ECO 650: Firms' Strategies and Markets

Innovation

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To innovate enables firm to acquire a competitive advantage toward its rival.

- Lowering its production cost.
- Improving its quality.
- Create a new product (completely new, new variety, new formula, new packaging,...)

Protection-Patent

- The story of Robert Kearns and its “intermittent windshield wiper"

  See The newyorker article: “the-flash-of-genius": https://www.newyorker.com/magazine/1993/01/11/the-flash-of-genius

- If an innovation is not protected $\Rightarrow$ The innovator fails to appropriate the rent of its innovation because of the risk of imitation
  - Large fixed cost difficult to recover for the innovator
  - Uncertainty: Proba for a new medecine to be approved for patient use is about 1/10 000, Proba to be published for a book, ...

- How to protect an innovation ?
  - Patents : In the US and EU the term of a patent is 20 years.
  - Copyright: Longer period $\backsimeq$ 50 years
  - Secret: Coca-Cola

https://www.uspto.gov/web/offices/ac/ido/oeip/taf/us_stat.htm

Table: Patents in the US

Year	**Patent applications**	**Patents granted**	Share
1973	110 000	79 000	71%
1983	112000	62000	55%
1993	189 000	110 000	58%
2003	366 000	187 000	49%
2015	630 000	325 000	52%
2019	669 434	391 103	52%

The patent dilemma

- A patent grants a “temporary" monopoly power to the innovator to protect the innovator and favor innovation
- The monopoly position creates a dead weight loss

Two key variables to control this balance:

- The lenght of the patent
- The breadth of the patent

The optimal lenght of a patent

Assumptions

- Assume an innovation creates a social surplus W at each period.
- The discount factor is δ.
- The innovation cost is C and is paid in $t = 0$.

The social value of Innovation is:

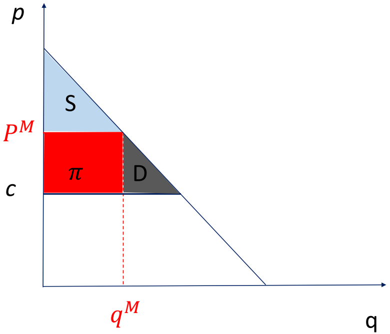
$$V = -C + W[\delta + \delta^2 + ...\delta^T]$$

When $T \to \infty, V \to W\frac{\delta}{1-\delta} - C$. V is increasing with δ. No reason to consider a limited time for the value of innovation.

The optimal lenght of a patent

Assumptions

- This innovation is protected by a patent for a lenght T.
- From $T+1$ and on, there is Bertand competition.
- We denote $\pi = \alpha W$ with $\alpha \in [0,1]$ the profit of the monopolist innovator. We have $W = S + \pi + D$. We denote $D = \beta W$.



The social value of an Innovation protected by a brevet for T periods is:

$$V_B = \underbrace{W\frac{\delta}{1-\delta} - C}_{\texttt{Social Value of innovation}} - \underbrace{\beta W \overbrace{\delta[1+\delta+...+\delta^{T-1}]}^{\texttt{L=Lenght of the patent}}}_{\texttt{Social cost of patent protection}}$$

The innovator's incentive to innovate is:

$$V_I = \alpha WL - C$$

Comparing V_I and V_B, we obtain :

$$V_I < V_B$$

$$(\alpha+\beta)L < \frac{\delta}{1-\delta}$$

Using $L = \frac{\delta(1-\delta^T)}{1-\delta}$

$$\Rightarrow \alpha+\beta < \frac{\delta}{1-\delta}\frac{1}{L} = \frac{1}{(1-\delta^T)} > 1$$

True!

- A single innovator protected by a patent innovates less than what would be socially optimal.
- The social value of an innovation protected by a patent decreases with L which increases with T.
- What happens with competition?

Innovation-Patent and competition

Assumptions

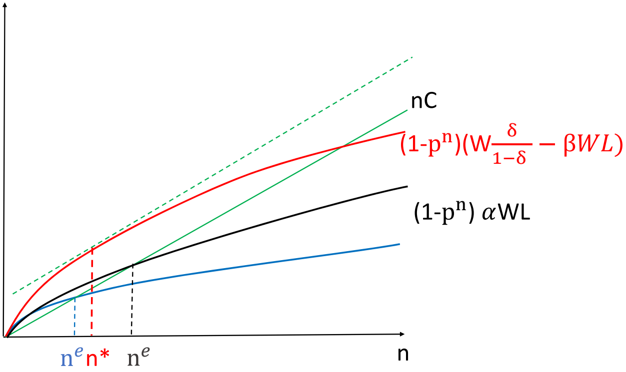
- Assume that there is free entry
- n firm can spend the cost C and each of them has a probability p to fail.
- Even if several firms innovate at the same time, only one gets the patent.

The probability that all firms fail is p^n.

The probability that at least one succeeds is $1 - p^n$.

Each firm has a probability $\frac{1}{n}$ to get the patent in case there is at least one innovation, i.e. $\frac{1}{n}(1 - p^n)$.

- At the social level, the optimal number of firm n maximizes $(1-p^n)(W\frac{\delta}{1-\delta}-\beta WL)-nC$
- FOC: $\frac{\partial((1-p^n)(W\frac{\delta}{1-\delta}-\beta WL))}{\partial n}=\frac{\partial(nC)}{\partial n}$
- Because of free entry, the number of firms that innovates in equilibrium is such that $(1-p^n)\alpha WL=nC$.



Remember

- When the lenght of the patent is too short, there is less firms that innovate compared to the social optimum.
- When the lenght of the patent is too long, there is too much entry. Race for patents leads to an overinvestment!
- The breadth of a patent defines how similar a product must be to infringe a patent. If the patent breadth is large it reduces the social value of the innovation and increases the profit of the innovator. $\Rightarrow$ Patent breadth and lenght are substitutable tools.

Alternative incentive mechanisms: Prizes or Subsidies

- A reward $R = \alpha WL$ to the innovator: same incentive to innovate as with a patent of lenght L but no deadweight loss.
- Offering a reward $R = C + \epsilon$ works also. The innovator is paid back for its innovation cost. But impossible when success is random
- Prizes require information about W, α and C + government funding $\Rightarrow$ taxes?
- Prices are often announced in advance : Lépine awards
- Numerous examples of targeted prizes:
  - **1795** : Napoleon 1st had organized a competition to reward the best food preservation process for army! Nicolas Appert invented “tinned food".
  - **1996** : The X prize (10 millions) to transport humans in space (100 km height)
  - **2006**: The H prize technical challenges (hydrogen production and storage, hydrogen vehicles, etc...)

The Arrow replacement effect

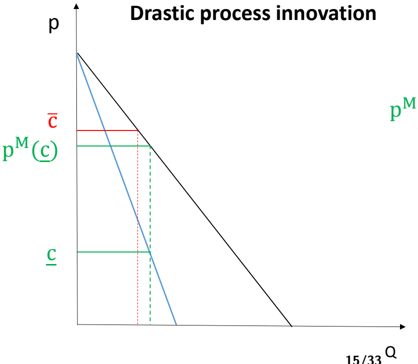
This effect highlighted by Arrow (1962) shows that paradoxically the innovation incentives of a monopoly might be lower than that of competing firms.

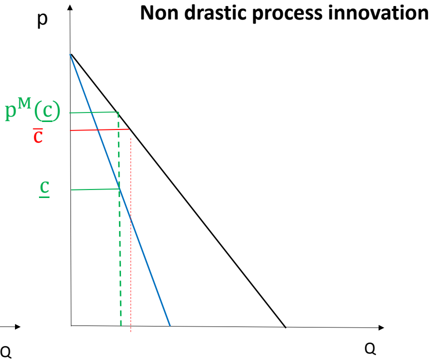
Assumptions

- Initially a firms' marginal cost is $\overline{c}$.
- In case of innovation the marginal cost is $\underline{c} < \overline{c}$.
- The monopoly price is denoted $p^M(c)$. In case of competition, firms compete a la Bertrand.
- Innovation can either be drastic or non drastric.

Innovation level

- Drastic innovation: $p^M(\underline{c}) < \overline{c}$
- Non drastic innovation: $p^M(\underline{c}) > \overline{c}$
- Monopoly price is such that : $Rm(q) = Cm(q)$





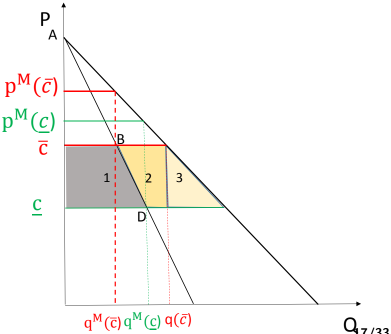
Competition *vs* Monopoly with drastic innovation

- Competitive situation [*ex post*-*ex ante*]
  - *ex ante*: 0
  - *ex post*:$(p^m(\underline{c}) - \underline{c})q^m(\underline{c})$
- Monopoly :[*ex post*-*ex ante*]
  - *ex ante*: $(p^m(\overline{c}) - \overline{c})q^m(\overline{c})$
  - *ex post*: $(p^m(\underline{c}) - \underline{c})q^m(\underline{c})$

It is immediate that incentives to innovate are lower in the monopoly case! This is because the monopoly replaces itself.

Competition vs Monopoly with non drastic innovation

- Competitive situation [*ex post*-*ex ante*= (1)+(2)]
  - *ex ante*: 0
  - *ex post*:$q(\bar{c})(\bar{c} - \underline{c})$
- Monopoly :[*ex post*-*ex ante*= (1)]
  - *ex ante*: $(p^m(\bar{c}) - \bar{c})q^m(\bar{c})$
  - *ex post*: $(p^m(\underline{c}) - \underline{c})q^m(\underline{c})$



Exercice 1:

Assumptions:

- Demand is linear, $p = a - q$
- Without innovation, the cost is $\overline{c}$.
- If one firm innovates, she has a unit cost $\underline{c}$.
- N firms compete a la Cournot.
- We denote $\phi = \frac{\overline{c} - \underline{c}}{a - \overline{c}}$ with $\phi < 1$.

Questions:

1. Determine the symmetric Cournot gain without innovation

1. Determine the symmetric Cournot gain without innovation.

- Firm j maximizes $(a - \sum_{j=1}^{n} q_j - \overline{c})q_j$.
- First order conditions are $a - 2q_j - \sum_{k \neq j}^{n} q_k - \overline{c} = 0$.
- In equilibrium $q_j = \frac{(a-\overline{c})}{n+1}$ and $\pi_j = \frac{(a-\overline{c})^2}{(n+1)^2}$.

Exercice 1: Solution

2. Determine the asymmetric Cournot equilibrium when one firm innovates.

- Firm 1 maximizes $(a - q_1 - \sum_{j=2}^{n} q_j - \underline{c})q_1$ Firm $j \neq 1$ maximizes $(a - q_1 - \sum_{j=2}^{n} q_j - \overline{c})q_j$.
- First order conditions are:

$$
\begin{aligned}
a - 2q_1 - \sum_{j=2}^{n} q_j - \underline{c} &= 0 \\
a - q_1 - 2q_j - \sum_{k=2,k\neq j}^{n} q_k - \overline{c} &= 0
\end{aligned}
$$

- Best reaction functions are $q_1 = \frac{a-\underline{c}-(n-1)q_j}{2}$ and $q_j = \frac{a-\overline{c}-q_1}{n}$.
- In eq. $q_1 = \frac{a-\underline{c}n+\overline{c}(n-1)}{n+1}$,$q_j = \frac{a+\underline{c}-2\overline{c}}{n+1}$, $P = \frac{a+\underline{c}+\overline{c}(n-1)}{n+1}$.
  $\pi_1 = \frac{((a-\overline{c})+n(\overline{c}-\underline{c}))^2}{(n+1)^2} = \frac{(a-\overline{c})^2}{(n+1)^2}(1+n\phi)^2$,
  $\pi_j = \frac{((a-\overline{c})-(\overline{c}-\underline{c}))^2}{(n+1)^2} = \frac{(a-\overline{c})^2}{(n+1)^2}(1-\phi)^2$.

Exercice 1: Solution

3. Determine the net gain to innovate.

- $\Delta = \frac{(a-\overline{c})^2}{(n+1)^2}((1+n\phi)^2-1) = \phi(a-\overline{c})^2\frac{n(n\phi+2)}{(n+1)^2}$

4. Determine the optimal market structure for a given ϕ.

- Maximizing Δ with respect to n, we obtain:

$$\frac{\partial \Delta}{\partial n} = \partial_n \frac{n(n\phi+2)}{(n+1)^2} = \frac{2}{(n+1)^3}(n\phi+1-n)$$

- We also check the second order condition:

$$\frac{\partial \Delta}{\partial n} = 0 \Rightarrow \hat{n} = \frac{1}{1-\phi}$$

$\frac{\partial^2 \Delta}{\partial n^2}\Big|_{n=\hat{n}} = \frac{2(\phi-1)^4}{(\phi-2)^3} < 0$ since $\phi < 1$.

- There exists a maximum in n which increases with the innovation level.

4. What is the optimal market structure in terms of innovation incentive when $\phi = \frac{1}{4}$? when $\phi = \frac{1}{2}$? when $\phi = \frac{2}{3}$?

- When $\phi = \frac{1}{4}$, $\hat{n} = 1$
- when $\phi = \frac{1}{2}$, $\hat{n} = 2$
- when $\phi = \frac{2}{3}$, $\hat{n} = 3$.

Conclusion: the market structure that gives the largest incentive to innovate is the monopoly when the innovation size is low and an oligopoly of intermediate level when the innovation size increases.

R&D diffusion and Cooperation

- Patent licensing
  - Incentive to sell the patent to other firms.
  - Patent trolls: Self defense system against infringement!
  - Patent pools : firms put in common their complementary patents often pro competitive (lower prices.)
- Firms voluntarily release their innovation : The open source software industry!
- R&D cooperation through "Research Joint Ventures" is often encouraged by antitrust legislation!
  - Obvious when research costs operate increasing returns to scale (e.g. high fix cost to build a lab)
  - More ambigous with decreasing return to scale.

Patent Licensing

Assumptions:

- An innovation reduces the marginal cost of an innovator from c to $c - x$.
- The innovator can choose a royalty rate r at which it licenses its new technology.
- We consider a 3-stage game :
  1. The innovator sets r,
  2. Other firms decide whether or not to become licensee,
  3. Firms compete à la Cournot.
- In a Cournot competition with n firms and an inverse demand $P = a - \sum_i^n q_i$, the optimal quantity is:

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

Patent Licensing

- In stage 3), the innovator i has a cost $c - x$ and its $n - 1$ competitors have a cost $c - x + r$.

$$q_i^* = \frac{1}{n+1}(a - (c - x) + (n-1)r)$$

$$q_l^* = \frac{1}{n+1}(a - 2r - (c - x)))$$

and

$$P^* = \frac{a + n(c - x) + (n-1)r}{n+1}$$

- It is straightforward that a licensee accepts any royalty $0 < r \leq x$.
- The innovator chooses r to maximize its profit:

$$\pi_i = (P - c + x)q_i^* + r(n-1)q_l^* = (q_i^*)^2 + r(n-1)q_l^*$$

- The FOC is:

$$\frac{\partial \pi_i}{\partial r} = 2q_i^* \frac{\partial q_i^*}{\partial r} + r(n-1)\frac{\partial q_l^*}{\partial r} = 0$$

- We obtain $\frac{\partial \pi_i}{\partial r} = \frac{(n-1)(n+3)(a-c-2r+x)}{(n+1)^2} > 0$. Therefore, the maximum is obtained for $r = x$.

- With licensing the innovator's profit is

$$\pi_i^* = \frac{(a-c)^2 + (2n+n^2-1)(a-c)x + x^2}{(n+1)^2}.$$

- Without licensing, the profit of the innovator would be $\hat{\pi}_i = \frac{(a-c+nx)^2}{(n+1)^2}$.
- $\hat{\pi}_i < \pi_i^*$: Whether the innovator licenses its patent or not, the competitive situation is the same and the marginal cost of the innovator is $c - x$ whereas, at $r = x$, the licensee's cost is c. The innovator now gets the additional profit of licensees.

Open source

- Firms who sell softwares use object code
- Open source softwares making the “source code" available for free have grown.
    - The operating system Linux
    - Web server Apache,
    - Web browser Firefox;
- The main rationale are
    - The existence of spillovers: the innovator benefits from the feedback of developers who fix bugs but also add developments and extensions.
    - The existence of a specificity of the software for the innovator (unapropriable component).

Exercice 2: R&D Cooperation

Assumptions:

- Demand is linear, $p = 2 - Q$ and two firms $i \in \{1,2\}$ compete à la Cournot.
- The cost of firm i is a function $c_i(w_i, x_j) = 1 - x_i - \beta x_j$ with $0 < \beta < 1$ representing a spillover, i.e. a benefit that a firm obtains from its rival's discovery (public part).
- We denote $\phi(x_i) = \frac{x_i^2}{2}$ the innovation cost.
- The timing we consider is 1) an investment stage which can be either non cooperative or cooperative, and 2) a competition stage.

Questions:

1. Determine the Cournot equilibrium in stage 2

Solution 2: R&D Cooperation

1. Determine the Cournot equilibrium in stage 2

- Each firm i maximizes $(1 - q_i - q_j + x_i + \beta x_j)q_i$.
- The FOC is $1 - 2q_i - q_j + x_i + \beta x_j = 0$.
- Crossing best reaction functions, we obtain $q_i(x_i, x_j) = \frac{1}{3}(1 + (2 - \beta)x_i - (1 - 2\beta)x_j)$;
- Gross profits are $\pi_i = \frac{1}{9}(1 - x_j + (2 - \beta)x_i + 2\beta x_j)^2$

2. Non Cooperative *R&D*: firms in stage 1 choose x_i and x_j. What is the equilibrium profit and quantity ?

- Net profits are $\Pi_i = \frac{1}{9}(1 - x_j + (2-\beta)x_i + 2\beta x_j)^2 - \frac{x_i^2}{2}$.
- Maximizing this function with respect to x_i, the FOC is: $\frac{2}{9}(1 - x_j + (2-\beta)x_i + 2\beta x_j)(2-\beta) - x_i = 0$.
- Using symmetry, $x_j = x_i$, we obtain

$$x_i^* = x_j^* = \frac{4-2\beta}{2\beta^2 - 2\beta + 5}.$$

- The equilibrium profit is

$$\pi_i^* = \frac{-2\beta^2 + 8\beta + 1}{(2\beta^2 - 2\beta + 5)^2} > 0$$

Solution 2: R&D Cooperation

3. Cooperative *R&D*: firms in stage 1 choose x_i and x_j that maximizes their joint profit. What is the equilibrium profit and quantity ?

- Each i maximizes $\Pi_1 + \Pi_2$ with respect to x_i
- Maximizing this function with respect to x_i, the FOC is:

$$\underbrace{\frac{2}{9}(1 - x_j + (2-\beta)x_i + 2\beta x_j)(2-\beta) - x_i}_{\frac{\partial \Pi_i}{\partial x_i}} +$$

$$\underbrace{\frac{2}{9}(1 - x_i + (2-\beta)x_j + 2\beta x_i)(2\beta - 1)}_{\frac{\partial \Pi_j}{\partial x_i}} = 0$$

.

- Using symmetry, $x_j = x_i$, we obtain

$$x_i^{coop} = x_j^{coop} = \frac{2(\beta+1)}{7 - 2\beta^2 - 4\beta}, \pi_i^{coop} = \frac{1}{7 - 2\beta^2 - 4\beta} > 0.$$

4. Compare the outcomes in the two cases.

A comparison shows that $\pi_i^{coop} > \pi_i^*$ for all $\beta \in [0,1]$.

Firms could when cooperating still choose the same investment as before, so this is necessarily profitable.

- $x_i^* > x_i^{coop}$ when $\beta < \frac{1}{2}$ to limit the R&D cost race.
- $x_i^* < x_i^{coop}$ when $\beta > \frac{1}{2}$ because firms internalize the strong spillover effect they exert on eachother which encourage them to invest.

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