R&D Collaboration in Collusive Networks

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In recent years, the scope for explicit or implicit market sharing agreements have increased. (Belleflamme and Bloch, 2004)

The antitrust authorities started to emphasize reciprocal market sharing agreements as an alternative form of collusion.

Sherman Act: the Addyston Pipes Case of 1899, the Supreme Court struck down a group of iron pipe producers which reserved some cities as exclusive domains of one of the sellers (Scherer and Ross, 1990)
R&D Agreements

- Article 5(f) of Draft R&D Block Exemption Regulation (2010) includes as “hardcore restrictions”:

  “R&D agreements which have their objective as the requirement to refuse to meet demand from customers in the parties’ respective territories,…”

- None of the parties may be fully excluded from exploiting the joint R&D results in the internal market.
Questions addressed

- What are the effects of collusive activity and the level of competition on the R&D levels and profits of the firms?

- What is the architecture of “incentive compatible” networks?

- Can collusive activity be beneficial from a social welfare point of view when there are R&D collaborations?
• Arrow’s replacement effect vs. Schumpeter (1943)

• Motta (1996): Non-cooperative R&D, monopoly leads to lower R&D levels, social welfare requires intermediate level of competition.

• Aghion et al (2002): Some intermediate level of competition might be optimal for innovations and productive efficiency.
Measures of Competition

- Number of firms
- Product substitutability
- Nature of competition
- Connectivity? Network Structure?
Literature (Networks)

- Bilateral (Delapierre and Mytelka, 1998)
  Nonexclusive (Milgrom and Roberts, 1992)

- Goyal and Moraga-Gonzalez (2001): R&D Networks

- Belleflamme and Bloch (2004): Market Sharing Agreements
The Game

- Stage 1: Network Formation with cost-free links
- Stage 2: Unilateral choice of costly R&D effort
- Stage 3: Product Market (Cournot competition)
Networks

- \( N = \{1, 2, \ldots, n\} \), \( n \geq 3 \) set of firms, each firm is associated to a *home market*.

- \( g = \{g_{ij}\}_{i,j \in N} \) is the network where \( g_{ij} \in \{0, 1\} \) defines a pair-wise relationship

- *i’s neighbors*: \( N_i = \{j \in N \setminus i : g_{ij} = 1\}\)

- \( \eta_i(g) \) is the cardinality of the set \( N_i(g) \)
Networks

- Regular Networks (every node has $k$ neighbours):

  Ex: $n = 4$

  The complete network

  The empty network
We can have different regular networks with same \((n, k)\):

Ex: \(n = 8, k = 2\)
Networks

- When firms form both R&D Collaboration and Collusive links, the structure matters!

Ex: $n = 6, k = 2$

- Firm 1 enters to the foreign markets 4, 5 and 6.
- In the two triangles, 1 competes with all in foreign markets 4, 5 and 6.
- In the cycle graph, 1 competes with all neighbours in the foreign market 6.
R&D effort levels and spillovers

- Firms choose an R&D effort level $e_i(g)$ to reduce marginal cost of production:

  $$c_i(\{e_i\}_{i\in N}) = \bar{c} - e_i - \beta \sum_{j\in N_i(g)} e_j$$

- $\beta \in [0, 1]$ measures spillovers

- Cost of effort: $Z(e_i) = \gamma ne_i^2$, $\gamma > 0$, $e_i \in [0, \bar{c}]$
Payoffs

- Firms choose quantities \( \{ q^i_j(g) \} \) \( i,j \in N \) \( g_{ij} = 0 \)

- Linear demand: \( Q = a - p, \ a > c \)

- Total profits of firm \( i \)

\[
\Pi_i(g) = \pi^i_i(g) + \sum_{j \in N} \pi^j_i(g)
\]

\[
\pi^j_i(g) = \left[ a - Q^j(g) - c_i(g) \right] q^j_i(g) - \gamma n \epsilon_i^2(g)
\]
• Focusing on regular networks, i.e. $\eta_i(g) = \eta_j(g) = k$:

$$
\Pi_i(g) = \left[ \frac{a - (n - k)c_i + (n - k - 1)c_m}{n - k + 1} \right]^2 + \\
+ \sum_{\begin{subarray}{c}
    r_{i,j} \\
    j \in N \\
    g_{ij} = 0
\end{subarray}} \left[ \frac{a - (n - k)c_i + r_{i,j}c_l + (n - k - r_{i,j} - 1)c_m}{n - k + 1} \right]^2 - \gamma ne_i^2
$$

$$
c_i(g) = \bar{c} - e_i - \beta ke_j \\
c_l(g) = \bar{c} - e_l - \beta e_i - \beta (k - 1)e_{l'} \\
c_m(g) = \bar{c} - e_m - \beta ke_{m'}
$$

• $r_{i,j}$ is the number of collaborators which firm $i$ faces in the foreign market $j$ that $i$ operates.
Focusing on regular networks, i.e. \( \eta_i(g) = \eta_j(g) = k \):

\[
\Pi_i(g) = \left[ \frac{a - (n - k)c_i + (n - k - 1)c_m}{n - k + 1} \right]^2 + \\
+ \sum_{\substack{r_{i,j} \\
j \in N \\
g_{ij} = 0}} \left[ \frac{a - (n - k)c_i + r_{i,j}c_l + (n - k - r_{i,j} - 1)c_m}{n - k + 1} \right]^2 - \gamma n e_i^2
\]

\[
c_i(g) = \bar{c} - e_i - \beta ke_j \\
c_l(g) = \bar{c} - e_l - \beta e_i - \beta(k - 1)e_l' \\
c_m(g) = \bar{c} - e_m - \beta ke_{m'}
\]

**Benchmark 1:** R&D Collaboration Networks, \( r_{i,j} = k \) for all \( n \).

**Benchmark 2:** R&D in Collusive Networks, \( \beta = 0 \).
R&D Collaboration and Collusion

- In the paper, we focus on 3 different families of regular networks:
  - Complete Components
  - Ring Lattice
  - Complete Bipartite Graph

- In the regular network with complete components, $r_{i,j} = k = 4$ in all foreign markets entered.
- In the complete bipartite graph $r_{i,j} = 0$. 

Regular Networks with Complete Components

- Example for $n = 12$

  $k = 1$  $k = 2$  $k = 3$  $k = 5$

- Maximum degree is $k = n/2 - 1$ (sparse networks)
- As $k$ grows, number of the components decreases, size of each complete component increases.
Regular Bipartite Networks

- Example for $n = 12$

- A set of nodes decomposed into two disjoint sets such that no two nodes within the same set are linked.
- Constructed by removing links one by one starting from the complete bipartite graph.
Ring Lattices (in Appendix)

- The number of collaborators faced in a foreign market is on average more in ring lattices than in regular bipartite networks!
Equilibrium Efforts

- $n = 20, \beta = 1$

- $e(g^k)$ declines with connectivity in both benchmark models.

*Benchmark 1:* more collaborators (competitors) becoming tougher
*Benchmark 2:* the number of firms in each market decreases, the number of foreign markets operated decreases.
**Proposition.** In regular networks with complete components with $\beta = 1$, $e(g^k)$ decreases with $k$. In regular bipartite graphs, $e(g^k)$ is nonmonotonic with respect to $k$. There exists $0 < \bar{k} < n/2$, which minimizes $e(g^k)$ and the maximum is reached at $k = n/2$, i.e. under complete bipartite-graph.
Equilibrium Efforts

- In the complete components, $e(g^k)$ is the lowest!

**Intuition:**
the number of collaborators to compete increases
the number of firms in each (home and foreign) market decreases,
the number of foreign markets operated decreases.

- Effects from both benchmark models added.
Equilibrium Efforts

- $e(g^K)$ is nonmonotonic in bipartite graphs!

*Intuition:* The reducing effect of competition with collaborators is offset by the cost reducing benefits of R&D since there are less markets that collaborators operate together. In each of those markets the number of collaborators is less.
**Equilibrium Profits**

- \( n = 20, \beta = 1 \)

Proposition. In regular networks with complete components and in regular bipartite graphs \( \Pi(g^k) \) increases in \( k \).
Equilibrium Profits

- $n = 20, \beta = 1$

- Profits are non-monotonic under complete components.
- The complete bipartite graph results in the highest industry profits while the lowest is obtained in the empty network.
Social Welfare

- Social welfare is the sum of consumer surplus and producers’ profits in all markets:

  \[ W(g) = \sum_{j=1}^{N} \frac{Q_j(g)^2}{2} + \sum_{i=1}^{N} \Pi_i(g) \]

- \( Q_j(g) = \sum_{i \in \mathcal{N}} q_{ij}(g) \) is the aggregate output in market \( j \) in network \( g \) for the homogeneous-product oligopoly.

- A network \( g \) is *efficient* if and only if \( W(g) \geq W(g') \) for all \( g' \).
When $\beta = 0$, i.e., when links define only the market sharing agreements, then social welfare is the lowest.

Social welfare can be higher for bipartite graphs than in absence of collusion!

When technological spillovers are high, the difference between bipartite graphs and the others gets even higher.
Jackson and Wolinsky (1996):

- A network $g$ is *stable* if and only if for all $i, j \in N$,
  (i) if $g_{ij} = 1$, then $\pi_i(g) \geq \pi_i(g - g_{ij})$ and $\pi_j(g) \geq \pi_j(g - g_{ij})$
  (ii) if $g_{ij} = 0$ and $\pi_i(g + g_{ij}) > \pi_i(g)$, then $\pi_j(g + g_{ij}) < \pi_j(g)$.

- A link can be severed unilaterally but can be formed iff two firms agree.
**Proposition.** Complete network is always stable.
Proposition. Stability of the empty network depends on the number of markets and the level of spillovers. There exists a threshold $0 < \beta^* < 1$ below which the empty network is stable. Empty network is never stable when $\beta = 1$. 
Main Results

1. R&D Collaboration and Collusive Agreements highlight the importance of network structure for equilibrium levels of R&D, profits and welfare!

2. Intermediate degrees of connectivity are socially optimal. Social welfare might be higher than in absence of collusion under some network structures.

3. Complete network is stable while the stability of empty network depends on the level of spillovers.
Further research

- Two types of links
- Link-specific quantities
- Differentiated products and innovation
- Firm/market heterogeneity
- Empirical work!
Thank you..