R&D networks and the nature of product market competition

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Motivation

R&D

1. R&D collaboration networks are pervasive in many markets
2. Indeed, R&D collaboration can be the means to achieve the necessary funding for a startup R&D process.
3. In some cases, collaboration consists in sharing of information,
4. In others, firms share research facilities or platforms.

Motivation

Spillovers

1. In any case, even without clear collaboration agreements, R&D investment has a public goods nature.
2. Interconnected firms may benefit from spillovers of the investment of other firms.
3. The spillover process can have different shapes.
   - In some cases, firms just receive a portion of the investment of the peers.
   - In other cases, the firms must invest a certain amount, in order to enjoy the spillovers.
   - Still in other cases, only the less investment firms receive spillover.

Motivation

Spillovers

1. Under market competition, spillovers are determinant in the investment decisions of firms.
2. The network setup, is appropriate to study the effects of spillover accross firms and their impact in the investment decision.

Competitive effects

1. In certain industries, firms act in a collaborative way in R&D investment, but are competitors in the product market.
2. The nature of product market competition has a definitive impact in collaborative R&D decisions.
3. In this paper we analyse several implications of the product market competition in R&D investment under the assumption that firms operate in a network.

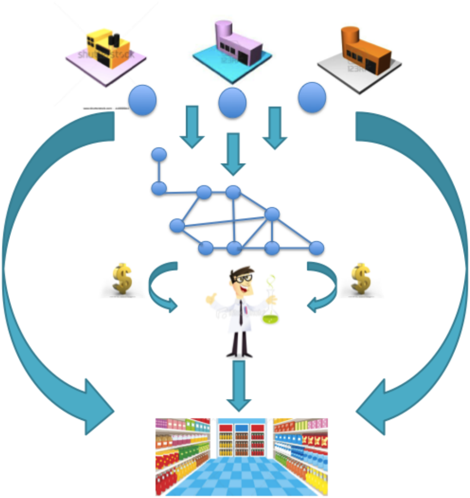
Objective

1. In this paper we want to investigate further the relationship between:
   - Product market competition
   - Spillover effects
   - Network structure
2. In the decision to invest in R&D

The model

- We assume that there are n firms that face a certain market demand for their product.
- Firms form a network.
- Play a two stage game.
  - In the first stage they individually invest an amount e_i in R&D
  - In the second stage they engage in product market competition
- The appropiate solution concept for the game is Subgame Perfect Equilibrium $\rightarrow$ *at each stage, each agent anticipates how his actions will influence the actions of all other agents at every future stage*.

the model



The model

Effects of R&D investment

1. Costs
   - The R&D investment of a firm decreases the marginal cost of production.
   - R&D investment has decreasing returns $\rightarrow$ the cost of R&D investment is a convex function.
2. Spillovers
   - The R&D investment of a firm decreases the marginal cost of production of firms connected to her.
   - R&D investment of firm i has no effect on the marginal cost of firms that are not directly connected to i.
   - The spillover effect is given by $\beta \in [0, 1]$ For simplicity we assume throughout that $\beta = 1$.

The model

The product market competition

When the firms compete in the product market, they can use different competition strategies. Namely:

- Quantity competition - Cournot competition
- Price competition - Bertrand competition
  - Homogeneous products
  - Heterogeneous products
- Quantity competition with sequential decision making - Stackelberg competition.

Roadmap

- Evaluate how does the type of competition in the product market influence the incentive for R&D under a fixed network structure.
  - Quantity setting oligopoly
  - Price setting oligopoly
- Analyse the effect of a change in the network structure in the investment decision of firms.
- Discuss work in progress.

Quantity setting oligopoly

- As Goyal and Moraga-Gonzalez (2001) we assume that firms sell an homogeneous product.
- The demand function is given by $p = a - Q$ where Q is the total quantity produced by all firms in the market, namely $\sum_{j \in N} q_j$.
- The marginal cost of the firm is given by

$$c_i = c - e_i - \sum_{j \in N_i} e_j,$$

where N_i denotes the set of neighbors of i.

Quantity setting oligopoly

- The timing of the game is as follows:
  1. Firms engage in cost-reducing R&D investment.
  2. Spillovers are realized.
  3. Firms choose their quantities, according to product market competition.

Quantity setting oligopoly (cont.)

Assumption (1)

Goyal and Moraga-González (2000)

- *All firms have the same number of connections, denoted k - networks are regular with degree k.*
- *Firms connected to firm i, only have as neighbors other neighbors of i.*
- *Neighboring firms are symmetric and non-neighboring firms are also symmetric in investment decisions.*

Quantity setting oligopoly (cont.)

- According to standard Cournot competition in the product market competition firm sets:

$$q_i = \frac{a - nc_i + \sum_{j \neq i} c_j}{n+1}$$

- The profit is, then, given by

$$\pi_i = \frac{(a - nc_i + \sum_{j \neq i} c_j)^2}{(n+1)^2} - \gamma e_i^2$$

$$\pi_i = \frac{A^2}{(n+1)^2} - \gamma e_i^2$$

Quantity setting oligopoly (cont.)

- Given the investment in R&D, we have:

$$A = a - n(c - e_i - \sum_{j \in N_i} e_j) + \sum_{j \in N_i} (c - e_i - e_j - \sum_{h \in N_j} e_h)$$

$$+ \sum_{m \in N_i} (c - e_m - \sum_{r \in Nm} e_r)$$

- Under the assumption G-MG, we can simplify the expression above and we obtain:

$$A = a - c + e_i(n - k) + e_l(n - k)k - e_m(k + 1)(n - k - 1)$$

Quantity setting oligopoly (cont.)

Strategic complementarities and substitutabilities in R&D investment

$$\pi_i = \frac{(a - c + e_i(n-k) + e_l(n-k)k - e_m(k+1)(n-k-1))^2}{(n+1)^2} - \gamma e_i^2$$

$$\frac{\partial \pi_i}{\partial e_i} = \frac{2(n-k)(a - c + e_i(n-k) + e_l(n-k)k - e_m(k+1)(n-k-1))}{(n+1)^2}$$

- The investment of firm i and of her neighbors are strategic complements
- The investment of firm i and of her non-neighbors are strategic substitutes.

Quantity setting oligopoly (cont.)

- Given that all firms have the same degree we obtain a symmetric level of investment for all firms in the market, that is given by:

$$e^k = \frac{(a-c)(n-k)}{\gamma(n+1)^2 - (n-k)(k+1)}$$

- The equilibrium profit as a function of the degree is

$$\pi(k) = \frac{(a-c)^2\gamma(\gamma(n+1)^2 - (n-k)^2)}{(\gamma(n+1)^2 - (n-k)(k+1))^2}.$$

- Some observations can be made in this context:
  1. Maintaing the degree (and considering only n for which a regular network exists, if more firms enter in the market, the investment in R&D decreases.
  2. Also, the profit is decreasing in the number of firms.

Quantity setting oligopoly (cont.)

- Under the same set of assumptions, G-MG draw the following proposition:

Proposition

Suppose firms are competitors in an homogeneous-product market. Then R&D effort of a firm is decreasing in the level of collaborative active.

Quantity setting oligopoly (cont.)

We now introduce a modification of assumption 1, under which we observe that the structure of the network and not only the degree is a driver of the investment of firms.

Assumption (2)

- *All firms have the same number of connections, denoted k - networks are regular with degree k.*
- *no further assumptions are imposed in terms of the neighborhood*

Quantity setting oligopoly (cont.)

Proposition

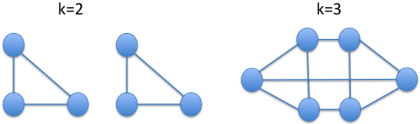
Under Assumption 2, the interconnection between firms affects non-monotonically the optimal investment in R&D.

- *For low cost of R&D, a higher degree of interconnection induces larger investment.*
- *For high levels of R&D costs, a higher degree of interconnection induces a decrease in the investment of firms.*

Quantity setting oligopoly (cont.)

Example

Consider the following example in which $n = 6$ firms participate in a regular network with degree $k = 2$ with the following structure:



$$e = \frac{4(a-c)}{49\gamma - 12} \qquad e = \frac{3(a-c)}{49\gamma - 60}$$

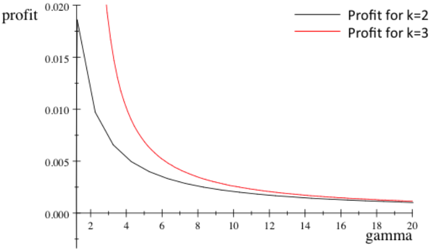
$$\pi = \frac{(a-c)^2\gamma(49\gamma-16)}{(49\gamma-12)^2} \qquad \pi = \frac{(a-c)^2\gamma(49\gamma-9)}{(49\gamma-60)^2}$$

It is easy to verify that for low γ, $e(3) > e(2)$.

Quantity setting oligopoly (cont.)

Example

Regarding the profits of the firms, we observe the following that the profit under k=3 is higher than the profit under k=2, which indicates that firms are better off under higher degrees of collaboration.



Quantity setting oligopoly (cont.)

Strategic vs non strategic effects of R&D

- As in Leahy and Neary (1997), we can evaluate the effects of R&D investment in terms of the strategic and non strategic effects.
- The profit of the firms is after product market interaction is given by

$$\pi_i(k) = \tilde{\pi}_i \left[c_i(e_i, e_l, e_m), q_i^*(e_i, e_l, e_m), q_l^*(e_i, e_l, e_m), q_m^*(e_i, e_l, e_m); k\right] - \gamma(e_i)$$

- The first order condition for profit maximization gives us:

$$\frac{\partial \tilde{\pi}}{\partial e_i} = 0 \Leftrightarrow \frac{\partial \tilde{\pi}}{\partial c_i}\frac{\partial c_i}{\partial e_i} + \frac{\partial \tilde{\pi}}{\partial q_l}\frac{\partial q_l}{\partial e_i} + \frac{\partial \tilde{\pi}}{\partial q_m}\frac{\partial q_m}{\partial e_i} = \gamma'(e_i)$$

Quantity setting oligopoly (cont.)

Strategic vs non strategic effects of R&D

$$\frac{\partial \tilde{\pi}}{\partial e_i} = 0 \Leftrightarrow \frac{\partial \tilde{\pi}}{\partial c_i}\frac{\partial c_i}{\partial e_i} + \frac{\partial \tilde{\pi}}{\partial q_l}\frac{\partial q_l}{\partial e_i} + \frac{\partial \tilde{\pi}}{\partial q_m}\frac{\partial q_m}{\partial e_i} = \gamma'(e_i)$$

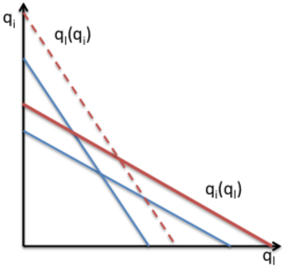
Direct effect Strategic effect.

- The direct effect is positive.
- The strategic effect with respect to neighbors is negative.
- The strategic effect with respect to non neighbors is positive.
- As we increase the number of neighbors, the more likely it is that firms prefer to reduce the investment in R&D

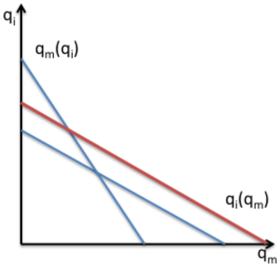
Strategic effects of R&D under shared neighbors

- When firm *i* increases her investment, a "pure" non-neighbor will decrease the investment, thus becoming less competitive, which is positive for firm *i*.
- When firm *i* increases her investment, a "pure" neighbor will increase the investment and firm *i*, despite obtaining the spillover, also faces tougher competition. (for full spillovers the balance of these two effects is negative).
- A shared neighbor increases the incentives for investment in R&D. On one side, if a non neighbor increases R&D the firm should decrease it, however, the shared neighbor will increase the R&D, leading firm i to also increase R&D if the cost is low enough.
- As the degree increases, agent i will have more shared neighbors, which, if the cost of investment is low induces a larger investment in R&D.

Strategic effects of R&D with quantity competition

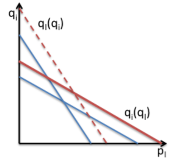


Reaction of neighbors to an increase of the investment of firm i

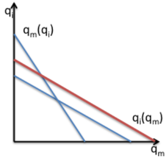


Reaction of non neighbors to an increase of the investment of firm i

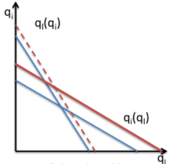
Strategic effects of R&D with quantity competition and shared neighbors



Reaction of pure neighbors to an increase of the investment of firm i



Reaction of pure non neighbors to an increase of the investment of firm i



Reaction of shared neighbors to an increase of the investment of firm i

Price setting oligopoly with differentiated product

We now consider that firms produce differentiated goods and compete in prices in the product market. The following assumptions will hold:

1. Demand of firm h is

$$q_h = a - p_h + b \sum_{r \neq h} p_r, \;\; b = \frac{z}{n-1}$$

2. The cost function and spillover process are the same as before.
3. Each firm chooses prices.
4. The profit outcome after price competition is:

$$\pi_h = \left(\frac{b}{b+2} \right)^2 \frac{1}{\Delta^2 b^2} \left(a\,(b+2) - ((1+b)\,\Delta - b)\,c_h + b \sum_{r \neq h} c_r \right)^2$$

Where $\Delta = (2 - b(n-1))$

Price setting oligopoly with differentiated product

- Notice that $\sum_{r \neq h} c_r = \sum_{l \in N_h} c_l + \sum_{m \notin N_h} c_m$
- In that case and using Assumption 1 we obtain:

$$e^* = \frac{1}{(k+1)} \frac{\left[\left(a + (z-1)\, c \right) \frac{(z-1)}{(2-z)^2} \right] < 0}{\left(\frac{(z-1)^2}{(2-z)^2} - \frac{\gamma}{(k+1)^2} \right) > 0}$$

- So, we can conclude that, under price competition, for any degree, the investment in R&D is always zero.
- We are assuming a full spillover, however this result holds even for intermediate spillover rates.
- In the absence of spillovers (in this case for k=0), for low enough costs, the investment is positive whereas for high costs, the investment is negative.

Price setting oligopoly with differentiated product

Strategic vs non strategic effects of R&D

$$\frac{\partial \tilde{\pi}}{\partial e_i} = 0 \Leftrightarrow \frac{\partial \tilde{\pi}}{\partial c_i}\frac{\partial c_i}{\partial e_i} + \frac{\partial \tilde{\pi}}{\partial q_l}\frac{\partial q_l}{\partial e_i} + \frac{\partial \tilde{\pi}}{\partial q_m}\frac{\partial q_m}{\partial e_i} = \gamma'(e_i)$$

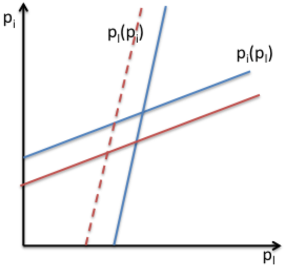
Direct effect Strategic effect.

- The direct effect is positive.
- The strategic effect is negative w.r.t. to neighbors or non neighbors.
- For degree $k > 0$, the strategic effect is dominant and the firm will invest zero.

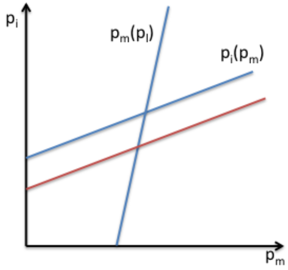
Price setting oligopoly with differentiated product and shared neighbors

- The firms have even less incentive to invest in R&D if they share a neighbor with non-neighbor firms.
- We can observe this in the following pictures of the market competition stage:

Strategic effects of R&D under price competition

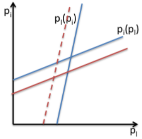


Reaction of neighbors to an increase of the investment of firm i

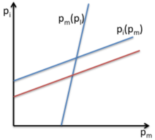


Reaction of non neighbors to an increase of the investment of firm i

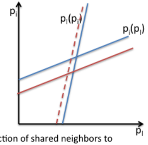
Strategic effects of R&D under price competition with shared neighbors



Reaction of pure neighbors to an increase of the investment of firm i



Reaction of pure non neighbors to an increase of the investment of firm i



Reaction of shared neighbors to an increase of the investment of firm i

Conclusions and Policy Implications

- The nature of product market competition affects the incentives for investment in R&D when firms form networks of collaboration.
- Price competition firms have no incentive to invest in R&D, unless some subsidy could be provided.
- Price setting firms will only invest in no network of collaboration exists.
- The shape of the network of collaboration has an effect in the level of investment of firms under quantity competition.

Conclusions and Policy Implications

- If the network is composed of separate clusters, an increase in the degree has and adversary effect on R&D investment.
- If the increase of the degree implies that clusters become interconnected, firms have a higher incentive to invest in R&D.
- We can conclude that it is possible to find a degree of collaboration that leads to higher investment.

Future research

- Analyse other shapes of networks and derive policy implications for R&D funding.
- Discuss welfare implications of our setup.
- Allow firms to endogenously form the network and evaluate the paths that lead to higher efficiency and stability in the market.
- Analyse other specifications for the spillover process (Amir and Wooders).
- Evaluate the anticompetitive aspects that can arise in networks under R&D collaboration.
- Analyse Stackelberg competition.

Thank you!