Week 2: Empirical Models of Competition with Differentiated Products

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Competition with Differentiated Products
Why We Care

- Many important markets are composed of differentiated products

- This means that sellers have some residual market power, potentially even when there are many firms

- The nature of differentiation matters for consumer demand and firm strategy

- Important for:
    - Competition analysis
    - New product introduction
    - Merger Analysis
    - Much more

- Examples

Bresnahan (1987)

Competition with Differentiated Products

- Develop model to test competition in the automobile sector between 1954-1956

- One of first papers to empirically model differentiated products in a structural setup:
    - Borenstein and Shephard (1996) good example of paper with non-differentiated products. Slides / paper online.
    - Substantial structure on differentiation collapsing attributes into one 'quality' dimension
    - Static competition, no endogenous attributes
    - Very specific, structured firm competition environment

- Empirical Context:
    - 1955 automobile market anomaly relative to other years
    - 45% greater sales than in 2 surrounding years
    - Lower quality adjusted prices
    - Consistent with a supply-side shock

Overview of Contribution

- Rigorous empirical explanation for otherwise puzzling market evolution

- Explicit test of Bertrand-Nash and Collusive behavior:
    - Test relies on fact that prices for products 'near' each other respond differently under collusion vs. Bertrand
    - Leverages multi-product within firm pricing as source of identification
    - Conduct hypothesis have direct implications for price and quantity comparitive statics with respect to demand elasticities (without knowing MC!)

- Patterns suggest collusion (tacit) in 1954 and 1956, and Bertrand-Nash in 1955

- No discussion of repeated game literature, though it applies to tacit collusion explicitly

Facts about Automobile Markets

Bresnahan (1987)

TABLE I

Year	(1) Auto Production[a]	(2) Real Auto Price-CPI[b]	(3) % Change Auto Price-Cagan[c]	(4) Auto Sales[d]	(5) Auto Quantity Index[e]
1953	6.13	1.01	NA	14.5	86.8
1954	5.51	0.99	NA	13.9	84.9
1955	7.94	0.95	−2.5	18.4	117.2
1956	5.80	0.97	6.3	15.7	97.9
1957	6.12	0.98	6.1	16.2	100.0

Notes: [a] Millions of units over the model year. [Source: *Automotive News.*]
  [b] (CPI New automobile component)/CPI. [Source: *Handbook of Labor Statistics.*]
  [c] Adjusted for quality change. [See Cagan (1971), especially pp. 232–3.]
  [d] Auto output in constant dollars, QIV of previous year through $QIII$ of named year, in billions of 1957 dollars. [Source: *National Income and Product Accounts.*]
  [e] (4)/(2), normalized so 1957 = 100.

Facts about Automobile Markets

Bresnahan (1987)

TABLE II

Year	(6) Per Capita Disposable Personal Income[f]	(7) Interest Rate[g]	(8) Durables Expenditures (Non-Auto)[h]	(9) Automakers Profits[i]
1953	1623	1.9	14.5	2.58
1954	1609	0.9	14.5	2.25
1955	1659	1.7	16.1	3.91
1956	1717	2.6	17.1	2.21
1957	1732	3.2	17.0	2.38

Notes: [f] Billions of 1957 dollars, *QIV* of previous year through *QIII* of named year. [Source: *National Income and Product Accounts.*]

[g] Three-month *T*-bill rate. [Source: *Statistical Abstract.*]

[h] Durables component of consumer expenditures minus component for automobiles and parts, billions of 1957 dollars. [Source: *National Income and Product Accounts.*]

Demand
Bresnahan (1987)

- Continuum of potential buyers with unit demand with differences in taste for quality x denoted by v_i

- Strong assumptions about demand to make model tractable

$$\begin{aligned}
U(x, Y, v) &= vx + Y - P \quad \text{if buy} \\
U(x, Y, v) &= v\gamma + Y - E \quad \text{if no buy}
\end{aligned}$$

- Y-P is money not spent on autos

- **Assumption:** v is uniformly distributed with density δ on $[0, V_{max}]$

- What do you think?

Demand
Bresnahan (1987)

- Consumer will select product that maximizes $vx_j - P_j$

- Aggregate into market demand by investigating indifferent consumers between two products h and i:

$$P_i - x_i v_{hi} = P_h - x_h v_{hi} \Rightarrow$$
$$v_{hi} = \frac{P_i - P_h}{x_i - x_h}$$

- If product j on other side of i then aggregate demand for i is:
$$q_i = \delta[\frac{P_j - P_i}{x_j - x_i} - \frac{P_i - P_h}{x_i - x_h}]$$

- Closer x imply cross-price derivative closer to own-derivative
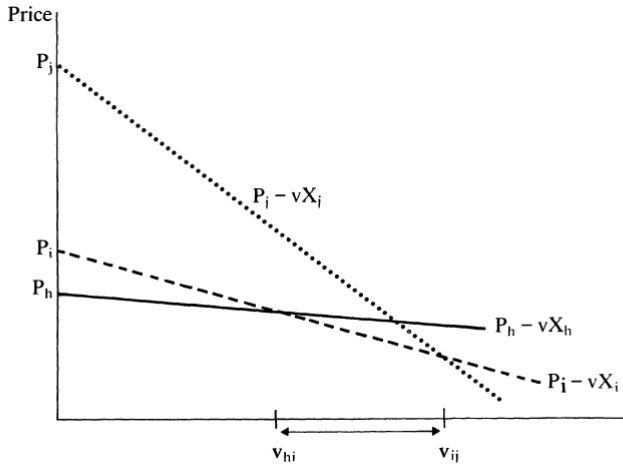
Demand
Bresnahan (1987)

Figure 1

Final Demand Equations
Bresnahan (1987)

- Final demand equations from model:

$$q_1 = \delta\left[\frac{P_2 - P_1}{x_2 - x_1} - \frac{P_1 - E}{x_1 - \gamma}\right]$$

$$q_i = \delta\left[\frac{P_j - P_i}{x_j - x_i} - \frac{P_i - P_h}{x_i - x_h}\right]$$

$$q_n = \delta\left[v_{max} - \frac{P_n - P_{n-1}}{x_n - x_{n-1}}\right]$$

- E, γ, v_{max}, and δ are parameters to estimate

- Firms are assumed to have cost function:

$$C(x, q) = A(x) + mc(x)q$$

- Assume that marginal cost is increasing and convex, μ parameter to estimate:

$$mc(t) = \mu e^t$$

- Profit function is:

$$\pi_i = P_i q_i - mc(x_i)q_i - A(x_i)$$

Supply: Firm Interactions

Bresnahan (1987)

- Bresnahan investigates two potential assumptions on firm interactions:
  - Collusion: All firms set prices to maximize sum of all profits
  - Nash-Bertrand: Each firm sets prices to maximize own profits

- Since quantities linear in prices, solution to profit maximization is linear in prices

- Only neighboring products have interactions with one another in supply and demand!!
  - Are these desirable substitution patterns?
  - What do you think about model of collusion?

Supply: Firm Interactions
Bresnahan (1987)

- Nash-Bertrand FOC:

$$\pi_i' = q_i + (P_i - mc(x_i))\frac{\partial q_i}{\partial P_i} = 0$$

- Multi-product or collusive FOC for i and $i+1$:

$$\pi_i' = q_i + (P_i - mc(x_i))\frac{\partial q_i}{\partial P_i} + (P_{i+1} - mc(x_{i+1}))\frac{\partial q_{i+1}}{\partial P_i} = 0$$

- If products closely spaced, impact of multi-product behavior is high
  - Examples in reality?

- Simultaneous FOC solution for all products in equilibrium

Supply: Firm Interactions

Bresnahan (1987)

- Let matrix H_{ij} represent cooperation with $H_{ij} = 1$ if products are cooperating and 0 otherwise. Example:

$$\begin{pmatrix} 1 & 1 & 0 \\ 1 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$
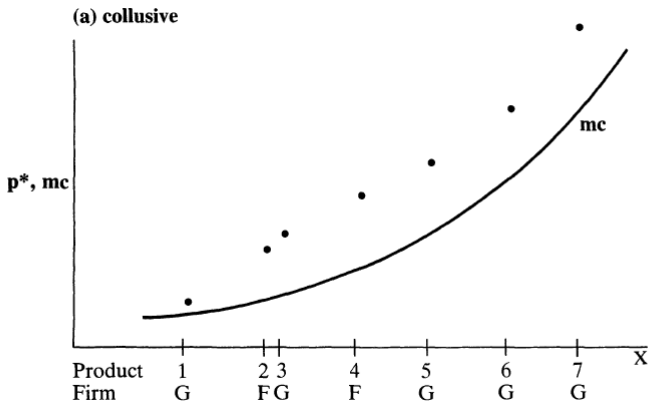
- Given this, the model supply FOC for product i is:

$$\begin{aligned} 0 \quad &= q_i + (P_i - mc(x_i))\frac{\partial q_i}{\partial P_i} + H_{i,i+1}(P_{i+1} - mc(x_{i+1}))\frac{\partial q_{i+1}}{\partial P_i} \\ &+ H_{i,i-1}(P_{i-1} - mc(x_{i-1}))\frac{\partial q_{i-1}}{\partial P_i} = 0 \end{aligned}$$

- Changing $H_{i,i+1}$ from 0 to 1 increases margins

Supply Model Implications

Bresnahan (1987)

• No full lines, model good for 50s.

Supply Model Implications
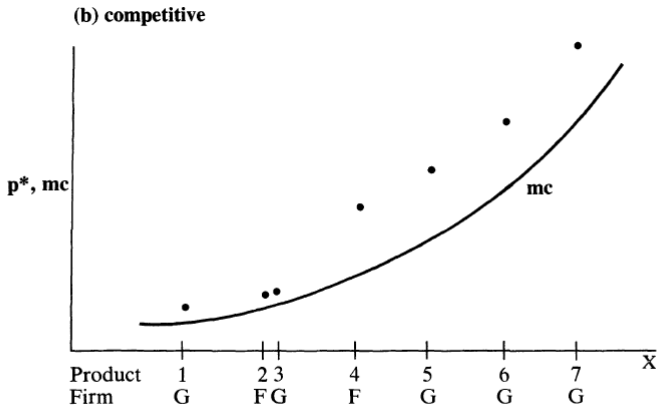## Bresnahan (1987)

Figure 2(b)

Equilibrium
Bresnahan (1987)

- Equilibrium solves the demand equations and supply equations simultaneously:

$$p = p^*(x, H, \gamma, V_{max}, \delta, \mu)$$
$$q = q^*(x, H, \gamma, V_{max}, \delta, \mu)$$

- In equilibrium cars spaced further apart in the product space are impacted less by change in firm behavior regimes.

- Prices are mapped to quality in equilibrium model: substitution patterns!

- Argue that options are discrete enough with differences in product space, which is good for model
  - Large cars further apart, made mostly by GM
  - Small cars a lot of different firms, close together

Econometric Model
Bresnahan (1987)

- **Assumption:** Proxies for quality from hedonic models like Rosen (1974) depend on both tastes and technology:

$$x(c) = \sqrt{\beta_0 + \Sigma_j z_j \beta_j}$$

- Functional form is arbitrary

- Steps to compute predicted prices and quantities conditional on $\beta, \gamma, \mu, \delta, V_{max}$ and Z:
    - Product assigned quality depending on β and z
    - Products ordered highest to lowest
    - Everything used to solve for P^* and Q^* and plugged plugged into likelihood function

Econometric Model
Bresnahan (1987)

- Data: quantity aggregation problem
    - Definition of different products central to study
    - Autombile is model only if distinct in *attributes* implying 80-85 models per year
    - Level of disaggregation of model finer than some data: aggregate predicted values
    - Have to deal with heeroskedasticity

- Likelihood function with assumed independent normal errors on price and quantity:

$$\prod_{i=1}^{N_p} \frac{1}{\sqrt{2\pi^2 p}} \exp\left[-\frac{(P_i - P_i^*)^2}{2\sigma^2 p} \right]$$

$$* \prod_{j=1}^{N_q} \frac{1}{\sqrt{2\pi k_j \sigma^2 q}} \exp\left[-\frac{(q_j - \sum q^* k, k I_j)^2}{2 k_j \sigma^2 q} \right]$$

Econometric Model
Bresnahan (1987)

- Alternative models to test hypotheses

- Hedonic price model follows Rosen (1974) but firm dummies for oligopoly:
    - Prices and quantities set in a recursive structure
    - Should hold if prices set in some non-maximizing way
    - Really different supply side might matter

$$P_i^* = exp[\alpha_0 + \Sigma_j \alpha_j z_{ij}$$
$$q_j^* = exp[\lambda_0 + \lambda_1(P_j - P_j^*)]$$

- Also look at identity matrix product model

Empirical Results
Bresnahan (1987)

- Cox Hypothesis Tests of different supply models:
    - Confronted with data, and alternative non-nested hypothesis
    - Likelihood ratio of two hypothesis is central test statistic
    - Computed assuming hypothesis true, test statistic asymptotically normal
    - Possible for two models to be rejected against each other

- Intuition for hypothesis test: If the residuals under null H_0 can be explained by statistically significant extent by H_1, then H_0 is rejected

- Collage of evidence

Empirical Results

Bresnahan (1987)

TABLE III
COX TEST STATISTICS

Hypotheses	C	N–C	'p'	H
a—1954				
Collusion	—	0.8951	0.9464	−1.934
Nash-Competition	−2.325	—	−0.8878	−2.819
"Products"	−3.978	3.029	—	−1.604
Hedonic	−12.37	−10.94	−13.02	—
b—1955				
Collusion	—	−10.36	−9.884	−13.36
Nash-Competition	−1.594	—	1.260	0.6341
"Products"	−0.7598	−4.379	—	−1.527
Hedonic	−3.353	−8.221	−5.950	—
c—1956				
Collusion	—	1.227	0.8263	1.629
Nash-Competition	−2.426	—	−4.586	0.8314
"Products"	−3.153	0.9951	—	4.731
Hedonic	−5.437	−9.671	−11.58	—

- **1954 and 1956:** Product and hedonic rejected, Nash rejected against coll. and hedonic, collusive not rej.
- **1955:** Collusion rejected always, Nash never rejected
- Coincidence with product expansion is interesting

Empirical Results: Overview

Bresnahan (1987)

- When non-rejected hypotheses are examined over time, the rest of the parameters are quite consistent!

- When you look at one hypotheis over time (e.g. collusion) parameters are not consistent in manner you expect. Other parameters have to fit conduct changes.

- β are generally consistent with what we would expect for different attributes in terms of sign

- Discussion of how competition model and significant expansion in quantity in 1955 are independent events. Not sure I completely understand this.

Empirical Results: Overview
Bresnahan (1987)

- Two central parameters V_{max} and δ show diverse tastes for automobile quality
    - 20 million wide and 0.4 deep which is pretty diffuse. Estimating a rectangle.
    - Used cars are not that close substitutes for lowest quality new car

- Counterfactual shows 25% quantity gain in 1955 under collusion, rather than 40% actual in data. This is shift in demand vs. shift in competitive model.

- Robustness: quality shocks and durability

Empirical Results
Bresnahan (1987)

TABLE IV
PARAMETER ESTIMATES 1954–56, <u>MAINTAINED</u> SPECIFICATION

Parameters	1954[a]	1955[b]	1956[a]
Physical Characteristics			
Quality Proxies			
Constant	47.91	48.28	50.87
	(32.8)	(43.2)	(29.4)
Weight #/1000	0.3805	0.5946	0.5694
	(0.332)	(0.145)	(0.374)
Length ″/1000	0.1819	0.1461	0.1507
	(0.128)	(0.059)	(0.146)
Horsepower/100	2.665	3.350	3.248
	(0.692)	(0.535)	(0.620)
Cylinders	−0.7387	−0.9375	−0.9639
	(0.205)	(0.115)	(0.186)
Hardtop Dummy	0.9445	0.4531	0.4311
	(0.379)	(0.312)	(0.401)
Demand/Supply			
μ — Marginal Cost	0.1753	0.1747	0.1880
	(0.024)	(0.020)	(0.035)
γ — Lower Endpoint	4.593	3.911	4.441
	(1.49)	(2.08)	(1.46)
V_{max} — Upper Endpoint	$1.92E+7$	$2.41E+7$	$2.83E+7$
	$(8.44E+6)$	$(9.21E+6)$	$(7.98E+6)$
δ — Taste Density	0.4108	0.4024	0.4075
	(0.138)	(0.184)	(0.159)

Empirical Results
Bresnahan (1987)

TABLE V(i)
PARAMETER ESTIMATES 1954–56, <u>COLLUSIVE</u> SPECIFICATION

Parameters	1954	1955	1956
Constant	47.91	−23.37	50.87
	(32.8)	(24.5)	(29.4)
Weight	0.3805	0.0103	0.5694
	(0.332)	$(5.43E-2)$	(0.374)
Length	0.1819	$-2.88E-3$	0.1507
	(0.128)	(0.102)	(0.146)
Horsepower	2.665	0.1165	3.248
	(0.692)	(0.106)	(0.620)
Cylinders	−0.7387	−1.309	−0.9639
	(0.205)	(1.52)	(0.186)
Hardtop	0.9445	1.468	0.4311
	(0.379)	(1.08)	(0.401)
μ	0.1753	1.344	0.1880
	(0.024)	(0.151)	(0.035)
γ	4.593	1.604	4.441
	(1.49)	(4.83)	(1.46)
$V_{\max}$	$1.92E+7$	$1.46E+8$	$2.83E+7$
	$(8.44E+6)$	$(6.74E+6)$	$(7.98E+6)$
δ	0.4108	$5.75E-2$	0.4075
	(0.138)	$(8.28E-2)$	(0.159)

Note: Figures in parentheses are asymptotic standard errors.

Final Thoughts and Discussion

Bresnahan (1987)

- Structural model and trade-offs between assumptions and credibility:
    - Data discussion not really big part of paper. Why? Probably because it's not very good.
    - Product differentiation is very stylized
    - Assumed supply side

- Maybe trust the collusive vs. competitive test, but would we be comfortable doing much more with this model?
    - Wouldn't want to do welfare
    - Wouldn't want to do new products

- No discussion of endogeneity as all product quality is subsumed in x. Correlation between errors and prices likely, not discussed here.

- Great example of clear structural work with product differentiation and supply side without BLP additions