Market Structure and Innovation: A Dynamic Analysis of the Global Automobile Industry

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The Question

What is the relationship between market structure and innovation?

- Extensively studied in the literature since Schumpeter (1942)

  "— the large-scale establishment or unit of control ... has come to be the most powerful engine of ... progress and in particular of the long-run expansion of output...

  ... perfect competition is not only impossible but also inferior, and has no title to being set up as a model of ideal efficiency." [p.106]

- "The second most tested set of hypotheses in IO..." [Aghion and Tirole (QJE, 1994)]

Existing Studies

- Older studies are mostly reduced form:
  Regress a measure of innovation (e.g. R&D expenditures, patent count,...) on a measure of market power (e.g. mark-up, Herfindhal,...)
  [surveyed by Kamien-Schwartz (1975, 1982), Cohen-Levin (1989), Ahn (2002), Aghion-Griffith (2005) and Gilbert (2006)]
- A few recent applications estimate a dynamic game:
  Xu (2008): electric motors in Korea
  Goettler & Gordon (2008): Intel v. AMD
  Siebert & Zulehner (2008): DRAM

In this Study

- We study the global automobile industry
  $\Rightarrow$ one of the most innovative
- Dramatic changes in market structure
  $\Rightarrow$ allow for mergers

Objectives of the Study

1. To construct a dynamic model of the global automobile industry and estimate primitives
   - Including mergers
   - Estimation is based on Bajari, Benkard, & Levin (2007) $\Rightarrow$ dynamic game with continuous control variable

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2. Characterize the different incentives for innovation:
   - Boost own demand
   - Affect innovation decision of competitors
   - Increase ownership share in (possible) future mergers
3. Study how changes in market structure (organic or discrete) affect innovation incentives, firm value and consumer utility
   - (Perform counterfactual experiments)

Demand Side Ingredients

- Each firm possesses some technological knowledge $\omega \in \mathbb{R}^+$ (observable state variable)
- Each product has some unobserved characteristics summarized in $\xi \in \mathbb{R}$ (unobservable state variable)
- Industry state is $\mathbf{s} = \{\mathbf{s}_\omega, \mathbf{s}_\xi, m\}$
  Where $\mathbf{s}_\omega = [\omega_1\ \omega_2\ \ldots\ \omega_n]$ and $\mathbf{s}_\xi = [\xi_1\ \xi_2\ \ldots\ \xi_n]$

Expected Demand

- The utility consumer i gets from good j is

$$u_{ij} \quad = \quad \theta_\omega \log(\omega_j + 1) + \theta_p \log(p_j) + \xi_j + \nu_{ij} \;\equiv\; \tilde{u}_j + \nu_{ij}$$

- ν_{ij} is the idiosyncratic utility assumed to follow an i.i.d. extreme value distribution

Data

Firm-year observations:

- Patent data from 1975 to 2005
  - ω_{1981} = sum of patents issued between 1975 and 1981
  - $\omega_{1982} = (1-\delta)\omega_{1981}$ + new patents issued in 1982
- Price and market share information from 1982 to 2005
  - Price: firm dummies from hedonic price regressions
  - Share: in terms of vehicles produced

Step 1: Estimation of Demand Parameters

Dependent variable: log sales relative to GM

	OLS	IV	IV
θ_ω	0.421***	0.420***	0.562***
	(0.014)	(0.017)	(0.081)
θ_p	−2.313***	−2.185***	−7.300***
	(0.188)	(0.626)	(2.860)
Time Fixed-Effects	No	No	Yes

Supply Side Timing

In each period the sequence of events is the following.

1. Firms observe individual and industry states.
2. Pricing and investment decisions are made.
3. Profits and investment outcomes are realized.
4. Individual and industry states are updated.
5. Mergers take place (if any).
6. State variables of merged firms are updated.

Profit Function

- Period profit function

$$\pi_j(\omega_j, \xi_j, \mathbf{s}^{-j}) = \max_{p_j} \left\{ [p_j - \mathrm{MC}_j(\omega_j, \xi_j)] m\sigma_j(\cdot) - \mathrm{FC}_j \right\}.$$

- f.o.c.

$$p_j + \theta_p (p_j - \mathrm{MC}_j(\omega_j, \xi_j))(1 - \sigma_j(\cdot)) = 0.$$

Step 1: Estimation of (Production) Cost Parameters

Dep. variable: log of marginal cost (recovered from f.o.c. system)

	γ_0	γ_1	γ_{11}	γ_2	γ_{22}
(1) constant	1.070***				
	(0.008)				
(2) linear-log	0.607***	0.017***		0.346***	
	(0.044)	(0.003)		(0.029)	
(3) quadratic	1.034***	0.256***	−0.165***	0.107***	0.007
	(0.011)	(0.035)	(0.021)	(0.007)	(0.005)

$$(2) \quad \mathrm{MC}_j = \gamma_0 + \gamma_1 \log(\omega_j/\omega_{GM}) + \gamma_2 \log(\xi_j/\xi_{GM}) + \varepsilon$$
$$(3) \quad \mathrm{MC}_j = \gamma_0 + \gamma_1 \tilde{\omega}_j + \gamma_{11} \tilde{\omega}_j^2 + \gamma_2 \tilde{\xi}_j + \gamma_{22} \tilde{\xi}_j^2 + \varepsilon$$

The Dynamic Problem

- The Bellman equation is

$$V_j(\omega_j, \xi_j, \mathbf{s}^{-j}) = \max_{x_j \in \mathbb{R}^+} \{\pi_j(\omega_j, \xi_j, \mathbf{s}^{-j}) - cx_j + \beta E V_j(\omega_j', \xi_j', \mathbf{s}'^{-j})\},$$

where x is the control variable (level of R&D or number of patents a firm applies for).

Laws of Motion

Laws of motion for the state variables

- $$\omega_j' = (1-\delta)\omega_j + x_j + \epsilon_{\omega j},$$

  ϵ_ω captures the randomness in the innovation process.

- $$\xi_j' = \xi_0 + \rho(\xi_j - \xi_0) + \epsilon_\xi,$$

  AR(1) process with fixed effects

Step 1: State Transition Function

- $\omega' = (1-\delta)\omega + x(1+\epsilon_\omega), \quad$ where $\epsilon_\omega \sim N(0, \sigma_{\epsilon_\omega})$.
- We set $\delta = 0.15$ and $\sigma_{\epsilon_\omega} = 0.1$

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- $\xi_j' = \xi_0 + \rho(\xi_j - \xi_0) + \epsilon_\xi$
- We set ξ_0 at the average of ξ_j over the 1982–2005 period
- and we estimate $\rho = 0.597$ (0.036) and $\epsilon_\xi = 0.193$

Allowing for Mergers

In an industry with two firms, A and B, with an exogenous probability of merging p_m, the value function for firm A will be:

$$\begin{aligned} V_A(\omega_A, \xi_A, \omega_B, \xi_B) &= \max_{x_A \in \mathbb{R}^+} \Big\{ \pi_A(\cdot) - cx_A \\ &+ \beta \Big[p_m \zeta_A(\cdot) EV_{AB}(\omega'_A + \omega'_B, (\xi'_A + \xi'_B)/2) \\ &+ (1 - p_m) EV_A(\omega'_A, \xi'_A, \omega'_B, \xi'_B) \Big] \Big\}, \end{aligned}$$

where

$$\zeta_A(\cdot) = \frac{E\tilde{V}_A(\omega'_A, \xi'_A, \omega'_B, \xi'_B)}{E\tilde{V}_A(\omega'_A, \xi'_A, \omega'_B, \xi'_B) + E\tilde{V}_B(\omega'_B, \xi'_B, \omega'_A, \xi'_A)}.$$

is the share of firm A in the total value of the merged firm.

Markov Perfect Equilibrium

Estimation Methodology

- Two-step procedure due to Bajari, Benkard and Levin (2007)
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  - (iii) Forward simulate the value functions.

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- Step 2: Use equilibrium conditions to recover dynamic parameters of the model

Step 1: Estimation of Policy Function

$$x_j = \sum_{k=0}^{3} \sum_{l=0}^{3-k} \sum_{m=0}^{3-k-m} \alpha_{klm} (\omega_j)^k (\sum \omega_{-j})^l (\xi_j)^m + e_j,$$

where e_j is approximation error from true policy function
$R^2 = 0.898$

Step 1: Putting it all together

- Estimated demand and supply parameters allow us to calculate $\pi_j(\omega_j, \xi_j, \mathbf{s}^{-j})$ for any $(\omega_j, \xi_j, \mathbf{s}^{-j})$ (need to solve $n \times n$ system of nonlinear equations)

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- Estimated policy and transition functions similarly give us $x_j(\omega_j, \xi_j, \mathbf{s}^{-j})$ and $(\omega_j', \xi_j', \mathbf{s}'^{-j})$ for any $(\omega_j, \xi_j, \mathbf{s}^{-j})$

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- Use all these to forward simulate the value function from $(\omega_{j0}, \xi_{j0}, s_0^{-j})$:

$$\begin{aligned} V(\omega_{j0}, \xi_{j0}, s_0^{-j}) &= [\pi(\omega_{j0}, \xi_{j0}, s_0^{-j}) - cx(\omega_{j0}, \xi_{j0}, s_0^{-j})] + \\ &\quad \beta[\pi(\omega_{j1}, \xi_{j1}, s_1^{-j}) - cx(\omega_{j1}, \xi_{j1}, s_1^{-j})] + \\ &\quad \beta^2[\pi(\omega_{j2}, \xi_{j2}, s_2^{-j}) - cx(\omega_{j2}, \xi_{j2}, s_2^{-j})] + \ldots . \end{aligned}$$

- $\beta = 0.92$; use 150 periods

Estimation: Step 2

- If the observed policy profile x is a MPE, it must be true that for all firms, all states, and all alternative policy profiles x':

$$V(j, s, x|c) \geq V(j, s, x'|c).$$

- Simulate alternative value functions using x' policies:
  $\mathbf{x}'(\mathbf{s}) = (\iota + a e_j)' \mathbf{x}(\mathbf{s})$
  (one firm invests $(1 + a)x$, while competitors follow x policy);
  we used $a \in \{-0.10, -0.08, \ldots, -0.02, 0.02, \ldots, 0.08, 0.10\}$

Estimation: Step 2

- Define

$$d(j, s, x'|c) = V(j, s, x|c) - V(j, s, x'|c) \tag{1}$$

- The minimum distance estimator of c is

$$\min_{c} \sum_{j,s,x'} (\min\{d(j, s, x'|c), 0\})^2 \tag{2}$$

- $\hat{c}$ = \$41.1m if MC is constant (benchmark)
- R&D-(granted) Patent ratio in the data:
  mean = \$15.6m; median = \$14.9m

c estimates: model sensitivity

How high a c discourages R&D enough to fit the patent data?

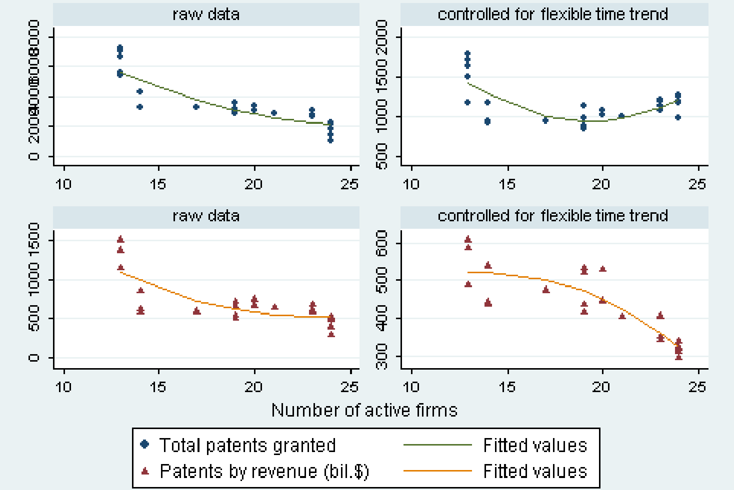
Varying demand		Varying policy	
IV	41.1	non-parametric	41.1
OLS	39.3	restricted (8 terms)	24.5
IV with FE	25.5	non-parametric in logs	40.3

Varying MC		Varying ξ_{A+B}	
constant	41.1	average A & B	41.1
quadratic	31.5	maximum A or B	46.6
log-linear	40.6	ω-weighted average	42.4

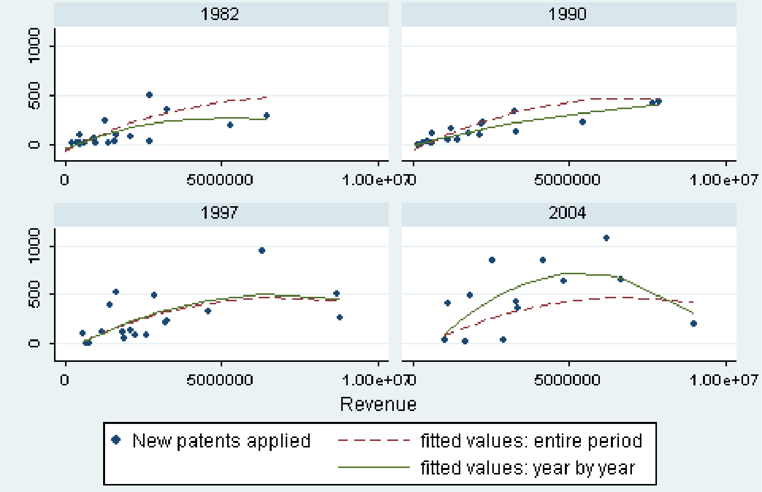
c estimates: parameter sensitivity

Discount factor		Depreciation rate		EU-US patent ratio	
0.92	41.1	0.15	41.1	2.2	41.1
0.90	40.1	0.05	10.6	1.0	48.1
0.94	43.5	0.25	56.3	3.0	40.0

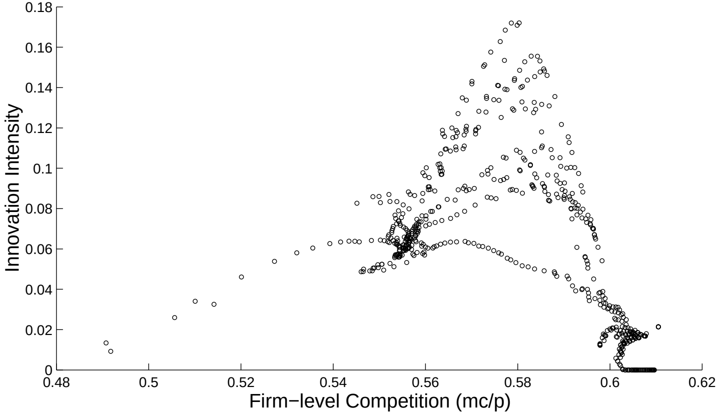
Competition and Innovation: Industry-Level (across time)



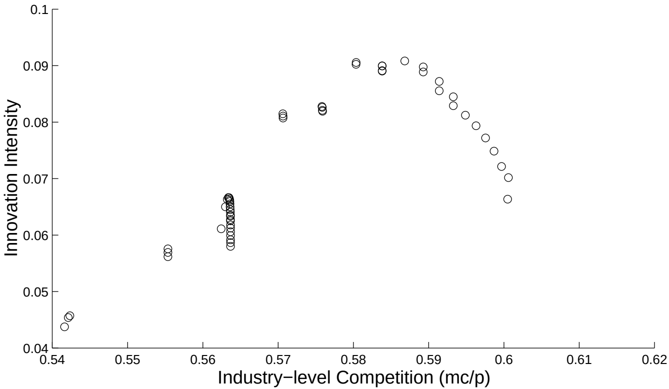
Competition and Innovation: Firm-Level (across firms)



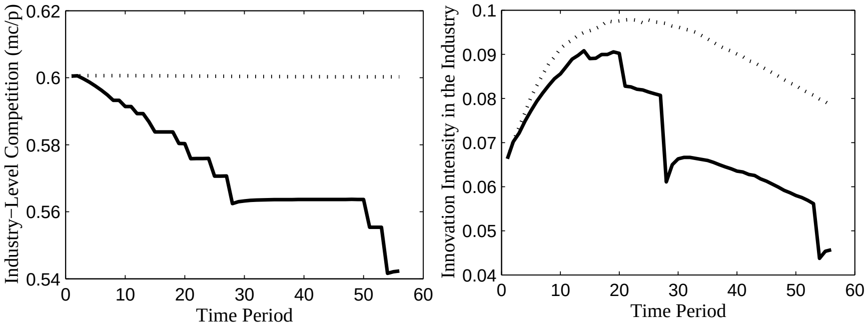
Competition and Innovation: Firm-Level ($t_0 = 1982$)



Competition and Innovation: Industry-Level ($t_0 = 1982$)

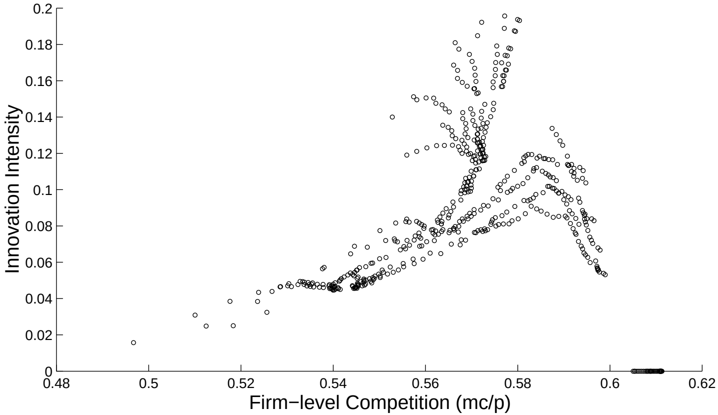


Understanding the Inverted-U

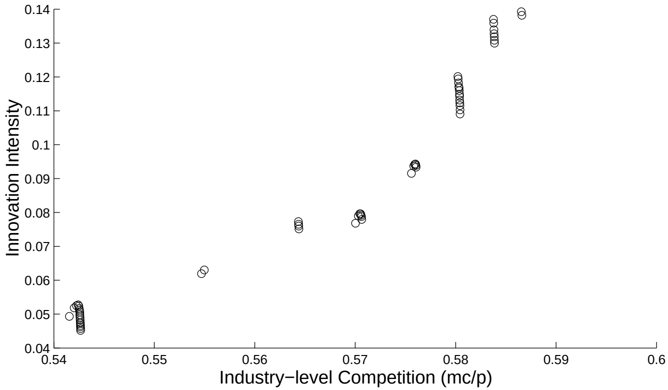


(dotted lines represent the evolution without mergers)

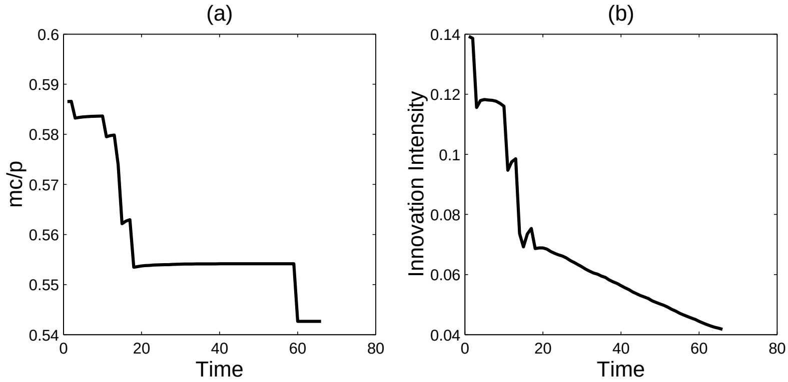
Competition and Innovation: Firm-Level ($t_0 = 2004$)



Competition and Innovation: Industry-Level ($t_0 = 2004$)



Understanding the Positive Relationship



Competition and Innovation: Counterfactual exercises

In the works now

- need to solve equilibrium for this
- without ξ state, but with mergers, feasible for $N = 4$

Conclusions

- We estimate a dynamic model of the global automobile industry to study how changes in market structure affect innovative activity, firm value and consumer utility
- Simulation results suggest that there is an inverted-U relationship between market concentration and innovative activity, at least if the initial industry state is not too concentrated.