Mergers, Innovation, and Entry-Exit Dynamics

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Mergers, Competition, & Innovation

- How do mergers affect welfare?
  - Conventional analysis (e.g., Williamson '68, Werden & Froeb '94, Nevo '00)
    - Static tradeoff (market power vs. productivity)
    - OK if mergers were exogenous, with static competition & innovation
- Otherwise, analysis is incomplete (e.g., Gilbert '06, U.S. DOJ & FTC '10)
  - Ex-post impact
    - Incentives to innovate $(+/\square)$
    - Incentives to merge $(+)$
  - Ex-ante impact
    - Option value $(+) \Longrightarrow$ exit $(\square)$, entry $(+)$, R&D $(+)$ $\Longrightarrow$ competition $(+)$ & innovation $(+)$
  - Challenge: Everything is endogenous, strategic, & forward-looking
- This paper
  - Empirical model of mergers, innovation, & entry-exit dynamics
  - Data on the consolidation process of the hard disk drive (HDD) industry
  - Simulate welfare under a tougher antitrust regime

Context

- Endogenous horizontal merger in dynamic game
  - Gowrisankaran ('97, '99)
    - Computational theory, oligopoly
  - Mermelstein, Nocke, Satterthwaite, & Whinston ('14)
    - Computational theory, duopoly, entry-exit & investment
  - Jeziorski ('14)
    - Structural empirics, oligopoly, product portfolio management
- This paper
  - Structural empirics, oligopoly, entry-exit & investment
- Also related to empirical works on:
  - Bargaining
  - Entry-exit
  - Innovation

Consolidation of the Hard Disk Drive Industry (1 of 3)

- Entry, shakeout, & merger

Figure 1: Number of HDD Manufacturers

Consolidation of the Hard Disk Drive Industry (2 of 3)

- Exit by merger

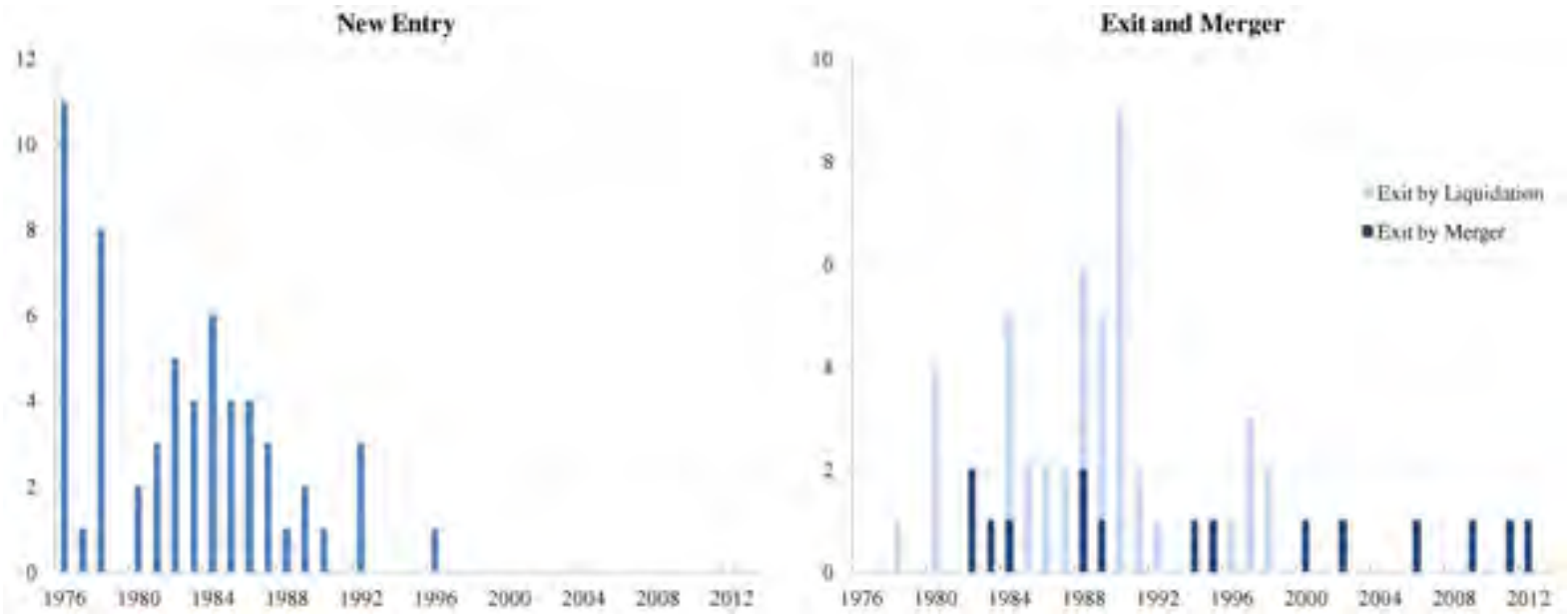


Figure 2: Mergers Have Become a Dominant Mode of Exit

- 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)

Consolidation of the Hard Disk Drive Industry (3 of 3)

- Herfindahl-Hirschman Index (HHI): 806 ('85) $\rightarrow$ 2,459 ('11) $\rightarrow$ 3,832 ('13)

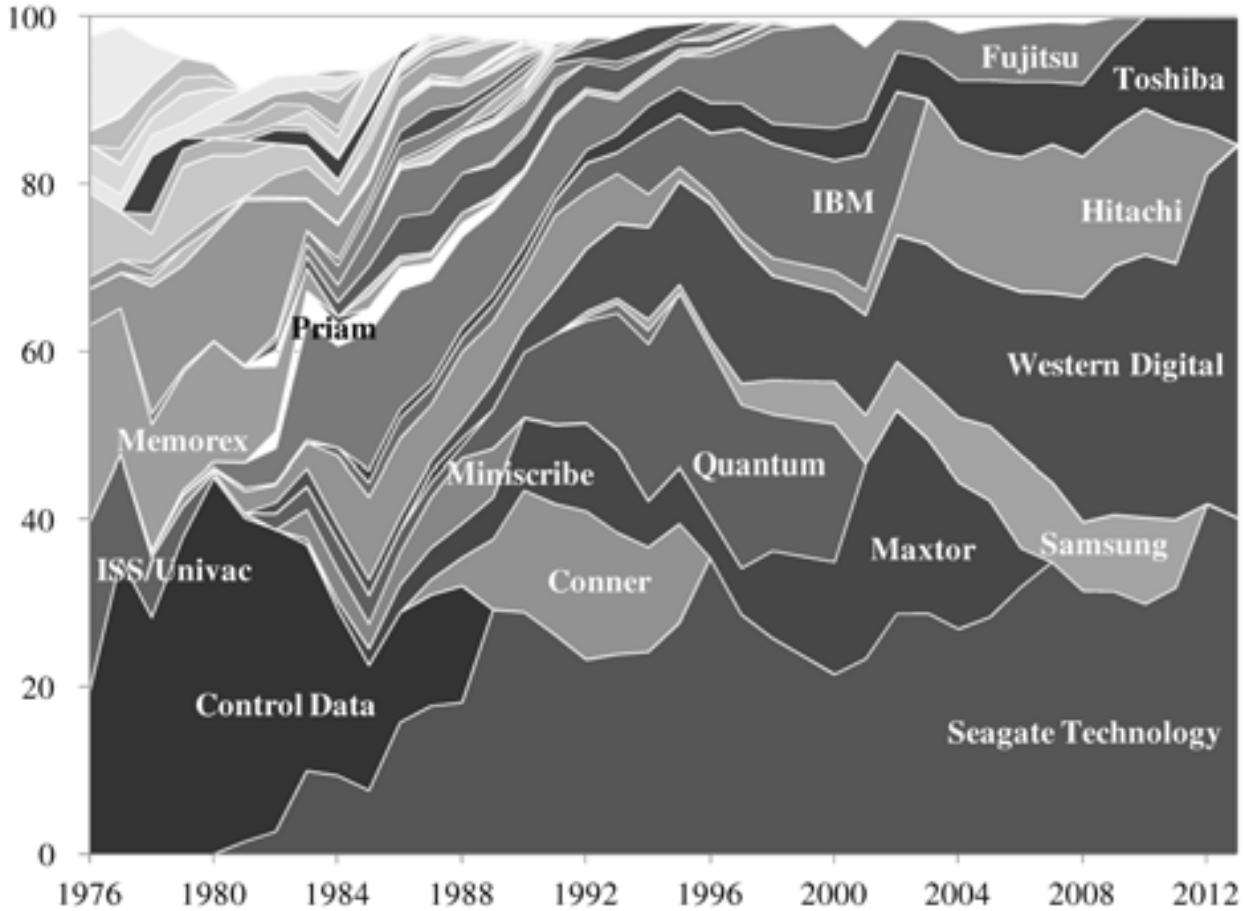


Figure 3: Market Share by Firm

Theorists' Checklist

1. Market power
   - $N \downarrow \implies P \uparrow \implies \Pi \uparrow$
   - In static Cournot with symmetric firms
2. Free riding (Stigler '50)
   - $q^{IN} \downarrow$ & $q^{OUT} \uparrow \implies \pi^{IN} \downarrow$ $\pi^{OUT} \uparrow$ (unless $fc^{IN} \downarrow\downarrow$)
   - In static Cournot with symmetric firms (Salant, Switzer, & Reynolds '83)
     - *Not* with heterogeneous firms (Perry & Porter '85)
     - *Not* in differentiated Bertrand (Deneckere & Davidson '85)
3. Efficiency gains
   - $mc^{IN} \downarrow$ (rationalization & synergies)
   - In static Cournot with *heterogeneous* firms (Farrell & Shapiro '90)
4. Mergers as strategic complements
   - $N \downarrow \implies v^{IN} \uparrow$
   - In *dynamic* Cournot with heterogeneous firms (Qiu & Zhou '07)

- Insights
  - Tug-of-war between free-riding & synergies
  - Cost-heterogeneity as a key determinant
  - Check how ms_{it} & mc_{it} change with mergers

Static Analysis (1 of 9)

Table 1: Market Shares before/after Mergers (%)

Year	Target name	Acquiror name	ms^T Before	ms^A Before	$ms^T + ms^A$ Before	$ms^T + ms^A$ After
1982	Burroughs	Memorex	1.85	7.83	9.68	2.73
1983	ISS/Univac	Control Data	0.75	27.08	27.83	19.85
1984	Vertex	Priam	0.93	2.52	3.45	2.78
1988	Plus Dev.	Quantum	0.89	1.41	2.30	4.64
1988	Imprimis	Seagate	13.92	18.16	32.08	29.23
1989	MiniScribe	Maxtor	5.68	4.99	10.68	8.53
1994	DEC	Quantum	1.65	18.60	20.25	20.68
1995	Conner	Seagate	11.94	27.65	39.58	35.41
2001	Quantum	Maxtor	13.87	13.87	27.73	26.84
2002	IBM	Hitachi	13.86	3.64	17.50	17.37
2006	Maxtor	Seagate	8.19	29.49	37.67	35.27
2009	Fujitsu	Toshiba	4.41	10.32	14.72	11.26
2011	Samsung	Seagate	6.89	39.00	45.89	42.82
2012	Hitachi	Western Digital	20.32	24.14	44.46	44.27
Average			7.51	16.33	23.85	21.55

- Observations
  1. Bigger firms acquire smaller firms: $ms^T < ms^A$
  2. Acquirors' market shares increase: $ms^A \uparrow$
  3. Combined market shares decrease: $ms^T + ms^A \downarrow$
     - Acquirors achieve expansion; some free-riding

Static Analysis (2 of 9)

- Product characteristics

Figure 4: High-tech but Commodities

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

Static Analysis (3 of 9)

- HDDs are physically durable, but...

Figure 5: An I.O. Economist Knows His OS & CPU but Not HDD

- ...Wintel drives the PC cycle, not HDDs

Static Analysis (4 of 9)

- 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 ($/GB)
  - X_t : PC shipments (in millions), as demand-shifter
  - Z_t : Average disk price ($/GB), as instrument for P_t

Table 2: Demand Estimates

Dependent variable:	(1)	(2)
log total EB shipped	OLS	IV
log price per GB (α_1)	□.8549***	□.8244***
	(.0188)	(.0225)
log PC shipment (α_2)	.8430***	1.0687***
	(.1488)	(.1817)
Constant (α_0)	□1.6452***	□2.4039***
	(.4994)	(.6084)
Number of observations	78	78
Adjusted R^2	.9971	.9971
First stage regression		
F-value	□	3009.80
Adjusted R^2	□	.9889

Note: Standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Static Analysis (5 of 9)

- Data patterns underlying demand estimates

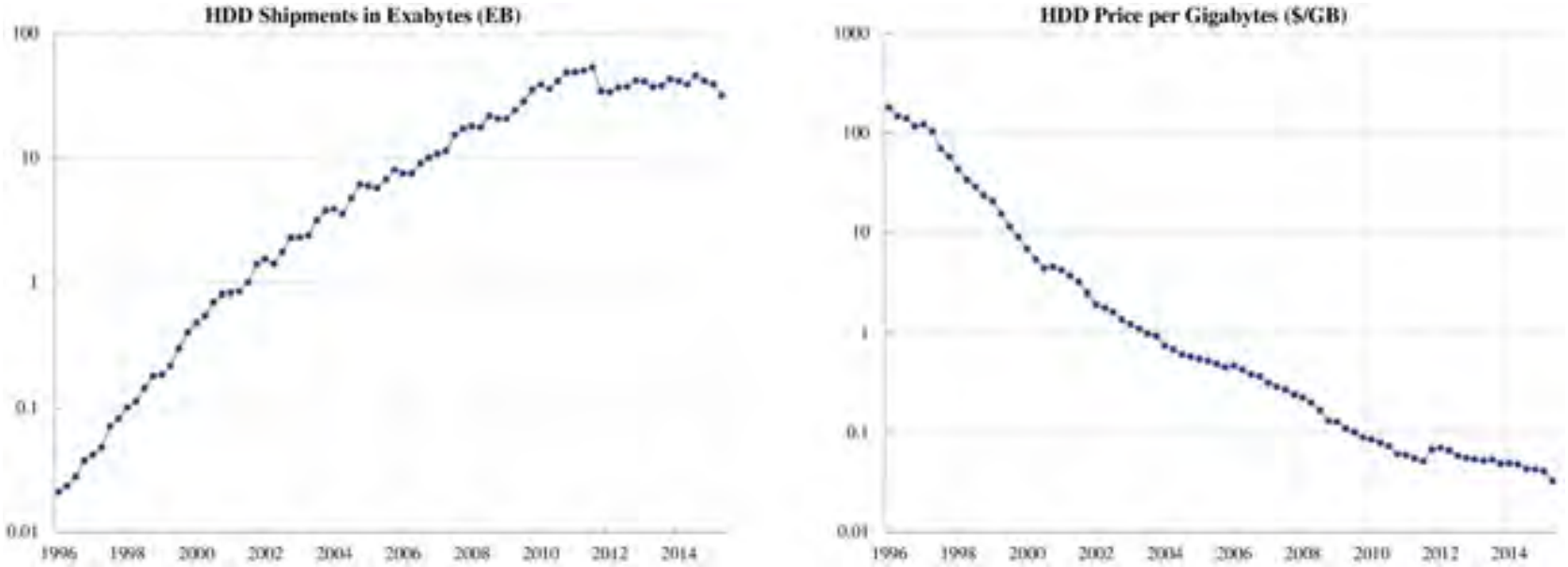


Figure 6: Shipments and Prices

Static Analysis (6 of 9)

- Data patterns underlying demand estimates

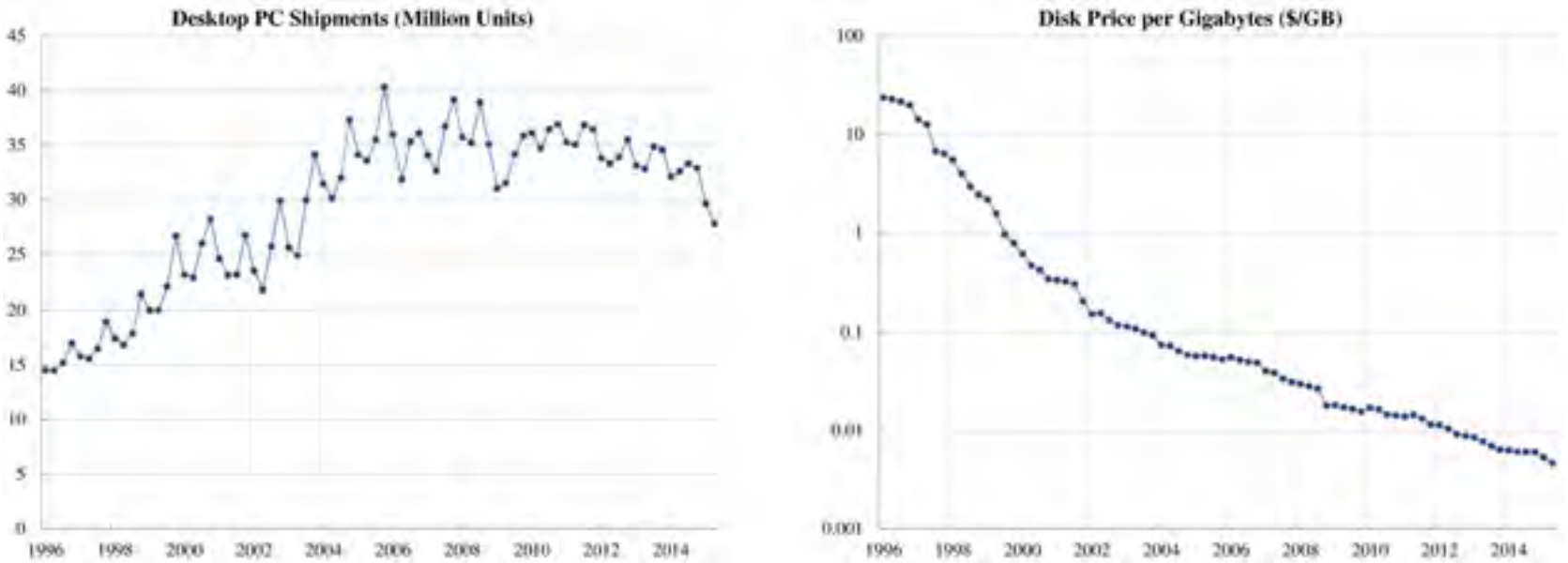


Figure 7: Market Size and Input Prices

Static Analysis (7 of 9)

- 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

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

  - In equilibrium, more efficient firms produce more
  - Larger firms have lower marginal costs

Static Analysis (8 of 9)

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

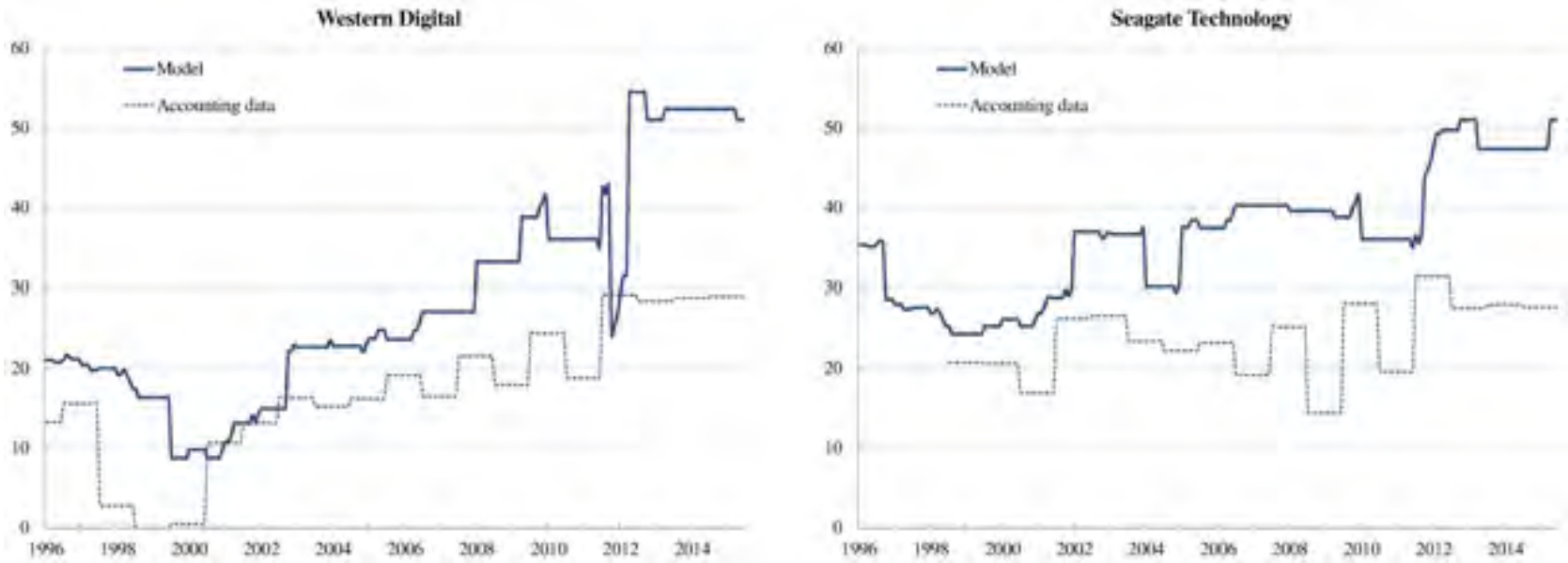


Figure 8: Profit Margins (%)

- Correlation between model & accounting data
  - Western Digital: .8398
  - Seagate Technology: .5407

Static Analysis (9 of 9)

Table 3: Marginal Costs before/after Mergers (US$)

Year	Target name	Acquiror name	Target (mc^T)	Acquiror (mc^A)			Rivals $\nabla mc^{\square A}$	Relative change $\nabla mc^A \square \nabla mc^{\square A}$
				Before	After	∇mc^A		
1982	Burroughs	Memorex	2068.21	2044.52	1469.62	□574.90	□590.44	15.53
1983	ISS/Univac	Control Data	1475.65	1395.39	1024.25	□371.14	□393.17	22.03
1984	Vertex	Priam	1081.94	1077.10	959.96	□117.14	□116.34	□0.80
1988	Plus Dev.	Quantum	510.52	508.93	427.49	□81.44	□71.62	□9.83
1988	Imprimis	Seagate	470.79	457.88	352.52	□105.37	□71.62	□33.75
1989	MiniScribe	Maxtor	424.29	426.40	362.50	□63.91	□53.12	□10.79
1994	DEC	Quantum	239.96	188.30	165.19	□23.10	□16.76	□6.35
1995	Conner	Seagate	191.85	143.95	116.45	□27.51	□3.84	□23.67
2001	Quantum	Maxtor	91.81	91.81	70.61	□21.20	□17.52	□3.68
2002	IBM	Hitachi	67.35	70.27	59.53	□10.73	□6.79	□3.94
2006	Maxtor	Seagate	57.46	51.39	50.84	□0.55	0.22	□0.76
2009	Fujitsu	Toshiba	48.69	47.01	44.56	□2.44	□2.42	□0.02
2011	Samsung	Seagate	54.15	45.01	39.29	□5.72	□3.74	□1.98
2012	Hitachi	Western Digital	47.75	46.66	37.21	□9.45	□7.63	□1.81
Average			487.89	471.04	370.00	□101.04	□96.77	□4.27

- Observations
  1. Acquirors' marginal costs decrease: $mc^A \downarrow$
  2. Industry-wide trend: $mc^{\square A} \downarrow$
  3. Acquirors out-perform industry trend: $\left|\nabla mc^A\right| > \left|\nabla mc^{\square A}\right|$ (synergies)

Dynamic Model (1 of 6)

- Goals
  - Endogenizing competition & innovation with merger
  - Tractable, estimable, & amenable for policy simulation
- Setup
  - Discrete time $t = 1, 2, ...$
  - State: $s_t = \{s_{it}\} = \{\omega_{it}\}$ or $(n_{00}, n_0, n_1, n_2, \ldots, n_M)$
  - Actions
    - Incumbents: $a_{it} \in \{exit, stay, invest, merge_1, merge_2, \ldots, merge_M\}$
    - Potential entrants: $a^0_{it} \in \{enter, out\}$
  - Payoff
    - Period profit $\pi_{it}(s_t)$
    - Fixed/sunk cost $(\kappa^x, \kappa^c, \kappa^i, \kappa^m, \kappa^e)$
    - Private cost shock $(\varepsilon^x_{it}, \varepsilon^c_{it}, \varepsilon^i_{it}, \varepsilon^m_{it}, \varepsilon^e_{it}) \sim$ i.i.d. $EV1$
    - Expected present value

Dynamic Model (2 of 6)

- Overview: Random-mover Dynamic Game

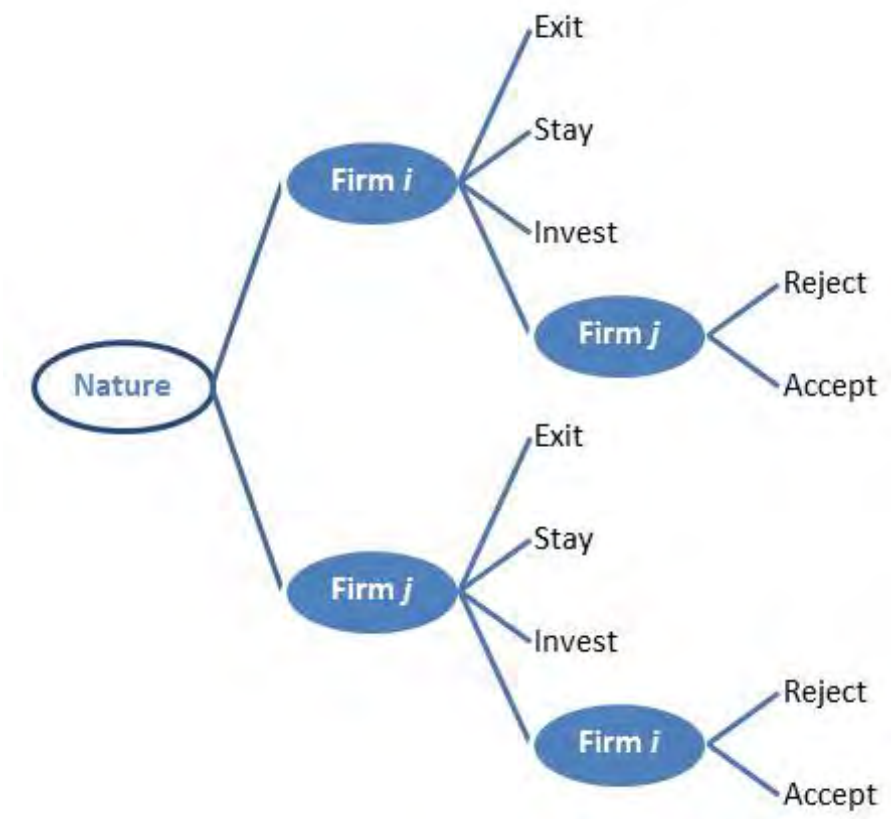


Figure 9: Game Tree within a Period (2-player Example)

Dynamic Model (3 of 6)

- Timeline
  1. Nature chooses proposer i
     - With recognition probability $\rho_i(s_t) = 1/n_{\max}$
  2. Firm i draws ε_{it}, and chooses action a_{it} (or a_{it}^0)
     - If $a_{it} = merge_j$, proposes acquisition price $p_{ij}(s_t)$ (take-it-or-leave-it offer)
     - Firm j chooses between $\{accept, reject\}$
     - Firm i sets $p_{ij}(s_t)$ slightly above j's stand-alone expected value
  3. Active firms earn period profits $\pi_{it}(s_t)$
  4. State transits from s_t to s_{t+1}
     - Dynamic actions implemented
     - Synergy & stochastic depreciation realize
  - "Hard to know where skeletons are from the outside. You have to dive into it and swim in the water" —Finis Conner
    - Co-founder of Seagate Technology, founder of Conner Peripherals & Conner Technology
    - From author's personal interview on April 20, 2015, in Corona del Mar, CA

Dynamic Model (4 of 6)

- State transition (i.e., how productivity changes with choice)
  - Incumbents
    - Exit: $\omega_{i,t+1} = \bar{\omega}_{00}$ (dead)
    - Stay: $\omega_{i,t+1} = \omega_{it}$
    - Invest: $\omega_{i,t+1} = \omega_{it} + 1$
    - Merge with j:

$$\begin{cases} \omega_{i,t+1} = \max\{\omega_{it}, \omega_{jt}\} + \Delta_{ijt} & \text{(acquirer)} \\ \omega_{j,t+1} = \bar{\omega}_{00} & \text{(target)} \end{cases}$$

      where synergy draw Δ_{ijt} ∼i.i.d. $Poisson(\lambda)$
    - Stochastic depreciation (exogenous):

$$\tilde{\omega}_{i,t+1} = \begin{cases} \omega_{it+1} & \text{with probability } 1 \square \delta \\ \omega_{it+1} \square 1 & \text{with probability } \delta \end{cases}$$

  - Potential entrants
    - Enter: $\omega_{i,t+1} = \bar{\omega}_1$ (lowest level)
    - Out: $\omega_{i,t+1} = \bar{\omega}_0$ (potential entrant)

Dynamic Model (5 of 6)

- Proposer i's value (*after* drawing ε_{it})
  - Incumbent

$$V_{it}(s_t, \varepsilon_{it}) = \pi_i(s_t) + \max\left\{ \bar{V}^x_{it}(s_t, \varepsilon^x_{it}), \bar{V}^c_{it}(s_t, \varepsilon^c_{it}), \bar{V}^i_i\left(s_t, \varepsilon^i_{it}\right), \left\{ \bar{V}^m_{ijt}\left(s_t, \varepsilon^m_{ijt}\right) \right\}_j \right\}$$

    - Alternative-specific values

$$\begin{aligned}
\bar{V}^x_i(s_t, \varepsilon^x_{it}) &= \kappa^x + \varepsilon^x_{it} + \beta E\left[\Lambda_{i,t+1}(s_{t+1}) | s_t, a_{it} = exit\right] \\
\bar{V}^c_i(s_t, \varepsilon^c_{it}) &= \kappa^c + \varepsilon^c_{it} + \beta E\left[\Lambda_{i,t+1}(s_{t+1}) | s_t, a_{it} = stay\right] \\
\bar{V}^i_i\left(s_t, \varepsilon^i_{it}\right) &= \kappa^c - \kappa^i + \varepsilon^i_{it} + \beta E\left[\Lambda_{i,t+1}(s_{t+1}) | s_t, a_{it} = invest\right] \\
\bar{V}^m_{ij}(s_t, \varepsilon^m_{ijt}) &= \kappa^c - \kappa^m + \varepsilon^m_{ijt} - p_{ij}(s_t) + \beta E\left[\Lambda_{i,t+1}(s_{t+1}) | s_t, a_{it} = merge\ j\right]
\end{aligned}$$

  - Potential entrant

$$V^0_{it}\left(s_t, \varepsilon^0_{it}\right) = \max\left\{ \bar{V}^e_i(s_t, \varepsilon^e_{it}), \bar{V}^o_i(s_t, \varepsilon^o_{it}) \right\}$$

    - Alternative-specific values

$$\begin{aligned}
\bar{V}^e_i(s_t, \varepsilon^e_{it}) &= \kappa^e + \varepsilon^e_{it} + \beta E\left[\Lambda_{i,t+1}(s_{t+1}) | s_t, a_{it} = enter\right] \\
\bar{V}^o_i(s_t, \varepsilon^o_{it}) &= \varepsilon^o_{it} + \beta E\left[\Lambda_{i,t+1}(s_{t+1}) | s_t, a_{it} = out\right]
\end{aligned}$$

Dynamic Model (6 of 6)

- Non-proposer i's value (*before* proposer j's action ε_{it})
  - When both i & j are incumbents

$$\begin{aligned} W_{it}^{j}(s_t) = & \pi_i(s_t) - \kappa^c + \sigma_{it}(a_{jt} = exit)\,\beta E\left[\Lambda_{i,t+1}(s_{t+1}) \mid s_t, a_{jt} = exit\right] \\ & + \sigma_{it}(a_{jt} = stay)\,\beta E\left[\Lambda_{i,t+1}(s_{t+1}) \mid s_t, a_{jt} = stay\right] \\ & + \sigma_{it}(a_{jt} = invest)\,\beta E\left[\Lambda_{i,t+1}(s_{t+1}) \mid s_t, a_{jt} = invest\right] \\ & + \sigma_{it}(a_{jt} = merge\ i)\,p_{ji}(s_t) \\ & + \sum_{k \neq i,j} \sigma_{it}(a_{jt} = merge\ k)\,\beta E\left[\Lambda_{i,t+1}(s_{t+1}) \mid s_t, a_{jt} = merge\ k\right] \end{aligned}$$

    - $\sigma_{it}(a_{jt} = action)$ is non-proposer's belief on proposer's choice
    - Simpler if proposer and/or non-proposer are potential entrants

- Anyone's value (*before* nature picks a proposer for time $t+1$)

$$\Lambda_{i,t+1}(s_{t+1}) = \rho_i(s_{t+1})\,EV_{i,t+1}(s_{t+1}) + \sum_{j \neq i} \rho_j(s_{t+1})\,W_{i,t+1}^{j}(s_{t+1})$$

Estimation (1 of 6): Preparing Data

- De-trending & discretizing the state space

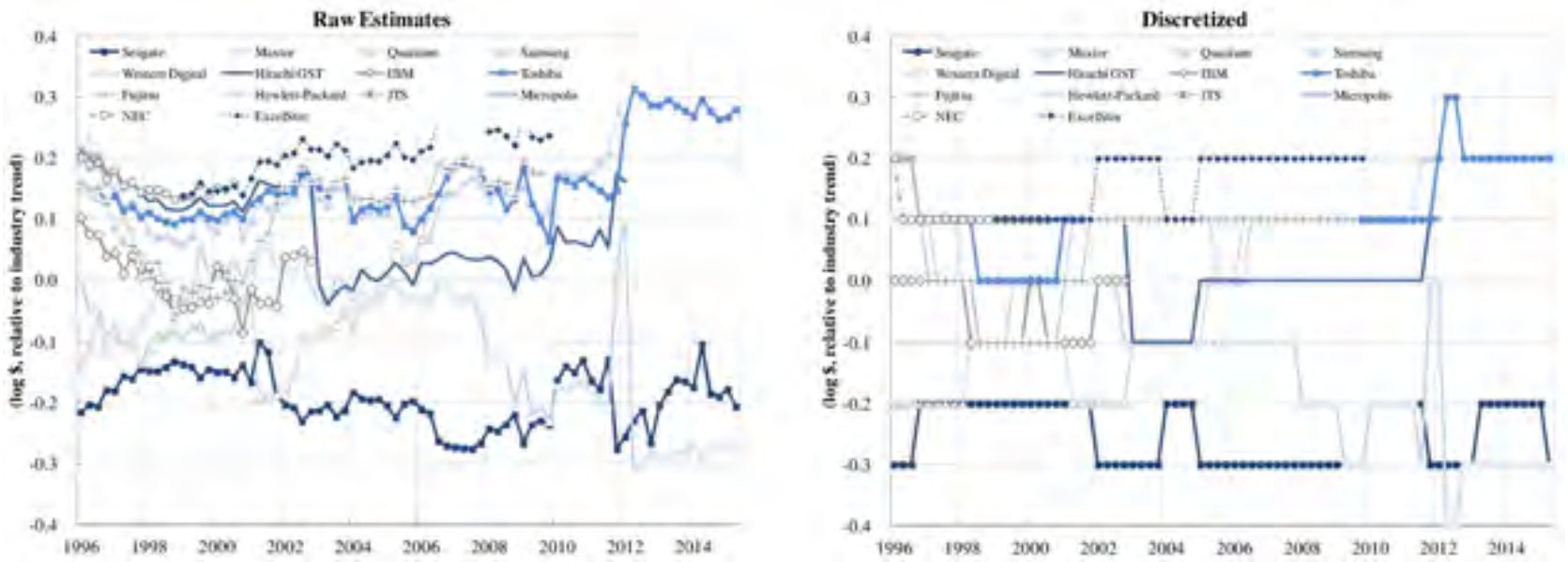


Figure 10: Marginal Cost Estimates by Firm (Relative to Kryder's Law)

Estimation (2 of 6): Approach

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

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

    - Recognition: $\hat{\rho}_i\left(s_t\right)=$
$$\begin{cases}1 & \text{if some } a_{it}\in\{exit,merger,enter\}\\ 1/n_{\max}\times\Pr\left(a_{it}=stay/out\right) & \text{if all } a_{it}\in\{stay,out\}.\end{cases}$$
    - Max joint log likelihood: $\hat{\kappa}=\arg\max_\kappa \frac{1}{T}\frac{1}{I}\sum_t\sum_i \ln\left[l_{it}\left(a_{it}|s_t;\kappa\right)\right]$
  - Inner loop: Solving the game (given parameter values)
    - Terminal values: $\Lambda_{i,T}\left(s_T\right)=\sum_{t=T}^{\infty}\beta^{t-T}\pi_{it}\left(s_T\right)$
    - Backward induction to solve for PBE/SE
    - Equilibrium choice probabilities:

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

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

Estimation (3 of 6): Results

- Parameter estimates
  - Sunk costs of innovation & merger

Table 4: ML Estimates of the Dynamic Parameters (Billion US$)

Parameter	Estimate	Confidence Interval
κ^i	3.5250	(under construction)
κ^m	6.4214	(under construction)

Note: The confidence intervals are constructed from the likelihood-ratio tests.

  - $\kappa^i \approx$ R&D expenditure over 12 quarters ($\$2 \sim \$3$ billion)
  - $\kappa^m \approx$ Acquisition price of a medium-productivity firm
  - Setting
    - Time period: 2000 Q1 through 2014 Q1 (earlier years to be included)
    - Discount factor (per quarter): $\beta = .975$
  - Other sunk costs
    - Exit cost (sell-off value): $\kappa^x = 0$
    - Entry cost: $\kappa^e = \infty$ (for now)
    - Operating fixed cost: $\kappa^c = \{\kappa^c_t\}$ in SGA+CAPEX data $\in (0.1, 0.5)$
  - Transition probabilities
    - Stochastic depreciation: $\delta = .0634$
    - Synergy (Poisson): $\lambda = 1.1667$

Estimation (4 of 6): Fit

- Number of firms & productivity distribution

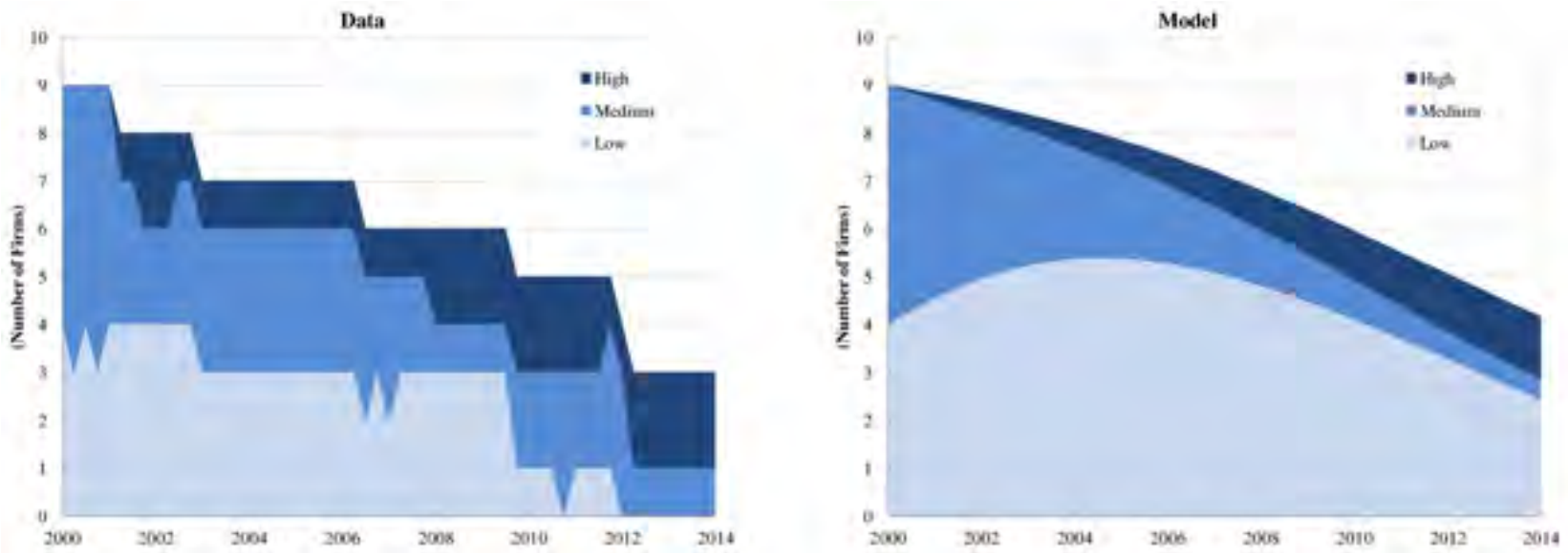


Figure 11: Fit of the Estimated Model (Mean of 10,000 simulations)

Estimation (5 of 6): Sanity Check

- Acquisition prices

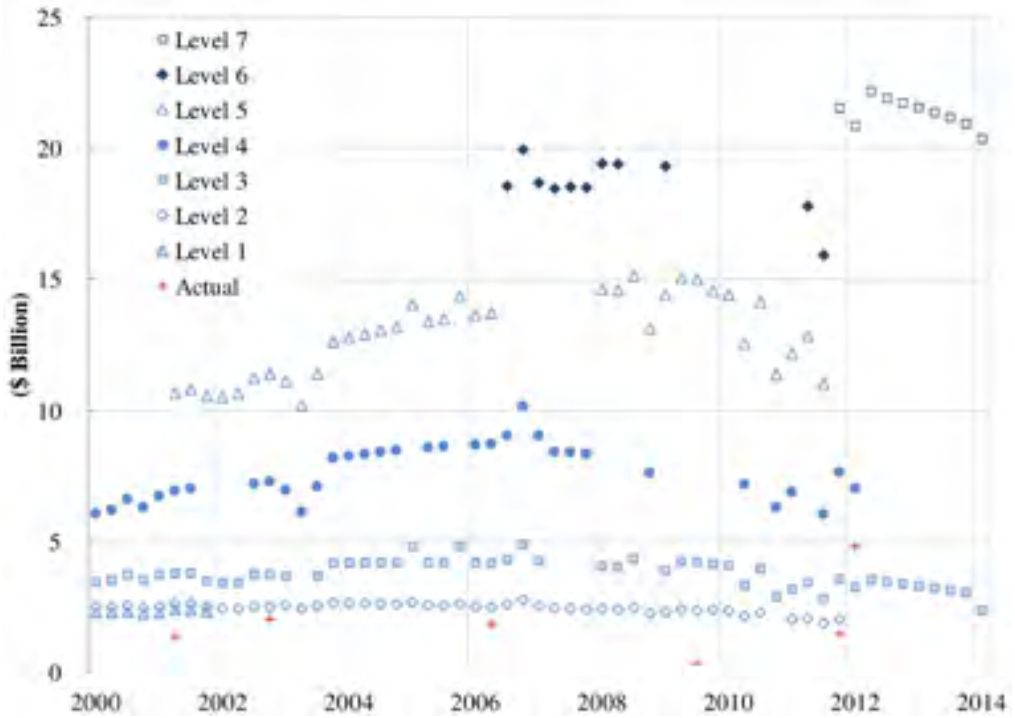


Figure 12: Firm Values in Estimated Model & Data

- Implied prices (target firms' reservation values) match actual transaction values

Estimation (6 of 6): Incentives to Innovate

- More competition, more (less) innovation?

Figure 13: Equilibrium R&D Strategies

- "Inverted U", *dynamic structural version*
  - Plateaus at $n \in \{3, 4, 5\}$
  - Nonstationarity (1): Demand growth ($M_t \uparrow$ in t)
  - Nonstationarity (2): Industry consolidation ($n_t \downarrow$ in t)

Counterfactual (1 of 5): Tougher Merger Policy

- How far should the industry consolidate?
  - Baseline/reality: Authorities block mergers whenever $n_t \leqslant 3$
  - Counterfactual: Authorities block mergers whenever $n_t \leqslant 5$
- More sophisticated version (under construction)
  - Baseline/reality: Authorities block mergers whenever $HHI_{t+1} > 4000$
  - Counterfactual: Authorities block mergers whenever $HHI_{t+1} > 2500$

Counterfactual (2 of 5): Welfare

- Non-monotonic impacts (relative to baseline)

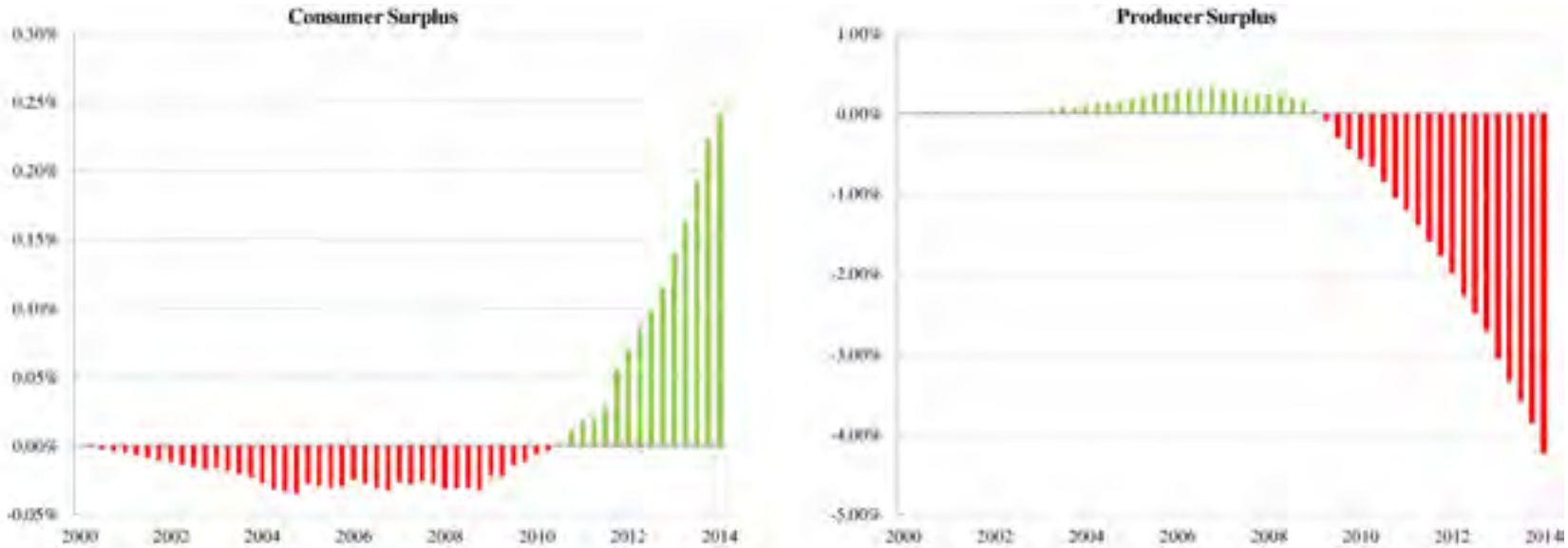


Figure 14: Counterfactual Welfare Outcomes

- CS: underperform $\rightarrow$ outperform (turning point in 2010)
- PS: outperform $\rightarrow$ underperform (turning point in 2009)
- SW: slight underperformance throughout ($\square 0.02\% \sim \square 0.10\%$)

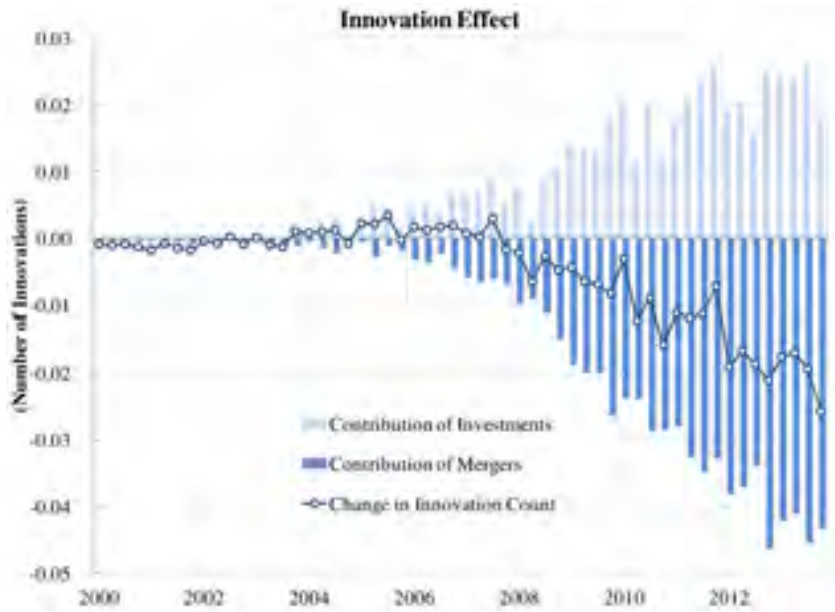
Counterfactual (3 of 5): Decomposition 1

- Decompose Δp (ΔCS) into Δm & Δmc (i.e., market power & productivity)
  - Further decompose Δm (or Δn) into exits & mergers

  - Ex-ante policy impacts
    - Exit-promotion: Less competition early on
    - Value destruction: Less merger *opportunities* in future $\Rightarrow$ lower Λ
  - Ex-post policy impacts
    - Pro-competitive effect of actually blocking mergers

Counterfactual (4 of 5): Decomposition 2

- Decompose Δp (ΔCS) into Δm & Δmc (i.e., market power & productivity)
  - Further decompose Δmc (or count of $\omega_{it} \uparrow$) into investments & mergers



  - Ex-ante policy impacts (cont.)
    - Investment-discouragement: Slightly less R&D at the beginning
    - Value destruction: Less merger *opportunities* in future $\Rightarrow$ lower Λ
  - Ex-post policy impacts (cont.)
    - In-house R&D substitutes for forgone synergies (but only imperfectly)
    - *Incentives to innovate* do not change much between $n \in \{3, 4, 5\}$

Counterfactual (5 of 5): Optimal Merger Policy

- 3 is about right

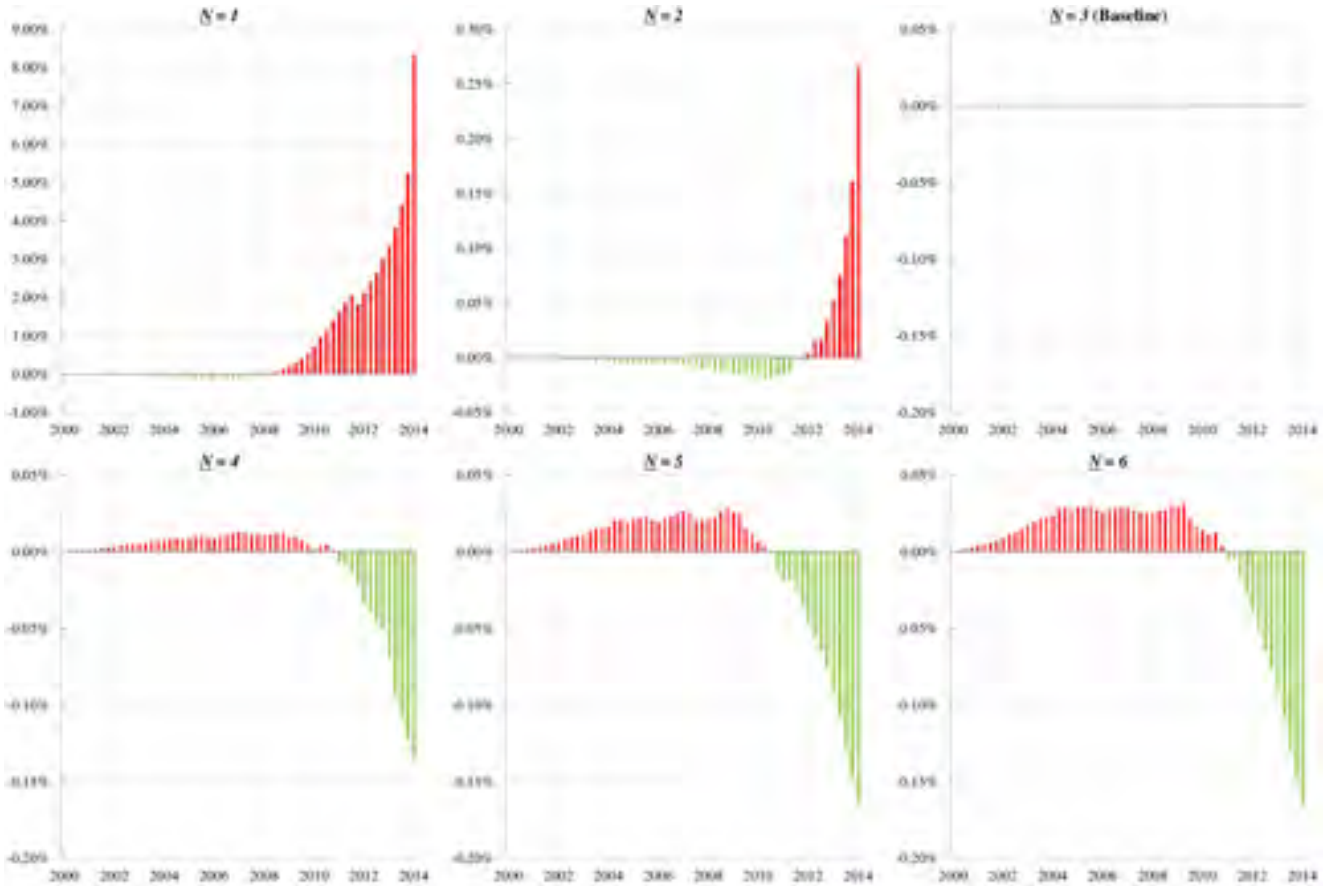


Figure 15: Counterfactual HDD Prices Relative to Baseline Regime

- 2 are few; 6 are many

Conclusion

- Mergers have become a dominant mode of exit (consolidation)
- Mergers often generated productivity improvement (synergies)
- Policy faces dynamic tradeoff ($\because$ value-destruction side effects)
  1. Ex-ante impact ($\square$) vs. ex-post impact ($+$)
  2. Higher exit rate partially offsets (ex-post) pro-competitive effect
  3. In-house R&D does not fully make up for forgone synergies
- Optimal threshold is 4 firms (± 1) for HDDs
- Framework applicable to other high-tech (e.g., computers & semiconductors)