are measured from the counterfactual to the observed economy, both starting from the observed knowledge capital

Common ownership in R&D decisions lowers R&D, growth, and welfare

	Change
R&D expenditure (%)	−21.2
Growth rate (pp)	−0.087
Social welfare (%)	−0.32
Total value of firms (%)	+1.08

- The growth rate falls from 1.252% to 1.165%

The internalization of business stealing dominates

	Full model	Business-stealing economy	Technology-spillover economy
R&D expenditure (%)	−21.2	−20.0	+18.8
Growth rate (pp)	−0.087	−0.080	+0.246
Social welfare (%)	−0.32	−0.16	+2.22
Total value of firms (%)	+1.08	+0.67	+0.75

- Business-stealing economy: knowledge does not spill over to other firms
- Technology-spillover economy: firms do not compete for customers or workers
- R&D falls in the full model, as in the business-stealing economy
- Firm value rises in both, but social welfare falls only in the business-stealing economy

Ownership links across industries account for most of the effect

	Full model	Rise only within industries	Rise only across industries
R&D expenditure (%)	−21.2	−1.9	−19.5
Growth rate (pp)	−0.087	−0.007	−0.080
Social welfare (%)	−0.32	−0.02	−0.29
Total value of firms (%)	+1.08	+0.10	+1.01

- Links across four-digit NAICS industries account for 92% of the growth effect
- Models with strategic interaction only within industries miss these links

Production and R&D ownership move growth in opposite directions

	R&D ownership	Production ownership	Both
R&D expenditure (%)	−21.2	+10.1	−13.2
Growth rate (pp)	−0.087	+0.036	−0.051
Social welfare (%)	−0.32	−0.95	−1.27
Total value of firms (%)	+1.08	+7.77	+8.94

- Raising production ownership softens competition and raises growth
- Both margins lower social welfare, and production ownership accounts for 75% of the loss

Conclusion

- Quantitative endogenous growth model with three inter-firm networks
 - Quantified with data on 638 publicly traded U.S. firms with patents
- Common ownership in the U.S.:
 - 1 Internalization of business stealing $\implies g \downarrow$ (dominates)
 - 2 Internalization of technology spillovers $\implies g \uparrow$
- Common ownership in R&D decisions raises firm value but lowers social welfare
 - Common owners internalize effects on firm values, not on consumers and workers

Appendix

Appendix contents

- Governance and robustness
- Mechanism
- Ownership measurement
- Calibration
- Other results
- Model and computation
- Background

The effect has the same sign under every governance model

	Proportional influence	Super-proportional influence	Blockholder threshold	Governance frictions (uniform)	Governance frictions (firm-specific)
Mean weight, 2004	0.20	0.17	0.11	0.08	0.08
Mean weight, 2019	0.42	0.42	0.43	0.16	0.20
R&D expenditure (%)	−21.2	−22.8	−29.1	−7.4	−9.7
Growth rate (pp)	−0.087	−0.096	−0.130	−0.029	−0.036
Social welfare (%)	−0.32	−0.35	−0.44	−0.09	−0.11

- The fall in growth ranges from 0.029 to 0.130 pp.
- The size follows how much each model raises the mean weight between 2004 and 2019.

The first two rows report mean off-diagonal weights. The other rows raise R&D ownership from K_{2004} to K with the observed weights in production decisions under each model. Proportional influence is the baseline.

Alternative models of corporate governance

- **Super-proportional influence:** $\tilde{\kappa}_{ij} = \frac{\sum_o \chi_{io} v_{io} s_{jo}}{\sum_o \chi_{io} v_{io} s_{io}}$ with $\chi_{io} = \sqrt{v_{io}}$ (Ederer and Pellegrino, 2026).
- **Blockholder threshold:** only owners with more than 5% of the votes influence the firm.
- **Governance frictions** (Azar and Ribeiro, 2022): firm i maximizes $\hat{V}^i + \tau_i \sum_{j \neq i} \kappa_{ij} \hat{V}^j$.
 - Uniform: $\tau_i = 0.3771$.
 - Firm-specific: $\tau_i = \frac{e^{\theta_0} \text{IHHI}_i}{1 + e^{\theta_0} \text{IHHI}_i}$ with $\theta_0 = 3.2454$ and $\text{IHHI}_i = \mathbf{v}_i^\top \mathbf{s}_i$.
- Each model nests the baseline and scales its own matrix to its own 2004 mean weight.

Governance frictions use the baseline estimates of Azar and Ribeiro (2022), which account for common ownership across industries.

The main counterfactual under alternative specifications

Specification	R&D expenditure (%)	Growth rate (pp)	Social welfare (%)
Baseline	−21.2	−0.087	−0.32
$\beta = 0.01$	−20.8	−0.080	−0.25
$\beta = 0.03$	−21.1	−0.091	−0.40
$\alpha = 0.08$	−19.5	−0.083	−0.35
$\alpha = 0.16$	−22.7	−0.090	−0.29
$\rho = 0.05$	−20.1	−0.040	−0.52
$\rho = 0.075$	−21.1	−0.065	−0.38
13F ownership, 1999–2017	−29.6	−0.111	−0.32

- R&D, growth, and welfare fall in every specification.

μ and δ are recalibrated in each specification. The 13F specification uses the holdings of Backus et al. (2021) for 2017, measures the rise from 1999, and corrects for unobserved owners as in Ederer and Pellegrino (2026).

Externalities in the Model

- Assume firms choose static variables $\{a_{i,t}, b_{i,t}, q_{i,t}\}$ to maximize static profits ($K = I$)
- Equilibrium quantity $q_i = \frac{1}{2}z_i - \frac{1}{2}\sum_{k \neq i} \sigma_{ik} q_k - \sqrt{\zeta} w_t$ and profit $\pi_i = q_i^2$

Technology-Spillover Externalities:

$$\frac{\partial \dot{z}_j}{\partial z_i} = \omega_{ji}, \quad \frac{\partial \pi_j}{\partial z_j} = 2q_j \frac{\partial q_j}{\partial z_j} = q_j$$

$$z_i \uparrow \quad \underbrace{\implies}_{\text{strong if } \omega_{ji} \text{ is large}} \quad z_j \uparrow \implies \pi_j \uparrow$$

Business-Stealing Externalities:

$$\frac{\partial \pi_j}{\partial z_i} = 2q_j \frac{\partial q_j}{\partial z_i} = 2q_j \left(-\frac{1}{2} \sigma_{ji} \frac{\partial q_i}{\partial z_i} \right) = -\frac{1}{2} \sigma_{ji} q_j$$

$$z_i \uparrow \implies q_i \uparrow \quad \underbrace{\implies}_{\text{strong if } \sigma_{ji} \text{ is large}} \quad q_j \downarrow \implies \pi_j \downarrow$$

The spillover force is weak

- Hold R&D policies at the observed state and raise R&D ownership from K_{2004} to K , to first order.
- The value that owners attach to a unit of a firm's knowledge
 - falls through business stealing, and
 - rises through spillovers to other firms that the owners hold.
- Spillovers reach other firms only gradually, at rate β . Even if the spilled knowledge took no business, the rise would be **25%** of the fall.
- The spilled knowledge also takes business from third firms held by the same owners, so the rise is only **5%** of the fall.

Firms weighted by knowledge capital.

Business-stealing and spillover channels

	Firms weighted by		
	Knowledge capital	Equally	R&D expenditure
Spilled knowledge takes no business	25	23	39
Spilled knowledge takes business	5	4	9

- Each entry: the rise through spillovers in the value that owners attach to a unit of a firm's knowledge, as a percent of the fall through business stealing.
- A unit of firm i 's knowledge adds knowledge to firm j at rate $\beta \tilde{\omega}_{ji}$.
- Under every weighting, the rise is at most 39% of the fall, and at most 9% once spilled knowledge takes business.

First order, holding R&D policies at the observed state, with the observed weights in production decisions. The first row ignores business taken from firms other than the source and recipient.

[Back to the spillover force](#)

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

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

R&D Externalities

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

Production and R&D ownership: levels

Production decisions	K_{2004}	K	K_{2004}	K
R&D decisions	K_{2004}	K_{2004}	K	K
Output (index)	100.00	98.91	100.00	98.91
R&D (% of value added)	3.49	3.84	2.82	3.03
Growth rate (%)	1.216	1.252	1.137	1.165
Social welfare (index)	100.00	99.05	99.65	98.73
Firm value share (%)	28.1	30.6	28.5	31.0

- Production ownership changes the matrix Q that maps knowledge capital into output, so 0.007 of its 0.036 pp come through the spillover term and 0.029 through the R&D term.

Output and social welfare are indexed to 100 in the first column. R&D is expenditure as a percent of value added. The firm value share is the total value of firms as a percent of social welfare.

[Back to production and R&D ownership](#)

Measuring ownership weights

- Form 13F: institutional investors with over \$100 million under management. Schedules 13D/G: owners of more than 5% of a firm's shares. Forms 3/4/5: officers, directors, and owners of more than 10%.
- The data report each owner's shares of cash-flow rights s_{io} and voting rights v_{io} .
- Observed owners hold 92% of the median sample firm's shares. The remaining owners are mainly small, dispersed shareholders, so κ_{ij} uses the observed holdings without a correction for unobserved owners.
- For 24% of firms, observed shares sum to more than one (median 106%) because some shares are counted in more than one filing. They are scaled proportionally to sum to one.
- The numerator of κ_{ij} sums over owners, so the mean weight splits by owner: the contribution of BlackRock, Vanguard, and State Street rose from 0.08 to 0.34, while that of all other owners fell from 0.12 to 0.08.

Base-year ownership matrix

- $\mathbf{K}_{2004}$ scales every off-diagonal weight of the observed $\mathbf{K}$ by 0.48, the ratio of the 2004 to the 2019 mean weight.
- It keeps the observed placement of ownership links and lowers only their average intensity.
- The measured 2004 matrix differs in its firms and in the placement of its links:
 - Only 287 of the 638 firms in 2019 are also in the 2004 sample.
 - Among them, the correlation of κ_{ij} between the two years is 0.43.
- Among the firms in both samples, the ratio of mean weights is 0.42, so the rise does not reflect changes in sample composition.
- Insiders have filed Forms 3, 4, and 5 electronically since mid-2003, so 2004 is the first year whose June holdings include them.

Sample of 638 firms in 2019

- Firms linked across Compustat, DISCERN 2.0 patents (Arora et al., 2024), the Hoberg–Phillips product similarity, and the ownership data.
- Firms with positive gross profits (revenue minus cost of goods sold) and at least ten patents within two years of t .
- The sample firms account for 22% of the sales and 62% of the R&D expenditure of all publicly traded Compustat firms with positive sales.
- Each year from 2004 to 2019 is constructed in the same way to measure the rise in common ownership.

The networks overlap only partly

- Correlation across firm pairs between product-market rivalry σ_{ij} and technological proximity $\tilde{\omega}_{ij}$: 0.29.
- 32% of the pairs in the top 5% by rivalry are also in the top 5% by technological proximity.
- Ownership weights are nearly uncorrelated with both: -0.03 with rivalry and 0.01 with proximity.
- Pairs in the same four-digit NAICS industry (97 industries) are 3.8% of all pairs but account for 16% of product-market rivalry and 22% of technological proximity, and only 3.7% of ownership weights.
- Firm-level mean weights account for 59% of the variance of ownership weights across pairs.
- Business stealing and technology spillovers therefore arise on partly different firm pairs.

Top 5 Shareholders of the Six Largest U.S. Firms

Nvidia	
Vanguard	9.57%
BlackRock	8.04%
Fidelity	4.25%
State Street	4.18%
Jensen Huang	3.36%

Microsoft	
Vanguard	9.84%
BlackRock	8.18%
State Street	4.25%
Capital Group	2.77%
Geode	2.55%

Alphabet	
Vanguard	8.11%
BlackRock	6.88%
Larry Page	5.80%
Sergey Brin	5.36%
Fidelity	3.74%

Amazon	
Jeffrey Bezos	8.17%
Vanguard	7.96%
BlackRock	6.94%
State Street	3.68%
Fidelity	3.39%

Apple	
Vanguard	9.90%
BlackRock	7.96%
State Street	4.21%
Geode	2.54%
Fidelity	2.23%

Broadcom	
Vanguard	10.17%
BlackRock	8.34%
Capital Group	6.71%
State Street	4.12%
Fidelity	3.02%

Holdings on June 30, 2026, from SEC Forms 13F (summed by fund family), Forms 4, and proxy statements. Alphabet: Class A and B.

Parameters

	Description	Value	Source
K	Ownership weights		SEC ownership filings
$\Psi^\top \Psi$	Product-market proximity		Form 10-K
α	Proximity $\rightarrow$ substitutability	0.12	Pellegrino (2025)
$\tilde{\Omega}$	Technological proximity		DISCERN 2.0 patents
β	Proximity $\rightarrow$ spillovers	0.02	Hopenhayn and Okumura (2026)
ζ/L	Labor-augmentation efficiency	0.0074	Cost of goods sold
ρ	Discount rate	0.10	Firms' discount rates
μ	R&D efficiency	0.0699	R&D share of business value added, 3.03%
δ	Obsolescence rate	0.0136	Growth of real GDP per capita, 1.165%

- μ and δ jointly match the 2019 R&D share and the average growth rate from 2004 to 2019.

Discount rates: Poterba and Summers (1995); Gormsen and Huber (2025). R&D: NCSSES National Patterns of R&D Resources. Value added and GDP: BEA.

[Recovering knowledge capital](#)

Recovering knowledge capital

- Quantities solve the profit identity, with gross profit π_i equal to revenue minus cost of goods sold:

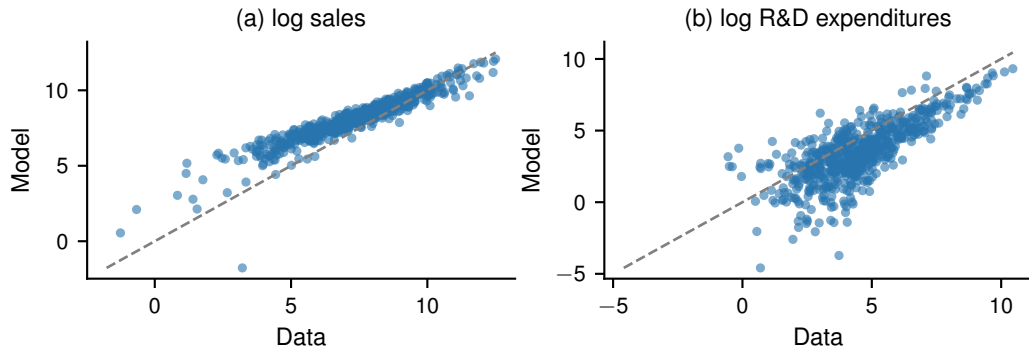
$$\pi_i = \sum_j \kappa_{ij} \sigma_{ij} q_i q_j = q_i^2 + q_i \sum_{j \neq i} \kappa_{ij} \sigma_{ij} q_j.$$

- Labor-augmentation efficiency matches total production cost: $\frac{\zeta}{L} \mathbf{q}^\top \mathbf{J} \mathbf{q} = \sum_i \text{COGS}_i$.
- Knowledge capital inverts the static equilibrium:

$$\mathbf{z} = \left(2 \frac{\zeta}{L} \mathbf{J} + \Sigma + \mathbf{K} \circ \Sigma \right) \mathbf{q}.$$

- The recovered $\mathbf{z}$ is the state of the observed economy, from which every counterfactual starts.

Untargeted firm-level sales and R&D



- Correlations between the model and the data: 0.94 for log sales and 0.75 for log R&D expenditure.

Each point is a firm in 2019. Horizontal axis: Compustat. Vertical axis: model. Panel (b) includes the 612 firms with positive R&D expenditure in the data. The model matches firm-level profits by construction.

Product-market rivalry and technological spillovers

- **Product-market rivalry Σ** (Pellegrino, 2025)
 - Cosine similarity of 10-K product descriptions for every pair of firms (Hoberg and Phillips, 2016).
 - $\alpha = 0.12$ maps proximity into substitutability; the implied elasticities are in line with IO estimates.
- **Technological spillovers $\Omega = \beta \tilde{\Omega}$**
 - $\tilde{\Omega}$: Jaffe similarity of patent shares across CPC main groups, from patents granted in $t - 2$ to $t + 2$, normalized so that each row sums to one (Jaffe, 1986; Liu and Ma, 2024).
 - $\beta = 0.02$ from Hopenhayn and Okumura (2026): the association between firms' knowledge-capital growth and the knowledge capital of technologically proximate firms.

Generalized Hedonic-Linear Demand (Pellegrino, 2025)

- $i \in \{1, 2, \dots, n\}$: firms / products
- 1 unit of product i provides
 - 1 unit of idiosyncratic characteristic $k \in \{1, 2, \dots, n\}$
 - $\psi_{k,i}$ unit of common 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:

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

Generalized Hedonic-Linear Demand (Pellegrino, 2025)

- Quality:

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

- Inverse demand:

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

- 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:

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

Microeconomic estimates and GHL demand (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

Price elasticities from Pellegrino (2025), Table 2. Micro estimates for automobiles from Berry et al. (1995).

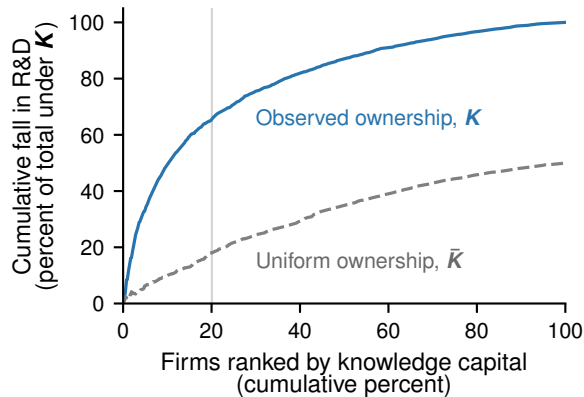
Microeconomic estimates and GHL demand (2/2)

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

Price elasticities from Pellegrino (2025), Table 2. Micro estimates from Nevo (2001) for cereals and Goeree (2008) for computers.

The placement of ownership weights accounts for most of the effect

- Raising R&D ownership to the uniform $\bar{K}$ lowers growth by only 0.028 pp, 68% less than raising it to K .
- The largest fifth of firms by knowledge capital does 82% of R&D and places the largest weights on other firms.
- Their R&D falls by 16.9% under K but by 4.6% under $\bar{K}$.



Firms ranked by knowledge capital in 2019. Each line cumulates the fall in R&D as a percent of the total fall under K . The vertical line marks the largest fifth, which accounts for 66% of the fall under K .

Ownership placement and R&D by firm size

Firm size (knowledge capital)	Share of R&D (%)	R&D change, K (%)	R&D change, $\bar{K}$ (%)	Rise in weight, K	Rise in weight, $\bar{K}$
Smallest 20%	1	-53.8	-66.8	0.15	0.28
Second 20%	3	-45.4	-54.7	0.18	0.26
Middle 20%	5	-39.8	-42.9	0.21	0.23
Fourth 20%	9	-38.4	-26.4	0.25	0.19
Largest 20%	82	-16.9	-4.6	0.31	0.14

- K raises the weights of the largest firms the most; $\bar{K}$ raises those of the smallest firms the most.
- The largest fifth accounts for 66% of the fall in R&D under K but 36% under $\bar{K}$.

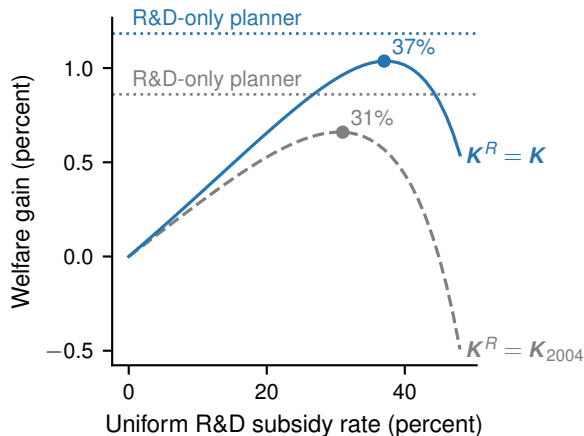
R&D contributes 0.771 pp to growth at the observed state

$$\frac{d \log Y_t}{dt} = \underbrace{\frac{\mathbf{z}_t^\top (\mathbf{Q}\mathbf{\Omega} + \mathbf{\Omega}^\top \mathbf{Q}) \mathbf{z}_t}{\mathbf{z}_t^\top \mathbf{Q} \mathbf{z}_t}}_{\text{Technology spillovers}} + \underbrace{\mu^2 \frac{\mathbf{z}_t^\top (\mathbf{Q}\tilde{\mathbf{X}} + \tilde{\mathbf{X}}^\top \mathbf{Q}) \mathbf{z}_t}{\mathbf{z}_t^\top \mathbf{Q} \mathbf{z}_t}}_{\text{R\&D}} \underbrace{- 2\delta}_{\text{Obsolescence}}$$

Component	Contribution to growth in 2019 (%)
Technology spillovers	3.105
R&D	0.771
Obsolescence	−2.711
Total	1.165

- Ownership in R&D decisions changes growth only through the R&D term.
- The spillover term is proportional to β , and the obsolescence term equals -2δ .

Common ownership raises the welfare-maximizing R&D subsidy



- A uniform subsidy, financed by lump-sum taxes, lowers every firm's R&D cost.
- Benchmark: an R&D-only planner, who takes product-market conduct as given and spends 2.25 (R&D ownership at 2004 intensity) and 2.85 (observed) times equilibrium R&D.
- The optimal rate rises from 31% to 37%, attaining 77% and 88% of the planner's gain.

K^R : ownership weights in R&D decisions. Both economies keep the observed weights in production decisions. Consumption-equivalent gains relative to no subsidy. Dotted lines: R&D-only planner.

R&D-only planner

- Takes the static equilibrium under the observed weights in production decisions as given and chooses only R&D:

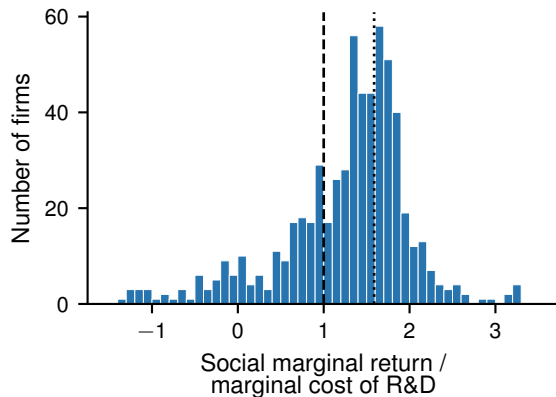
$$V^{**}(\mathbf{z}_0) \equiv \max_{\{\mathbf{x}_t\}} \int_0^\infty e^{-\rho t} \left\{ \mathbf{z}_t^\top \mathbf{Q} \mathbf{z}_t - \mathbf{x}_t^\top \mathbf{x}_t \right\} dt \quad \text{s.t.} \quad \dot{\mathbf{z}}_t = (\mathbf{\Omega} - \delta \mathbf{I}) \mathbf{z}_t + \mu \mathbf{x}_t.$$

- $V^{**}(\mathbf{z}) = \mathbf{z}^\top \mathbf{X}^{**} \mathbf{z}$ and $\mathbf{x} = \mu \mathbf{X}^{**} \mathbf{z}$, where

$$0 = \mathbf{Q} - \mu^2 (\mathbf{X}^{**})^2 + \mathbf{X}^{**} \left(\mathbf{\Phi}^{**} - \frac{\rho}{2} \mathbf{I} \right) + \left(\mathbf{\Phi}^{**} - \frac{\rho}{2} \mathbf{I} \right)^\top \mathbf{X}^{**}, \quad \mathbf{\Phi}^{**} \equiv \mathbf{\Omega} - \delta \mathbf{I} + \mu^2 \mathbf{X}^{**}.$$

- The planner's R&D is not restricted in sign, so its gain bounds the gain with nonnegative R&D.
- A subsidy, like the planner, leaves product-market conduct unchanged.
- Scaling all firms' R&D in the same proportion closes 76% and 88% of the squared distance to the planner's R&D, close to the shares the subsidy attains.

A uniform subsidy under-rewards the firms that do most R&D



- Ratio of the social to the private marginal return to R&D: median 1.40; 30% of firms below one, 10% negative.
- The 37% subsidy aligns incentives only at a ratio of 1.59.
- Firms above this ratio are 37% of firms but do 70% of R&D.
- Ratios are lower for firms central in rivalry and higher for central sources of spillovers and for firms that place large weight on other firms' values.

Observed economy, 630 firms with positive R&D. The dashed line marks one and the dotted line $1/(1-s)$ at $s = 37\%$.

Network positions and the ratio of social to private returns to R&D

	Social / private return to R&D
Initial knowledge capital (thousands)	−1.87*** (0.48)
Product-market rivalry centrality	−2.21*** (0.30)
Technological spillover centrality	2.28*** (0.24)
Ownership centrality	2.78*** (0.29)
Observations	605
R^2	0.39

- Profits taken from rivals count toward the private return but not the social return.
- Spilled knowledge raises the social return but not the private return.
- Business stealing dominates, so firms that place large weight on other firms have lower private returns relative to their social returns.

Firm-level OLS at the observed state for the firms with positive R&D in both the data and the model, HC1 standard errors. Centralities are eigenvector centralities divided by their maximum: right eigenvectors of $\mathbf{K}$ and $\mathbf{\Sigma}$ and the left eigenvector of $\tilde{\mathbf{\Omega}}$, each with a zero diagonal. *** $p < 0.01$.

Market Clearing

- Final-good market clearing:

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

- Inelastic production labor supply:

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

Static Cournot Game

- Firm i 's static objective is given by:

$$\sum_j \kappa_{ij} \pi_{j,t}$$

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

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

Assumption

Given w_t , $z_{i,t}$, and $\{a_{j,t}, b_{j,t}, q_{j,t}\}_{j \neq i}$, firm i chooses $a_{i,t}$, $b_{i,t}$, and $q_{i,t}$ to maximize $\sum_j \kappa_{ij} \pi_{j,t}$ subject to $\zeta a_{i,t} + b_{i,t} = z_{i,t}$

Dynamic R&D Game $\implies$ 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

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

- Gross profit: $\sum_j \kappa_{ij} \pi_{j,t} = \mathbf{z}_t^T \mathbf{Q}^i \mathbf{z}_t$
- R&D cost: $\sum_j \kappa_{ij} d_{j,t} = \sum_j \kappa_{ij} x_{j,t}^2$
- Law of motion: $\dot{\mathbf{z}}_t = \mathbf{\Omega} \mathbf{z}_t + \mu \mathbf{x}_t - \delta \mathbf{z}_t$
- Firm i 's HJB equation:

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

Static Profits

- 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: $L = \sum_i \frac{q_{i,t}}{a_{i,t}} \implies \sqrt{\zeta w_t} = \frac{\zeta}{L} \sum_i q_{i,t}$
- $\mathbf{q}_t = \mathbf{N} \mathbf{z}_t$ where $\mathbf{N} \equiv \left\{ 2 \frac{\zeta}{L} \mathbf{1}_{n \times n} + \Sigma + \mathbf{K} \circ \Sigma \right\}^{-1}$
- $\mathbf{N}_i$: the i th row of $\mathbf{N}$
- Ownership-weighted gross profit:

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

where

$$\mathbf{Q}^i = \frac{1}{2} \sum_j \kappa_{ij} \sum_h \kappa_{jh} \sigma_{jh} (\mathbf{N}_j^T \mathbf{N}_h + \mathbf{N}_h^T \mathbf{N}_j)$$

Stacked Riccati equations

- $V^i(\mathbf{z}) = \mathbf{z}^\top \mathbf{X}^i \mathbf{z}$, where $\mathbf{X}^1, \dots, \mathbf{X}^n$ solve

$$0 = \mathbf{Q}^i - \mu^2 \sum_j \kappa_{ij} \mathbf{X}_j^j (\mathbf{X}_j^j)^\top + \left(\Phi - \frac{\rho}{2} \mathbf{I} \right)^\top \mathbf{X}^i + \mathbf{X}^i \left(\Phi - \frac{\rho}{2} \mathbf{I} \right), \quad i = 1, \dots, n.$$

- $\mathbf{X}_j^j$: the j th column of $\mathbf{X}^j$. $\Phi \equiv \Omega + \mu^2 \tilde{\mathbf{X}} - \delta \mathbf{I}$ depends on all firms' policies.
- A stable solution has all eigenvalues of $\Phi - \frac{\rho}{2} \mathbf{I}$ with negative real parts, so values are finite.
- Algorithm: iterate backward from $\mathbf{X}^i = 0$,

$$-\frac{\mathbf{X}_\tau^i - \mathbf{X}_{\tau-\Delta}^i}{\Delta} = \mathbf{Q}^i - \mu^2 \sum_j \kappa_{ij} \mathbf{X}_{j,\tau}^j (\mathbf{X}_{j,\tau}^j)^\top + \left(\Phi_\tau - \frac{\rho}{2} \mathbf{I} \right)^\top \mathbf{X}_\tau^i + \mathbf{X}_\tau^i \left(\Phi_\tau - \frac{\rho}{2} \mathbf{I} \right),$$

which selects the limit of finite-horizon equilibria (Cartigny and Michel, 2003).

Computational complexity and scale

Model	Storage	Arithmetic per update	Number of firms	Productivity state space
Cavenaile et al. (2026)	$O(k^n)$	–	4	Discrete grid
This paper	$O(n^3)$	$O(n^4)$	638	Continuous

- The equilibrium with 638 firms solves in 19 seconds on an Apple M4 Pro laptop with 24 GB of memory, using six threads.

k is the number of grid points for each firm's productivity. Storage counts the coefficients of the n matrices $\mathbf{X}^i$.

Summary of equilibrium

Description	Expression
Production	$\mathbf{q}_t = \mathbf{N}\mathbf{z}_t$
R&D	$\mathbf{x}_t = \mu \tilde{\mathbf{X}}\mathbf{z}_t$
Law of motion	$\dot{\mathbf{z}}_t = \Phi \mathbf{z}_t$
Surplus of the final-goods producer	$\frac{1}{2} \mathbf{q}_t^\top \Sigma \mathbf{q}_t$
Gross profits of firms	$\mathbf{q}_t^\top (\mathbf{K} \circ \Sigma) \mathbf{q}_t$
Labor income	$\frac{\zeta}{L} \mathbf{q}_t^\top \mathbf{J} \mathbf{q}_t$
Output	$Y_t = \mathbf{q}_t^\top \left(\frac{\zeta}{L} \mathbf{J} + \frac{1}{2} \Sigma + \frac{1}{2} \Sigma \circ (\mathbf{K} + \mathbf{K}^\top) \right) \mathbf{q}_t$
Consumption	$C_t = Y_t - \mathbf{x}_t^\top \mathbf{x}_t$

Social welfare and the total value of firms

- Output $Y_t = \mathbf{z}_t^\top \mathbf{Q} \mathbf{z}_t$ with $\mathbf{Q} = \frac{1}{2} \mathbf{N}^\top \left(2 \frac{\zeta}{L} \mathbf{J} + \Sigma + \Sigma \circ (\mathbf{K} + \mathbf{K}^\top) \right) \mathbf{N}$.

- Social welfare $V(\mathbf{z}_0) = \int_0^\infty e^{-\rho t} (Y_t - \sum_i x_{i,t}^2) dt = \mathbf{z}_0^\top \mathbf{X} \mathbf{z}_0$, where

$$0 = \mathbf{Q} - \mu^2 \tilde{\mathbf{X}}^\top \tilde{\mathbf{X}} + \mathbf{X} \left(\Phi - \frac{\rho}{2} \mathbf{I} \right) + \left(\Phi - \frac{\rho}{2} \mathbf{I} \right)^\top \mathbf{X}.$$

- Total value of firms $V^P(\mathbf{z}_0) = \int_0^\infty e^{-\rho t} \sum_i (\pi_{i,t} - x_{i,t}^2) dt = \mathbf{z}_0^\top \mathbf{X}^P \mathbf{z}_0$ replaces $\mathbf{Q}$ by

$$\mathbf{\Pi} = \frac{1}{2} \mathbf{N}^\top \left(\Sigma \circ (\mathbf{K} + \mathbf{K}^\top) \right) \mathbf{N}.$$

- $\mathbf{Q} - \mathbf{\Pi}$ is labor income plus the final-goods producer's surplus, which no owner's objective contains.
- Firm value share: V^P/V .

Balanced Growth Path (BGP)

- Linear R&D strategy: $\mathbf{x}_t = \mu \tilde{\mathbf{X}} \mathbf{z}_t$ where $\tilde{\mathbf{X}} = [\mathbf{x}_1^1 \cdots \mathbf{x}_n^n]^T$ and $\mathbf{x}_i^j$ is the i th column of $\mathbf{X}^j$
- The law of motion is rewritten as $\dot{\mathbf{z}}_t = \Phi \mathbf{z}_t$ where

$$\Phi \equiv \underbrace{\Omega}_{\text{Technology spillovers}} + \underbrace{\mu^2 \tilde{\mathbf{X}}}_{\text{R\&D}} - \underbrace{\delta I}_{\text{Obsolescence}}$$

Theorem

If the solution is stable and Φ is irreducible with nonnegative off-diagonal elements, then:

- Φ has a real dominant eigenvalue, g , with a strictly positive eigenvector, $\mathbf{z}^*$.
- From any strictly positive initial state, the knowledge capital distribution converges to a scalar multiple of $\mathbf{z}^*$, and all firms' knowledge capital grows asymptotically at rate g .

- Proof: Perron–Frobenius Theorem
- In the observed economy, R&D responds negatively to rivals' knowledge capital, so 69% of the off-diagonal elements of Φ are negative and the assumption fails

Example: Symmetric Equilibrium

Assumption

- Symmetric product-market rivalry, technological spillover, and ownership networks:

$$\sigma_{ij} = \sigma, \omega_{ij} = \omega, \kappa_{ij} = \kappa \quad \forall i \neq j$$

- R&D strategy: $x_{i,t}^* = \mu (\tilde{x}_1 z_{i,t} + \tilde{x}_2 \sum_{j \neq i} z_j)$

- $\tilde{x}_1$: market size effect (> 0)

- $\tilde{x}_2$: strategic substitutability (< 0) / complementarity (> 0)

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

- Positive off-diagonal elements of Φ require $\omega + \mu^2 \tilde{x}_2 > 0$

- Technology spillovers (ω) must be strong relative to strategic substitutability ($\tilde{x}_2 < 0$)

Property of BGP

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

Knowledge Capital: $\zeta \mathbf{a}_{i,t} + \mathbf{b}_{i,t} = \mathbf{z}_{i,t}$

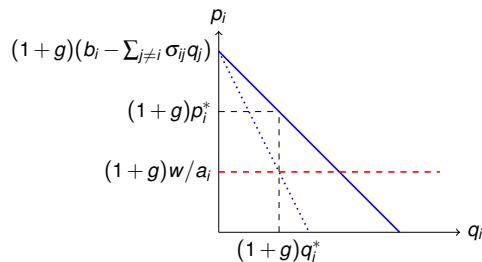
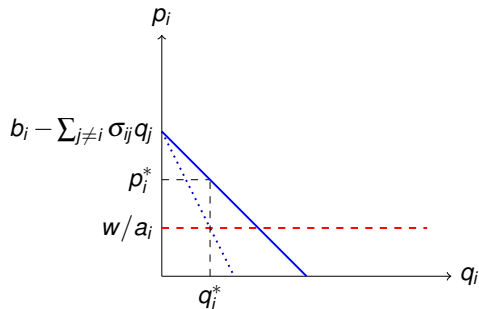
Linear Production Technology: $\mathbf{q}_{i,t} = \mathbf{a}_{i,t} l_{i,t}$

Inelastic Labor Supply: $L = \sum_i l_{i,t}$

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

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

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) markup stay the same
- Demand elasticity is constant on BGP despite linear demand

Interior linear solution and nonnegativity

- The analysis uses the interior linear solution, which keeps the Riccati and Lyapunov systems tractable.
- In the four combinations, negative quantities arise only with production ownership at the 2004 intensity: 26 firms, 0.19% of absolute quantity.
- Negative R&D: at most 40 firms in the four economies (8 in the observed economy) and 81 firms under the R&D-only planner.
- Re-solving production with nonnegative quantities and setting negative R&D to zero changes discounted consumption by at most 0.013% and leaves the signs of the effects on growth and welfare unchanged.

Merger Guidelines

*“For example, **the partial owner may decide not to develop a new product feature** to win market share from the firm in which it has acquired an interest, because doing so will reduce the value of its investment in its rival.”*

2023 Merger Guidelines by the U.S. Department of Justice and the Federal Trade Commission

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