Industry Costs and Research Aggregation in Dynamic Competition

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Background

Many industries have trade associations which aggregate industry relevant information

Association of Equipment Manufacturers

"[The] North America Construction Equipment Industry Trends Report...is a quarterly state of the industry report for the construction industry that asks participants about their unit volume of demand, company employment, unit volume of inventories, capital spending, profit margins, wages and salaries, prices of input materials, prices charged, shortages, export performance and planning scenarios. To share in the results of this important survey, your company must participate by providing data on your company's performance..." [1]

[1] www.aem.org/market-data/market-intelligence-domestic/surveys/

Background

Information sharing between competitors can promote collusive behavior

- Information exchange agreements of competitively relevant variables are analyzed under the rule of reason

Antitrust Guidelines for Collaborations Among Competitors (FTC and US DOJ - April 2000)

"The central question is whether the relevant agreement likely harms competition by increasing the ability or incentive profitably to raise price above or reduce output, quality, service, or innovation below what likely would prevail in the absence of the relevant agreement."

Motivation

Sharing individualized or current/future prices is restricted by anti-trust law

- Precedent for controlling/eliminating factors that facilitate collusion
- Airline Tariff Publishing Case, GE Westinghouse price books, etc.

Sharing other industry information is generally unrestricted

- We study the impact of the exchange of information about firm costs

Questions

How is information on costs of production disseminated without an information exchange agreement?

- Price competition with private information on costs
- Framework is dynamic but finite (two-period)
- Allows for multiple dimensions of private cost information

How does sharing industry-wide relevant cost information affect market welfare?

- Compare ex-ante pricing outcomes with and without information exchange
- Examine how incentives to collect information changes

Industry-wide costs

Main departure: firms possess information about different cost parameters

- Industry-wide (common) costs: labor, common inputs
- Firm-specific (private) costs: capital expenditures, support

Literature has examined cases where firms have a single parameter of uncertainty.

- For information sharing in a static environment, this is without loss: analysis can be done on each parameter separately
- Separability is restrictive when considering how information is released through competition.

Example - private valued costs

Firm i's cost structure: θ_i private cost parameter with $\theta_i \in \{low, high\}$

- Firm receives signal about probability that cost is high, e.g. $s_{i,\theta} = \Pr(\theta_i = high)$
- Chooses price, $p_{i,1}$ given signal on cost

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Firm j observes price and infers cost of firm i

- High price $\rightarrow$ likely to have high cost
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When choosing prices in future, firm j responds to a high price with high price

- Firm i's future profits increases in firm j's price.
- Firm i has incentive to set a high price initially (competition softening)

Competition softening

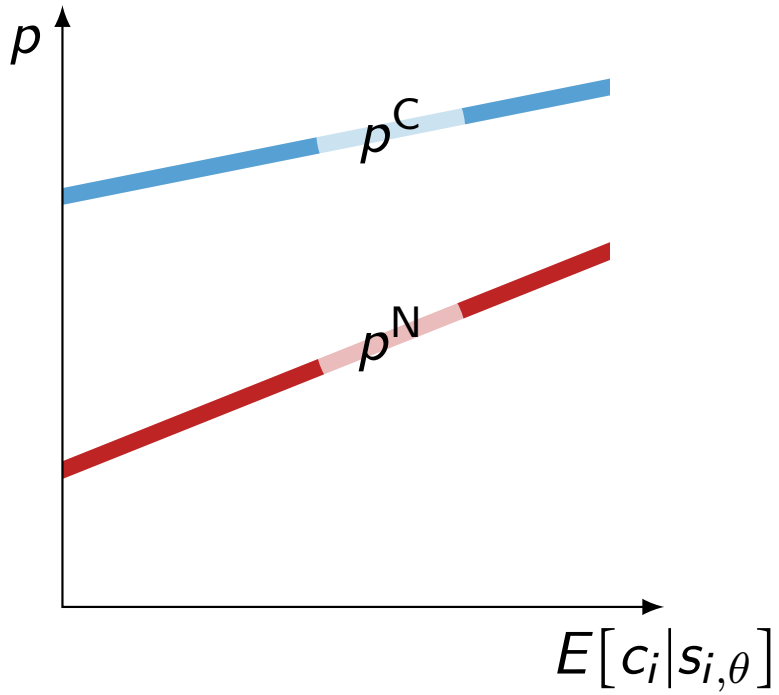

Figure: Initial price with (p^C) and without (p^N) competition softening.

Example - industry costs

Firm i's cost structure: ρ common cost parameter, θ_i private cost parameter with $\rho \in \{low, high\}$; $\theta_i \in \{low, high\}$

- Firm receives signals about probability that cost is high for each component e.g. $s_{i,\theta} = \Pr(\theta_i = high)$ and $s_{i,\rho} = \Pr(\rho = high)$
- Chooses price given signals of cost

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Firm j's future price depends on belief

- believe high $s_{i,\theta}$, larger price increase
- believe high $s_{i,\rho}$, smaller price increase

Example - price informativeness

Learning of firm j depends on the equilibrium strategy of firm i.

Strategy 1: Firm i price varies with $s_{i,\theta}$ more than $s_{i,\rho}$

- Firm j's belief about $s_{i,\theta}$ and therefore θ_i is more responsive to firm i's price
- High price by firm i will lead to a high future price by firm j
- Incentive to soften competition is higher

Strategy 2: Firm i price varies with $s_{i,\theta}$ less than $s_{i,\rho}$

- Firm j's future price is less responsive to firm i's price
- Incentive to soften competition is lower

Competition softening with industry-wide costs

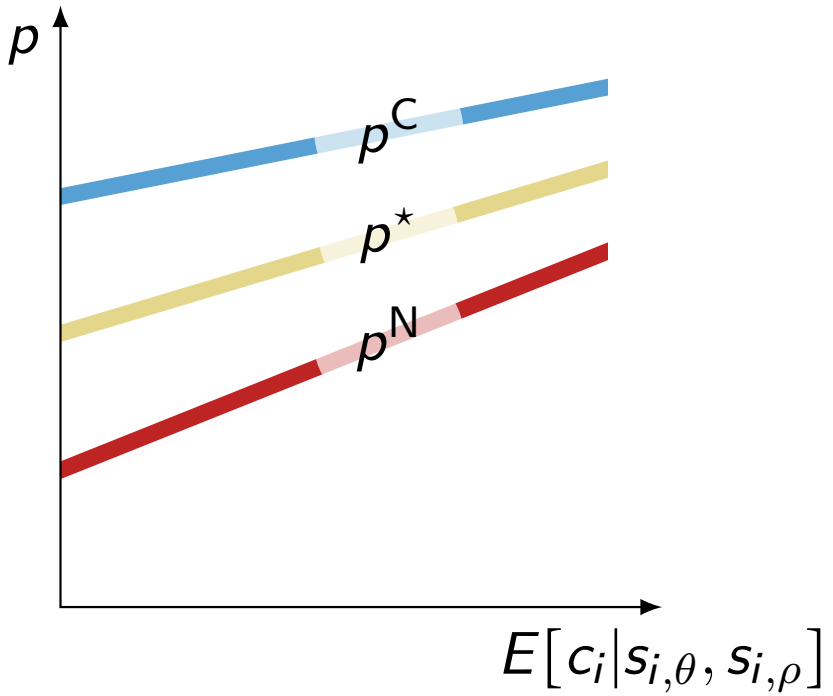

Figure: Initial price with (p^C, $p^\star$) and without (p^N) competition softening, and with ($p^\star$) and without (p^C) information sharing.

Outline of results

Existence and uniqueness of a symmetric linear equilibrium in generalized dynamic competition model

- Price is increasing in information on each cost component, relative weights depend on substitutability of demand
- Competition softening increases with equilibrium informativeness of price

Aggregating industry cost information

- increases expectation and covariance of prices
- increases firm profits and decreases welfare of consumers when demand is relatively inelastic
- reduces value of acquiring firm-specific cost information prior to sharing of industry relevant costs

Outline of results

For an arbitrary number of firms n:

- Strategic interaction between individual firms, and therefore competition softening, decreases as number of firms grow
- For large n, information sharing can increase both consumer and producer surplus

Literature

1. Information sharing, use, and acquisition
   - Information sharing - Gal-Or (1986), Raith (1996), Vives (2001),...
   - Competitive Concerns - Kuhn and Vives (1994), Kuhn (2001)
   - Equilibrium and efficient use of information - Angeletos and Pavan (2007), Columbo et al (2014), Myatt and Wallace (2015a, 2015b)
2. Information revealed in the course of competition.
   - Competition softening - Mailath (1989), Mester (1992), Jeitschko et al. (2018)
   - Signal jamming - Bonatti et al. (2017), Mirman et. al. (1993, 1994)

Outline

1. Model
2. Equilibrium Characterization
3. Welfare Analysis
4. Value of Information
5. Large markets (n firms)

Model

- Two symmetric firms, i and j
- Commonly known demand: $q_{i,t} = a - bp_{i,t} + ep_{j,t}$, with $|e| \leq b$; $e > 0$ is substitutes, $e < 0$ is complements
- Initially unknown constant marginal cost $c_i = \theta_i + \rho$
  - θ_i costs of individual firm
  - ρ costs common to each firm
  - $(\theta_i, \theta_j, \rho)$ are jointly normal and independent, $x \sim N(\mu_x, \sigma_x^2)$
- Profits are $\pi_{i,t}(p_{i,t}, p_{j,t}) = \left(p_{i,t} - c_{i,t}\right) q_{i,t}$
- Firms maximize sum of profits over two periods,

$$\pi_{i,1}\left(p_{i,1}, p_{j,1}\right) + \pi_{i,2}\left(p_{i,2}, p_{j,2}\right)$$

Timeline

There are two rounds of competition.

1. Prior to first period competition, firm receives independent signals about its cost components,

$$s_{i,\theta} \big| \theta_i \sim N\left(\theta_i, \sigma^2_{s,\theta,i}\right), \quad s_{i,\rho} \big| \rho \sim N\left(\rho, \sigma^2_{s,\rho,i}\right)$$

2. Given signals, firm chooses initial price $p_{i,1}$
3. First period profits are realized and first period prices $\mathbf{p}_1 = (p_{i,1}, p_{j,1})$ are observed
4. Prior to second round of competition, firm observes (θ_i, ρ) (Only uncertainty remaining is θ_j.)
5. Given $(\theta_i, \rho, \mathbf{p}_1)$, firm chooses price $p_{2,i}$

Pricing strategies

We constrain attention to symmetric linear pricing strategies,

$$p_{i,t} = p_{0,t} + p_{\theta,t}\mathbb{E}\left[\theta_i\right] + p_{\rho,t}\mathbb{E}\left[\rho\right] + p_{c_j,t}\mathbb{E}\left[c_j\right]$$

When opponent plays a linear strategy, firm's best response is linear.

- Uni-dimensional information implies full revelation, and all equilibria are linear
- With multi-dimensional information, nonlinear iso-price curves lead to tractability problems

First period pricing

Firm i's first period profit maximization problem is

$$\max_{p} \mathbb{E}\left[\left(a - bp + ep_{j,1}\right)(p - c_i) + \pi^{\star}_{i,2}\left(\theta_i, \rho, \mathbf{p}_1\right) \middle| s_{i,\rho}, s_{i,\theta}\right].$$

- First period price affects first period profits in a standard way
- Additional effect on second period profits by manipulation of the opposing firm's second period beliefs,

$$\frac{\partial}{\partial p_{i,1}} \pi^{\star}_{i,2}\left(\theta_i, \rho, \mathbf{p}_1\right)$$

- A (symmetric) linear pricing strategy is

$$p_{i,1} = p_0 + p_\theta \mathbb{E}[\theta_i | s_{i,\theta}] + p_\rho \mathbb{E}[\rho | s_{i,\rho}]$$

Second period profits

In equilibrium, second period profits are:

$$\pi^{\star}_{i,2}\left(\theta_i, \rho, \mathbf{p}_1\right) = \frac{1}{4b}\left(a - bc_i + e\mathbb{E}\left[\left. p^{\star}_{j,2}\right| \rho, p_1\right]\right)^2.$$

Firm i influences competitor's price, $p^{*}_{j,2}$, through the "public" expectation of cost, $\mathbb{E}[c_i|\rho, \mathbf{p}_1]$.

$$\frac{\partial}{\partial p_{i,1}}\pi^{\star}_{i,2}\left(\theta_i, \rho, \mathbf{p}_1\right) = \frac{1}{2b}\left(a - bc_i + e\mathbb{E}\left[\left. p^{\star}_{j,2}\right| \rho, \mathbf{p}_1\right]\right)\frac{\partial}{\partial p_{i,1}}\mathbb{E}\left[\left. p^{\star}_{j,2}\right| \rho, \mathbf{p}_1\right]$$

Information in price

Given linear first period pricing strategies

$$\frac{\partial}{\partial p_{i,1}}\mathbb{E}\left[\left.p^{\star}_{j,2}\right|\rho,\mathbf{p}_1\right]=\underbrace{\frac{be}{4b^2-e^2}}_{\text{demand}}\underbrace{\frac{\partial}{\partial p_{i,1}}\mathbb{E}\left[\left.c_i\right|\rho,\mathbf{p}_1\right]}_{\text{information}}$$

Informativeness parameter, κ, defines how much an increase in first period price increases "public" belief about firm-specific cost.

$$\kappa\equiv\frac{\partial}{\partial p_{i,1}}\mathbb{E}\left[\left.c_i\right|\rho,\mathbf{p}_1\right]=\frac{\sigma_\theta^2\bar{\tau}_{s,\theta}p_\theta}{\sigma_\rho^2\left(1-\bar{\tau}_{s,\rho}\right)\bar{\tau}_{s,\rho}p_\rho^2+\sigma_\theta^2\bar{\tau}_{s,\theta}p_\theta^2}$$

and $\bar{\tau}_{s,x}=\dfrac{\sigma_x^2}{\sigma_x^2+\sigma_{s,x}^2}$

Informativeness parameter

$$\kappa = \frac{\sigma_\theta^2 \bar{\tau}_{s,\theta} p_\theta}{\sigma_\rho^2 \left(1 - \bar{\tau}_{s,\rho}\right) \bar{\tau}_{s,\rho} p_\rho^2 + \sigma_\theta^2 \bar{\tau}_{s,\theta} p_\theta^2}$$

Presence of $\bar{\tau}_{s,\rho} \in (0, 1)$ prevents price from being fully informative

- Continuum of types $(s_{i,\theta}, s_{i,\rho})$ that choose price $p_{i,1}$ in equilibrium.
- True value of ρ informs likelihood of signal $s_{i,\rho}$ received which informs likelihood of signal $s_{i,\theta}$ received.

First period price informativeness depends on price coefficients.

- Ex: increase of p_ρ decreases informativeness of price

Coefficients of optimal first period prices depend on κ.

Equilibrium

Fixed point where first period price coefficients (p_θ, p_ρ) imply a κ for which (p_θ, p_ρ) are optimal.

Theorem

There exists a unique symmetric linear equilibrium. In this equilibrium,

- $p_\rho = p_\theta = 1/2$ *when markets are independent* $(e = 0)$.
- $p_\theta < 1/2$, $p_\theta < p_\rho$ *when goods are substitutes* $(e > 0)$;
- $p_\rho < p_\theta < 1/2$ *when goods are complements* $(e < 0)$;
- p_θ *is decreasing in* κ

Equilibrium: outline of proof

1. Equations for p_θ and p_ρ come from matching coefficients

$$p_\theta = \frac{1}{2+\beta\kappa} \text{ and } p_\rho = \frac{1-\left(\frac{b-e}{2b-e}\right)\beta\kappa}{2-\frac{e}{b}\bar{\tau}_{s,\rho}-\frac{1}{2}\left(1-\bar{\tau}_{s,\rho}\right)\beta^2\kappa^2}$$

2. Combine these with definition of κ and solve

$$\kappa = \frac{\sigma_\theta^2\bar{\tau}_{s,\theta}p_\theta}{\sigma_\rho^2\left(1-\bar{\tau}_{s,\rho}\right)\bar{\tau}_{s,\rho}p_\rho^2+\sigma_\theta^2\bar{\tau}_{s,\theta}p_\theta^2}$$

Equilibrium: outline of proof

$$\underbrace{(2+\beta\kappa)^2\left(1-\left(\frac{b-e}{2b-e}\right)\beta\kappa\right)^2 b\sigma_{s,\rho}^2\bar{\tau}_{s,\rho}^2\kappa}_{\text{LHS}}$$

$$=\underbrace{\left((2b-e\bar{\tau}_{s,\rho})-\frac{1}{2}\left(1-\bar{\tau}_{s,\rho}\right)\beta^2\kappa^2 b\right)^2\left(2-(1-\beta)\kappa\right)\sigma_\theta^2\bar{\tau}_{s,\theta}}_{\text{RHS}}$$

3. RHS is decreasing in κ
4. LHS is
   - Increasing in κ; or
   - Increasing-then-decreasing in κ; where LHS is decreasing, LHS is concave and RHS is convex

Equilibrium: proof (graphical)

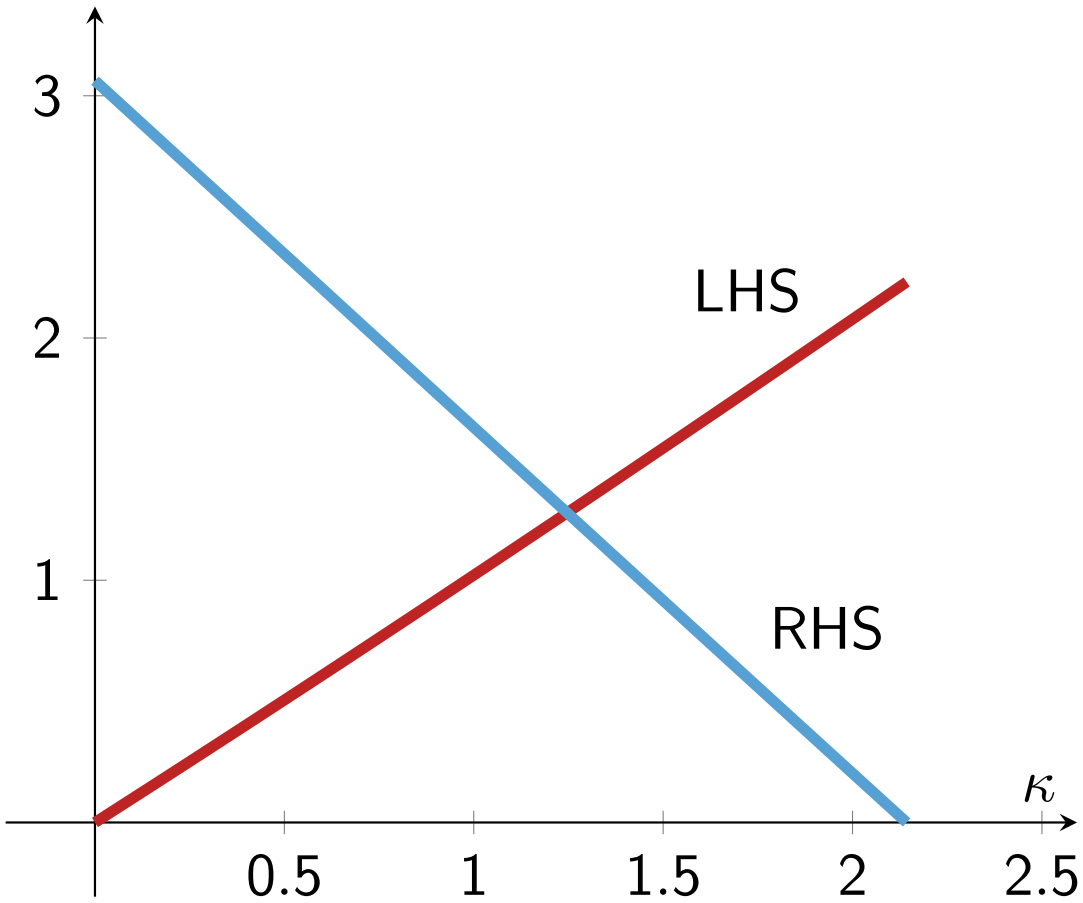

Figure: LHS and RHS for substitutes ($e/b = 0.5$).

Equilibrium: proof (graphical)

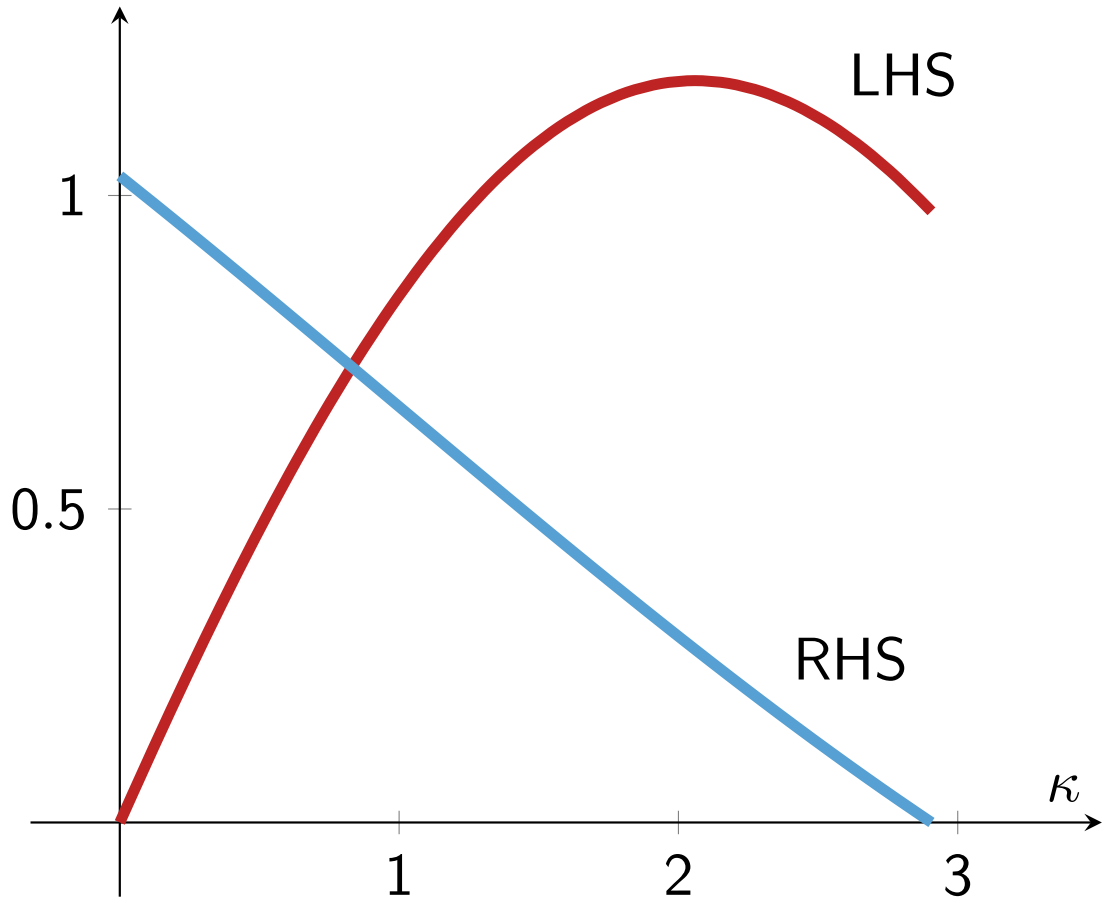

Figure: LHS and RHS for complements ($e/b = -0.975$).

Information aggregation

Firms share information about the common cost component, as in a trade association.

- Additional information at a (potentially) reduced cost

How does this affect the pricing of firms?

- The information on common cost is now identical
- All private information is in the private cost component
- Qualitatively, return to model with private-valued costs.

Informativeness with aggregation

A linear strategy is denoted:

$$p_{i,1}^{c} = p_{0,c} + p_{\theta,c}\mathbb{E}[\theta_i|s_{i,\theta}] + p_{\rho,c}\mathbb{E}[\rho|s_{\rho}]]$$

Informativeness parameter:

$$\kappa = \frac{\sigma_{\theta}^{2}\bar{\tau}_{s,\theta}p_{\theta,c}}{\sigma_{\rho}^{2}\left(1-\bar{\tau}_{s,\rho}\right)\bar{\tau}_{s,\rho}p_{\rho,c}^{2} + \sigma_{\theta}^{2}\bar{\tau}_{s,\theta}p_{\theta,c}^{2}}$$

The aggregated signal on common costs, s_{ρ}, is commonly known, and $s_{i,\theta}$ can be inferred by firm j.

- Approximately, $\bar{\tau}_{s,\rho} = 1$
- Informativeness parameter reduces to $\kappa = 1/p_{\theta,c}$.

Equilibrium with aggregation

Theorem

The unique equilibrium is linear and

1. *First period price coefficients satisfy*

$$p_{\theta,c} \leq p_{\theta}, \text{ with } \kappa = \frac{1}{p_{\theta,c}}.$$

2. *Ex-ante, expected first period prices are higher and expected second period prices are the same*

Welfare Analysis

Consumer surplus

Expected consumer surplus in each period of competition is represented by

$$\begin{aligned}\mathbb{E}\left[u\left(\mathbf{p}\right)\right] &= -2a\mathbb{E}[p_i] + b\mathbb{E}[p_i^2] - e\mathbb{E}[p_i p_j] \\ &= \left(-2a + (b-e)\mathbb{E}[p_i]\right)\mathbb{E}[p_i] + b\,\mathrm{Var}(p_i) - e\,\mathrm{Cov}(p_i, p_j).\end{aligned}$$

Consumer surplus

- decreases in $\mathbb{E}[p_i]$ (in equilibrium, $a > (b-e)\mathbb{E}[p_i]$),
- increases with $\mathrm{Var}(p_i)$, and
- decreases in $\mathrm{Cov}(p_i, p_j)$ when $e > 0$ (increases when $e < 0$).

Producer Surplus

Expected producer surplus in each period of competition is

$$\mathbb{E}[\Pi] = 2\left[(a-(b-e)\mathbb{E}[p_i])\left(\mathbb{E}[p_i]-\mathbb{E}[c_i]\right)+b\left(\mathrm{Cov}\left(c_i,p_i\right)-\mathrm{Var}(p_i)\right)\right.$$
$$\left.-e\left(\mathrm{Cov}\left(c_i,\mathbb{E}[p_j]\right)-\mathrm{Cov}\left(p_i,\mathbb{E}[p_j]\right)\right)\right].$$

Producer surplus

- increases with expected price,
- increases as price becomes more correlated with cost, and
- decreases as other firm's price becomes more correlated with cost.

Information Sharing

When firms share industry cost information

- Expected prices increase in the first period and are the same in the second period.
- Covariance of prices increases
- Competing effects on the variance of prices

Proposition

For large a relative to b and e, sharing common cost information will increase expected producer surplus and decrease expected consumer surplus.

Value of Information

Value of information

Effect of increased precision of cost information

First period

- Improves information on the first period price decision - reduces variance of signals around true parameters
- Does not change expectation of signals
- Can change the first period pricing strategy - how to use information in each component

Second Period

- Only impact in second period would be thorough change in strategies or inferences about opponent

Value of information

We consider an equilibrium setting where acquisition of more precise information is costly

- Benefit of marginal (unobserved) increase in precision
- Envelope theorem - does not effect strategy in first period
- Unobserved deviation - does not effect informativeness of other firms price
- Second period profits not impacted

Changes in first period profit with respect to the precision $\tau_{i,\theta}$

$$\frac{\partial}{\partial \tau_{i,\theta}} \mathbb{E}\left[\pi_{i,1}\right] = \frac{\partial}{\partial \tau_{i,\theta}} \text{Var}(\mathbb{E}[\theta_i | s_{i,\theta}]) b \left(1 - p_{i,\theta}\right) p_{i,\theta}$$

Value of information with information sharing

Changes in first period profit with respect to $\tau_{i,\theta}$

$$\frac{\partial}{\partial \tau_{i,\theta}} \mathbb{E}\left[\pi_{i,1}^{c}\right] = \frac{\partial}{\partial \tau_{i,\theta}} \text{Var}(\mathbb{E}[\theta_i | s_{i,\theta}]) b \left(1 - p_{\theta,c}\right) p_{\theta,c}$$

Proposition (Relative value of information)

The value of increased precision in information in private costs is lower when firms share industry relevant information,

$$\frac{\partial}{\partial \tau_{i,\theta}} \mathbb{E}\left[\pi_{i,1}\right] > \frac{\partial}{\partial \tau_{i,\theta}} \mathbb{E}\left[\pi_{i,1}^{c}\right].$$

Idea: Value depends on how much information is used in first period strategy - $p_{\theta,c} < p_{\theta} < 1/2$

Large Markets

Extension to n firms

There are n firms each with demand

$$q^i\left(p_i, p_{-i}\right) = a - bp_i + \frac{e}{n-1}\sum_{j \neq i} p_j.$$

All assumptions on the information structure are the same as before

- When $n = 2$ return to the base model.

Equilibrium pricing - n firms

Theorem

In the linear equilibrium of the n-firm model,

$$p_{i1}\left(s_{i\theta}, s_{i\rho}\right) = p_{0n} + p_{\theta n}\mathbb{E}\left[\theta_i \middle| s_{i\theta}\right] + p_{\rho n}\mathbb{E}\left[\rho \middle| s_{i\rho}\right],$$

$$\text{where, } p_{\theta n} = \frac{1}{2+\beta_n\kappa}, \quad p_{\rho n} = \frac{b - \left(\frac{b-e}{2b-e}\right)\beta_n\kappa}{2b - e\overline{\tau}_\rho - \frac{1}{2}\left(1-\overline{\tau}_\rho\right)\beta_n^2\kappa^2},$$

$$\text{and } \beta_n = \frac{e^2}{\left(2b-e\right)\left(2\left(n-1\right)b+e\right)}.$$

Note: strategic interaction between individual firms, β_n is reduced as number of firms grows.

Large number of firms

As number of firms becomes large, interaction term vanishes

$$\beta_n = \frac{e^2}{(2b-e)\left(2(n-1)b+e\right)} \quad \Longrightarrow \quad \lim_{n \nearrow \infty} \beta_n = 0.$$

Theorem

In the linear equilibrium of the large-n extension, equilibrium prices are

$$p_{i1}\left(s_{i\theta}, s_{i\rho}\right) = p_{0\infty} + p_{\theta\infty}\mathbb{E}\left[\theta_i \middle| s_{i\theta}\right] + p_{\rho\infty}\mathbb{E}\left[\rho \middle| s_{i\rho}\right].$$

Letting $r = e/b$,

$$p_{0\infty} = \frac{1}{2-r}\left(\frac{a}{b} + \frac{1}{2}r\mu_\theta + \mu_\rho\right) - \frac{\mu_\rho}{2-r\overline{\tau}_\rho}, \quad p_{\theta\infty} = \frac{1}{2}, \quad p_{\rho\infty} = \frac{1}{2-r\overline{\tau}_\rho}.$$

Welfare - large n

For any level of information precision, first-period consumer and producer surplus with $n \to \infty$ are

$$\mathbb{E}[u_{1\infty}] \propto (1-r)\,\mathrm{Var}(p_{i1}^{\star}) - r\,\mathrm{Cov}\left(p_{i1}^{\star}, p_{j1}^{\star}\right) + C_u,$$

$$\mathbb{E}[\Pi_{1\infty}] \propto \left(\mathrm{Cov}(c_i, p_{i1}^{\star}) - \mathrm{Var}(p_{i1}^{\star})\right) + \left(\mathrm{Cov}\left(p_{i1}^{\star}, p_{j1}^{\star}\right) - \mathrm{Cov}\left(c_i, p_{j1}^{\star}\right)\right) r + C_\pi.$$

where C_u and C_π are constants and i, j are any firms $i \neq j$.

Second period strategies only depend on average expected opponent's cost which is deterministic

- Information precision has no impact on second period welfare

Information sharing - large n

With a large number of firms, information sharing implies all firms learn true value for ρ.

- Impact of information sharing: $\bar{\tau}_\rho \to \bar{\tau}_{\rho,c} = 1$ when $\bar{\tau}_\rho > 0$.

Producer surplus is increasing in precision $\overline{\tau}_\rho$.

- Producer surplus strictly improves when $\overline{\tau}_\rho \in (0, 1)$.

Consumer surplus increases with information sharing if either

- firms are selling goods are not too substitutable ($e << b$, i.e. $r << 1$), or
- information prior to sharing is dispersed ($\bar{\tau}_\rho << 1$)

Conclusion

Characterize the unique symmetric linear equilibrium with common and private cost parameters

- How do firms use information on each cost component
- How informative is price about private information

Aggregating industry-wide cost information ($n = 2$)

- Increases expected prices and covariance of prices
- Decreases consumer surplus and increases profits when goods relatively inelastic
- Lowers value of collecting private cost information

Conclusion

Can aggregation of cost information harm competition?

Number of firms is small

- Competition softening may lead to increased prices
- Incentive to distort prices upward can facilitate implicit collusion

Large number of firms

- Large space of parameters where both consumer and producer surplus increases with information sharing
- Beneficial when information is dispersed or products are not very substitutable