EMPIRICAL ANALYSIS OF INNOVATION IN OLIGOPOLY INDUSTRIES

Lectures 4 and 5:
Dynamic strategic behavior in firms' innovation

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Dynamic strategic behavior in firms' innovation: Outline

- 1. Competition and Innovation: static analysis
- 2. Dynamic games of oligopoly competition
- 3. Creative destruction and the incentives to innovate of incumbents and new entrants
- 4. Competition and innovation in the CPU industry: Intel and AMD
- 5. Environmental regulation and adoption of green technologies

2. 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 disparaty 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, expontetial, 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 detemine a positive or a negative relatioship betwween 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) **Increasing uncertainty** in returns to R&D due competition (asymmetric info)**.**
- To study these factors, we need dynamic games with uncertainty, and asymmetric multi-product firms.

3. Dynamic games of oligopoly competition

Dynamic games of oligopoly competition

- Firms compete in investment decisions that have returns in the future, involve substantial uncertainty, and can have important effects on competitors' profits.

  - Investment in R&D, innovation.
  - Product design / quality
  - Market entry / exit ...

- Understanding the dynamic strategic interactions between firms decisions (e.g., dynamic complementarity or substitutability) is important to understand the forces behind the dynamics of an industry or to evaluate policies.

- Empirical dynamic games provide a framework to study these questions and perform policy analysis.

Some recent applications of DG to innovation

- Competition in R&D and product innovation between Intel and AMD: Goettler and Gordon (JPE, 2011).
- Product innovation of incumbents and new entrants in the hard drive industry: Igami (JPE, 2017).
- Complementarities between investment in R&D and exporting: Aw, Roberts, and Xu (AER, 2011).
- Product differentiation and innovation in the automobile industry: Hasmi & Van Biesebroeck (RStat, 2016).

Dynamic Games: Basic Structure

- Follows the framework in Ericson-Pakes (1995).

- Time is discrete and indexed by t. The game is played by N firms [potential entrants] that we index by i.

- Firms compete in two different dimensions: a static dimension and a dynamic dimension.

- We denote the dynamic dimension as the "investment decision".

Dynamic Games: Basic Structure (2)

- Let a_{it} be the variable that represents the investment decision of firm i at period t.

- This investment decision can be an entry/exit decision, R&D, product quality, etc.

- Every period, firms observed the state variables (e.g., their capital stocks) and compete in prices or quantities in a static Cournot or Bertand model.

- Let p_{it} be the static decision variables (e.g., price) of firm i at period t.

Dynamic Games: Basic Structure (3)

• I start presenting a simple dynamic game of market entry-exit and "quality" choice where every period incumbent firms compete a la Bertrand.

• The dynamic investment decision $a_{it} \in \{0, 1, ..., J\}$ represents the R&D or quality choice if $a_{it} > 0$, and $a_{it} = 0$ if the firm is not active in the market at period t.

• The action is taken to maximize the expected and discounted flow of profits in the market,

$$E_t \left(\sum_{r=0}^{\infty} \delta^r \ \Pi_{it+r} \right)$$

where $\delta \in (0, 1)$ is the discount factor, and Π_{it} is firm i's profit at period t.

Profit function

- The profits of firm i at time t are given by

$$\Pi_{it} = VP_{it} - FC_{it} - EC_{it} - IC_{it} + SV_{it}$$

where:

VP_{it} represents variable profit;
FC_{it} is the fixed cost of operating;
EC_{it} is a one time entry cost
IC_{it} is an investment cost
SV_{it} is the exit value of scrap value

Variable profit function

• The variable profit VP_{it} is an "indirect" variable profit function that comes from the equilibrium of a static Bertrand game with differentiated product.

• The marginal cost is $c_i(a_{it}, z_t)$, where z_t is the a vector of exogenous state variables, and produces a product with quality $v_i(a_{it}, z_t)$.

• Consumer utility of buying product i is $u_{it} = \nu_i(a_{it}, z_t) - \alpha(z_t)\ p_{it} + \varepsilon_{it}$, where $\nu_i(.)$ and $\alpha(.)$ are functions, and ε_{it} is a consumer-specific i.i.d. extreme value type 1 random variable.

Variable profit function (2)

- The variable profit of an active firm is:

$$VP_{it} = (p_{it} - c_i(a_{it}, z_t))\ q_{it}$$

where p_{it} and q_{it} represent the price and the quantity sold by firm i at period t, respectively.

- According this model, the quantity is:

$$q_{it} = \frac{H_t\ 1\{a_{it} > 0\}\ \exp\{v_i(a_{it}, z_t) - \alpha(z_t)\ p_{it}\}}{1 + \sum_{j=1}^{N} 1\{a_{jt} > 0\}\ \exp\{v_j(a_{jt}, z_t) - \alpha(z_t)\ p_{jt}\}} = H_t\ s_{it}$$

where H_t is the number of consumers in the market (market size) and s_{it} is the market share of firm i.

Variable profit function (3)

• Under the Nash-Bertrand assumption the first order conditions for profit maximization are:

$$q_{it} + (p_{it} - c_i(a_{it}, z_t)) \ (-\alpha(z_t)) \ q_{it} \ (1 - s_{it}) = 0$$

or

$$p_{it} = c_i(a_{it}, z_t) + \frac{1}{\alpha(z_t)\,(1 - s_{it})}$$

• These N equations define a Bertrand equilibrium with prices $p_t^* = (p_{1t}^*, p_{2t}^*, ..., p_{Nt}^*)$ and market shares:

$$s_{it}^* = \frac{1\{a_{it} > 0\} \ \exp\{v_i(a_{it}, z_t) - \alpha(z_t) \ p_{it}^*\}}{1 + \sum_{j=1}^{N} 1\{a_{jt} > 0\} \ \exp\{v_j(a_{jt}, z_t) - \alpha(z_t) \ p_{jt}^*\}}$$

Model: Variable profit function (4)

• Equilibrium prices depend on the vector of product qualities of the active firms in the market $(\mathbf{a}_t)$, and on the exogenous variables z_t: $p_{it}^* = p_i^*(\mathbf{a}_t, z_t)$.

• Similarly, the equilibrium market shares s_{it}^* is a function of $(\mathbf{a}_t, z_t)$: $s_{it}^* = s_i^*(\mathbf{a}_t, z_t)$.

• Therefore, the indirect or equilibrium variable profit of an active firm is:

$$\begin{aligned} VP_{it} &= a_{it} \; H_t \; (p_i^*(\mathbf{a}_t, z_t) - c_i(z_t)) \; s_i^*(\mathbf{a}_t, z_t) \\ &= a_{it} \; H_t \; \theta_i^{VP}(\mathbf{a}_t, z_t) \end{aligned}$$

where $\theta_i^{VP}(.)$ is a function that represents variable profits per capita.

Fixed cost

• The fixed cost is paid every period that the firm is active in the market, and it has the following structure (mode of entry-exit):

$$FC_{it} = 1\{a_{it} > 0\} \left[\theta_i^{FC}(a_{it}, z_t) + \varepsilon_{it}^{FC}(a_{it})\right]$$

• $\theta_i^{FC}(a_{it}, z_t)$ is a function that represents the fixed operating cost of firm i if it produces a product with quality a_{it}. z_t is a vector of exogenous state variables that are common knowledge to all the firms.

• $\varepsilon_{it}^{FC}(a_{it})$ are a zero-mean shocks that is private information of firm i.

Fixed cost (2)

• There are two main reasons why we incorporate these private information shocks in the model.

• First, as shown in Doraszelski and Satterthwaite (2012), it is a way to guarantee that the dynamic game has at least one equilibrium in pure strategies.

• Second, they are convenient econometric errors. If private information shocks are independent over time and over players, and unobserved to the researcher, they can 'explain' players heterogeneous behavior without generating endogeneity problems.

Entry cost

• The entry cost is paid only if the firm was not active in the market at previous period (entry-exit model):

$$EC_{it} = 1\{a_{it} > 0 \ \& \ a_{it-1} = 0\} \ \left[\theta_i^{EC}(a_{it}, z_t) + \varepsilon_{it}^{EC}(a_{it})\right]$$

• $\theta_i^{EC}(a_{it}, z_t)$ is a function that represents the entry cost of firm i if the initial product quality is a_{it}.

• $\varepsilon_{it}^{EC}(a_{it})$ are private information shocks in the entry cost

Investment cost

• There are also costs of adjusting the level of quality, or repositioning product characteristics. For instance,

$$IC_{it} = 1\{a_{it-1} > 0\} \left(\theta_i^{AC(+)}(z_t) \; 1\{a_{it} > a_{it-1}\} + \theta_i^{AC(-)}(z_t) \; \{a_{it} < a_{it-} \right.$$

• $\theta_i^{AC(+)}(z_t)$ and $\theta_i^{AC(-)}(z_t)$ represents the costs of increasing and reducing quality, respectively, once the firm is active.

• In this specification the adjustment costs are lump-sum. We could consider more flexible specifications with (asymmetric) linear, quadratic, and lump-sum ACs.

State variables

- The payoff relevant state variables of this model are:

- (1) the exogenous state variables affecting demand and costs, z_t, and market size H_t. For notational simplicity, we represent them in the vector $\mathbf{z}_t$

- (2) the previous qualities of all the firms $\mathbf{a}_{t-1} \equiv \{a_{it-1} : i = 1, 2, ..., N\}$;

- (3) the private information shocks $\{\varepsilon_{it} : i = 1, 2, ..., N\}$.

State variables (2)

• The specification of the model is completed with the transition rules of these state variables.

• (1) Exogenous state variables follow an exogenous Markov process with transition probability function $F_z(\mathbf{z}_{t+1}|\mathbf{z}_t)$.

• (2) The transition of the qualitiy choices is trivial in this model. We could extend it to stochastic evolution. However, note that future returns of investment in quality is uncertain.

• (3) Private information shock ε_{it} is i.i.d. over time and independent across firms with CDF G_i.

Timing of decisions and state variables

• In this example, firms' dynamic decisions are made at the beginning of period t and they are effective during the same period.

• An alternative timing that has been considered in many applications is that there is a one-period time-to-build, i.e., the decision is made at period t, and entry costs are paid at period t, but the firm is not active in the market until period $t+1$. This is in fact the timing of decisions in Ericson and Pakes (1995).

• All the results below can be easily generalized to this model with time-to-build.

Markov Perfect Equilibrium

• Most of the recent literature in IO studying industry dynamics focuses on studying a Markov Perfect Equilibrium (MPE), as defined by Maskin and Tirole (Econometrica, 1988).

• The key assumption in this solution concept is that players' strategies are functions of only payoff-relevant state variables.

• In this model, the payoff-relevant state variables for firm i are $(\mathbf{y}_t, \mathbf{z}_t, \varepsilon_{it})$.

• We use $\mathbf{x}_t$ to represent the vector of common knowledge state variables, i.e., $\mathbf{x}_t \equiv (\mathbf{y}_t, \mathbf{z}_t)$.

Markov Perfect Equilibrium (2)

• Let $\boldsymbol{\alpha} = \{\alpha_i(\mathbf{x}_t, \varepsilon_{it}) : i \in \{1, 2, ..., N\}\}$ be a set of strategy functions, one for each firm.

• A MPE is a set of strategy functions $\boldsymbol{\alpha}^*$ such that every firm is maximizing its value given the strategies of the other players.

• For given strategies of the other firms, the decision problem of a firm is a single-agent dynamic programming (DP) problem.

Markov Perfect Equilibrium (3)

• Let $V_i^{\boldsymbol{\alpha}}(\mathbf{x}_t, \varepsilon_{it})$ be the value function of the DP problem that describes the best response of firm i to the strategies $\boldsymbol{\alpha}_{-i}$ of the other firms.

• This value function is the unique solution to the Bellman equation:

$$V_i^{\boldsymbol{\alpha}}(\mathbf{x}_t, \varepsilon_{it}) = \max_{a_{it}} \left\{ \begin{array}{l} \Pi_i^{\boldsymbol{\alpha}}(a_{it}, \mathbf{x}_t) - \varepsilon_{it}(a_{it}) \\ \\ +\delta \int V_i^{\boldsymbol{\alpha}}(\mathbf{x}_{t+1}, \varepsilon_{it+1}) \; dG_i(\varepsilon_{it+1}) \; F_i^{\boldsymbol{\alpha}}(\mathbf{x}_{t+1} | a_{it}, \mathbf{x}_t) \end{array} \right\}$$

where $\Pi_i^{\boldsymbol{\alpha}}(a_{it}, \mathbf{x}_t)$ and $F_i^{\boldsymbol{\alpha}}(\mathbf{x}_{t+1} | a_{it}, \mathbf{x}_t)$ are the expected one-period profit and the expected transition of the state variables, respectively, for firm i given the strategies of the other firms.

Markov Perfect Equilibrium (4)

- For the quality choice game, the expected one-period profit $\Pi_i^{\alpha}(a_{it}, \mathbf{x}_t)$ is:

$$\Pi_i^{\alpha}(a_{it}, \mathbf{x}_t) = \left[\sum_{a_{-it}} \Pr\left(\alpha_{-i}(\mathbf{x}_t, \varepsilon_{-it}) = a_{-it} \mid \mathbf{x}_t\right) \ \theta_i^{VP}(a_{it}, a_{-it}, \mathbf{z}_t) \right]$$

$$- \left[\theta_i^{FC}(a_{it}, \mathbf{z}_t) + (1 - a_{it-1}) \ \theta_i^{EC}(a_{it}, \mathbf{z}_t) \right]$$

And the expected transition of the state variables is:

$$F_i^{\alpha}(\mathbf{x}_{t+1} | a_{it}, \mathbf{x}_t) = 1\{y_{it+1} = a_{it}\} \ F_z(\mathbf{z}_{t+1} | \mathbf{z}_t)$$

$$\left[\prod_{j \neq i} \Pr\left(\alpha_j(\mathbf{x}_t, \varepsilon_{jt}) = y_{j,t+1} \mid \mathbf{x}_t\right) \right]$$

Markov Perfect Equilibrium (5)

• A firm's best response function gives his optimal strategy if the other firms behave, now and in the future, according to their respective strategies.

• In this model, the best response function of player i is:

$$\alpha_i^*(\mathbf{x}_t, \varepsilon_{it}) = \arg\max_{a_{it}} \left\{ v_i^{\boldsymbol{\alpha}}(a_{it}, \mathbf{x}_t) - \varepsilon_{it}(a_{it}) \right\}$$

• $v_i^{\boldsymbol{\alpha}}(a_{it}, \mathbf{x}_t)$ is the conditional choice value function that represents the value of firm i if: (1) the other firms behave according to their strategies in $\boldsymbol{\alpha}$; and (2) the firm chooses alternative a_{it} today and then behaves optimally forever in the future.

$$v_i^{\boldsymbol{\alpha}}(a_{it}, \mathbf{x}_t) \equiv \Pi_i^{\boldsymbol{\alpha}}(a_{it}, \mathbf{x}_t) + \delta \int V_i^{\boldsymbol{\alpha}}(\mathbf{x}_{t+1}, \varepsilon_{it+1}) \; dG_i(\varepsilon_{it+1}) \; F_i^{\boldsymbol{\alpha}}(\mathbf{x}_{t+1} | a_{it}, \mathbf{x}_t)$$

Markov Perfect Equilibrium (6)

• A Markov perfect equilibrium (MPE) in this game is a set of strategy functions $\boldsymbol{\alpha}^*$ such that for any player i and for any $(\mathbf{x}_t, \varepsilon_{it})$ we have that:

$$\alpha_i^*(\mathbf{x}_t, \varepsilon_{it}) = \arg\max_{a_{it}} \left\{ v_i^{\boldsymbol{\alpha}^*}(a_{it}, \mathbf{x}_t) - \varepsilon_{it}(a_{it}) \right\}$$

Conditional Choice Probabilities

• Given a strategy function $\alpha_i(\mathbf{x}_t, \varepsilon_{it})$, we can define the corresponding *Conditional Choice Probability (CCP)* function as :

$$
\begin{aligned}
P_i(a|\mathbf{x}) &\equiv \Pr\left(\alpha_i(\mathbf{x}_t, \varepsilon_{it}) = a \mid \mathbf{x}_t = \mathbf{x}\right) \\
&= \int 1\{\alpha_i(\mathbf{x}_t, \varepsilon_{it}) = a\} \; dG_i(\varepsilon_{it})
\end{aligned}
$$

• From now on, we use CCPs to represent players' strategies, and use the terms 'strategy' and 'CCP' as interchangeable.

MPE in terms of CCPs

• A MPE is a vector of CCPs, $\mathbf{P} \equiv \{P_i(a|\mathbf{x}) : \text{for any } (i, a, x)\}$, such that:

$$P_i(a|\mathbf{x}) = \Pr\left(a = \arg\max_{a_i} \left\{ v_i^{\mathbf{P}}(a_i, \mathbf{x}) - \varepsilon_i(a_i) \right\} \mid \mathbf{x} \right)$$

• $v_i^{\mathbf{P}}(a_i, \mathbf{x})$ is a conditional choice probability function, but it has a slightly different definition that before. Now, $v_i^{\mathbf{P}}(a_i, \mathbf{x})$ represents the value of firm i if the firm chooses alternative a_i today and

all the firms, including firm i, behave according to their respective CCPs in $\mathbf{P}$.

• Every MPE in this dynamic game can be represented using this mapping.

MPE in terms of CCPs (2)

- The form of this equilibrium mapping depends on the distribution of ε_i.

- For instance, in the entry/exit model, if ε_i is $N(0,1)$:

$$P_i(1|\mathbf{x}) = \Phi\left(v_i^{\mathbf{P}}(1,\mathbf{x}) - v_i^{\mathbf{P}}(0,\mathbf{x}) \right)$$

- In the model with endogenous quality choice, if $\varepsilon_i(a)$'s are extreme value type 1 distributed:

$$P_i(a|\mathbf{x}) = \frac{\exp\left\{ v_i^{\mathbf{P}}(a,\mathbf{x}) \right\}}{\sum_{j=0}^{J} \exp\left\{ v_i^{\mathbf{P}}(j,\mathbf{x}) \right\}}$$

3. 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.

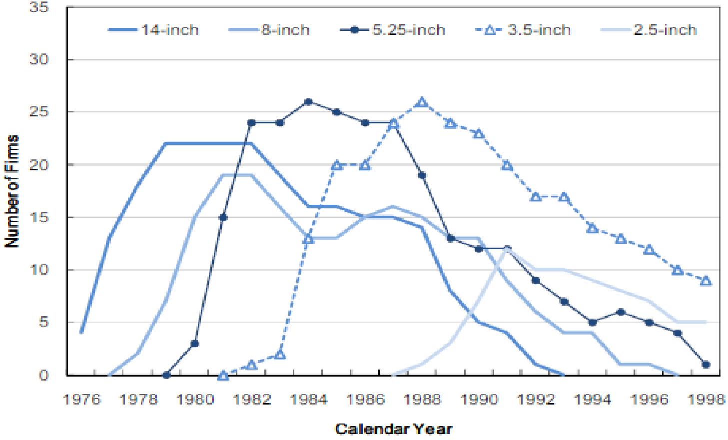
• In other words, the survival of existing products / technologies / firms is at the cost of preemting the birth of new ones.

• 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.

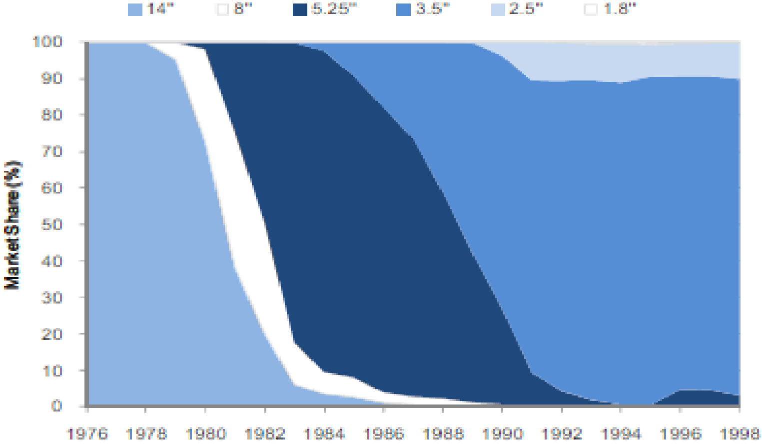
HDD: Different generations of products

Figure 2: Shifting Generations of Technology

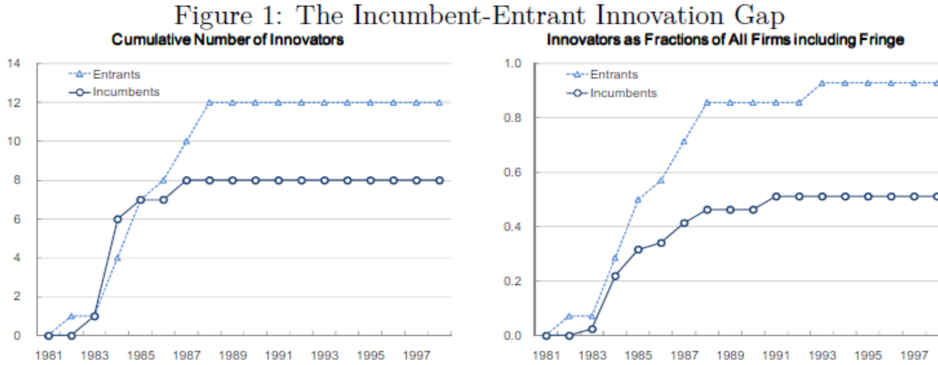


HDD: Different generations of products

Figure 12: Aggregate Market Share by Diameter



Adoption new tech: Incumbents vs. New Entrants



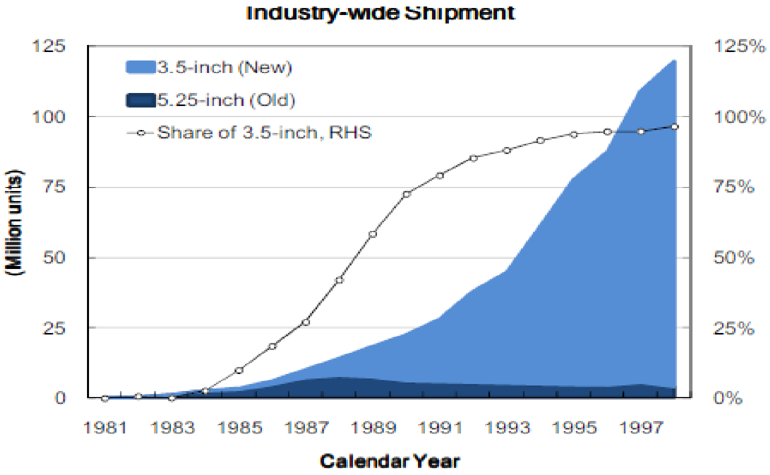
Adoption new tech: Incumbents vs. New Entrants

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

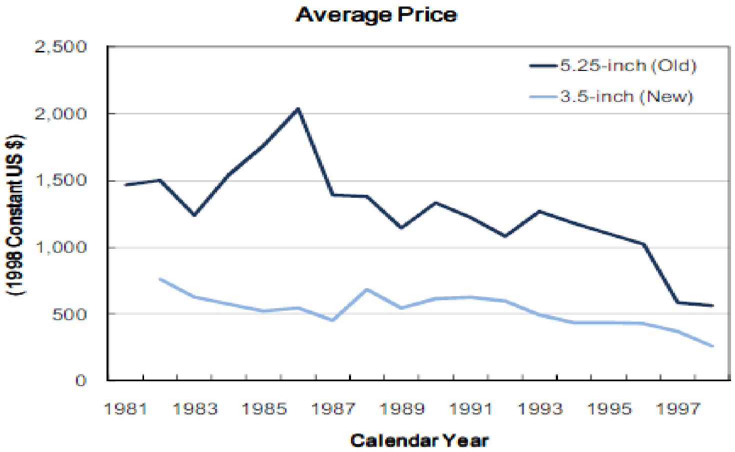
- He consider three main factors that contribute to the relative propensity to innovate of incumbents and potential entrants.

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**.

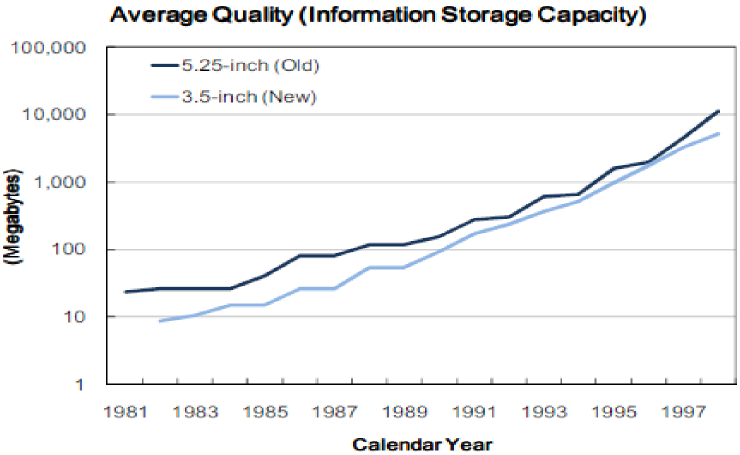
Market shares New/Old products



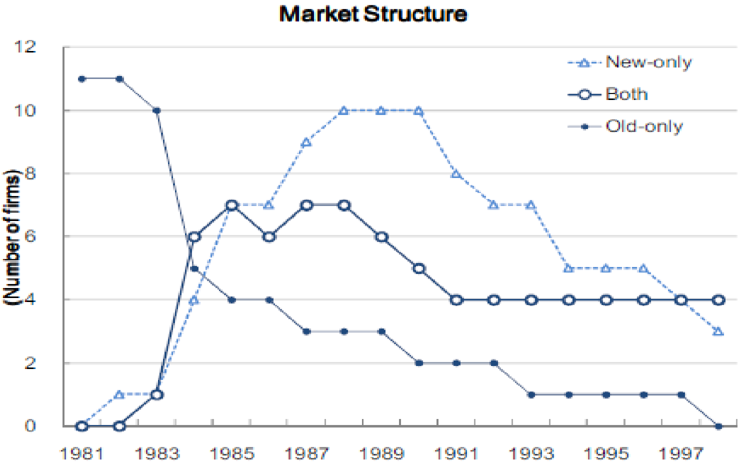
Average Prices: New/Old products



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:

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

• Initialy, $N_0^{both} = N_0^{new} = 0$.

• Timing within a period t:

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

• There is no differentiation across firms (perhaps true, but assumption comes from data limitations).

• Estimation:

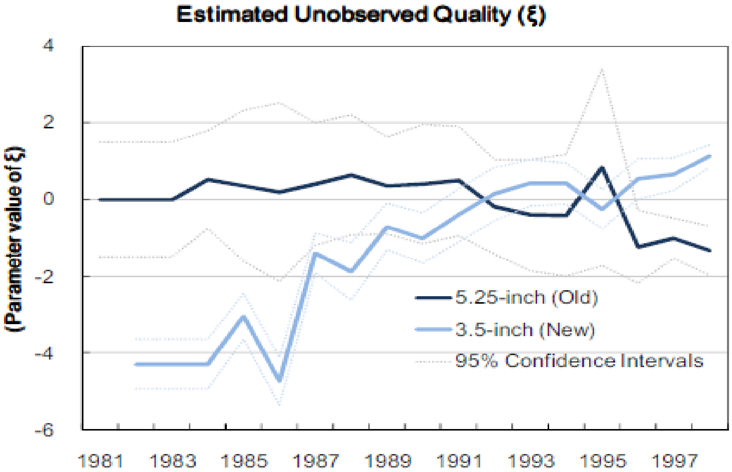
$$\ln\left(\frac{s_j}{s_k}\right) = \alpha_1 \left[p_j - p_k\right] + \alpha_2 \left[1_j^{new} - 1_k^{new}\right] + \alpha_3 \left[x_j - x_k\right] + \xi_j - \xi_k$$

• Data: multiple periods and regions.
• IVs: Hausman-Nevo. Prices in other regions.

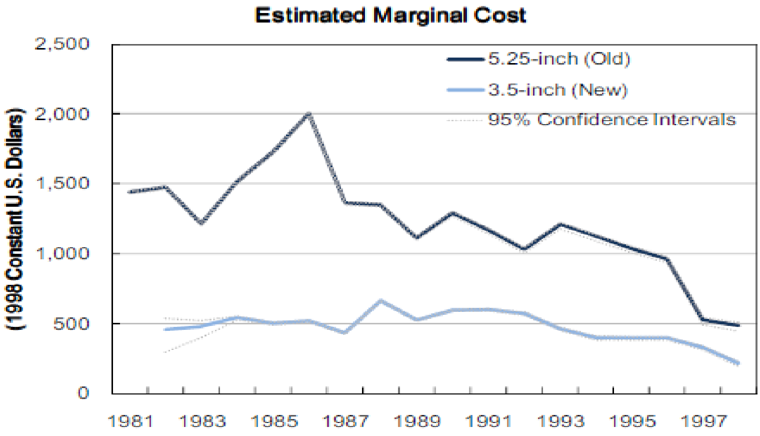
Estimates of Demand

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

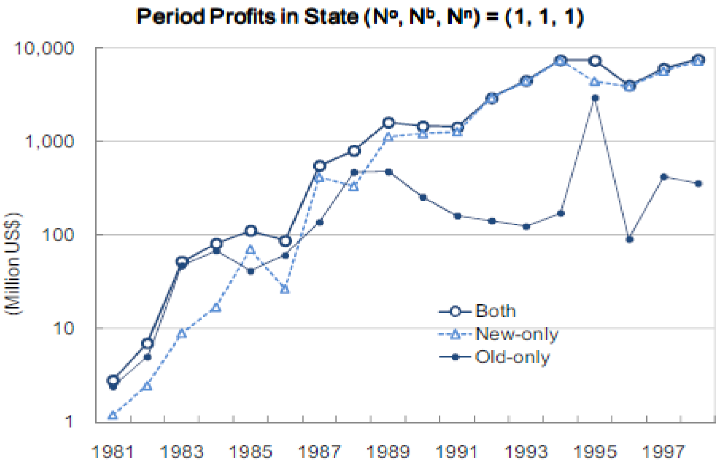
Evolution of unobserved Quality (epsi)



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

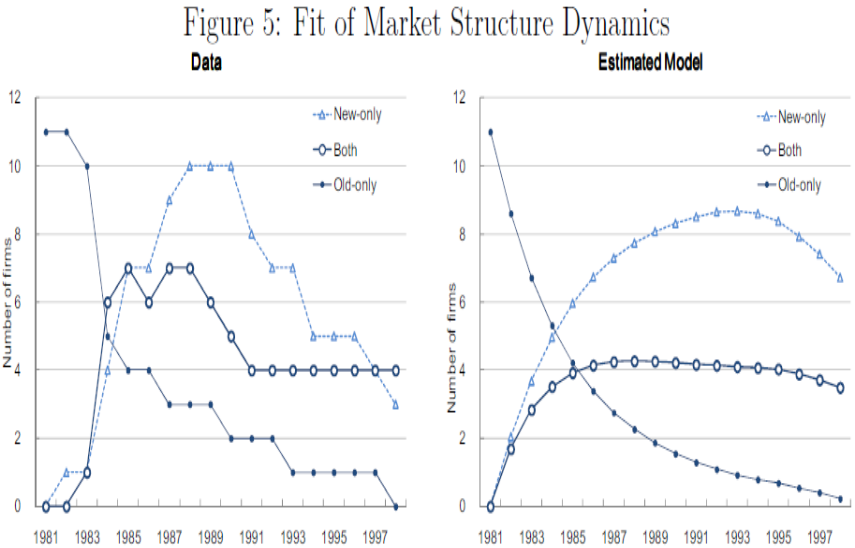
Estimates of Dynamic Parameters

- Different estimates depending on the order of move within a period.

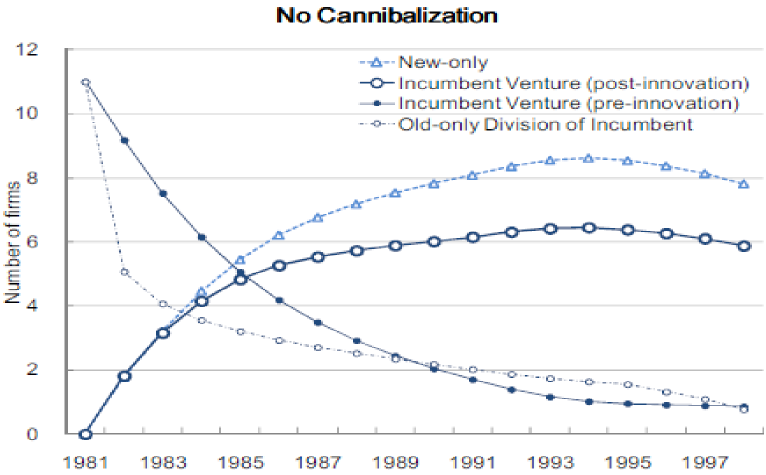
- Cost for innovation is smaller for incumbents than for new entrants ($\kappa^{inc} < \kappa^{pe}$). Organizational inertia does not seem an important factor.

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

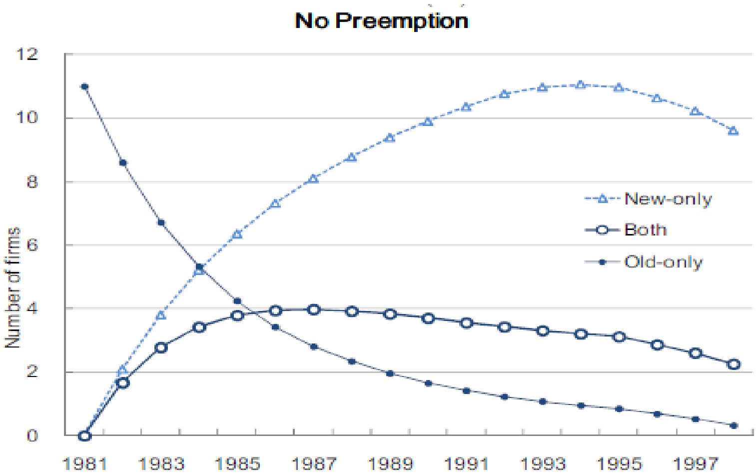
Estimated Model: Goodness of fit



Counterfactual: Removing Cannibalization



Counterfactual: Removing Preemption



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

Introduction

- Study competition between Intel and AMD in the PC microprocessor industry.
- Incorporates durability of the product as a potentially important factor.
- Two forces drive innovation:
  - competition between firms for the technological frontier;
  - since PCs have little physical depreciacion, firms have the incentive to innovate to generate a tenological 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: several antitrust lawsuits claiming Intel's anticompetitive practices, e.g., rewarding PC manufacturers that exclusively use Intel microprocessors.
  - Intel foreclosures 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.
- Firmst 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 performance (speed) doubles every 7 quarters, i.e., Moore'e law.
- AMD and Intel extensively cross-license each other's technologies, i.e., positive spillovers.

The PC microprocessor industry (3)

- As microprocessors are durable, replacement drives and important part of demand.
- The importance of replacement is partly exogenous (new consumers arriving to the marker), and 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, prices and sales fall as replacement demand drops. Firms must continue to innovate to rebuild replacement demand.

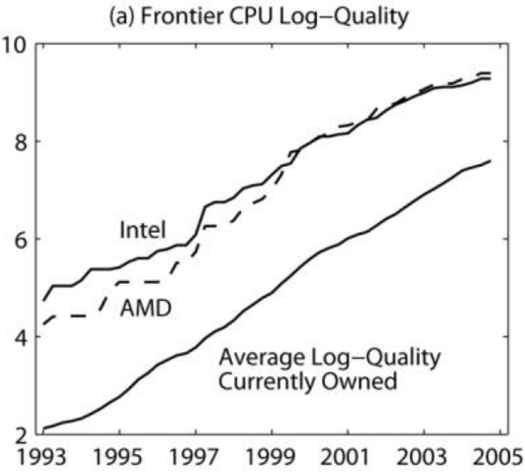
Data

- 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

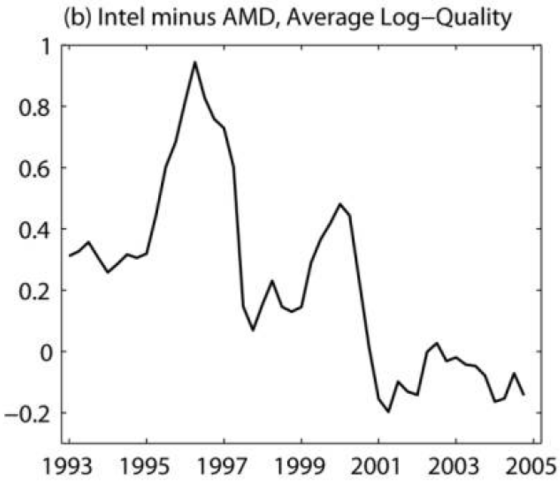
- Intel cofounder Gordon Moore predicted in 1965 that the number of transistors ina CPU (and therefore the CPU speed) would double every 2 years.
- Following figure shows "Moore's law" over the 48 quarters in the data.
- Quality is measured using processor speed.
- Quarterly % change in CPU speed is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

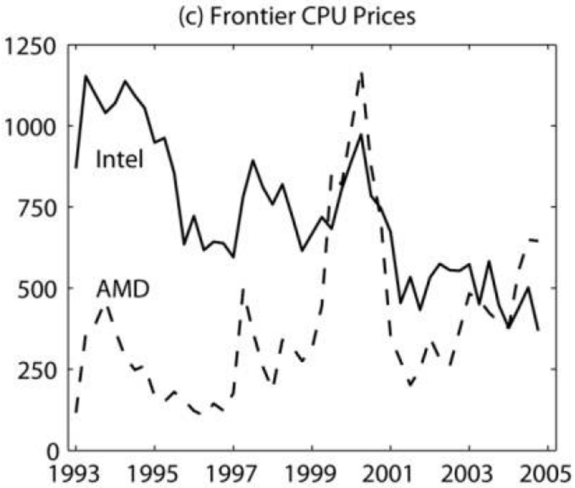
Moore's Law (Frontier CPU speed)

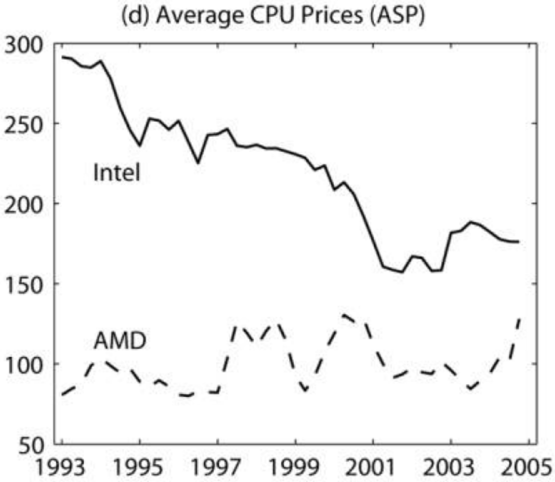


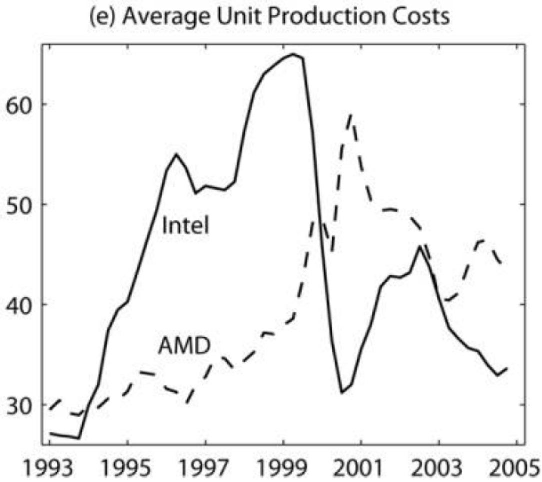
Differential log-quality between Intel and AMD

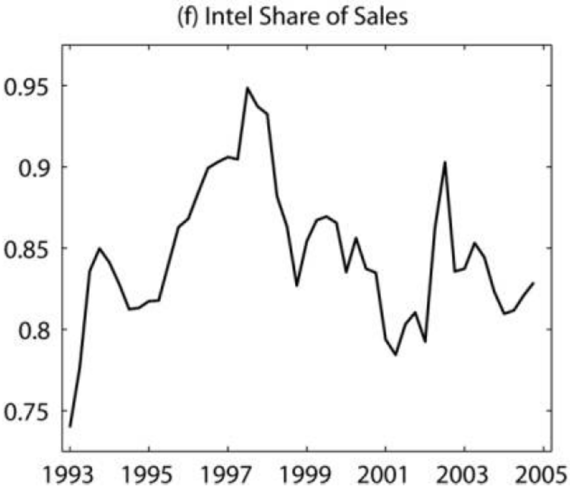
- Intel's initial quality advantage is moderate in 1993–94.
- Then, it becomes large in 1995-96 when Intel releases the Pentium.
- AMD's responded in 1997 introducing the K6 processor that narrows the gap.
- But parity is not achieved until the mid-2000 when AMD released the Athlon.


(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
60
50
40
30
Intel
AMD
1993
1995
1997
1999
2001
2003
2005


(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 a fixed proportion 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 endogenous, determined by last purchase.
- The distribution of currently owned products by consumerts is represented by the vector Δ_t.
- Δ_t affects current consumer demand. [Details]

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;
  - 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 consuerms 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:

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

- 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.

- Parameter λ_1 captures an spillover effect from the innovation of other 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 that of an increasing ed 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 effiiency: $a_{0,intel}$, $a_{0,amd}$, 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
$q_{\text{Intel},t} - q_{\text{AMD},t}$	47.4	17.6	27.3
$q_{\text{Intel},t} - \bar{\Delta}_t$	94.4	31.6	43.0
AMD price equation:			
Average AMD price	100.4	2.3	122.9
$q_{\text{Intel},t} - q_{\text{AMD},t}$	−8.7	11.5	−22.3
$q_{\text{AMD},t} - \bar{\Delta}_t$	16.6	15.4	5.9
Intel share equation:			
Constant	.834	.007	.846
$q_{\text{Intel},t} - q_{\text{AMD},t}$	.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 $q_{\text{Intel},t} - q_{\text{AMD},t}$	1.257	.239	1.352
Mean $\mathcal{I}(q_{\text{Intel},t} \geq q_{\text{AMD},t})$	.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
$\max(0, q_{\text{competitor},t} - q_{\text{own},t})$, λ_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 symmetruic 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 anticompetitive 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

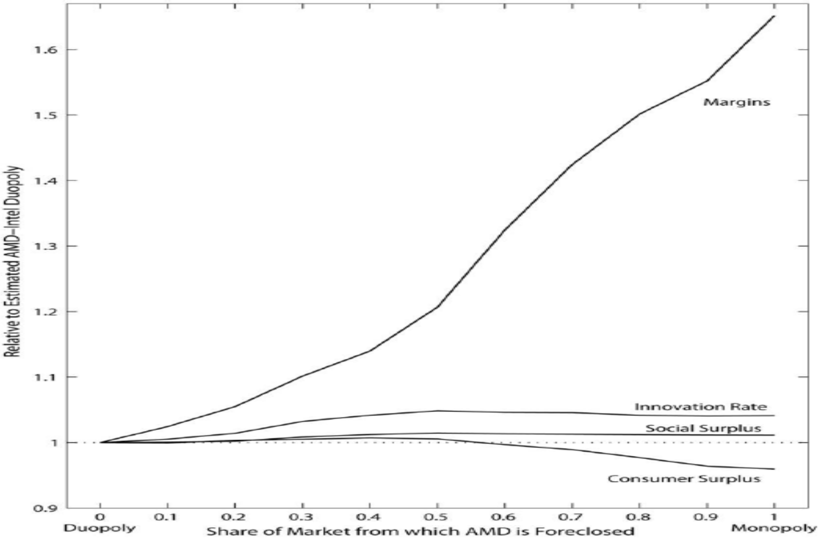
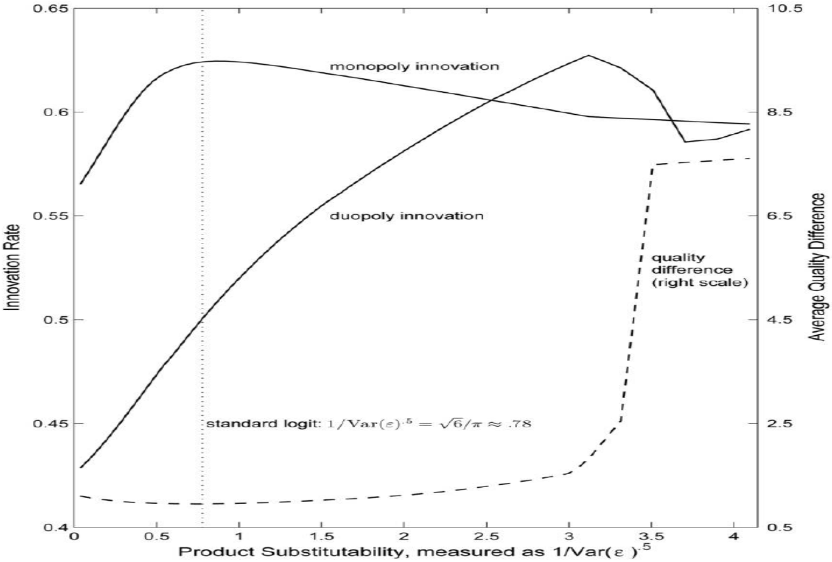


FIG. 6.—Foreclosing AMD from the market

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.

Environmental regulation and adoption of green technologies: Ryan (2012)

- **Stephen Ryan (2012): "The Costs of Environmental Regulation in a Concentrated Industry," Econometrica.**

1. Motivation and Empirical Questions
2. The US Cement Industry
3. The Regulation (Policy Change)
4. Empirical Strategy
5. Data
6. Model
7. Estimation and Results

Empirical Questions

• Most previous studies that measure the welfare effects of environmental regulation (ER) have ignored dynamic effects of these policies.

• ER has potentially important effects on firms' entry and investment decisions, and, in turn, these can have important welfare effects.

• This paper estimates a dynamic game of entry/exit and investment in the US cement industry.

• The estimated model is used to evaluate the welfare effects of the 1990 Amendments to the Clean Air Act (CAA).

US Cement Industry (1)

- For the purpose of this paper, the most important features of the US cement industry are:

  (1) Indivisibilities in capacity investment, and economies of scale

  (2) Highly polluting and energy intensive industry

  (3) Local competition, and highly concentrated local markets

US Portland Cement Industry (2)

Indivisibilities in capacity investment, and economies of scale

• Portland cement is the binding material in concrete, which is a primary construction material.

• It is produced by first pulverizing limestone and then heating it at very high temperatures in a rotating kiln furnace.

• These kilns are the main piece of equipment. Plants can have one or more kilns (indivisibilities).

• Marginal cost increases rapidly when a kiln is close to full capacity.

US Cement Industry (3)

Highly polluting and energy intensive industry

• The industry generates a large amount of pollutants by-products.

• Second largest industrial emitter of Sulfure Dioxide (SO2) and Carbon Dioxide (CO2), and a major source of NOx (Nitric oxide and Nitrogen Dioxide) and particulates.

• High energy requirements and pollution make the cement industry an important target of environmental policies.

US Cement Industry (4)

Local competition, and highly concentrated local markets

• Cement is a commodity difficult to store and transport, as it gradually absorbs water out of the air rendering it useless.

• Transportation costs per unit value are large.

• This is the main reason why the industry is spatially segregated into regional markets. These regional markets are very concentrated.

The Regulation / Policy Change

- The Clean Air Act (CAA) is a (the) main environmental Act in US. The 1990 ammedment was a major revision.

- It has been the most important new environmental regulation affecting this industry in the last three decades.

- It added new categories of regulated emissions.

- Cement plants were required to undergo an environmental certification process. Environmental permits of operation.

- This regulation encourage firms to adopt equipement (furnaces) environmentally cleaner. This may have increased sunk costs, fixed operating costs or investment costs in this industry.

Evaluation of Policy Effects

- Previous evaluations of these policies have ignored effects on entry/exit and on firms' capacity investment.

- They have found that the regulation contributed to reduce marginal costs and therefore prices. Positive effects on consumer welfare and total welfare.

- Ignoring effects on entry/exit and on firms' investment could imply an overestimate of these positive effects.

Empirical Strategy (1)

- Specify a model of the cement industry, where oligopolists make optimal decisions over entry, exit, production, and investment given the strategies of their competitors.

- Estimate the model for the cement industry using a 20 year panel and allowing the structural parameters to differ before and after the 1990 regulation. Changes in cost parameters are attributed to the new regulation.

- The MPEs before and after the regulation are computed and they are used for welfare comparisons.

Preview of Empirical Results

- Amendments roughly doubled sunk costs of entry, to $35M. The larger entry cost reduced net entry and the number of plants over time, increasing market power.

- Amendments led to higher investment by incumbents, but lower aggregate market capacity.

- Consumer welfare decreased 25% due to lower entry and increased market power (approx. $1.2B).

- Static analysis would ignore the benefits of increased market power on incumbent firms, and welfare effect could have wrong sign.

Data (1)

- Period: 1980 to 1999 (20 years); 27 regional markets.
- Index local markets by m, plants by i and years by t.

$$Data = \{S_{mt},\ W_{mt},\ P_{mt},\ n_{mt},\ q_{imt},\ i_{imt},\ s_{imt}\}$$

S_{mt} = Market size

W_{mt} = Input prices (electricity prices, coal prices, natural gas prices, and manufacturing wages)

P_{mt} = Output price

n_{mt} = Number of cement plants

q_{imt} = Quantity produced by plant i

s_{imt} = Capacity of plant i (number and capacity of kilns)

i_{imt} = Investment in capacity by plant i

Data (2)

- **USGS Minerals Yearbook**
- Market-level data for prices and quantities
- 27 markets covering United States 1980-1999
- 517 market-year observations
- Energy prices, labor inputs from Dept. Energy

- **Portland Cement Association Plant Information Survey**
- Every plant in United States 1980-1998
- Kiln-level data on capacity and production
- 2233 plant-year observations

Industry Trends

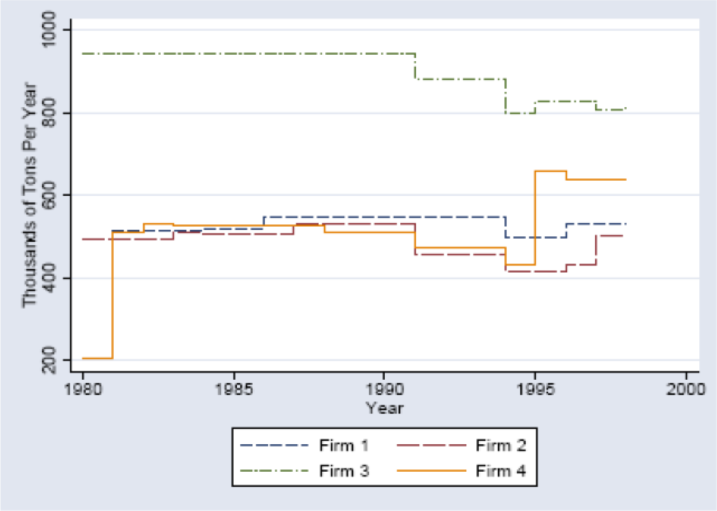
Year	Production	Imports	Consumption	Price	Plants	Capacity Per Kiln
1980	68,242	3,035	70,173	111.90	151	239
1981	65,054	2,514	66,092	103.70	147	267
1982	57,475	2,231	59,572	95.76	143	287
1983	63,884	2,960	65,838	91.01	143	292
1984	70,488	6,016	76,186	89.70	141	297
1985	70,665	8,939	78,836	84.71	136	305
1986	71,473	11,201	82,837	81.48	133	305
1987	70,940	12,753	84,204	78.07	132	314
1988	69,733	14,124	83,851	75.50	127	327
1989	70,025	12,697	82,414	72.04	123	337
1990	69,954	10,344	80,964	69.02	119	345
1991	66,755	6,548	71,800	66.37	119	352
1992	69,585	4,582	76,169	64.25	119	357
1993	73,807	5,532	79,701	63.58	118	363
1994	77,948	9,074	86,476	68.06	118	364
1995	76,906	10,969	86,003	72.56	118	367
1996	79,266	11,565	90,355	73.64	118	376
1997	82,582	14,523	96,018	74.60	118	383
1998	83,931	19,878	103,457	76.45	118	393

Summary statistics

Table 2: Summary Statistics

Variable	Minimum	Mean	Maximum	Standard Deviation
Demand Data				
MARKETQ	186	2,835.84	10,262	1,565.34
PRICE	36.68	67.46	138.99	13.68
PLANTS	1	4.75	20	1.94
WAGE	20.14	31.72	44.34	4.33
COAL	15.88	26.64	42.33	8.13
ELECTRICITY	4.23	5.68	7.6	1.01
POPULATION	689,584	10,224,352	33,145,121	7,416,485
GAS	3.7	6.21	24.3	2.21
Production Data				
QUANTITY	177	699	2348	335
CAPACITY	196	797	2678	386
Investment				
INVESTMENT	-728	2.19	1,140	77.60

Figure 1: Capacity of Cement Plants in Colorado and Wyoming



Model (1)

- Regional homogenous-goods market.
- Every period, incumbent firms compete in quantities in a static equilibrium (Cournot) subject to their capacity constraints.
- They also decide entry-exit, and investment in capacity (time-to-build).
- Firms invest in future capacity and this decision is partly irreversible (and therefore dynamic).
- Incumbent firms also make optimal decisions over whether to exit.

Demand and Variable Costs

- **Inverse demand curve (iso-elastic):**

$$\log P_{mt} = \alpha_{mt} + \frac{1}{\epsilon} \log Q_{mt}$$

- **Production costs:**

$$\begin{aligned} C(q_{imt}) &= (MC + \omega_{imt})\ q_{imt} \\ &+ CAPCOST * 1\left\{\frac{q_{imt}}{s_{imt}} > \nu\right\}\left(\frac{q_{imt}}{s_{imt}} - \nu\right)^2 \end{aligned}$$

s_{imt} = installed capacity
q_{imt}/s_{imt} = degree of capacity utilization
ω_{imt} = idiosyncratic shock in MC
MC, $CAPCOST$ and ν are parameters.

Costs of Capacity Investment

- **Investment costs**

$$
\begin{aligned}
IC_{imt} \quad = \quad & I\left\{i_{imt} > 0\right\}\left(\theta_0^{(+)} + \theta_1^{(+)} * i_{imt} + \theta_2^{(+)} * i_{imt}^2\right) \\
& + I\left\{i_{imt} < 0\right\}\left(\theta_0^{(-)} + \theta_1^{(-)} * i_{imt} + \theta_2^{(-)} * i_{imt}^2\right)
\end{aligned}
$$

Sunk Costs and Scrap Value

- **Entry cost**

$$EC_{imt} = 1\left\{s_{imt} = 0 \text{ and } i_{imt} > 0\right\} \left(SUNK + \varepsilon_{imt}^{EC}\right)$$

- **Scrap value**

$$SV_{imt} = 1\left\{s_{imt} > 0 \text{ and } i_{imt} = -s_{imt}\right\} \left(SCRAP + \varepsilon_{imt}^{SV}\right)$$

State variables: Dynamic decisions

- Vector of state variables:

$$\mathbf{s}_{mt} = \{\alpha_{mt}, W_{mt}, s_{imt} : i = 1, 2, ..., n_{mt}\}$$

- Incumbent firm:

$$V(\mathbf{s}_{mt}, \varepsilon_{imt}) = \max_{i_{imt}} \{\pi(i_{imt}, \mathbf{s}_{mt}) + \beta \; E_t \left(V(\mathbf{s}_{mt+1}, \varepsilon_{imt+1})\right)\}$$

- Potential entrant:

$$V^e(\mathbf{s}_{mt}) = \max \{0 \; ; \; \pi^e(\mathbf{s}_{mt}) + \beta \; E_t \left(V(\mathbf{s}_{mt+1}, \varepsilon_{imt+1})\right)\}$$

Markov Perfect Equilibrium

- Strategy / investment functions:

$$i_{imt} = i(\mathbf{s}_{mt}) = i(\alpha_{mt}, W_{mt}, s_{imt} : i = 1, ...)$$

- Given other firms strategy functions, each firm chooses a strategy to maximize its intertemporal value.

Estimation Demand Curve

• Includes local market region fixed effects (estimated with 19 observations per market).

• Instruments: local variation in input prices.

• The market specific demand shocks, α_{mt}, are estimated as residuals in this equation.

Demand estimates

Table 3: Constant Elasticity of Demand Results

Variable	Coefficient	Standard Error
Elasticity	-2.954	(0.378)
Intercept	20.362	(1.564)
Alaska, Hawaii, Oregon, and Washington	-0.345	(0.219)
Arizona, Nevada, and New Mexico	0.296	(0.197)
Arkansas and Oklahoma	-0.577	(0.175)
California North	0.172	(0.188)
California South	1.047	(0.184)
Colorado and Wyoming	-0.130	(0.193)
Florida	0.366	(0.177)
Georgia and Tennessee	-0.406	(0.173)
Idaho, Montana, and Utah	-0.366	(0.186)
Illinois	-0.623	(0.176)
Indiana	-0.529	(0.183)
Iowa, Nebraska, and South Dakota	-0.294	(0.171)
Kansas	-0.574	(0.178)
Kentucky, Mississippi, North Carolina, and Louisiana	-0.307	(0.174)
Maryland, Virginia, and West Virginia	-0.472	(0.177)
Michigan and Wisconsin	0.295	(0.174)
Missouri	-0.020	(0.178)
New York and Maine	-0.116	(0.175)
Ohio	-0.755	(0.177)
Pennsylvania East	0.283	(0.175)
Pennsylvania West	-0.917	(0.175)
South Carolina	-0.430	(0.183)
Texas North	0.242	(0.181)
Texas South	-0.221	(0.186)

All market-specific fixed effects are relative to Alabama. Instruments were gas prices, coal prices, electricity prices, and skilled labor wage rates. There are a total of 517 observations. Parameters were estimated using a LIML specification.

Estimation Variable Costs

- From the Cournot equilibrium conditions.

- Firm specific cost shocks, ω_{imt}, are estimated as residuals in this equation.

Estimates variable costs

Parameter	Mean	Median	95% Confidence Interval
CAPCOST ($\times 10^7$)	1.904	1.482	[1.105, 3.782]
BINDING LEVEL (ν)	1.903	1.900	[1.806, 2.016]
MARGINAL COST	32.330	30.929	[30.761, 37.296]
CAPCOST DUMMY ($\times 10^7$)	-1.379	-1.378	[-3.056, 0.642]
BINDING DUMMY	0.0268	0.0522	[-0.131, 0.180]
MC DUMMY	2.4107	3.247	[-2.23, 4.36]

Estimates variable costs

• Parameters associated with "Dummy After 1990 Amedments" are not statistically significant.

• Not statistically significant different in marginal costs before and after 1990.

• Binding capacity utilization level $= \dfrac{\exp\{v\}}{1+\exp\{v\}} =$ roughly 87%.

• Very expensive to produce beyond this capacity level (CAPCOST $= 1.9$)

Reduced Form Estimation Investment Strategy

- Assumption:

$$i_{imt} = i(\alpha_{mt}, W_{mt}, s_{imt}, s_{-imt}) = i\left(\alpha_{mt}, W_{mt}, s_{imt}, \sum_{j \neq i} s_{jmt}\right)$$

Entry and exit probits

Parameter	Coefficient	Standard Error
Exit Policy		
Constant	-1.306	0.183
CAP	-1.55×10^{-3}	2.81×10^{-3}
ϵ	-4.60×10^{-5}	8.80×10^{-5}
SUMCAP	4.50×10^{-5}	1.70×10^{-5}
Late Dummy	-0.301	0.081
Entry Policy		
Constant	-1.68	0.210
SUMCAP	3.71×10^{-5}	3.60×10^{-5}
Late Dummy	-0.491	0.242

Sample size for exit policy function = 2233; sample size for entry policy function = 414.

Entry and exit probits

- CAP = Own capacity.
  - Negative effect on exit
- SUMCAP = Capacity of competitors
  - Positive effect on exit;
- ϵ = Demand shock
  - Negative effect on exit.
- Late Dummy: Both entry and exit less likely after Amendments.

- As operation costs have not changed, must reflect investment or entry cost shifts.

Investment cost parameters

Parameter	Median	Standard Deviation	95% Confidence Interval
Early Period			
ADJPOS	30,522	146.72	[30,491, 30,963]
INVPOS	131	1.98	[125, 131]
INVPOS2	0.018	0.001	[0.018, 0.021]
ADJNEG	22,646	597.99	[21,754, 23,562]
INVNEG	-1,115.78	114.17	[-1,279, -925]
INVNEG2	35.06	4.01	[28.428, 40.742]
SCRAP	84,016	456	[82,640, 84,109]
Late Period			
ADJPOS	27,631	30.32	[27,562, 27,663]
INVPOS	70.20	0.75	[69.36, 71.67]
INVPOS2	0.015	1.2E-5	[0.015, 0.015]
ADJNEG	22,216	999	[20,062, 22,996]
INVNEG	-1,553	118.88	[-1,645, -1,291]
INVNEG2	55.18	2.59	[49.38, 57.25]
SCRAP	54,801	424	[54,423, 55,749]

Investment cost parameters

- Investment cost parameters, lump-sum (ADJPOS), lineat (INVPOS), and quadratic (INVPOS2) have decreased after the Amedments.

Entry costs before and after

Parameter	Mean (000 $)	Standard Deviation	95% Confidence Interval
Before Amendments	120,976	11,603	[93,321, 132,865]
After Amendments	162,470	7,728	[145,133, 173,115]

Counterfactual experiments

Table 11: Counterfactual Policy Experiments

	Post-Amendments (High Sunk Costs)	Counterfactual (Low Sunk Costs)	Social Planner (Low Sunk Costs)
New Market			
Producer profit	293,627.77	180,720.27	-1,433,854.25
Consumer welfare	278,981.72	1,081,812.47	5,888,001.63
Periods with no firms	26.74	5.51	2.06
Periods with one firm	262.58	191.05	347.94
Periods with two firms	60.10	147.14	0.00
Periods with three firms	0.56	5.54	0.00
Periods with four firms	0.02	0.76	0.00
Total welfare	572,609.49	1,262,532.73	4,454,147.38
Profits of firm 1	294,158.99	178,771.62	-1,433,854.25
Average size of active firm	747.90	1,301.05	7,952.91
Average market capacity	934.51	1,862.23	7,952.91
Average market quantity	814.16	1,622.72	7,150.67
Average market price	96.22	81.69	39.03
Market with Two Incumbents			
Producer profit	290,798.04	288,092.02	175,521.07
Consumer welfare	2,256,603.91	2,285,601.13	6,908,995.41
Periods with no firms	0.00	0.00	0.00
Periods with one firm	0.00	0.00	0.00
Periods with two firms	347.56	326.65	350.00
Periods with three firms	2.44	23.35	0.00
Periods with four firms	0.00	0.00	0.00
Total welfare	2,547,401.95	2,573,693.15	7,084,516.48
Profits of firm 1	265,583.73	265,582.15	64,333.19
Average size of active firm	1,146.03	1,334.40	4,804.54
Average market capacity	2,299.12	2,736.13	9,609.08
Average market quantity	2,003.32	2,384.19	8,502.02
Average market price	75.55	71.44	35.79