Estimating the Innovators Dilemma: Structural Analysis of Creative Destruction in the Hard Disk Drive Industry, 1981 to 1998

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Objective and Motivation

Objective

To study why incumbent firms would appear either reluctant about or incapable of making drastic innovations.

Motivation

- The Incumbent-Entrant Innovation Gap
- Competing Forces on Innovation Timing Decisions
    - Cannibalization
    - Different Costs
    - Preemption
    - Institutional Environment

Data and Regularity

Data

- Transition from 5.25- to 3.5-inch generations (old and new)
- Firm-year (n=259) level data on characteristics (1981-98)
- Product category level data on HDD sales

Regularity

- In 1981: 11 incumbents and 0 actual entrants
- Manufacturing of the new HDDs should have been easier for incumbents than for entrants.
- By 1990: 8 innovating incumbents and at least 12 entrants

Question

If the new HDD market could accommodate more than 11 active firms, why did incumbents not innovate as aggressively as entrants?

Model Setup

Firm state: $s_{it} \in \{old\ only, both, new\ only, potential\ entrant\}$.
Industry state is their aggregation: $s_t = \{N_t^{old}, N_t^{both}, N_t^{new}, N_t^{pe}\}$,
$s_{-it} = \{s_{jt}\}_{j \neq i}$, $N_t^{pe} = 4$ for any t.

$$\pi_{it} = \pi^{type}(s_t) = \pi(s_{it}, s_{-it}; D_t, C_t) \quad (1)$$

Choice sets:

- "old" firm: $\{exit, stay, innovate\}$, innovation cost, κ^{inc}
- "both" firm: $\{exit, stay\}$
- "new" firm: $\{exit, stay\}$
- potential entrant: $\{quit, enter\}$, entrant cost, κ^{ent}

$$V^{old}(s_t, \epsilon_{it}) = \pi_t^{old}(s_t)$$

$$+\max\left\{\begin{array}{l} \epsilon_{it}^0, \\ -\phi + \beta E(V_{t+1}^{old}(s_{t+1}, \epsilon_{it+1}))|s_{it}, \epsilon_{it}) + \epsilon_{it}^1, \\ -\phi + \beta E(V_{t+1}^{both}(s_{t+1}, \epsilon_{it+1})|s_t, \epsilon_{it}) - \kappa^{inc} + \epsilon_{it}^2 \end{array}\right\}. \quad (2)$$

$$V^{pe} = \max\{\epsilon_{it}^0, \beta E[V_{t+1}^{new}(s_{t+1}, \epsilon_{it+1})|s_t, \epsilon_{it}] - \kappa^{ent} + \epsilon_{it}^1\} \quad (3)$$

- $\epsilon_{it} \overset{i.i.d.}{\sim}$ extreme value
- Sequential-move dynamic game
- Type-symmetric strategies

Model Setup

Assume demand, cost, and market structure will stay constant after the sample period T. Therefore, the terminal value of firms are:

$$V_T^{old} = \sum_{\tau=T}^{\infty} \beta^{\tau} \pi_T^{old}(s_T) \tag{4}$$

- Terminal value functions for other type of firms are similarly defined.
- Through backward induction, we can write the expected value functions from year T all the way back to year 0.

Estimation: Static Demand

A buyer k purchasing an HDD of product category j, that is, a combination of generation g (diameter), quality x (storage capacity in megabytes) and unobserved characteristics ξ_j, enjoys utility:

$$u_{kj} = \alpha_0 + \alpha_1 p_j + \alpha_2 I(g_j = new) + \alpha_3 x_j + \xi_j + \epsilon_{kj}. \qquad (5)$$

- Subscripts for buyer category, geographical regions, and year t are suppressed.

Estimation: Static Demand

With mean utility of outside good normalized to zero, Berry(1994)'s inversion provides:

$$\ln(\frac{ms_j}{ms_0}) = \alpha_1 p_j + \alpha_2 I(g_j = new)) + \alpha_3 x_j + \xi_j \tag{6}$$

- ms_o is market share of outside goods(removable HDDs).
- In the paper, it is stated that $u_{k0} = 0$, but we believe it to be a typo (i.e. $u_{k0} = \alpha_0 + \epsilon_{k0}$).

IV estimation use the following variables as instruments for p_j:

- The prices in the other region and user category (Hausman 1996; Nevo 2001)
- The number of product models (not firms) (Bresnahan 1981; Berry, Levinsohn, and Pakes 1995)

Estimation: Period Competition and Marginal Costs

Given homogeneous goods, firms have Cournot competition. Marginal costs of producing old and new goods, mc_{old} and mc_{new}, are assumed to be common across firms and constant with respect to quantity. Firms maximize their profit:

$$\pi_i = \sum_{g \in A_i} \pi_{ig} = \sum_{g \in A_i} (p_g - mc_g) q_{ig}. \tag{7}$$

- $g, h \in \{old, new\}$, $g \neq h$. A_i is the set of generations produced by firm i.

First order condition is:

$$p_g + \frac{\partial p_g}{Q_g} q_{ig} + \frac{\partial p_h}{Q_g} q_{ih} = mc_g. \tag{8}$$

We can infer the marginal costs of production, mc_{old} and mc_{new}, from equation (8), and π_i from equation (7).

Estimation: Costs of Innovation, Entry, and Operation

Having obtained the static demand and cost estimates from the last two steps, we plug these profit variables back into the expected value function and solve the dynamic discrete choice game. The CCPs are:

$$pr^{old}(d_{it} = exit) = \exp(0)/B, \tag{9}$$

$$pr^{old}(d_{it} = stay) = \exp[-\phi + \beta E_\epsilon V^{old}_{t+1}(s_{t+1})]/B, \tag{10}$$

$$pr^{old}(d_{it} = innovate) = \exp[-\phi + \beta E_\epsilon V^{both}_{t+1(s_{t+1})} - \delta^t \kappa^{inc}]/B, \tag{11}$$

where,

$$B = \exp(0) + \exp[-\phi + \beta E_\epsilon V^{old}_{t+1}(s_{t+1})] + \exp[-\phi + \beta E_\epsilon V^{both}_{t+1(s_{t+1})} - \delta^t \kappa^{inc}]. \tag{12}$$

Overal Likelihood Function

The contribution of an old firm i in year t to the likelihood is

$$f^{old}(d_{it}|s_t;\phi,\kappa^{inc},\delta) = pr_t^{old}(d_{it}=exit)^{I(d_{it}=exit)}\times pr_t^{old}(d_{it}=stay)^{I(d_{it}=stay)}\times pr_t^{old}(d_{it}=innovate)^{I(d_{it}=innovate)}. \tag{13}$$

- The contributions of the other three types of firms take similar forms.

Year t has $N_t=(N_t^{old},N_t^{both},N_t^{new},N_t^{pe})$ active firms of which $X=(X_t^{old},X_t^{both},X_t^{new})$ exit and $E=(E_t^{old},E_t^{new})$ innovate. The joint likelihood is $\prod_{t=0}^{T-1} P(N_t,X_t,E_t)$ and the MLE yields:

$$\arg\max_{\phi,\kappa^{inc},\kappa^{ent}} ln(\prod_{t=0}^{T-1} P(N_t,X_t,E_t)). \tag{14}$$

Important Results

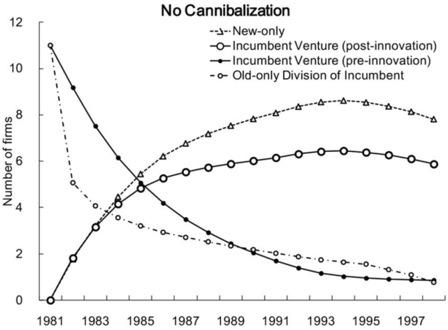
TABLE 4
MAXIMUM LIKELIHOOD ESTIMATES OF THE DYNAMIC PARAMETERS

	Assumed Order of Moves		
	Old-Both-New-PE (1)	PE-New-Both-Old (2)	PE-Old-Both-New (3)
Fixed cost of operation (ϕ)	.1474	.1472	.1451
	[−.02, .33]	[−.02, .33]	[−.03, .33]
Incumbents' sunk cost (κ^{inc})	1.2439	1.2370	1.2483
	[.51, 2.11]	[.50, 2.10]	[.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

- Incumbents have cost advantages over entrants to start innovating.
- Other estimates used in counterfactual analysis are reported in the paper.

Rational Innovator's Dilemma - Cannibalization

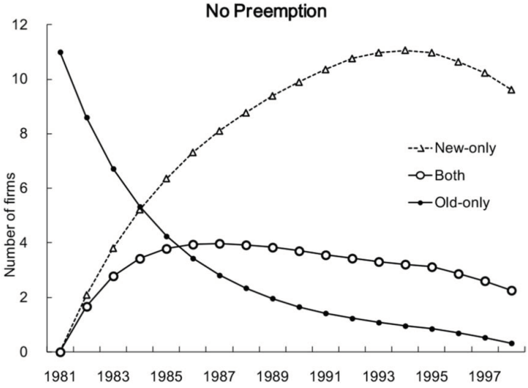
- Isolate innovation decision from profit maximization.
- Split each incumbent firm into two separate entities:
  - "Legacy": independent old-only firm - $\{exit, stay\}$.
  - "Corporate venture": potential entrant - $\{quit, enter\}$.



- The incumbent-entrant gap shrinks by 57 percent.

Rational Innovator's Dilemma - Preemption

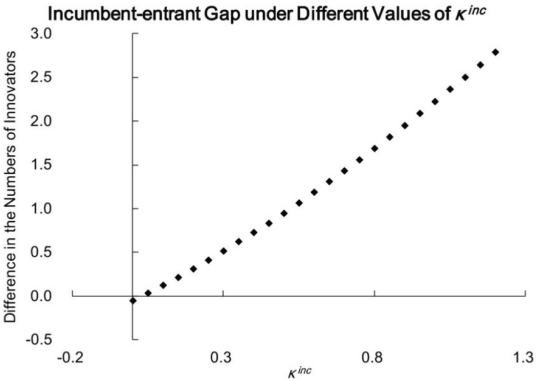
- Force potential entrants to ignore incumbents innovations.
- $\tilde{s}_t = (\tilde{N}_t^{old}, \tilde{N}_t^{both}, \tilde{N}_t^{new}, \tilde{N}_t^{pre}) = (N_t^{old} + N_t^{both}, 0, N_t^{new}, N_t^{pre})$



- The incumbent-entrant gap widens by 38 percent.

Rational Innovator's Dilemma - Sunk Cost

- Recall: $\hat{\kappa}^{inc} = 1.24$ and $\hat{\kappa}^{ent} = 2.25$.
- Hold $\kappa^{ent} = 2.25$, simulate with $\kappa^{inc} \in [0, 1.2]$.



- The incumbent-entrant gap will close-up when $\kappa^{inc} = 0$.

Counterfactual:Policy Experiments

- The ex ante counterfactual:
  - Only the first innovators can produce and sell new HDDs.
  - All of rules are common knowledge from 1981.
- The ex post counterfactual:
  - Firms ignore any patent claims by the first mover until 1988.
  - All but one producers of new HDDs go out of business in 1988.
- License fees:
  - Simulation is under the ex post patent counterfactuals frame.
  - Producers pay license fees to patent owner.

TABLE 7
WELFARE ANALYSIS OF INNOVATION/COMPETITION POLICIES

	Consumer Surplus (1)	Producer Surplus (2)	Fixed Cost of Operation (3)	Sunk Cost of Innovation (4)	Social Welfare (1 + 2 + 3 + 4)	Change from Baseline
Baseline	52.7	4.0	−9.7	−25.7	21.3	. . .
Broad patent:						
Ex ante	42.1	6.9	−5.7	−8.7	34.6	+62.5%
Ex post	28.3	4.9	−8.0	−23.2	2.0	−90.8%
License fees:						
25%	51.2	4.8	−9.6	−25.0	21.5	+.7%
50%	50.5	5.2	−9.6	−24.1	22.0	+3.3%
75%	47.2	6.5	−9.4	−24.1	20.1	−5.8%

NOTE.—Each number is the sum of discounted present values as of 1981.