

Ownership Structure and Economic Growth

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Ownership Structure \Rightarrow Economic Growth?

- BlackRock, Vanguard, State Street, and Fidelity control 30% of votes of S&P 500 firms
- Top 10 chaebols account for half of stock market capitalization and exports in Korea

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- Top 10 chaebols account for half of stock market capitalization and exports in Korea
- Firms maximize shareholder values \implies
Partially internalize externalities for commonly owned firm
- Ownership structure (common ownership, cross ownership, M&A, FDI, ...) \implies
Economic growth?
 - Business stealing effect
 - Technology spillover effect

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Quantitative Schumpeterian Growth Model with Ownership Structure

- Existing Schumpeterian growth models:
 - Lack of strategic interaction (e.g., monopolistic competition)
 - Very few firms in Markov perfect equilibrium
- This paper: Many oligopolists + Ownership structure

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 - Ownership structure
 - Product market rivalry
 - Technology spillover

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- Quantify three inter-firm networks for publicly listed patenting firms in the US ($\simeq 1000$ firms)
 - Ownership structure
 - Product market rivalry
 - Technology spillover
- Common ownership in the US:
 - Internalization of business stealing $\Rightarrow g \downarrow \downarrow$
 - Internalization of technology spillover $\Rightarrow g \uparrow$

Literature

- Competition & Innovation:

d'Aspremont and Jacquemin (1988); 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); Anton et al. (2023, 2024); Kini et al. (2024); 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)

Simple Static Partial Equilibrium Model

- Firm $i \in \{1, \dots, n\}$ chooses quantity q_i and R&D effort x_i
- Linear inverse demand: $\mathbf{p}(\mathbf{q}) = \mathbf{b} - \mathbf{\Sigma}\mathbf{q}$
- CRS production technology with marginal cost: $\mathbf{m}(\mathbf{x}) = \mathbf{a} - \mathbf{\Omega}\mathbf{x}$
- Quadratic cost of R&D: $c(x_i) = \frac{1}{2}x_i^2$

Common Ownership Weights

- $\mathbf{K} = [\kappa_{ij}]$: common ownership weights that firm i places on the value of firm j
- More overlapping ownership b/w firm i and $j \implies$ Higher κ_{ij}
- Diagonal elements κ_{ii} are normalized to 1 for all firm i
- $\mathbf{K} = \mathbf{I}$: dispersed ownership (each firm maximizes its own value)
- $\mathbf{K} = [\mathbf{1}]$: monopoly (maximizes total producer surplus)

Proportional Influence

Cournot & R&D Game

- Firm i 's profit:

$$\begin{aligned}\pi_i(\mathbf{q}, \mathbf{x}) &= [p_i - m_i]q_i - c(x_i) \\ &= \left[b_i - \sum_{j=1}^n \sigma_{ij}q_j - a_i + \sum_{j=1}^n \omega_{ij}x_j \right] q_i - \frac{1}{2}x_i^2\end{aligned}$$

- Given $\{q_j, x_j\}_{j \neq i}$, firm i chooses q_i and x_i to maximize $\sum_j \kappa_{ij} \pi_j(\mathbf{q}, \mathbf{x})$

Impact of Common Ownership on R&D

- Comparative statics where $\{q_k, x_k\}_{k \neq i}$ are held constant:

$$\frac{\partial x_i}{\partial \kappa_{ij}} = \frac{q_j}{2 - \omega_{ii}^2} (2\omega_{ij} - \omega_{ii}\sigma_{ij}) \quad \forall j \neq i$$

- SOC: $2 > \omega_{ii}^2$
- Internalize business stealing effect: $\partial^2 x_i / \partial \kappa_{ij} \partial \sigma_{ij} < 0$
- Internalize technology spillover effect: $\partial^2 x_i / \partial \kappa_{ij} \partial \omega_{ij} > 0$

Overview of Identification Strategy

Networks	Measurement
Common ownership \mathbf{K}	Institutional investor holdings in 13f filings (Backus et al., 2021)
Product market rivalry Σ	Product proximity (Hoberg and Phillips, 2016): Text analysis of business description in 10k filings
Technology spillover Ω	Technology proximity (Jaffe, 1986; Bloom et al., 2013): Patent classification

Schumpeterian Growth Model

- Linear quadratic aggregator (final good):

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

- Linear inverse demand:

$$\mathbf{p}_t = \mathbf{b}_t - \Sigma \mathbf{q}_t$$

- CRS production technology (intermediate good):

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

- Each firm has knowledge capital $z_{i,t}$
- Each firm allocates 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

$$d\mathbf{z}_t = \left(\underbrace{\mathbf{\Omega}\mathbf{z}_t}_{\text{tech spillover}} + \underbrace{\mu\mathbf{x}_t}_{\text{R\&D}} \right) dt + \underbrace{\gamma\mathbf{z}_t dW_t}_{\text{shocks}}$$

- $\mathbf{\Omega} = [\omega_{ij}]$: technology spillover matrix
- $x_{i,t} = \sqrt{d_{i,t}}$
 - $d_{i,t}$: R&D cost in terms of final good
 - Innovation elasticity is 0.5
- μ, γ : positive scalars

Market Clearing and Preference

- Inelastic labor supply:

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

- Final good market clearing:

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

- Risk neutral representative household:

$$\max \mathbf{E}_t \left[\int_t^\infty \exp(-\rho s) C_s ds \right]$$

Cournot-Nash Equilibrium

- Firm i 's gross profit before subtracting dynamic R&D cost:

$$\pi_{i,t} = p_{i,t}q_{i,t} - w_t l_{i,t} = \left(b_{i,t} - \frac{w_t}{a_{i,t}} - \sum_j \sigma_{ij} q_{j,t} \right) q_{i,t} \quad \text{where} \quad \zeta a_{i,t} + b_{i,t} = z_{i,t}$$

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


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- Given w_t , $z_{i,t}$, and $\{q_{j,t}\}_{j \neq i}$, firm i chooses $a_{i,t}$, $b_{i,t}$, and $q_{i,t}$ to maximize $\sum_j \kappa_{ij} \pi_{j,t}$
- Quantity is a linear function of knowledge capital:

$$\mathbf{q}_t(\mathbf{z}_t) = \left\{ \underbrace{2 \frac{\zeta}{L} \mathbf{J}}_{\text{labor cost}} + \underbrace{\Sigma}_{\text{substitutability}} + \underbrace{\mathbf{K} \circ \Sigma}_{\text{ownership} \times \text{substitutability}} \right\}^{-1} \mathbf{z}_t$$

- $\mathbf{J} = [1]$
- Ownership-weighted gross profits are expressed in quadratic form: $\sum_j \kappa_{ij} \pi_{j,t} = \mathbf{z}_t^T \mathbf{Q}^i \mathbf{z}_t$ 

Linear-Quadratic Differential Game

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

$$\max_{\{x_{i,t}\}_{t \geq 0}} V^i(\mathbf{z}_0) \equiv \mathbf{E}_0 \left[\int_0^\infty \exp(-\rho t) \left\{ \sum_j \kappa_{ij} (\pi_{j,t} - x_{j,t}^2) \right\} dt \right]$$

subject to $d\mathbf{z}_t = (\boldsymbol{\Omega}\mathbf{z}_t + \mu\mathbf{x}_t) dt + \gamma\mathbf{z}_t dW_t$

- Firm i 's HJB equation:

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

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 Riccati
- All public patenting firms in the US in our dataset $\simeq 1000$ firms \implies
 $1000^3 = 1$ billion undetermined coefficients (20 seconds on my laptop)

Oligopolistic Schumpeterian	Computation time	# of firms	Productivity space
Cavenaile et al. (2023)	$O(2^n)$	4	6 grid
Our model	$O(n^4)$	≈ 1000	Continuous

Balance Growth Path

- R&D strategy: $x_{i,t} = (\mu \mathbf{X}_i^i)^T \mathbf{z}_t$ where \mathbf{X}_i^i is the i th column of \mathbf{X}^i
- The law of motion is rewritten as $d\mathbf{z}_t = \Phi \mathbf{z}_t dt + \gamma \mathbf{z}_t dW_t$ where

$$\Phi \equiv \underbrace{\Omega}_{\text{spillover}} + \underbrace{\mu^2 [\mathbf{X}_1^1 \dots \mathbf{X}_n^n]^T}_{\text{R\&D}}$$

Theorem

Consider the deterministic economy ($\gamma = 0$). If Φ is irreducible, then:

- There exists largest positive eigenvalue of Φ , g , and associated positive eigenvector, \mathbf{z}^* .
- 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 \mathbf{z}^* .

- Proof: Perron–Frobenius Theorem
- “ Φ is irreducible” \iff “All firms are directly or indirectly connected technologically”

Intuition of the Existence of BGP

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

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

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

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

- Linear and quadratic term in \mathbf{q}_t of output grow at the same rate:

[Equilibrium Summary](#)

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

Aggregation

- Apply Ito's lemma:

$$\begin{aligned} \log Y_t &= \log (\mathbf{z}_t^T \mathbf{Q} \mathbf{z}_t) \\ d\mathbf{z}_t &= \mathbf{\Phi} \mathbf{z}_t dt + \gamma \mathbf{z}_t dW_t \end{aligned} \implies \mathbf{E}_t [g_t | \mathbf{z}_t]$$

- Expected utility is expressed in quadratic form:

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

- Solve the equilibrium once \implies Can compute expected growth and utility for any \mathbf{z}_t

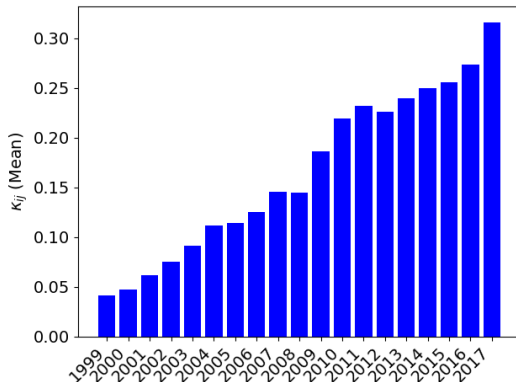
Decomposition

X

Common Ownership K

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

Proportional Influence



Product Market Rivalry Σ

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

$$\underbrace{\sigma_{ij}}_{\text{substitutability}} = \alpha \times \text{product similarity b/w } i \text{ and } j \quad (i \neq j)$$

Technological Proximity $\tilde{\Omega}$

- 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)
- Jaffe (1986) technology proximity measure $\tilde{\omega}_{ij}$:
 - Cosine similarity of the technological profiles b/w firm i and j

Distribution of Knowledge Capital

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

Technology Spillover $\Omega = \beta \times \text{Technology Proximity } \tilde{\Omega}$ First Stage

$$z_{i,t+1} - z_{i,t} = \beta \sum_{j \neq i} \tilde{\omega}_{ij,t} z_{j,t} + \text{Year FE}_t + \epsilon_{i,t}$$

	(1)	(2)	(3)
	$z_{i,t+1} - z_{i,t}$	$z_{i,t+1} - z_{i,t}$	$z_{i,t+1} - z_{i,t}$
$\sum_{j \neq i} \tilde{\omega}_{ij,t} z_{j,t}$	0.000191*** (0.000035)	0.000152*** (0.000035)	0.000140*** (0.000039)
$\sqrt{\text{R\&D Expenditure}}$.037** (0.021)	
Year Fixed Effects	✓	✓	✓
IV			✓
IV 1st Stage F-statistics			4176
No. observations	16,324	15,173	14,181

SEs clustered by years and 4-digit naics industries are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

- IV: Firm-specific tax price of R&D from federal and state-specific rules (Bloom et al., 2013)

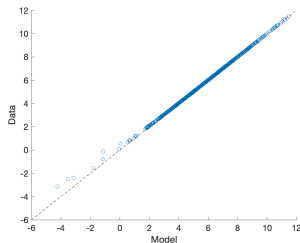
Identification: Summary

- Publicly available data + Compustat

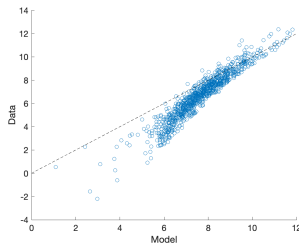
Notation	Description	Value	Source
Σ	Product proximity		Form 10-K, Hoberg and Phillips (2016)
$\tilde{\Omega}$	Technological proximity		USPTO, Patent classification
\mathbf{K}	Common ownership weights		Form 13F, Backus et al. (2021)
α	Product proximity \rightarrow Substitutability	.12	Pellegrino (2024)
β	Technological proximity \rightarrow Spillover	.00014	Estimate the law of motion
γ	St.d. of idiosyncratic shocks	.027	Estimate the law of motion
ζ/L	Labor augmentation efficiency	.0063	Compustat, Cost of goods sold
ρ	Discount rate	.10	
μ	R&D efficiency	.05	1.6% economic growth rate

Fit b/w Model and Data

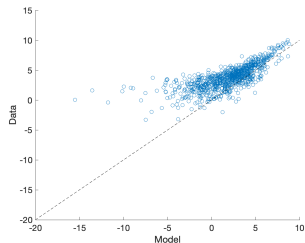
- Model (x -axis) vs Data (y -axis) : firm-level profits (targeted), sales and R&D expenditures



(a) Log of Profit (Targeted)



(b) Log of Sales



(c) Log of R&D Expenditure

Exercise: Different Ownership Structures

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

Total Output

Total Output in 2017 (Social Optimum: 100)	Ownership (Baseline: 2017)				
	Dispersed	Mean=1999	Uniform	Baseline	Monopoly
Baseline	91.30	91.02	90.78	89.08	89.17
Only Business Steal $\Omega = [0]$					
Only Tech Spill $\Sigma = \mathbf{I}, \zeta/L = 0$					

- Inelastic labor supply \implies Changes arise from product misallocation
- Common ownership exacerbates product misallocation

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Only Business Steal $\Omega = [0]$	91.30	91.02	90.78	89.08	89.17
Only Tech Spill $\Sigma = \mathbf{I}, \zeta/L = 0$	75.00	75.00	75.00	75.00	75.00

- Inelastic labor supply \implies Changes arise from product misallocation
- Common ownership exacerbates product misallocation

Total R&D Expenditure

Total R&D in 2017 (Social Optimum: 100)	Ownership (Baseline: 2017)				
	Dispersed	Mean=1999	Uniform	Baseline	Monopoly
Baseline	26.16	25.90	25.56	22.36	19.36
Only Business Steal $\Omega = [0]$					
Only Tech Spill $\Sigma = \mathbf{I}, \zeta/L = 0$					

- Internalization of business stealing $>$ Internalization of technology spillover
- Network heterogeneity is important

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Only Business Steal $\Omega = [0]$	28.15	27.79	27.07	23.42	19.80
Only Tech Spill $\Sigma = \mathbf{I}, \zeta/L = 0$					

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Only Business Steal $\Omega = [0]$	28.15	27.79	27.07	23.42	19.80
Only Tech Spill $\Sigma = \mathbf{I}, \zeta/L = 0$	18.27	18.34	18.75	18.86	19.84

- Internalization of business stealing > Internalization of technology spillover
- Network heterogeneity is important

Expected Growth Rate

Expected Economic Growth Rate in 2017 (%)	Ownership (Baseline: 2017)				
	Dispersed	Mean=1999	Uniform	Baseline	Monopoly
Baseline	1.796	1.793	1.791	1.753	1.713
Only Business Steal $\Omega = [0]$					
Only Tech Spill $\Sigma = \mathbf{I}, \zeta/L = 0$					

- In baseline, the expected growth rate is
 - 0.043 pp (2.4%) lower compared to dispersed ownership, and
 - 0.040 pp (2.2%) lower compared to common ownership level in 1999.

Expected Growth Rate

Expected Economic Growth Rate in 2017 (%)	Ownership (Baseline: 2017)				
	Dispersed	Mean=1999	Uniform	Baseline	Monopoly
Baseline	1.796	1.793	1.791	1.753	1.713
Only Business Steal $\Omega = [0]$	1.097	1.094	1.093	1.062	1.020
Only Tech Spill $\Sigma = \mathbf{I}, \zeta/L = 0$					

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Baseline	1.796	1.793	1.791	1.753	1.713
Only Business Steal $\Omega = [0]$	1.097	1.094	1.093	1.062	1.020
Only Tech Spill $\Sigma = \mathbf{I}, \zeta/L = 0$	2.051	2.054	2.068	2.072	2.107

- In baseline, the expected growth rate is
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 - 0.040 pp (2.2%) lower compared to common ownership level in 1999.

Expected Social Welfare

Expected Social Welfare (Social Optimum: 100)	Ownership (Baseline: 2017)				
	Dispersed	Mean=1999	Uniform	Baseline	Monopoly
Baseline	87.72	87.42	87.16	85.25	85.18
Only Business Steal $\Omega = [0]$					
Only Tech Spill $\Sigma = \mathbf{I}, \zeta/L = 0$					

- In baseline, consumption equivalent welfare loss is
 - 2.8% CE compared to dispersed ownership, and
 - 2.5% CE compared to common ownership level in 1999.

Expected Social Welfare

Expected Social Welfare (Social Optimum: 100)	Ownership (Baseline: 2017)				
	Dispersed	Mean=1999	Uniform	Baseline	Monopoly
Baseline	87.72	87.42	87.16	85.25	85.18
Only Business Steal $\Omega = [0]$	88.83	88.53	88.30	86.44	86.41
Only Tech Spill $\Sigma = \mathbf{I}, \zeta/L = 0$					

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Expected Social Welfare

Expected Social Welfare (Social Optimum: 100)	Ownership (Baseline: 2017)				
	Dispersed	Mean=1999	Uniform	Baseline	Monopoly
Baseline	87.72	87.42	87.16	85.25	85.18
Only Business Steal $\Omega = [0]$	88.83	88.53	88.30	86.44	86.41
Only Tech Spill $\Sigma = \mathbf{I}, \zeta/L = 0$	68.81	68.82	68.88	68.89	69.02

- In baseline, consumption equivalent welfare loss is
 - 2.8% CE compared to dispersed ownership, and
 - 2.5% CE compared to common ownership level in 1999.

Firm Value Share

Firm Value Share in 2017 (%)	Ownership (Baseline: 2017)				
	Dispersed	Mean=1999	Uniform	Baseline	Monopoly
Baseline	28.74	29.63	33.43	33.34	40.92
Only Business Steal $\Omega = [0]$					
Only Tech Spill $\Sigma = \mathbf{I}, \zeta/L = 0$					

- In baseline, firm value share is
 - 5.6% lower compared to dispersed ownership, and
 - 4.7% lower compared to common ownership level in 1999.

Firm Value Share

Firm Value Share in 2017 (%)	Ownership (Baseline: 2017)				
	Dispersed	Mean=1999	Uniform	Baseline	Monopoly
Baseline	28.74	29.63	33.43	33.34	40.92
Only Business Steal $\Omega = [0]$	27.91	28.80	32.60	33.51	40.14
Only Tech Spill $\Sigma = \mathbf{I}, \zeta/L = 0$					

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Only Business Steal $\Omega = [0]$	27.91	28.80	32.60	33.51	40.14
Only Tech Spill $\Sigma = \mathbf{I}, \zeta/L = 0$	64.82	64.81	64.76	64.74	64.63

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 - 5.6% lower compared to dispersed ownership, and
 - 4.7% lower compared to common ownership level in 1999.

When Common Ownership Affects only R&D Decisions

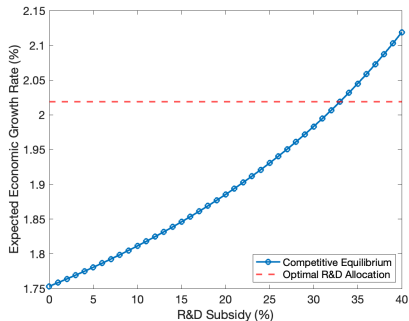
- Common ownership only influence R&D decisions (d'Aspremont and Jacquemin, 1988)

	Ownership Structure		
	Dispersed	Common R&D	Baseline
Output (Social Optimum: 100)	91.30	91.30	89.08
R&D Expenditure (Social Optimum: 100)	26.17	19.76	22.36
Expected Growth Rate (%)	1.796	1.726	1.753
Expected Social Welfare (Social Optimum: 100)	87.72	87.49	85.25
Firm Value Share (%)	28.74	29.04	34.34

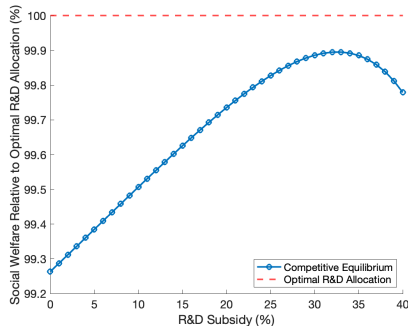
- Lowest R&D expenditure and expected growth rate
- Intermediate social welfare and firm value share

Uniform R&D Subsidy

Social Optimum



(a) Expected Growth



(b) Expected Social Welfare

- Optimal rate is $s = 33\%$, which increases g by 0.25 pp (14%)
- CE Welfare loss relative to optimal R&D allocation is reduced to 0.1% (Initially 0.7%)

Conclusion

- Quantitative Schumpeterian growth model with ownership structure
 - Utilize micro data and computational capability
- Common ownership in the US:
 1. Internalization of business stealing effect $\Rightarrow g \downarrow \downarrow$
 2. Internalization of technology spillover effect $\Rightarrow g \uparrow$
- Application:
 - Chaebols in Korea
 - Zaibatsu (pre-WWII) and cross-shareholding (late 20th century) in Japan
 - FDI / multinational companies and international technology diffusion

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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%

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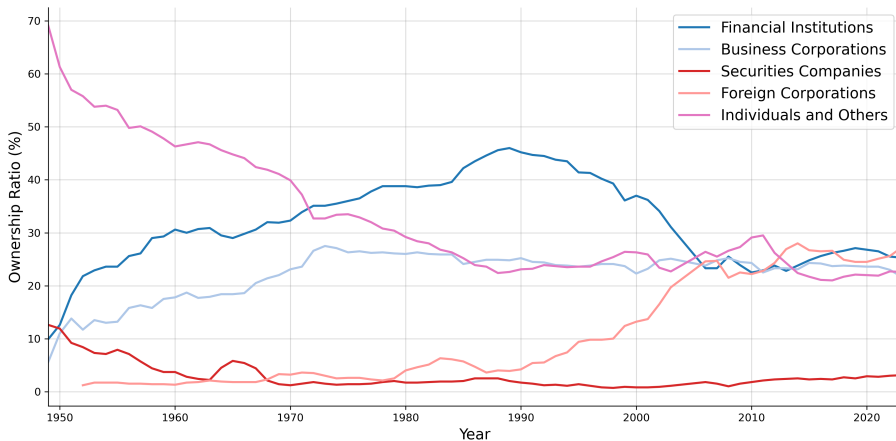
Shareholding percentage	Microsoft	Google	Amazon
OpenAI (ChatGPT)	49%	—	—
Anthropic (Claude)	—	14%	23%

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

Ownership Ratio by Holder Types in Japan



Rotemberg (1984) Proportional Influence

- $o \in \{1, 2, \dots, n_o\}$: owners
- s_{io} : the proportion of shares in firm i owned by owner o where $\sum_o s_{io} = 1$
- $\hat{V}_{i,t}$: value of firm i
- $\tilde{V}_{o,t} \equiv \sum_i s_{io} \hat{V}_{i,t}$: value of owner o
- Firms' objective:

$$\sum_o s_{io} \tilde{V}_{o,t} \propto \sum_j \kappa_{ij} \hat{V}_{j,t}$$

where

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

Total Surplus

- Total surplus for product i :

$$ts_i(\mathbf{q}, \mathbf{x}) = \pi_i(\mathbf{q}, \mathbf{x}) + cs_i(\mathbf{q}) = q_i \left[b_i - \frac{1}{2} \sum_{j=1}^n \sigma_{ij} q_j - a_i + \sum_{j=1}^n \omega_{ij} x_j \right] - \frac{1}{2} x_i^2$$

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

R&D Allocation and Externalities

- Firms maximize common owner weighted profits:

$$\mathbf{x}^* = (\mathbf{K} \circ \mathbf{\Omega})[\mathbf{\Sigma} + \mathbf{K} \circ \mathbf{\Sigma} - \mathbf{\Omega}(\mathbf{K} \circ \mathbf{\Omega})]^{-1}(\mathbf{b} - \mathbf{a})$$

- Firms maximize common owner weighted total surplus (★):

$$\mathbf{x}_{TS}^* = (\mathbf{K} \circ \mathbf{\Omega}) \left[\frac{1}{2}(\mathbf{\Sigma} + \mathbf{K} \circ \mathbf{\Sigma}) - \mathbf{\Omega}(\mathbf{K} \circ \mathbf{\Omega}) \right]^{-1}(\mathbf{b} - \mathbf{a})$$

- $\mathbf{K} = [1]$ in (★) \implies Social Optimum
- Externalities: (i) Appropriability, (ii) Business stealing, (iii) Technology spillover

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:

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

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:

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

- 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:

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

Static Profits

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

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

where

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

Riccati Equations

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

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

- $\mathbf{X}_i^i \equiv$ the i th column of \mathbf{X}^i
- $\Phi \equiv \Omega + \mu^2 \begin{bmatrix} \mathbf{X}_1^1 & \dots & \mathbf{X}_n^n \end{bmatrix}^T$
- Algorithm: Given $\begin{bmatrix} \mathbf{X}_\tau^1 & \dots & \mathbf{X}_\tau^n \end{bmatrix}$, update $\begin{bmatrix} \mathbf{X}_{\tau-\Delta}^1 & \dots & \mathbf{X}_{\tau-\Delta}^n \end{bmatrix}$ by

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

Summary of Equilibrium

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

Output and Expected Utility

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

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

- Expected utility:

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

where X is the solution of the Lyapunov equation (obtained from households' HJB equation):

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

Social Optimum

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

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

where X^* is the solution of the Riccati equation (obtained from planner's HJB equation):

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

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

Stochastic Process of Output

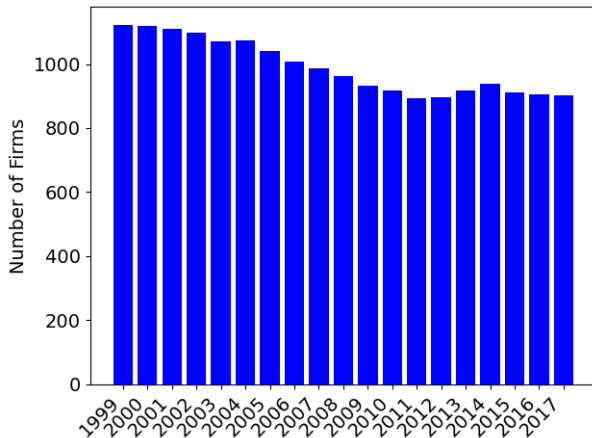
- Applying It's lemma,

$$d \log Y_t = \left[\frac{\mathbf{z}_t^T (Q\Phi + \Phi^T Q) \mathbf{z}_t}{Y_t} + \gamma^2 \left\{ \frac{\sum_i z_{i,t}^2 Q_{ii}}{Y_t} - \frac{2\mathbf{z}_t^T Q \text{diag}(\mathbf{z}_t^2) Q \mathbf{z}_t}{Y_t^2} \right\} \right] dt + \frac{2\gamma \mathbf{z}_t^T Q \text{diag}(\mathbf{z}_t)}{Y_t} dW_t$$

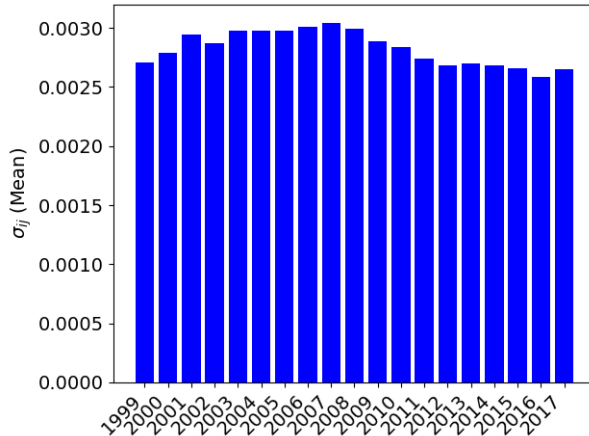
where $Y_t = \mathbf{z}_t^T Q \mathbf{z}_t$ and $\Phi = \Omega + \mu^2 \tilde{X}$

Description	Expression
Tech Spillover	$\mathbf{z}_t^T (Q\Omega + \Omega Q) \mathbf{z}_t / Y_t$
R&D	$\mu^2 \mathbf{z}_t^T (Q\tilde{X} + \tilde{X}^T Q) \mathbf{z}_t / Y_t$
Ito	$\gamma^2 \left\{ \sum_i z_{i,t}^2 Q_{ii} / Y_t - 2\mathbf{z}_t^T Q \text{diag}(\mathbf{z}_t^2) Q \mathbf{z}_t / Y_t^2 \right\}$
Total	$\mathbf{E} [d \log Y_t]$

Number of Sample Firms

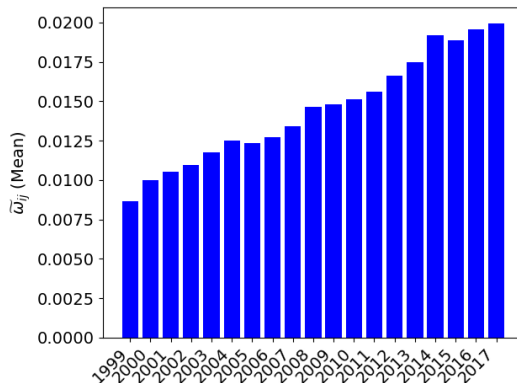


Trend of Product Substitutability

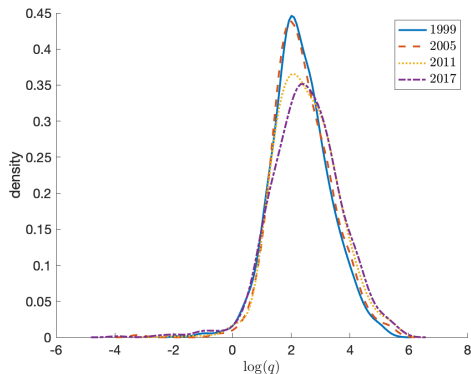


Technological Proximity

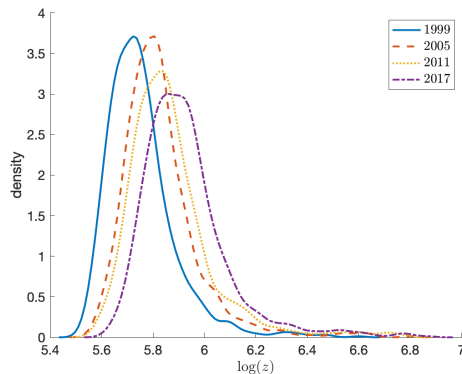
- Merge USPTO data with Compustat firms using DISCERN 2 dataset (Arora et al., 2024)
- Jaffe measure, Group-level patent classification, Stack for 5 years



Distributions of Estimated Knowledge Capital and Quantity



(a) Log of Quantity



(b) Log of Knowledge Capital

First Stage [Back](#)

	(1)
Dependent Variable:	$z_{i,t}$
User cost of R&D	-39.495^{***} (4.7044)
Year Fixed Effects	✓
No. observations	12,947

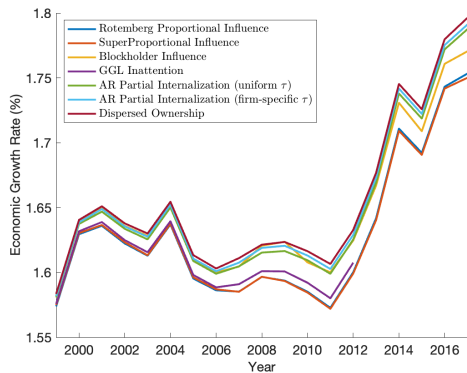
SEs clustered by years and 4-digit naics industries are reported in parentheses.

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

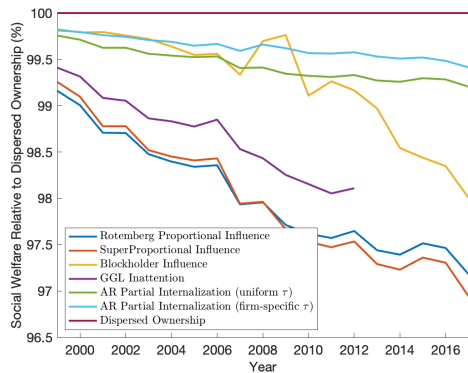
Alternative Corporate Governance Models: Ederer and Pellegrino (2024)

1. Super-proportional influence: $\tilde{\kappa}_{ij} = \frac{\sum_{z=1}^Z s_{iz} \gamma_{iz} s_{jz}}{\sum_{z=1}^Z s_{iz} \gamma_{iz} s_{iz}}$ where $\gamma_{iz} = \sqrt{s_{iz}}$
2. Blockholder influence: $\tilde{\kappa}_{ij} = \frac{\sum_{z=1}^Z s_{iz} b_{iz} s_{jz}}{\sum_{z=1}^Z s_{iz} s_{jz}} \quad (i \neq j)$, where $b_{iz} = 1$ if $s_{iz} > 5\%$
3. Rational investor inattention
 - Gilje et al. (2020) (GGL) estimate the probability that an investor votes against Institutional Shareholders Service recommendations
 - Utilize the estimate to capture the investor's level of attention
4. Governance frictions and entrenchment
 - Azar and Ribeiro (2021) (AR) estimate an objective function where the manager of firm i discounts other firms' profit by τ_i

Alternative Corporate Governance Models



(a) Expected Growth



(b) Expected Social Welfare

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