Mergers, Innovation, and Entry-Exit Dynamics

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Mergers, Competition, & Innovation

- How far should an industry (be allowed to) consolidate?
  - Conventional analysis (e.g., Williamson '68, Werden & Froeb '94, Nevo '00)
    - Static tradeoff (market power vs. productivity)
    - OK if mergers were exogenous
    - OK if competition & innovation were exogenous
  - ...but they are not
    - Demsetz ('73): Monopoly = winner of competition & innovation
    - Berry & Pakes ('93): Merger-investment dynamics reverse static intuition
    - Gilbert & Greene ('15): FTC-DOJ always try to assess "impact on innovation"
  - ...and welfare tradeoff becomes dynamic
    - Tirole ('88) quoting Schumpeter ('42): "If one wants to induce firms to undertake R&D, one must accept the creation of monopolies as a necessary evil"

Dynamic Welfare Tradeoff

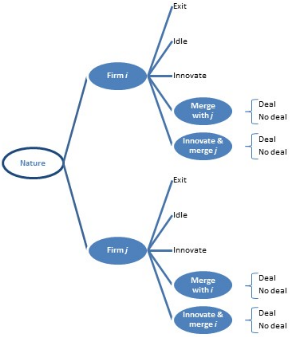
- With endogenous mergers, innovation, & entry-exit
  - Static effect of allowing a merger
    - Competition $(-)$
    - Synergy $(+)$
  - Ex-post effect of new market structure
    - Mergers $(+) \implies$ competition $(-)$
    - Innovation $(+/-/\text{inv-U}/\text{plateau})$
  - Ex-ante effect of permissive merger policy
    - Option value $(+) \implies$ net entry $(+)$, R&D $(+)$ $\implies$ competition $(+)$ & innovation $(+)$
- Dynamic welfare tradeoff
  - But how do we quantify all these?
  - Challenge: Everything is endogenous, strategic, & forward-looking
- This paper
  - Empirical model of mergers, innovation, & entry-exit dynamics
  - Consolidation of the hard disk drive (HDD) industry
  - Optimal merger policy under dynamic welfare tradeoff

Triple Trouble for Empirical Analysis

- Dynamics of mergers & innovation
  1. Rare events = sparse data $\Longrightarrow$ no experiment; need a model
  2. Dynamic games = multiple equilibria $\Longrightarrow$ no "full-solution" estimation
  3. Innovative industries = global & nonstationary $\Longrightarrow$ no "2-step" estimation
- Our approach
  - Tractable & estimable model
  - Extend Rust ('87) to random-mover dynamic game
- Context
  - Single-agent dynamic discrete choice
    - Pakes ('86), Rust ('87)
  - Dynamic game (with stochastically alternating moves)
    - Baron & Ferejohn ('89), Okada ('96), Iskhakov, et al. ('14, '16)
  - ...with endogenous mergers
    - Gowrisankaran ('95, '99), Jeziorski ('14)
  - ...& endogenous innovation
    - Mermelstein, Nocke, Satterthwaite, & Whinston ('14), Marshall & Parra ('15)

Model (1 of 2)

- Goals
  - Endogenizing mergers, innovation, & competition
  - Tractable, estimable, & useful for policy simulation
- Overview: Random-mover dynamic game



  - Click for graphic illustration

Model (2 of 2)

- Timeline
  1. Nature picks mover i with recognition prob $\rho_i(\omega_t) = 1/n_{\max}$
  2. Firm i makes discrete choice a_{it}
     - Take-it-or-leave-it (TIOLI) offer $\Longrightarrow$ acquisition price $p_{ij}(\omega_t)$
     - Sensitivity check: 50-50 Nash Bargaining (NB)
  3. All active firms earn period profits $\pi_{it}(\omega_t)$
  4. State transits from ω_t to ω_{t+1}
     - Stochastic synergy realizes: $\Delta_{ijt} \sim$i.i.d. $Poisson(\lambda)$
- "Hard to know where skeletons are from the outside. You have to dive into it and swim in the water" —Finis Conner (founder of Seagate & Conner)
  - From author's personal interview on April 20, 2015, in Corona del Mar, CA
- Unique sequential equilibrium
  - Finite horizon + sequential move + discrete choice
  - Effectively a single-agent problem, repeated T times
  - Backward induction

Industry & Data (1 of 2)

- Entry, shakeout, & mergers

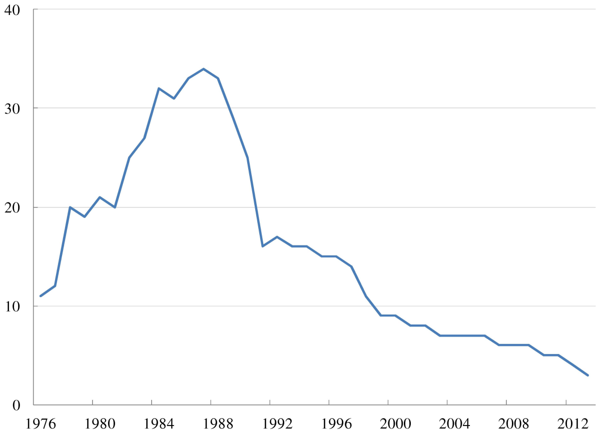
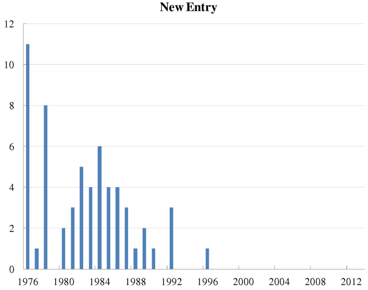
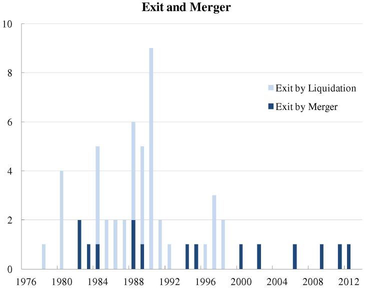


Figure: Number of HDD Manufacturers

- Mergers: Dominant mode of exit





- HDD is not alone
  - "Exits are dwarfed by mergers in the IT epoch" (Jovanovic & Rousseau '08)
  - "M&As account for a large portion of firm turnover: between 1981 and 2010, approximately 4.5% of active public firms merged in a given year, while the exit rate due to poor performance was 3.7%" (Dimopoulos & Sacchetto '14)

Empirical Analysis (Roadmap for Next 10 Slides)

- Pairing 3 data elements with 3 model elements

Table: Overview of Empirical Analysis

Step	Data	Model	Method
1. Demand	Panel A	Log-linear demand	IV regression
2. Variable cost	Panel B	Cournot competition	First-order condition
3. Sunk cost	Panel C	Dynamic discrete choice	Maximum likelihood

- Data (Source: *TrendFocus* 1996–2016)
  - A. Aggregate sales
  - B. Firm-level market shares
  - C. Mergers, innovation, & entry-exit

Estimation Task 1: Demand (1 of 3)

- Product characteristics: High-tech but commodities

hard drive by HITACHI

- Same capacity, same speed, similar reliability, & no luck in branding
- "Completely undifferentiated product" —Peter Knight
  - Former senior vice president at Conner Peripherals & Seagate Technology
  - Former president of Conner Technology
  - From author's personal interview on June 30, 2015, in Cupertino, CA

Estimation Task 1: Demand (2 of 3)

- HDDs are physically durable, but...

  - ...OS & CPU (Wintel) drives the PC cycle, not HDDs

Estimation Task 1: Demand (3 of 3)

- Log-linear demand for data storage

$$\log Q_t = \alpha_0 + \alpha_1 \log P_t + \alpha_2 \log X_t + \varepsilon_t$$

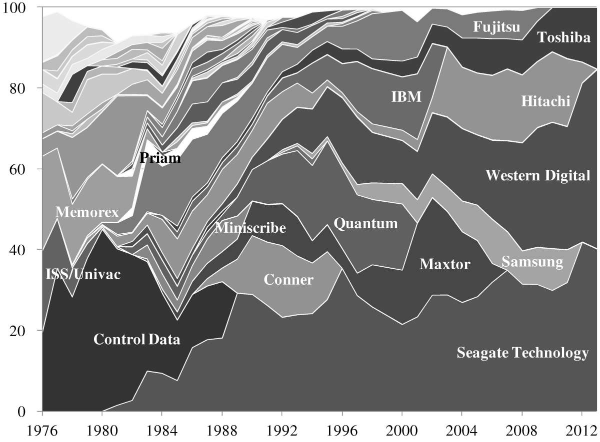
- Q_t : Total exabytes shipped (1EB = 1 billion GB)
- P_t : Average HDD price per gigabytes (\$/GB)
- X_t : PC shipments (in millions) as demand-shifter
- Z_t : IV = Disk price (\$/GB)

Table: Demand Estimates

	(1) OLS	(2) OLS	(3) IV	(4) IV
Log HDD price per GB (α_1)	−1.112	−1.046	−1.054	−1.043
	(0.035)	(0.046)	(0.032)	(0.038)
Log PC shipment (α_2)	–	0.271	–	0.276
	(–)	(0.095)	(–)	(0.086)
Number of observations	83	83	83	83
First-stage regression				
Log disk price per GB	–	–	0.813	0.567
	(–)	(–)	(0.026)	(0.032)
Thai flood dummy	–	–	0.263	0.548
	(–)	(–)	(0.079)	(0.070)

Estimation Task 2: Marginal Costs (1 of 3)

- Market share by firm (HHI: 806 ('85) → 2,459 ('11) → 3,832 ('13))



- "Most mergers were to kill competitors, because it's cheaper to buy them." —Reggie Murray (Ministor)
- "The industry has to pool people & talents, for further break-through."—Currie Munce (HGST/IBM)

Estimation Task 2: Marginal Costs (2 of 3)

- Use Cournot FOC to recover marginal costs

$$P_t + \frac{dP}{dQ} q_{it} = mc_{it}$$

  - P_t & q_{it} : observed
  - $\frac{dP}{dQ}$: estimated
- Intuition

$$q_{it} > q_{jt} \iff mc_{it} < mc_{jt}$$

  - In equilibrium, more efficient firms produce more
  - Larger firms have lower marginal costs
- Interpretation *à la* Kreps & Scheinkman ('83)

  0. $\{mc_{it}\}$ pre-determined (state of expertise)
  1. $\{q_{it}\}$ pre-commitment (re-tooling of obsolete equipment)
  2. $\{p_{it}\}$ set in fierce competition

Estimation Task 2: Marginal Costs (3 of 3)

- Assessment of fit
  - Model: Variable economic profit (excluding any fixed or sunk costs)
  - Data: Gross accounting profit (including some fixed & sunk costs)

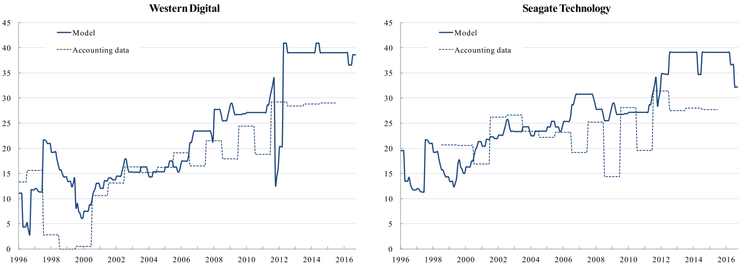


Figure: Profit Margins (%)

- Correlation between model & accounting data
  - Western Digital: .75
  - Seagate Technology: .51

Estimation Task 3: Sunk Costs (1 of 4)

Table: List of Parameters and Key Specifications

Parameter	Notation	Empirical approach
1. Static estimates		
Demand	$\alpha_0, \alpha_1, \alpha_2$	Already estimated (step 1)
Variable costs	mc_{it}	Already estimated (step 2)
Period profits	$\pi_{it}(\omega_t)$	Already estimated (step 2)
2. Dynamics (sunk costs)		
Innovation, mergers, and entry	$\kappa^i, \kappa^m, \kappa^e$	MLE
Logit scaling parameter	σ	MLE
Base fixed cost of operation	ϕ_0	MLE
Time-varying fixed cost of operation	$\phi_t(\omega_{it})$	Accounting data
Liquidation value	$\kappa^x = 0$	Calibrated (industry background)
3. Dynamics (transitions)		
Annual discount factor	$\beta = 0.9$	Calibrated (literature's standard)
Prob. stochastic depreciation	$\delta = 0.04$	Implied by mc_{it}
Average synergy	$\lambda = 1$	Implied by mc_{it}
4. Other key specifications		
Terminal period	$T = Dec\text{-}2025$	Sensitivity analysis
Bargaining power	TIOLI: $\zeta = 1$	Sensitivity analysis
Recognition probability	$\rho = \frac{1}{n_{\max}} = \frac{1}{14}$	Sensitivity analysis

- Simple & transparent: Parsimonious model, bite-sized identification

Estimation Task 3: Sunk Costs (2 of 4)

- Full-solution approach with nested fixed-point algorithm
  - Outer loop: Maximum likelihood estimation
    - Contribution (of firm i at time t)

$$l_{it}\left(a_{it}|\omega_t;\kappa\right) = \rho_i(\omega_t) \prod_{action \in A_{it}(\omega_t)} \Pr\left(a_{it} = action\right)^{1\{a_{it}=action\}}$$

    - Recognition: $\hat{\rho}_i\left(\omega_t\right) =$

$$\begin{cases} 1 & \text{if some } a_{it} \in \{merge, innovate, enter, exit\} \\ 1/n_{\max} \times \Pr\left(a_{it} = stay/out\right) & \text{if all } a_{it} \in \{idle, out\}. \end{cases}$$

    - Max likelihood: $\hat{\kappa} = \arg\max_\kappa \frac{1}{T}\frac{1}{I}\sum_t \sum_i \ln\left[l_{it}\left(a_{it}|\omega_t;\kappa\right)\right]$
  - Inner loop: Solving the game (given parameter values)
    - Backward induction from T
    - Compare choice prob.: predicted ($\tilde{P}$) vs. data ($\bar{P}$)

$$\Pr\left(a_{it} = action\right) = \frac{\exp\left(\tilde{V}_{it}^{action}\right)}{\exp\left(\tilde{V}_{it}^{x}\right) + \exp\left(\tilde{V}_{it}^{c}\right) + \exp\left(\tilde{V}_{it}^{i}\right) + \sum_{j\neq i}\exp\left(\tilde{V}_{ijt}^{m}\right)}$$

$$\Pr\left(a_{it}^0 = action\right) = \frac{\exp\left(\tilde{V}_{it}^{action}\right)}{\exp\left(\tilde{V}_{it}^{e}\right) + \exp\left(\tilde{V}_{it}^{o}\right)}$$

Estimation Task 3: Sunk Costs (3 of 4)

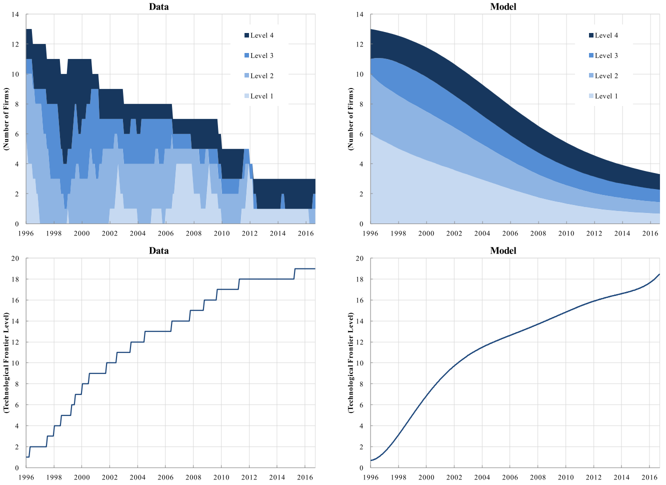
Table: MLE of Dynamic (Sunk Cost) Parameters

Specification	(1)	(2)	(3)	(4)
Bargaining (ζ):	1 (TIOLI)	0.5 (NB)	1	1
Synergy (λ):	1	1	0	2
Terminal period (T):	2025	2025	2025	2025
Base fixed cost, ϕ_0	0.011	0.011	0.012	0.011
	[0.001, 0.020]	[0.000, 0.021]	[0.001, 0.022]	[0.001, 0.019]
Catch-up innovation, κ^i	0.48	0.51	0.52	0.47
	[0.26, 0.69]	[0.28, 0.75]	[0.27, 0.77]	[0.26, 0.68]
Frontier innovation, κ^{i4}	0.85	0.91	0.97	0.84
	[0.39, 1.42]	[0.42, 1.54]	[0.45, 1.63]	[0.26, 0.68]
Merger/bargaining, κ^m	1.27	1.21	1.34	1.31
	[0.81, 1.86]	[0.72, 1.84]	[0.81, 2.00]	[0.86, 1.88]
Entry, κ^e	0.17	0.16	0.15	0.18
	[–]	[–]	[–]	[–]
Logit scaling, σ	0.55	0.60	0.63	0.54
	[0.41, 0.80]	[0.45, 0.87]	[0.47, 0.91]	[0.40, 0.78]

- Estimates (slightly) move, in the right directions.
- More sensitivity analysis (in paper): ζ, T, ρ

Estimation Task 3: Sunk Costs (4 of 4)

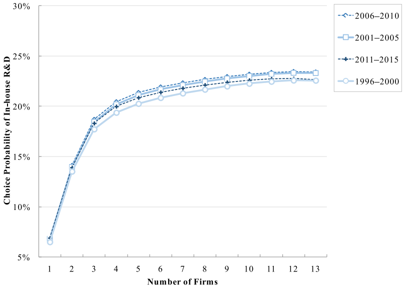
- Fit: # of firms & frontier technology

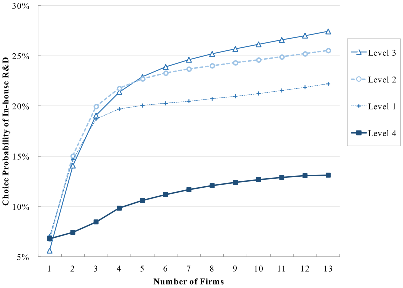


- Firm-value estimates match historical acquisition prices, too.

Result (1 of 2): Incentive to Innovate

- Structural competition-innovation curve: "Plateaux"

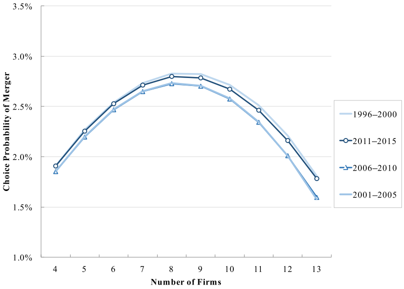


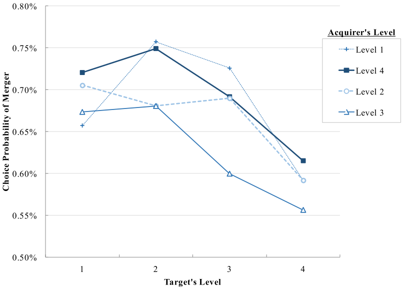


  - Upward-sloping (∵ replacement vs. preemption)
  - Heterogeneous (∵ continuation values creates dynamics)

Result (2 of 2): Incentive to Merge

- Who merges with whom, & when?





- Mergers are strategic complements (Qiu & Zhou '06).
- All pairings possible (as in data); non-monotonic due to:
  - Acquisition price: Lower targets more affordable
  - Rationalization: Higher targets more attractive
  - Synergy: Common or heterogeneous (in paper)

Counterfactual: Optimal Merger Policy (1 of 4)

- How far should the industry (be allowed to) consolidate?
  - Consider static ("commitment") policy with threshold $\underline{N}$
    - Baseline $\underline{N} = 3$: Block mergers if $n_t \leqslant 3$
    - Counterfactuals: Block mergers if $n_t \leqslant \{1, 2, 4, 5, 6, \ldots\}$
  - Is $\underline{N} = 3$ in reality? Yes
    - FTC ('13) reviewed all merger cases (1996–2011)

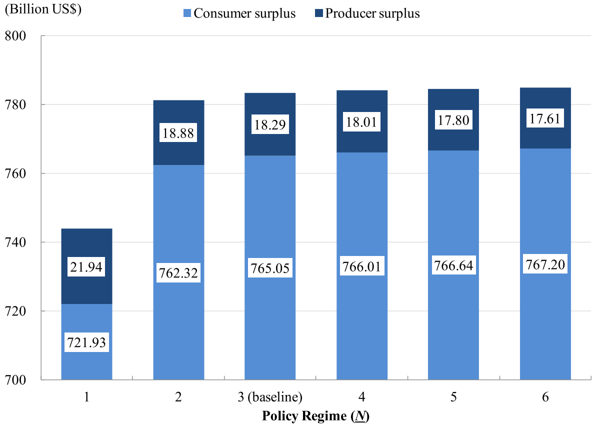
    (i) Blocked 0% of 5-to-4 mergers in high-tech

    (ii) Blocked 33% of 4-to-3 mergers in high-tech

    (iii) Blocked 100% of 3-to-2 & 2-to-1 mergers in high-tech
    - Belief shared by: former chief economists, consultants, & HDD veterans

Counterfactual: Optimal Merger Policy (2 of 4)

- Welfare performance across different policy thresholds



- Stricter policies ($\underline{N} = 4, 5, 6$) slightly improve social welfare
- More permissive policies ($\underline{N} = 1, 2$) significantly reduce social welfare

Counterfactual: Optimal Merger Policy (3 of 4)

Table: Competition and Innovation Outcomes of Counterfactual Policies

Policy regime ($\underline{N}$)	1	2	3 (Baseline)	4	5	6
(A) Average # of firms	5.80	6.12	6.24	6.32	6.39	6.46
(B) Average tech. frontier	13.62	13.71	13.73	13.74	13.74	13.75
(C) Total # of mergers	6.08	4.87	4.15	3.60	3.12	2.66
(D) Total # of innovations	45.45	47.84	48.79	49.41	49.94	50.48
(E) Total # of entries	0.10	0.05	0.03	0.02	0.02	0.02
(F) Total # of exits	6.22	7.06	7.65	8.14	8.60	9.03

- $\underline{N} = 4, 5, 6$: slightly more competition, less mergers, more exits
- $\underline{N} = 1, 2$: less competition, more mergers, less exits
- Mergers to monopoly/duopoly do not help innovations, either.

Counterfactual: Optimal Merger Policy (4 of 4)

- More results (in paper)
  - In fast-declining industries ($T = 2016$ or 2020, instead of 2025)
    - Optimal $\underline{N} = 5$ (instead of $\underline{N} \geqslant 6$)
    - Slightly more permissive
  - Optimal ex-post ("surprise" or "bate-and-switch") policy
    - Promise $\underline{N} = 1$ but implement $\underline{N} \geqslant 3$
    - But can "surprise" only once
  - Price-based policy (e.g., Farrell & Shapiro '90) *coming soon*
    - Instead of threshold $\underline{N}$
    - Block if prices increase by 1%, 5%, 10%, etc.

Conclusion

- Findings
    1. Exit by merger: Consolidation
    2. Competition-innovation: Positive plateaux
    3. Optimal policy: $\underline{N} = 3, 4, 5, 6, \ldots$ but never 1 or 2
    - Dynamic welfare tradeoff ($\because$ value-creation/destruction side effects)
- Approach
    - Random-mover dynamic game
    - Addressing high-tech merger trilemma:
        - Sparse data
        - Multiple equilibria
        - Global & nonstationary
    - Applicable to other contexts (e.g., computers & semiconductors), too