ECO 2901
EMPIRICAL INDUSTRIAL ORGANIZATION

Lecture 11:
Dynamic games of innovation

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Dynamic games of firms' innovation: Outline

- 1. Competition and Innovation: static analysis
- 2. Creative destruction and the incentives to innovate of incumbents and new entrants
- 3. Competition & innovation in CPU industry: Intel vs AMD

1. Competition and Innovation: Static analysis

Competition and Innovation

- Long lasting debate on the effect of competition on innovation (e.g., Schumpeter, Arrow).
- Apparently, there are contradictory results between a good number of theory papers showing that "competition" has a negative effect on innovation (Dasgupta & Stiglitz, 1980: Spence, 1984), and a good number of reduced-form empirical papers showing a positive relationship between measures of competition and measures of innovation (Porter, 1990; Geroski, 1990; Blundell, Griffith and Van Reenen 1999).
- Vives (JIND, 2008) presents a systematic theoretical analysis of this problem that tries to explain the apparent disparity between existing theoretical and empirical results.

Competition and Innovation: Vives (2008) [2]

- Vives considers:
- **[1] Different sources of exogenous increase in competition**.
  (i) reduction in entry cost; (ii) increase in market size; (iii) increase in degree of product substitutability.
- **[2] Different types of innovation**.
  (i) process or cost-reduction innovation; (ii) product innovation / new products.
- **[3] Different models of competition and specifications**.
  (i) Bertrand; (ii) Cournot
- **[4] Specification of demand**
  linear, CES, exponential, logit, nested logit.

Competition and Innovation: Vives (2008) [3]

- Vives shows that
  - [1] the form of increase in competition
  - and [2] the type of innovation

  are key to determine a positive or a negative relationship between competition and innovation.

- However, the results are very robust:
  [3] the form of competition (Bertrand or Cournot)
  and [4] the specification of the demand system.

Vives (2008): Model

- Static model with symmetric firms, endogenous entry.
- Profit of firm i:

$$\pi_j = [p_j - c(z_j)] \;\; s \; d(p_j, p_{-j}, n; \alpha) - z_j - F$$

$s =$ market size; $n =$ number of firms

$d(p_j, p_{-j}, n; \alpha) =$ demand per-consumer;
$\alpha =$ degree of substitutability;

$c(z_j) =$ marginal cost (constant); $z_i =$ expenditure in cost reduction;
$c' < 0$ and $c'' > 0$

$F =$ entry cost

Equilibrium

- Nash equilibrium for simultaneous choice of (p_j, z_j). Symmetric equilibrium. There is endogenous entry.

- Marginal condition w.r.t cos-reduction R&D (z) is: $-c'(z)$ s $d(p, n; \alpha) - 1 = 0$. Since $c'' > 0$, this implies

$$z = g(s \; d(p, n; \alpha))$$

  where $g(.)$ is an increasing function.

- The incentive to invest in cost reduction increases with output per firm, $q \equiv s \; d(p, n; \alpha)$.

Equilibrium (2)

- Any exogenous change in competition (say in α, s, or F) has three effects on output per firm and therefore on investment in cost-reduction R&D.

$$\frac{dz}{d\alpha} = g'(q)\left[\frac{\partial\left[s\ d(p,n;\alpha)\right]}{\partial\alpha} + \frac{\partial\left[s\ d(p,n;\alpha)\right]}{\partial p}\frac{\partial p}{\partial\alpha} + \frac{\partial\left[s\ d(p,n;\alpha)\right]}{\partial n}\frac{\partial n}{\partial\alpha}\right]$$

- $\dfrac{\partial\left[s\ d(p,n;\alpha)\right]}{\partial\alpha}$ is the **direct demand effect,**
- $\dfrac{\partial\left[s\ d(p,n;\alpha)\right]}{\partial p}\dfrac{\partial p}{\partial\alpha}$ is the **price pressure effect.**
- $\dfrac{\partial\left[s\ d(p,n;\alpha)\right]}{\partial n}\dfrac{\partial n}{\partial\alpha}$ is the **number of entrants effect.**
- The effects of different changes in competition on cost-reduction R&D can be explained in terms of these three effects.

Summary of comparative statics

- **(i) Increase in market size.**
  - Increases per-firm expenditures in cost-reduction;
  - Effect on product innovation (# varieties) can be either positive or negative.
- **(ii) Reduction in cost of market entry.**
  - Reduces per-firm expenditures in cost-reduction;
  - Increases number of firms and varieties.
- **(iii) Increase in degree of product substitution.**
  - Increases per-firm expenditures in cost-reduction;
  - # varieties may increase or decline.

Some limitations in this analysis

- The previous analysis is static, without uncertainty, with symmetric and single product firms.
- Therefore, the following factors that relate competition and innovation are absent from the analysis.
- (1) **Preemptive motives.**
- (2) **Cannibalization of own products**.
- (3) **Demand dynamics: durability. Endogenous obsolescence** generates incentives to product innovation**.**
- To study these factors, we need dynamic games with uncertainty, and asymmetric multi-product firms.

2. Creative destruction: incentives to innovate of incumbents and new entrants

Innovation and creative destruction (Igami, 2017)

• Innovation, the creation of new products and technologies, necessarily implies the "destruction" of existing products, technologies, and firms.

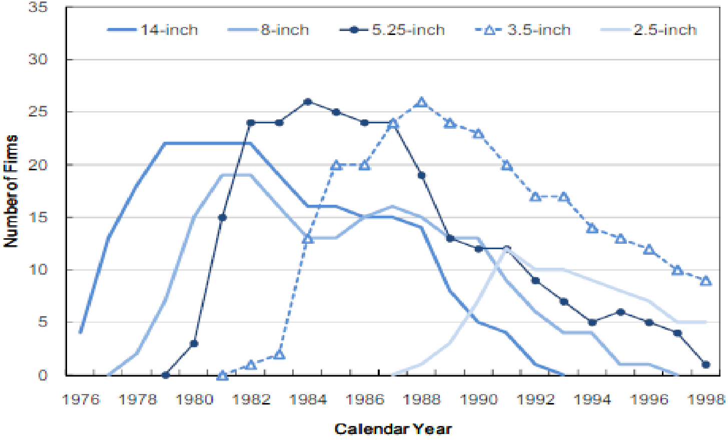
• In other words, the survival of existing products / technologies / firms is at the cost of preempting the birth of new ones.

• The speed (and the effectiveness) of the innovation process in an industry depends crucially on the dynamic strategic interactions between "old" and "new" products/technologies.

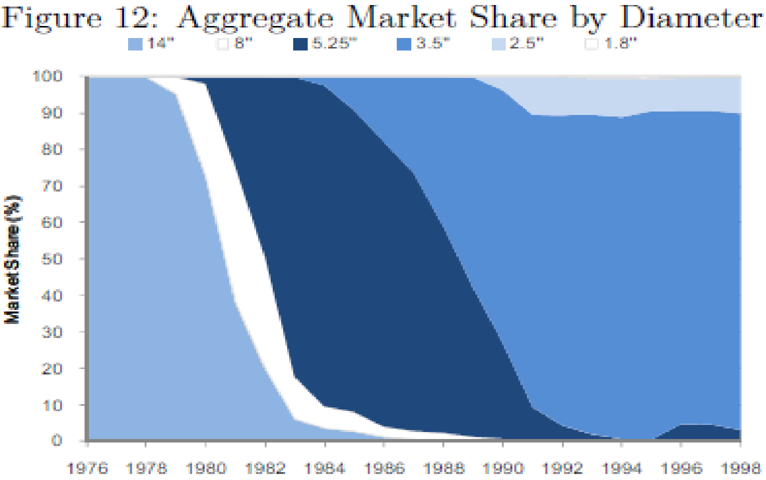
• Igami (JPE, 2017) studies these interactions in the context of the Hard-Disk-Drive (HDD) industry during 1981-1998.

HDD: Different generations of products

Figure 2: Shifting Generations of Technology

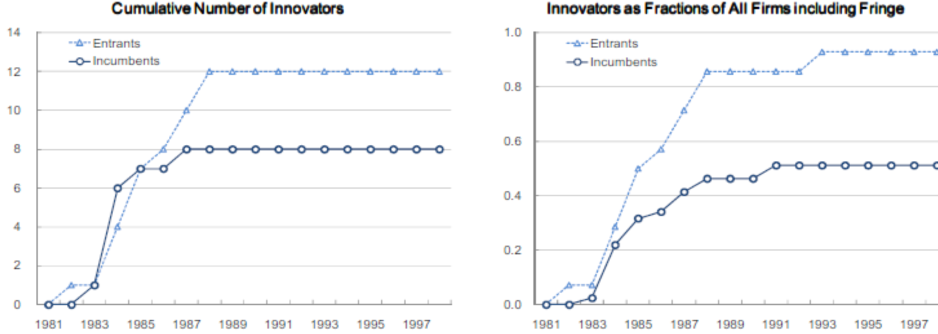


HDD: Different generations of products



Adoption new tech: Incumbents vs. New Entrants

Figure 1: The Incumbent-Entrant Innovation Gap



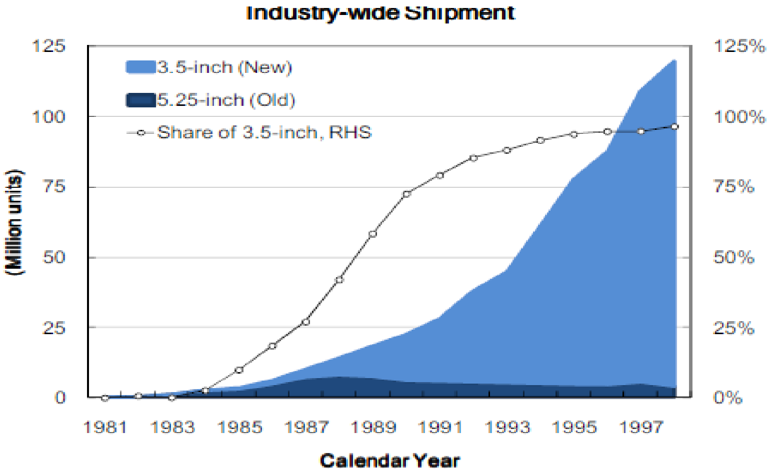
Adoption new tech: Incumbents vs. New Entrants

• Igami focuses on the transition from 5.25 to 3.5 inch products.

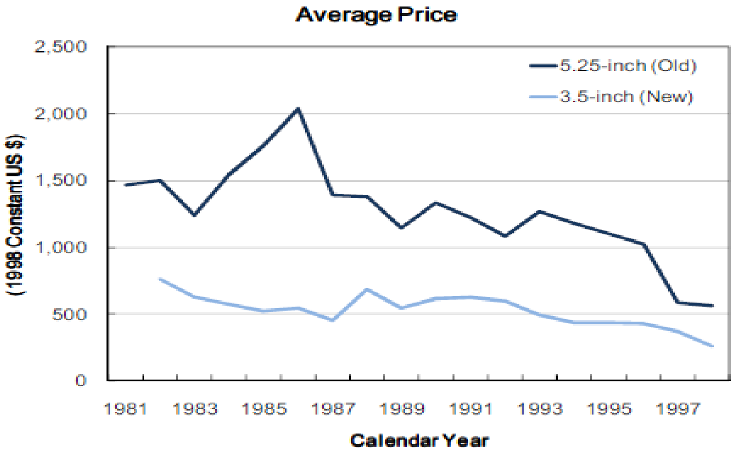
• He consider three main factors that contribute to the relative propensity to innovate of incumbents and potential entrants.

Cannibalization. For incumbents, the introduction of a new product reduces the demand for their pre-existing products.
Preemption. Early adoption by incumbents can deter entry and competition from potential new entrants.
Differences in entry/innovation costs. It can play either way. Incumbents have knowledge capital and **economies of scope**, but they also have **organizational inertia**.

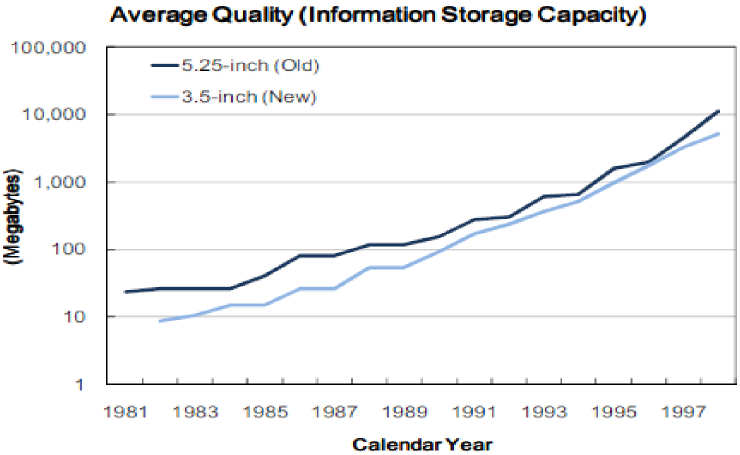
Market shares New/Old products



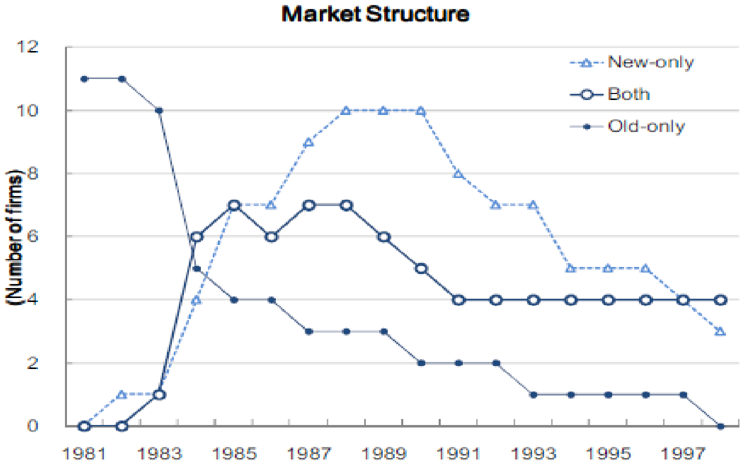
Average Prices: New/Old products



Average Quality: New/Old products



Market Structure: New/Old products



Model

• Market structure at period t is described by four type of firms according to the products they produce:

$$s_t = \{N_t^{old}, N_t^{both}, N_t^{new}, N_t^{pe}\}$$

• Timing within a period t:

1. Incumbents compete (a la Cournot) $\longrightarrow$ Period profits $\pi_t(s_{it}, s_{-it})$
2. N_t^{old} firms simultaneously choose $a_{it}^{old} \in \{exit, stay, innovate\}$
3. N_t^{both} observe a_t^{old} and simul. choose $a_{it}^{both} \in \{exit, stay\}$
4. N_t^{new} observe a_t^{old}, a_t^{both} and simul. choose $a_{it}^{new} \in \{exit, stay\}$
5. N_t^{pe} observe a_t^{old}, a_t^{both}, a_t^{new} and simul. choose $a_{it}^{pe} \in \{entry, noentry\}$.

Model [2]

• Given these choices, next period market structure is obtained, s_{t+1}, and demand and cost variables evolve exogenously.

• Why imposing this order of move? This Assumption, together with:
- Finite horizon T,
- Homogeneous firms (up to the i.i.d. private shocks) within type,

implies that there is a **unique Markov Perfect equilibrium**.

• This is very convenient for estimation (Igami uses a standard/Rust Nested Fixed Point Algorithm for estimation) and especially for counterfactuals.

Model: Demand

• Simple logit model of demand. A product is defined as a pair {technology, quality}, where technology $\in \{old, new\}$ and *quality* represents different storage sizes.

• Estimation:

$$\ln\left(\frac{s_j}{s_k}\right) = \alpha_1\left[p_j - p_k\right] + \alpha_2\left[1_j^{new} - 1_k^{new}\right] + \alpha_3\left[x_j - x_k\right] + \xi_j - \xi_k$$

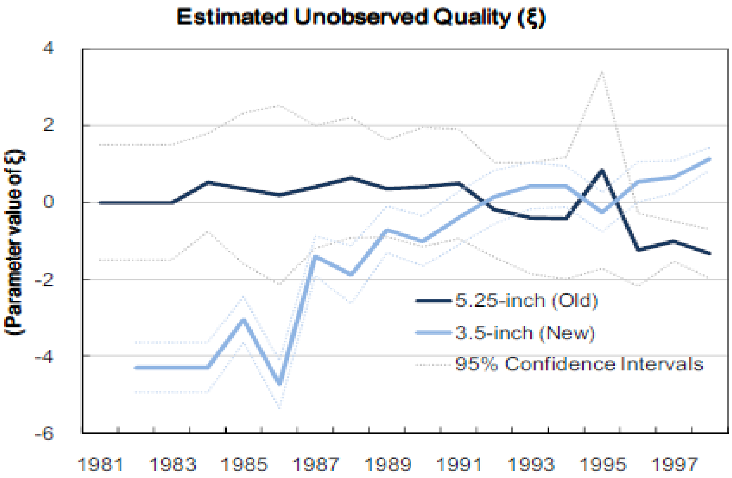
• Data: 72 quarters and 4 regions.

• IVs: Hausman-Nevo. Prices in other regions.

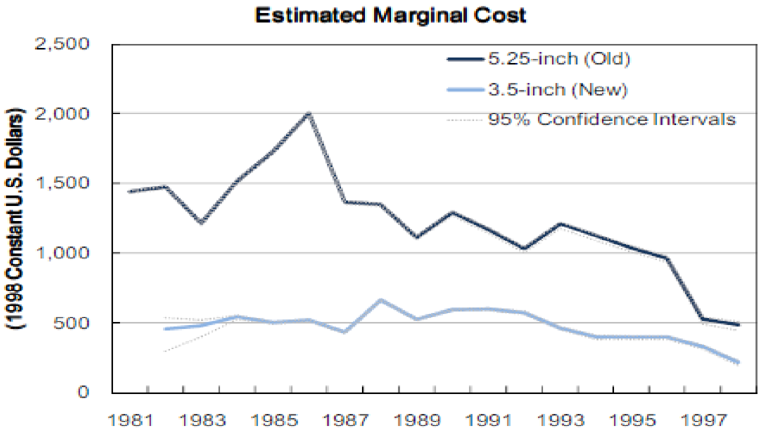
Estimates of Demand

Market definition:	Broad		Narrow	
Estimation method:	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)
Price ($000)	-1.66^{***}	-2.99^{***}	$-.93^{**}$	-3.28^{***}
	(.45)	(.55)	(.46)	(.63)
Diameter = 3.5-inch	$.84^{*}$	.75	1.75^{***}	$.91^{**}$
	(.46)	(.45)	(.31)	(.38)
Log Capacity (MB)	.18	$.87^{***}$	.04	1.20^{***}
	(.33)	(.27)	(.26)	(.31)
Year dummies	*Yes*	*Yes*	*Yes*	*Yes*
Region/user dummies	–	–	*Yes*	*Yes*
Adjusted R^2	.43	.33	.50	.28
Number of obs.	176	176	405	405
Partial R^2 for Price	–	.32	–	.16
P-value	–	.00	–	.00

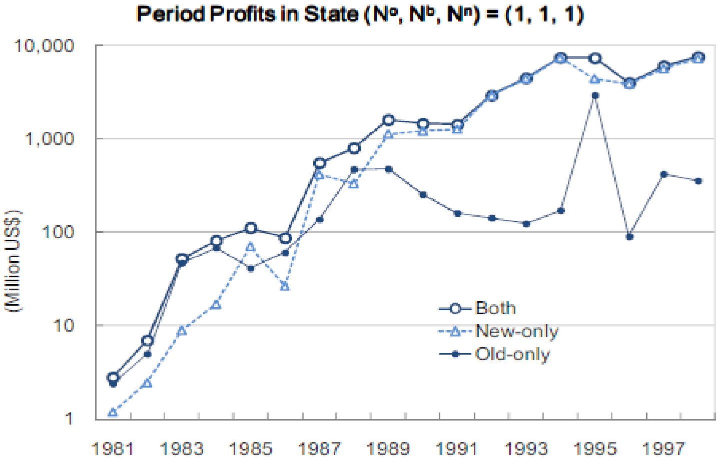
Evolution of unobserved Quality (epsi)



Evolution of Marginal Costs



Evolution of Period Profits [keeping market structure]



Estimates of Dynamic Parameters

Table 4: Estimates of the Dynamic Parameters

(\$ Billion)	Maximum Likelihood Estimates		
	(1)	(2)	(3)
Assumed order of moves:	Old-Both-New-PE	PE-New-Both-Old	PE-Old-Both-New
Fixed cost of operation (ϕ)	0.1474	0.1472	0.1451
	[−0.02, 0.33]	[−0.02, 0.33]	[−0.03, 0.33]
Incumbents' sunk cost (κ^{inc})	1.2439	1.2370	1.2483
	[0.51, 2.11]	[0.50, 2.10]	[0.51, 2.11]
Entrants' sunk cost (κ^{ent})	2.2538	2.2724	2.2911
	[1.74, 2.85]	[1.76, 2.87]	[1.78, 2.89]
Log likelihood	−112.80	−112.97	−113.46

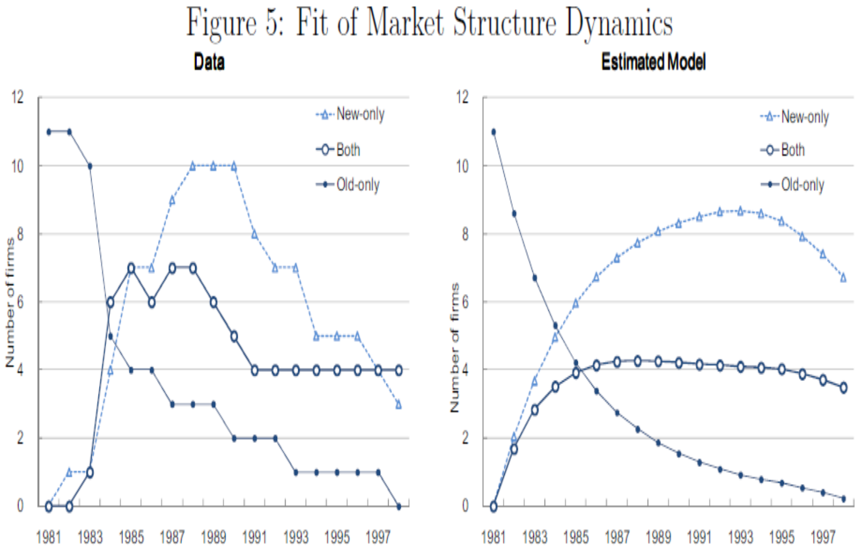
Estimates of Dynamic Parameters

- Estimates are pretty robust to changes in the order of move within a period.

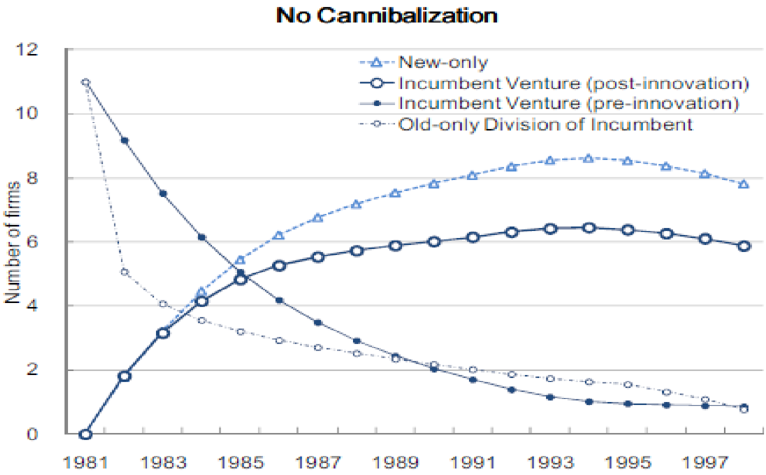
- Cost for innovation is smaller for incumbents than for new entrants ($\kappa^{inc} < \kappa^{pe}$). Economies of scope seem more important than organizational inertia.

- Magnitude of entry costs are comparable to the annual R&D budget of specialized HDD manufacturers, e.g., Seagate Tech: between $\$0.6B - \$1.6B$.

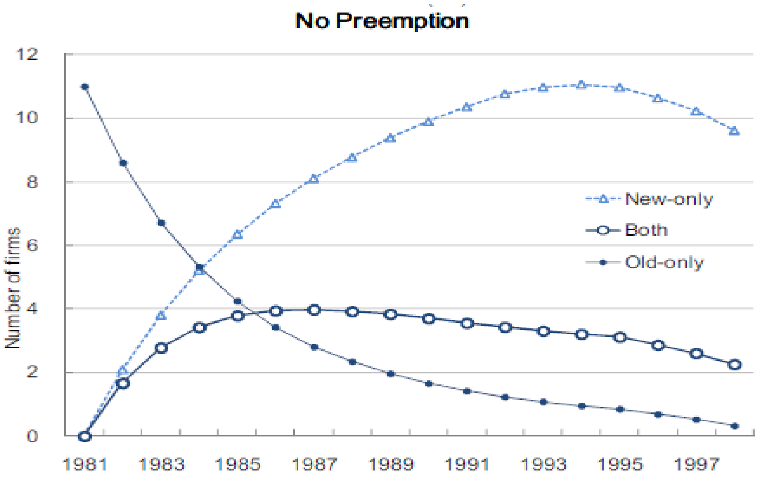
Estimated Model: Goodness of fit



Counterfactual: Removing Cannibalization



Counterfactual: Removing Preemption



3. Competition and Innovation: Intel & AMD (Goettler & Gordon, 2011)

Introduction

- Competition between Intel and AMD in PC microprocessor industry.
- Incorporates durability of the product as a potentially important factor for innovation (endogenous technological obsolescence).
- Two forces drive innovation:

  - competition between firms for the technological frontier;

  - since PCs have little physical depreciation, firms have the incentive to innovate to generate a technological depreciation of consumers' installed PCs that encourages them to upgrade [most of the demand during the period $>$89% was upgrading].
- Duopolists face both forces, whereas a monopolist faces only the latter (but in a stronger way).

The PC microprocessor industry

- Very important to the economy:
  - Computer equipment manufacturing industry generated 25% of U.S. productivity growth from 1960 to 2007.
- Innovations in microprocessors are directly measured via improved performance on benchmark tasks. Most important: CPU speed.
- Interesting also from the point of view of antitrust:
  - In 2004, AMD sued Intel claiming anti-competitive practices:
    * Intel rewarded PC manufacturers that exclusively use Intel microprocessors.
    * Intel foreclosured AMD to access some consumers.
  - Intel settled these claims in 2009 with a $1.25 billion payment to AMD.

The PC microprocessor industry (2)

- Market is essentially a duopoly, with AMD and Intel selling 95% CPUs.
- Firms have high R&D intensities, **R&D/Revenue** (1993-2004):
  - AMD 20% ; and Intel 11%
- Innovation is rapid: new products are released nearly every quarter.
- CPU speed doubles every 7 quarters, i.e., **Moore's law**.
- AMD and Intel extensively cross-license each other's technologies, i.e., positive spillover.

The PC microprocessor industry (3)

- As microprocessors are durable, replacement drives and important part of demand.
- The importance of replacement is:
  - partly exogenous: relative importance of new consumers arriving to the marker;
  - partly endogenous: speed of improvements in frontier microprocessors that encourages consumers to upgrade.
- In 2004, 82% of PC purchases were replacements.
- After an upgrade boom, (replacement) demand drops, and prices drop too. Firms must continue to innovate to rebuild replacement demand. Cycles.

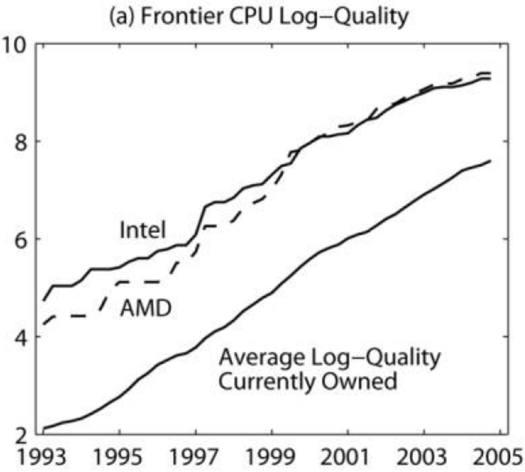
Data

- Proprietary data from a market research firm specializing in the microprocessor industry.
- Quarterly data from Q1-1993 to Q4-2004 (48 quarters).
- Information on: shipments in physical units for each type of CPU; manufacturers' average selling prices (ASP); **production costs**; CPU characteristics (speed).
- All prices and costs are converted to base year 2000 dollars.
- Quarterly R&D investment levels, obtained from firms' annual reports.

Moore's Law

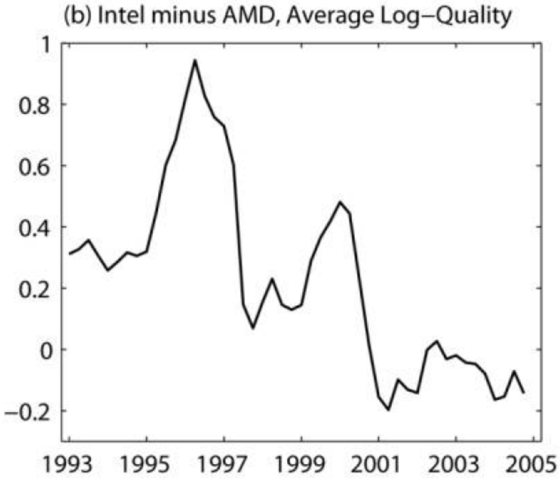
- Intel cofounder Gordon Moore predicted in 1965 that the number of transistors in a CPU (and therefore the CPU speed) would double every 2 years.
- Following figure shows "Moore's law" over the 48 quarters in the data.
- Quality is measured using processor speed.
- Quarterly % change in CPU speed is 10.2% for Intel and 11% for AMD.

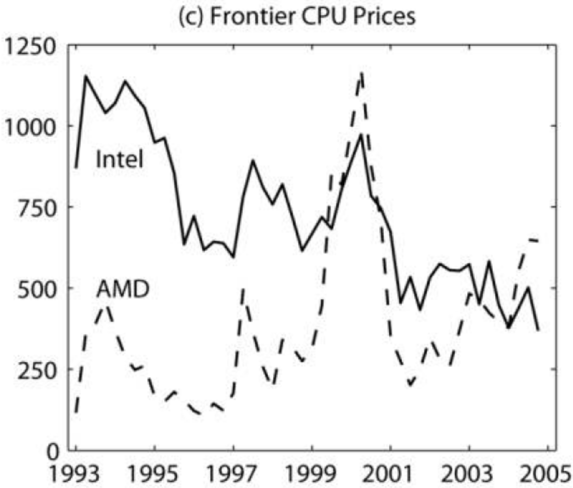
Moore's Law (Frontier CPU speed)

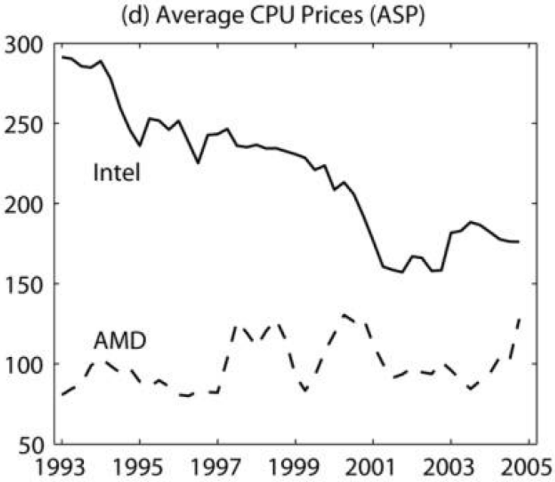


Differential log-quality between Intel and AMD

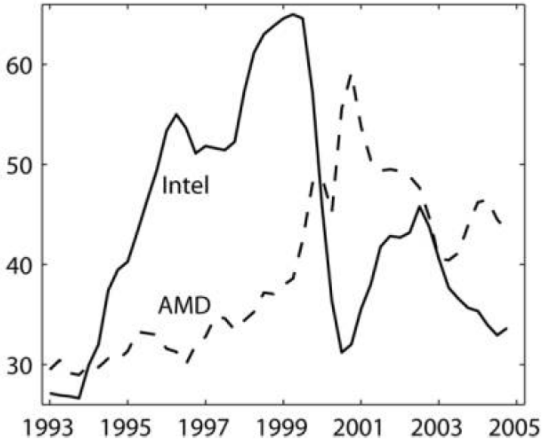
- Intel's initial quality advantage is moderate in 1993–94.
- Then, it becomes large in 1995-96 when Intel releases the Pentium.
- AMD's responded in 1997 introducing the K6 processor that narrows the gap.
- But parity is not achieved until the mid-2000 when AMD released the Athlon.

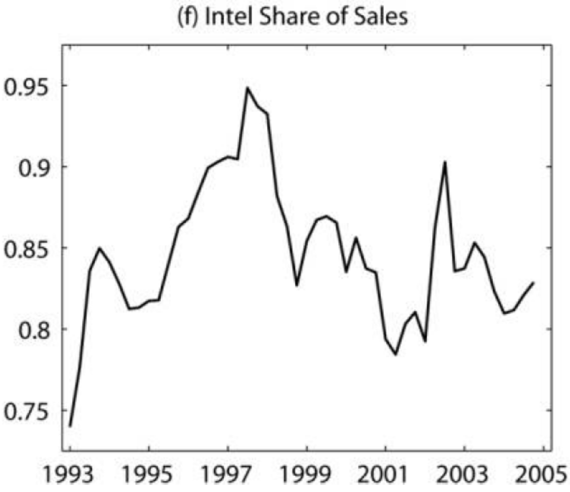

(b) Intel minus AMD, Average Log–Quality
1
0.8
0.6
0.4
0.2
0
−0.2
1993
1995
1997
1999
2001
2003
2005


(c) Frontier CPU Prices
1250
1000
750
500
250
0
1993
1995
1997
1999
2001
2003
2005
Intel
AMD


(d) Average CPU Prices (ASP)
300
250
200
150
100
50
1993
1995
1997
1999
2001
2003
2005
Intel
AMD

(e) Average Unit Production Costs




(f) Intel Share of Sales
0.95
0.9
0.85
0.8
0.75
1993
1995
1997
1999
2001
2003
2005

Model: General features

- Dynamic model of an oligopoly with differentiated and durable products.
- Each firm j sells a single product and invests in R&D to improve its quality.
- If investments are successful, quality improves next quarter by δ %; otherwise it is unchanged.

  log quality: $q_{jt} \in \{0, \delta, 2\delta, 3\delta, \ldots\}$.
- Consumers: a key feature of demand for durable goods is that the value of the no-purchase option is determined by last purchase.
- Δ_t = Vector with: [# consumers with $q = 0$; # consumers with $q = \delta$; # consumers with $q = 2\delta$; ...]

Model: General features (2)

- Firms and consumers are forward looking.
- A consumer's i state space consists of $(q^*_{it}, q_t, \Delta_t)$:
  - q^*_{it} = the quality of her currently owned product;
  - q_t = vector of firms' current qualities q_t;
  - Δ_t = distribution of qualities of consumers currently owned products.
- Δ_t is part of the consumers' state space because it affects expectations on future prices.
- State space for firms is (q_t, Δ_t).
- Given these state variables firms simultaneously choose prices p_{jt} and investment x_{jt}.

Model: Consumer Demand

- Authors: *"We restrict firms to selling only one product because the computational burden of allowing multiproduct firms is prohibitive"*.

- Consumers own no more than one microprocessor at a time. Utility for a consumer i from firm j's new product with quality q_{jt} is given by:

$$u_{ijt} = \gamma \; q_{jt} - \alpha \; p_{jt} + \xi_j + \varepsilon_{ijt}$$

- Utility from the no-purchase option is:

$$u_{i0t} = \gamma \; q_{it}^{*} + \varepsilon_{i0t}$$

- A consumer maximizes her intertemporal utility given her beliefs about the evolution of future qualities and prices given (q_t, Δ_t).

Model: Consumer Demand

- Market shares for consumers currently owning q^* are:

$$s_{jt}(q^*) = \frac{\exp\{v_j(q_t, \Delta_t, q^*)\}}{\sum_{k=0}^{J} \exp\{v_k(q_t, \Delta_t, q^*)\}}$$

- Using Δ_t to integrate over the distribution of q^* yields the market share of product j.

$$s_{jt}(q^*) = \sum_{q^*} s_{jt}(q^*) \; \Delta_t(q^*)$$

- Transition rule of Δ_t. By definition, next period Δ_{t+1} is determined by a known closed-form function of Δ_t, q_t, and s_t.

$$\Delta_{t+1} = F_{\Delta}(\Delta_t, q_t, s_t)$$

Model: Firms. per period profits

- The period profit function is:

$$\pi_j(p_t, q_t, \Delta_t) = M\ s_j(p_t, q_t, \Delta_t)\ \ [p_{jt} - mc_j(q_{jt})]$$

- The specification of the marginal cost is:

$$mc_j(q_{jt}) = \lambda_{0j} - \lambda_1(q_t^{\max} - q_{jt})$$

- Marginal costs are smaller for non-frontier firms.

Model: Firms. Innovation process

- Relationship between investment in R&D (x_{jt}) and log-quality improvement ($\Delta q_{jt+1} = q_{jt+1} - q_{jt}$).
- Log-Quality improvement can take two values, 0 or δ.
- The probability that $\Delta q_{jt+1} = \delta$ is (Pakes & McGure, 1994):

$$\chi_j(x_{jt}, q_{jt}) = \frac{a_j(q_{jt})\ x_{jt}}{1 + a_j(q_{jt})\ x_{jt}}$$

- $a_j(q_{jt})$ is the "investment efficiency" function.
- It is a decreasing function, to capture the idea of increasing difficulty of advancing the frontier relative to catching up.

Model: Firms' Bellman equation

- Let $W_j(q_t, \Delta_t)$ be the value function. The Bellman equation is:

$$W_j(q_t, \Delta_t) = \max_{x_{jt}, p_{jt}} \left[\pi_j(p_t, q_t, \Delta_t) - x_{jt} + \beta \; \mathbb{E}_t \left[W_j(q_{t+1}, \Delta_{t+1}) \right] \; \right]$$

- The decision variables are continuous, and the best response function should satisfy the F.O.C.

$$\begin{aligned} \frac{\partial \pi_{jt}}{\partial p_{jt}} + \beta \frac{\partial \mathbb{E}_t \left[W_{j,t+1} \right]}{\partial p_{jt}} &= 0 \\ \frac{\partial \pi_{jt}}{\partial x_{jt}} - 1 + \beta \frac{\partial \mathbb{E}_t \left[W_{j,t+1} \right]}{\partial x_{jt}} &= 0 \end{aligned}$$

Model: Markov Perfect Equilibrium

- (1) firms' and consumers' equilibrium strategies depend only on current payoff relevant state variables (q_t, Δ_t).
- (2) consumers have rational expectations about firms' policy functions.
- (3) each firm has rational expectations about competitors' policy functions and about the evolution of the ownership distribution.

Estimation

- Marginal cost parameters (λ_0, λ_1) are estimated in a first step because the dataset includes data on marginal costs.

- The rest of the structural parameters,

$$\theta = (\gamma,\ \alpha,\ \xi_{intel},\ \xi_{amd},\ a_{0,intel},\ a_{0,amd},\ a_1)$$

  Demand: γ, α, ξ_{intel}, ξ_{amd}; Investment innovation efficiency: $a_{0,intel}$, $a_{0,amd}$, a_1.

- θ is estimated using Indirect Inference or Simulated Method of Moments (SMM).

Estimation: Moments to match

- Mean of innovation rates $q_{j,t+1} - q_{jt}$ for each firm.
- Mean R&D intensities $x_{jt} / revenue_{jt}$ for each firm.
- Mean of differential quality $q_{intel,t} - q_{amd,t}$, and share of quarters with $q_{intel,t} \geq q_{amd,t}$.
- Mean of gap $q_t^{\max} - \overline{\Delta}_t$.
- Average prices, and OLS estimated coefficients of the regressions of p_{jt} on $q_{intel,t}$, $q_{amd,t}$, and average $\overline{\Delta}_t$.
- OLS estimated coefficients of the regression of $s_{intel,t}$ on $q_{intel,t} - q_{amd,t}$.

Empirical and predicted moments

TABLE 1
EMPIRICAL AND SIMULATED MOMENTS

Moment	Actual	Actual Standard Error	Fitted
Intel price equation:			
Average Intel price	219.7	5.9	206.2
$q_{\mathrm{Intel},t} - q_{\mathrm{AMD},t}$	47.4	17.6	27.3
$q_{\mathrm{Intel},t} - \bar{\Delta}_t$	94.4	31.6	43.0
AMD price equation:			
Average AMD price	100.4	2.3	122.9
$q_{\mathrm{Intel},t} - q_{\mathrm{AMD},t}$	−8.7	11.5	−22.3
$q_{\mathrm{AMD},t} - \bar{\Delta}_t$	16.6	15.4	5.9
Intel share equation:			
Constant	.834	.007	.846
$q_{\mathrm{Intel},t} - q_{\mathrm{AMD},t}$	.055	.013	.092
Potential upgrade gains:			
Mean $(\bar{q}_t - \hat{\Delta}_t)$	1.146	.056	1.100
Mean innovation rates:			
Intel	.557	.047	.597
AMD	.610	.079	.602
Relative qualities:			
Mean $q_{\mathrm{Intel},t} - q_{\mathrm{AMD},t}$	1.257	.239	1.352
Mean $\mathcal{I}(q_{\mathrm{Intel},t} \geq q_{\mathrm{AMD},t})$	.833	.054	.929
Mean R&D/revenue:			
Intel	.114	.004	.101
AMD	.203	.009	.223

Parameter estimates

TABLE 2
PARAMETER ESTIMATES

Parameter	Estimate	Standard Error
Price, α	.0131	.0017
Quality, γ	.2764	.0298
Intel fixed effect, ξ_{Intel}	$-.6281$	.0231
AMD fixed effect, ξ_{AMD}	-3.1700	.0790
Intel innovation, $a_{0,\text{Intel}}$	.0010	.0002
AMD innovation, $a_{0,\text{AMD}}$	.0019	.0002
Spillover, a_1	3.9373	.1453
Stage 1 marginal cost equation:		
Constant, λ_0	44.5133	1.1113
$\max(0,\ q_{\text{competitor},t} - q_{\text{own},t}),\ \lambda_1$	-19.6669	4.1591

Parameter estimates

- Demand: Dividing γ by α: consumers are willing to pay \$21 for enjoying during 1 quarter a $\delta = 20\%$ increase in log quality.
- Dividing $\xi_{intel} - \xi_{amd}$ by α: consumers are willing to pay \$194 for Intel over AMD.
- The model needs this strong brand effect to explain the fact that AMD's share never rises above 22 percent in the period during which AMD had a faster product.
- Intel and AMD's innovation efficiencies are estimated to be .0010 and .0019, respectively, as needed for AMD to occasionally be the technology leader while investing much less.

Counterfactuals

TABLE 3
INDUSTRY OUTCOMES UNDER VARIOUS SCENARIOS

	AMD-INTEL DUOPOLY (1)	SYMMETRIC DUOPOLY (2)	MONOPOLY (3)	NO SPILLOVER DUOPOLY (4)	MYOPIC PRICING AMD-Intel (5)	MYOPIC PRICING Monopoly (6)
Industry profits ($ billions)	408	400	567	382	318	322
Consumer surplus (CS)	2,978	3,012	2,857	3,068	2,800	2,762
CS as share of monopoly CS	1.042	1.054	1.000	1.074	.980	.967
Social surplus (SS)	3,386	3,412	3,424	3,450	3,118	3,084
SS as share of planner SS	.929	.906	.940	.916	.828	.819
Margins, $(p - mc)/mc$	3.434	2.424	5.672	3.478	2.176	2.216
Price	194.17	146.73	296.98	157.63	140.06	143.16
Frontier innovation rate	.599	.501	.624	.438	.447	.438
Industry investment ($ millions)	830	652	1,672	486	456	787
Mean quality upgrade (%)	261	148	410	187	175	181
Intel or leader share	.164	.135	.143	.160	.203	.211
AMD or laggard share	.024	.125		.091	.016	

From current duopoly (1) to Intel Monopoly (3)

- Innovation rate increases from 0.599 to 0.624
- Mean quality upgrade increases 261% to 410%
- Investment in R&D: increases by $1.2B$ per quarter: more than doubles.
- Price increases in \$102 (70%)
- Consumer surplus declines in \$121M (4.2%)
- Industry profits increase in \$159M
- Social surplus increases in \$38M (less than 1%)

From current duopoly (1) to symmetric duopoly (2)

- Innovation rate declines from 0.599 to 0.501
- Mean quality declines from 261% to 148%
- Investment in R&D: declines by 178M per quarter
- Price declines in \$48 (24%)
- Consumer surplus increases in \$34M (1.2%)
- Industry profits decline in \$8M
- Social surplus increases in \$26M (less than 1%)

From current scenario (1) to myopic pricing

- It reduces prices, increases CS, and reduces firms' profits.
- Innovation rates and investment in R&D decline dramatically.
- Why? The higher induce firms to innovate more rapidly.
- Prices are higher with dynamic pricing because firms want to preserve future demand.

Counterfactuals

- The finding that innovation by a monopoly exceeds that of a duopoly reflects two features of the model:
  - the monopoly must innovate to induce consumers to upgrade;
  - the monopoly is able to extract much of the potential surplus from these upgrades because of its substantial pricing power.
- If there were a steady flow of new consumers into the market, such that most demand were not replacement, the monopoly would reduce innovation below that of the duopoly.

Counterfactuals: Foreclosure

- In 2009, Intel paid AMD $1.25 billion to settle claims that Intel's anti-competitive practices foreclosed AMD from many consumers.
- To study the effect of such practices on innovation, prices, and welfare, the authors perform a series of counterfactual simulations in which they vary the portion of the market to which Intel has exclusive access.
- Let ζ be the proportion of foreclosure market. Intel market share becomes:

$$s_j^* = \zeta \, \widehat{s}_j + (1-\zeta) \; s_j$$

where s_j is the market share when AMD is competing, and $\widehat{s}_j$ is the market share when Intel competes only with the outside alternative.

Counterfactuals: Foreclosure

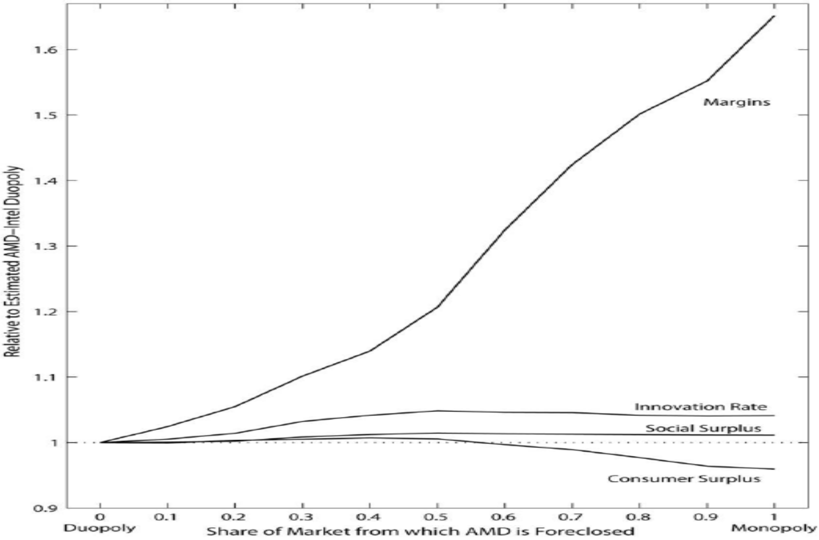
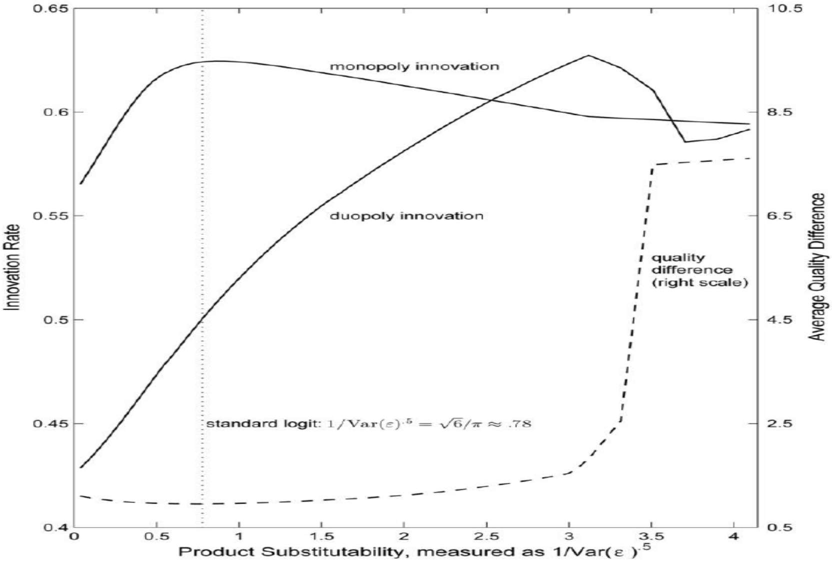


FIG. 6.—Foreclosing AMD from the market

Counterfactuals: Foreclosure

- Margins monotonically rise steeply.
- Innovation exhibits an inverted U with a peak at $\zeta = 0.5$.
- Consumer surplus is actually higher when AMD is barred from a portion of the market, peaking at 40% foreclosure.
- This finding highlights the importance of accounting for innovation in antitrust policy:
  - the decrease in consumer surplus from higher prices can be more than offset by the compounding effects of higher innovation rates.

Counterfactuals: Product substitutability



Counterfactuals: Product substitutability

- Innovation in the monopoly exhibits an inverted U as substitutability increases.
- Innovation in the duopoly increases as substitutability increases until Var( ) becomes too small for firms with similar qualities to coexist.
  - Beyond this "shakeout" threshold, the laggard eventually concedes the market as evidenced by the sharp increase in the quality difference.
- Duopoly innovation is higher than monopoly innovation when substitutability is near the shakeout threshold.

Summary of results

- The rate of innovation in product quality would be 4.2% higher if Intel were a monopolist, consistent with Schumpeter.
- Without AMD, higher margins spur Intel to innovate faster to generate upgrade sales.
- As in Coase's (1972) conjecture, product durability can limit welfare losses from market power.
- This result, however, depends on the degree of competition from past sales. If first-time purchasers were to arrive sufficiently faster than we observe, innovation in an Intel monopoly would be lower, not higher, since upgrade sales would be less important.