Research and development (R&D)

What will a market look like in the future?

- which firms?
- which products?
- which production technology?

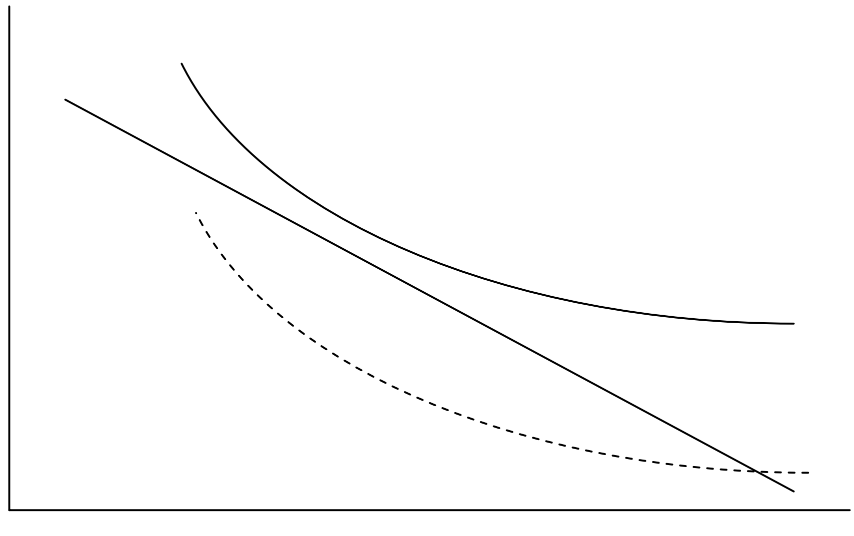
Depends on:

- entry deterrence
- regulation
- innovation ←
- …

Two kinds of innovation

- Product innovation
- Process innovation

Product innovation a special case of process innovation?



Process innovation

What is the value of an innovation?

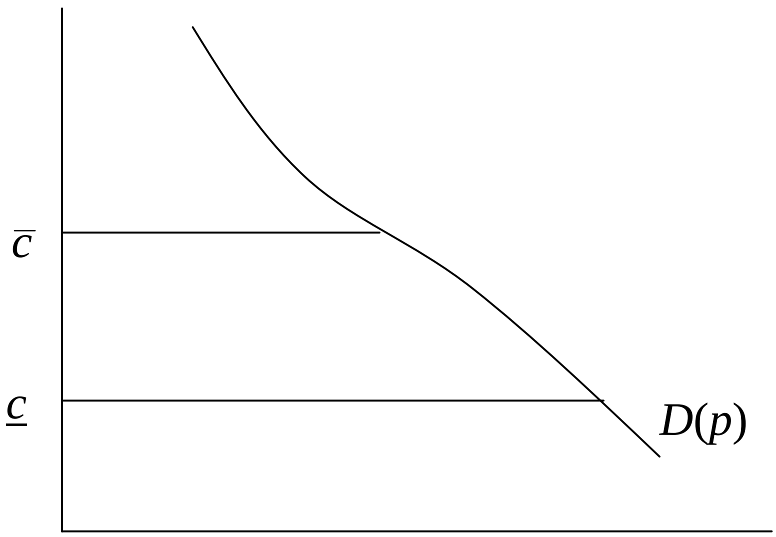
- for society
- for the innovating firm

It depends on the situation

Consider a firm making an innovation that is patent-protected forever.

Constant unit costs.
The innovation reduces costs from $\bar{c}$ to $\underline{c}$, $\bar{c} > \underline{c}$.

The value to a social planner:



$$V^s = \frac{1}{r}\int_{\underline{c}}^{\bar{c}} D(c)\,dc$$

The private value:

(1) monopoly

$$\pi(p, c) = (p - c)D(p)$$

$$p^m(c) = \text{argmax}_p\ \pi(p, c)$$

$$\pi^m(c) = \pi(p^m(c), c)$$

$$\frac{d\pi^m(c)}{dc} = \frac{\partial\pi}{\partial p}\frac{dp^m}{dc} + \frac{\partial\pi}{\partial c} = \frac{\partial\pi(p^m, c)}{\partial c} = -D(p^m(c))$$

$$p^m(c) > c,\ \forall\ c \Rightarrow D(p^m(c)) < D(c),\quad \forall\ c.$$

$$V^m = \frac{1}{r}\int_{\underline{c}}^{\bar{c}} D(p^m(c))dc < V^s$$

(2) competition

Suppose all firms in the market have constant unit costs $\bar{c}$.

Homogeneous products, price competition.

$p = \bar{c}$. $\pi = 0$.

One firm makes an innovation, getting $c = \underline{c}$.

Two cases to consider:

(i) the innovation is <u>drastic</u>: $p^m(\underline{c}) \leq \bar{c}$.

Even at the monopoly price, the innovating firm takes the whole market.

(ii) the innovation is <u>non-drastic</u>: $p^m(\underline{c}) > \bar{c}$.

Also now, the innovating firm takes the whole market, but has to set $p = \bar{c}$.

Consider a non-drastic innovation.

$$\pi^c = (\bar{c} - \underline{c})D(\bar{c})$$

$$V^c = \frac{1}{r}(\bar{c} - \underline{c})D(\bar{c}) = \frac{1}{r}\int_{\underline{c}}^{\bar{c}} D(\bar{c})dc$$

$$\forall\ c > \underline{c},\quad p^m(c) > p^m(\underline{c}) > \bar{c}$$

$$\Rightarrow D(p^m(c)) < D(\bar{c}),\ \ \forall\ c > \underline{c}.$$

$$\Rightarrow V^m < V^c.$$

$$D(\bar{c}) < D(c),\ \ \forall\ c < \bar{c}.$$

$$\Rightarrow V^c < V^s$$

$$\Rightarrow V^m < V^c < V^s$$

Exercise 10.1: This ranking also holds for drastic innovations

Why is $V^m < V^c$?

The <u>replacement effect</u> of an innovation. (Arrow, 1962)

In the competition case, the innovating firm escapes a zero-profit situation.

In the monopoly case, the innovating firm replaces one monopoly situation with another one.

Because of the replacement effect, competition is good for firms' incentives to innovate.

Exercises 10.2, 10.3.

(3) a monopolist threatened by entry

Suppose the entrant innovates in case the monopolist does not. This increases the monopolist's incentives to innovate, since now the alternative is worse.

$\pi^d(c_1, c_2)$ – profit per period in a duopoly when own cost is c_1 and rival's cost is c_2.

If the monopolist does *not* innovate and the other firm enters and does innovate, then the monopolist earns $\pi^d(\bar{c}, \underline{c})$ and the new firm earns $\pi^d(\underline{c}, \bar{c})$.

Assumption: $\pi^m(\underline{c}) \geq \pi^d(\bar{c}, \underline{c}) + \pi^d(\underline{c}, \bar{c})$

Value of the innovation for the monopolist:

$$V^m = \frac{1}{r}[\pi^m(\underline{c}) - \pi^d(\bar{c}, \underline{c})]$$

$$\Rightarrow V^m - V^c = \frac{1}{r}[\pi^m(\underline{c}) - \pi^d(\bar{c}, \underline{c}) - \pi^d(\underline{c}, \bar{c})] \geq 0$$

Opposite ranking, because of the efficiency effect: a monopolist earns more than two duopolists.

The two effects:

- the replacement effect
- the efficiency effect

Patent race:

Two firms, incumbent and potential entrant, fight to be first to make an innovation with an ever-lasting patent.

The more valuable the innovation is for the incumbent, the more resources it spends on being first, and the greater is the probability that it will win the race and get even more control over the market.

If the efficiency effect dominates the replacement effect, then $V^m > V^c$ and the incumbent gets even more control over the market.

Opposite, if $V^c > V^m$, then the entrant takes over, at least in expectation.

Tirole, Sec. 10.2

Strategic technology adoption

Technology without patent protection.
Technology adoption is costly.

Two firms, homogeneous products.
Constant unit costs $\bar{c}$. Zero profits.

Low-cost technology is available: $\underline{c} < \bar{c}$

Non-drastic innovation: If only one firm adopts the new technology, then it earns $\bar{c} - \underline{c}$ per unit per period.

Assume: $D(\bar{c}) = 1$.
Value of innovation: $V = \dfrac{\bar{c} - \underline{c}}{r}$
Value for non-innovating firm: 0.

Costs of adoption $\Rightarrow$ A firm will not want to adopt if the other one has already adopted.

Strategic incentives to adopt early. But what happens when both know they both have such incentives?

Adoption costs are decreasing over time: $C(t)$,
$C(0)$ very high, $C'(t) < 0$, $C''(t) > 0$.

Net present value of adopting new technology at time t, given that none of the firms adopted before time t, is:

$$L(t) = [V - C(t)]e^{-rt}$$

This is the value of being *technology leader*.

The follower does not adopt: $F(t) = 0, \forall\, t$.

(i) The technology leader picked in advance – technology adoption without strategic considerations.

The leader maximizes $L(t)$:

$$L'(t) = \left\{ \underbrace{-C'(t)}_{\substack{\text{marginal gain} \\ \text{from delay}}} \underbrace{-r[V - C(t)]}_{\substack{\text{marginal cost} \\ \text{from delay}}} \right\} e^{-rt} = 0$$

$$C(t^*) = V + \frac{C'(t^*)}{r} < V$$

(ii) Strategic considerations

Both firms consider technology adoption

Define t^c by: $L(t^c) = 0$

$\Rightarrow C(t^c) = V \;\Rightarrow\; t^c < t^*$

A firm never adopts before t^c.
The best response to the other firm's adoption at $t' > t^c$ is to adopt at $t \in (t^c, t')$.
The best response to the other firm's adoption at t^c is not to adopt at all.
The best response to the other firm not adopting is to adopt at $t^* > t^c$.

The only possible equilibrium is one in mixed strategies.

At each point t, each firm has a subjective probability $p(t)$ that the other firm adopts the technology at t, given that none of the firms has adopted so far.

In equilibrium, the firms are indifferent between adopting and not at each $t \geq t^c$.

Payoff to each firm if they both adopt at time t:

$$B(t) = -C(t)e^{-rt}$$

Equilibrium condition:

$$L(t)[1 - p(t)] + B(t)p(t) = F(t)$$

$$[V - C(t)][1 - p(t)] - C(t)p(t) = 0$$

$$\Rightarrow p(t) = 1 - \frac{C(t)}{V}, \quad t \geq t^c$$

- A strong strategic incentive for adoption
- But what if profits are positive with competition?

  - product differentiation?

Network externalities

Positive externalities between consumers

Example: telephone, telefax

More generally: network effects

Example: system goods, such as
- computers / software,
- video cassette recorders / video cassettes

When a new technology is available, each consumer must decide whether to switch.

A coordination problem: the more consumers switching, the higher is the utility for each from switching.

Excess inertia: consumers wait longer than what is socially optimum because no-one wants to be first to switch to the new technology.

Excess momentum: consumers switch too early because they do not want to be left with the old technology.

On the supply side:
- which technology to offer?
- standardization of new technology
- compatibility with other products

A model of consumer behaviour with network externalities

Two consumers.
Two technologies: old and new.

q = network size $\in \{1, 2\}$

$u(q)$ = a consumer's utility with *old* technology
$v(q)$ = a consumer's utility with *new* technology

Positive network externalities:

$$u(2) > u(1), \quad v(2) > v(1)$$

Better to be together than separate:

$$u(2) > v(1), \quad v(2) > u(1)$$

		Consumer 2	
		New	Old
Consumer 1	New	$v(2), v(2)$	$v(1), u(1)$
	Old	$u(1), v(1)$	$u(2), u(2)$

Two pure-strategy equilibria: {New, New} and {Old, Old}.

Excess inertia:
If the consumers play {Old, Old} and $v(2) > u(2)$.

Excess momentum:
If the consumers play {New, New} and $v(2) < u(2)$.

A more sophisticated model

Dynamic analysis: Two periods.
Incomplete information about the other consumer's preferences.

A consumer of type θ has preferences

$$u_\theta(q) \text{ and } v_\theta(q), \; q \in \{1, 2\}, \; \theta \in [0, 1].$$

The higher θ is, the more interested the consumer is in switching to new technology:

$$\frac{d\left[v_\theta(2) - u_\theta(1)\right]}{d\theta} > 0$$

Network externalities:

$u_\theta(2) > u_\theta(1), \; \forall \; \theta;$

$v_\theta(2) > v_\theta(1), \; \forall \; \theta.$

The highest θ-type prefers switching even if he is alone:

$v_1(2) > v_1(1) > u_1(2) > u_1(1)$

The lowest θ-type is the opposite:

$u_0(2) > u_0(1) > v_0(2) > v_0(1)$

- Coordination problems only for consumer types in the middle range.

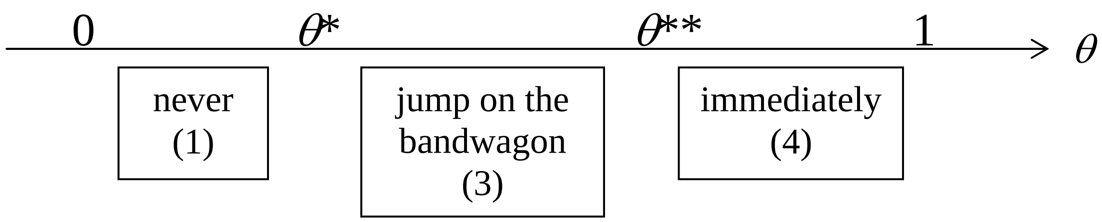
Consumers are independently and uniformly distributed on [0,1].

Four possible strategies for a consumer:

(1) Never switch
(2) Do not switch in period 1; switch in period 2 regardless of what happened in period 1.
(3) Do not switch in period 1; switch in period 2 if and only if the other consumer switched in period 1.
(4) Switch in period 1.

Strategy (2) is dominated by strategy (4): Strategy (4) fairs never worse than (2), and if the opponent plays strategy (3), then strategy (4) is strictly better than (2).

Equilibrium play depends on θ:



A consumer of type θ^* is indifferent between the old technology with a small network and the new technology with a big network:

$$u_{\theta^*}(1) = v_{\theta^*}(2)$$

A consumer of type θ^{**} is indifferent between:

(a) switching to a big network only if the other consumer switched in period 1, and otherwise staying in a big network; and

(b) switching in period 1, implying being in a small network if the other consumer plays strategy (1) and in a big network otherwise

$$v_{\theta^{**}}(2)(1 - \theta^{**}) + u_{\theta^{**}}(2)\theta^{**} = v_{\theta^{**}}(1)\theta^{*} + v_{\theta^{**}}(2)(1 - \theta^{*})$$

$$\Leftrightarrow$$

$$[v_{\theta^{**}}(2) - u_{\theta^{**}}(2)]\theta^{**} = [v_{\theta^{**}}(2) - v_{\theta^{**}}(1)]\theta^{*}$$

$$\Rightarrow v_{\theta^{**}}(2) > u_{\theta^{**}}(2)$$

<u>Excess inertia may occur</u>: In the case where both consumers have θs just below θ^{**}, no-one switches to the new technology because they play the jump-on-the bandwagon strategy, even if $v_{\theta}(2) > u_{\theta}(2)$.

<u>The supply side</u>

<u>Stage 1</u>: Each firm decides whether its product is to be compatible with rival firms' products.
<u>Stage 2</u>: Price or quantity competition.

<u>Trade-off</u>: Compatibility implies a larger market, but tougher competition.

Vertical product differentiation

Quality competition

Consumers agree on what is the best product variant.
But they differ in their willingness to pay for quality.

s – quality
θ – measure of a consumer's taste for quality.

If a consumer of type θ buys a product of quality s at price p, her net utility is:

$$U = \theta s - p$$

$F(\theta)$ – cumulative distribution function of consumer type

$F(\theta')$ – fraction of consumers with type $\theta \leq \theta'$.

Unit demand: If $\theta s - p \geq 0$, then a consumer of type θ buys one unit of the good.

One firm:

At price p, its demand is $D(p) = 1 - F\left(\frac{p}{s}\right)$.

Two firms:

Suppose $s_1 < s_2$, $p_1 < p_2$. The indifferent consumer:

$$\tilde{\theta} s_1 - p_1 = \tilde{\theta} s_2 - p_2$$

$$\tilde{\theta} = \frac{p_2 - p_1}{s_2 - s_1}$$

Product 2 *quality dominates* product 1 if:

$$\tilde{\theta} < \frac{p_1}{s_1} \Leftrightarrow \frac{p_2}{s_2} < \frac{p_1}{s_1}$$

Otherwise, $\left(\frac{p_2}{s_2} \geq \frac{p_1}{s_1}\right)$, demand is:

$$D_1(p_1, p_2) = F\left(\frac{p_2 - p_1}{s_2 - s_1}\right) - F\left(\frac{p_1}{s_1}\right)$$

$$D_2(p_1, p_2) = 1 - F\left(\frac{p_2 - p_1}{s_2 - s_1}\right)$$

Assume:

Consumers uniformly distributed across $[\underline{\theta}, \overline{\theta}]$.

Consumers sufficiently different:

$$\overline{\theta} > 2\underline{\theta}$$

(avoiding quality dominance in equilibrium)

Firm 2 is the high-quality producer: $s_2 > s_1$.

Production costs independent of quality: c

Equilibrium in prices

$$\tilde{\theta} = \frac{p_2 - p_1}{s_2 - s_1}$$

Firm 1's profit: $\pi_1 = (p_1 - c)\left(\frac{p_2 - p_1}{s_2 - s_1} - \max\left[\underline{\theta}, \frac{p_1}{s_1}\right]\right)$

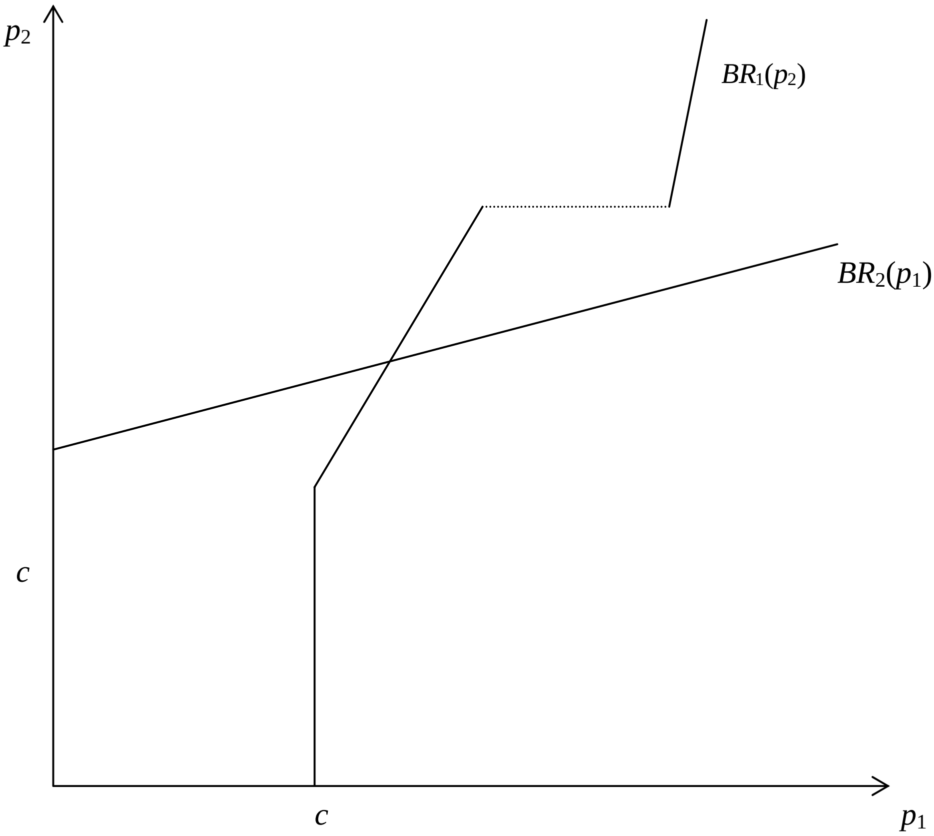
Best response of firm 1:

$$p_1 = \begin{cases} \frac{1}{2}\left[c + \frac{s_1}{s_2} p_2\right], \text{ if } p_2 > c + \underline{\theta}(s_1 + s_2) \\ \frac{1}{2}\left[c + p_2 - \underline{\theta}(s_2 - s_1)\right], \text{if } c + \underline{\theta}(s_1 + s_2) \geq p_2 \geq c + \underline{\theta}(s_2 - s_1) \\ c, \text{ if } p_2 < c + \underline{\theta}(s_2 - s_1) \end{cases}$$

Firm 2's profit: $\pi_2 = (p_2 - c)\left(\overline{\theta} - \frac{p_2 - p_1}{s_2 - s_1}\right)$

Best response of firm 2:

$$p_2 = \frac{1}{2}\left[c + p_1 + \overline{\theta}(s_2 - s_1)\right]$$



Equilibrium prices:

$$p_1 = c + \frac{1}{3}\left(\overline{\theta} - 2\underline{\theta}\right)\left(s_2 - s_1\right)$$
$$p_2 = c + \frac{1}{3}\left(2\overline{\theta} - \underline{\theta}\right)\left(s_2 - s_1\right)$$

Condition for the market being *covered*, $\underline{\theta} \geq \frac{p_1}{s_1}$:

$$c \leq \tfrac{1}{3}[\underline{\theta}(2s_1 + s_2) - (\overline{\theta} - \underline{\theta})(s_2 - s_1)]$$

- The high-quality firm sets the higher price:

$$p_2 - p_1 = \tfrac{1}{3}(\overline{\theta} + \underline{\theta})(s_2 - s_1) > 0$$

- The high-quality firm has the higher demand:

$$\tilde{\theta} = \frac{p_2 - p_1}{s_2 - s_1} = \tfrac{1}{3}(\overline{\theta} + \underline{\theta}) < \tfrac{1}{2}(\overline{\theta} + \underline{\theta})$$

$$D_1 = \tilde{\theta} - \underline{\theta} = \tfrac{1}{3}(\overline{\theta} - 2\underline{\theta})$$

$$D_2 = \overline{\theta} - \tilde{\theta} = \tfrac{1}{3}(2\overline{\theta} - \underline{\theta})$$

- The high-quality firm has the higher profit:

$$\pi_1(s_1, s_2) = (p_1 - c)D_1 = \tfrac{1}{9}(\overline{\theta} - 2\underline{\theta})^2(s_2 - s_1)$$

$$\pi_2(s_1, s_2) = (p_2 - c)D_2 = \tfrac{1}{9}(2\overline{\theta} - \underline{\theta})^2(s_2 - s_1)$$

- Firms' profits are increasing in the quality difference

<u>Two-stage game</u>

Stage 1: Firms choose qualities
Stage 2: Firms choose prices

Stage 1 – feasible quality range: $[\underline{s}, \overline{s}]$
Assume: $c \le \tfrac{1}{3}[\underline{\theta}(2\underline{s} + \overline{s}) - (\overline{\theta} - \underline{\theta})(\overline{s} - \underline{s})]$

In equilibrium: $s_1 = \underline{s}$, $s_2 = \overline{s}$ (or the opposite).

- Asymmetric equilibrium
- Maximum differentiation

What if …

- $c > \frac{1}{3}[\underline{\theta}(2\underline{s} + \bar{s}) - (\bar{\theta} - \underline{\theta})(\bar{s} - \underline{s})]$
    - the low-quality firm will choose a quality above $\underline{s}$.

- $\bar{\theta} < 2\underline{\theta}$
    - only one firm active in the market:
      $p_1 = c$, $D_1 = 0$, $\pi_1 = 0$
      $p_2 = c + \frac{1}{2}\bar{\theta}(\bar{s} - \underline{s})$, $D_2 = 1$, $\pi_2 = \frac{1}{2}\bar{\theta}(\bar{s} - \underline{s})$
    - natural monopoly: low consumer heterogeneity makes price competition too intense for the low-quality firm

Natural duopoly for a range of consumer heterogeneity greater than $\bar{\theta} > 2\underline{\theta}$.

Vertical differentiation: the number of firms determined by *consumer heterogeneity*.

Horizontal differentiation: the number of firms determined by *market size*.