Lecture 3 - Innovation

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Innovation and Market Structure

Innovation as a margin of competition

Innovation is the **dynamic** margin of competition: firms try to change the game by shifting **costs** and **demand**.

Why IO cares

▶ Innovation changes **prices, mark-ups, and welfare** today
▶ Innovation changes **market structure** tomorrow (entry/exit, dominance, concentration)
▶ Policy trade-off: **static efficiency** (low prices) vs **dynamic efficiency** (strong incentives)

Types of innovation (and what we model today)

Process innovation (this lecture's workhorse case)

▶ Lowers marginal (or average) cost, e.g. a better production method

▶ Think: a shift from c_0 to $c_1 < c_0$

Product innovation

▶ Raises willingness to pay, expands demand, or creates new varieties

▶ Often analysed with differentiated products and quality ladders (later in the course)

Stages (high level): Research $\rightarrow$ Development $\rightarrow$ Adoption

Learning objectives

▶ Compute the **private value** of a process innovation under different market structures

▶ Define **drastic vs non-drastic** innovations and explain the **replacement effect** (Arrow 1972)

▶ Understand how **free entry + endogenous R&D** link innovation to **concentration** (Dasgupta and Stiglitz 1980)

> **i** Today: roadmap
>
> 1. Benchmark model: value under **monopoly**, **perfect competition**, and **social planner**
> 2. **Drastic vs non-drastic** innovations and the **replacement effect**
> 3. Innovation with **oligopoly** and **entry threat**
> 4. **Concentration** and **R&D** (Dasgupta and Stiglitz 1980)

Discussion: Why does innovation matter for growth?

Before the Industrial Revolution (~1760–1840), global GDP per capita was roughly flat for centuries. Since then, it has grown exponentially.

> **i Question for you**
>
> ▶ What role did innovation (new production methods, machinery, transport) play in this transformation?
> ▶ Why might market structure affect the *rate* of innovation — and therefore long-run growth?
> ▶ Should we expect monopolies or competitive markets to innovate more? (We'll answer this formally in a moment.)

Market structure and innovation: a two-way relationship

Market structure → innovation

▶ Competition affects profits, appropriability, and the gain from becoming "better" than rivals

Innovation → market structure

▶ Cost/demand shifts affect entry, market shares, and concentration (and can create dominance)

Measuring incentives: willingness to pay (WTP)

▶ **Firm WTP**: the max lump-sum payment that leaves profits
  unchanged $\Rightarrow$ WTP $= \Delta\pi$

▶ **Planner WTP**: the max lump-sum payment that leaves welfare
  unchanged $\Rightarrow$ WTP $= \Delta W$

In what follows we compute WTP for: **Monopoly** (before/after),
perfect competition (before; exclusive rights after), and the **social
planner**.

Benchmarks: Value of a Process Innovation

Setup: linear demand + cost-reducing innovation

Inverse demand

$$P(Q) = A - Q$$

Technology

▶ Constant marginal cost $c \in \{c_0, c_1\}$
▶ Process innovation reduces marginal cost from c_0 to c_1 with $c_1 < c_0 < A$

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i Goal

Compute the value of moving from c_0 to c_1 under different market structures.

Monopoly benchmark: problem and solution

Problem

$$\max_{Q} \ (A - Q - c)Q$$

Solution

$$Q^m(c) = \frac{A - c}{2}, \qquad P^m(c) = \frac{A + c}{2}, \qquad \pi^m(c) = \frac{(A - c)^2}{4}$$

Monopoly WTP for innovation

WTP for the innovation

$$\Delta\pi^m = \pi^m(c_1) - \pi^m(c_0) = \frac{(A - c_1)^2 - (A - c_0)^2}{4}$$

> **i** Interpretation
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> $\Delta\pi^m$ is the monopolist's value of *exclusive* access to the lower cost c_1 (it is incremental because the firm already earns rents at c_0).

Perfect competition benchmark (innovation creates rents)

Before innovation (all firms at MC c_0):

- Competitive price: $P_0^{pc} = c_0$
- Firm profit: $\pi = 0$

After innovation (innovator has exclusive use / patent):

- **Drastic**: innovator behaves as a monopolist with cost c_1
- **Non-drastic**: innovator is constrained by the competitive fringe at cost c_0 (limit pricing)
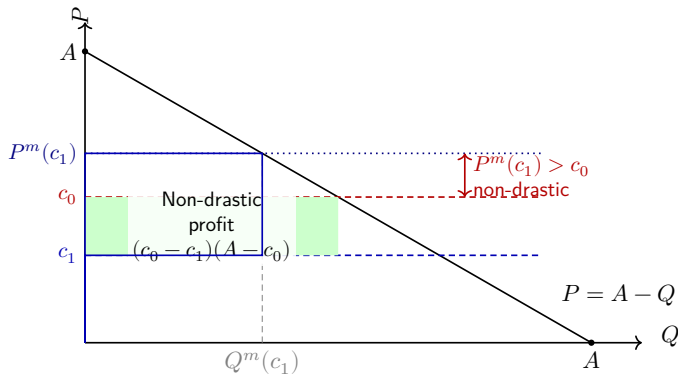
Innovator profit / WTP

$$\Delta\pi^{pc} = \begin{cases} \pi^m(c_1) & \text{(drastic)} \\ (c_0 - c_1)(A - c_0) & \text{(non-drastic, } p = c_0) \end{cases}$$

Why the non-drastic formula? If the innovator sets $p = c_0$, quantity is $Q = A - c_0$, so profits are $(p - c_1)Q = (c_0 - c_1)(A - c_0)$.

Drastic innovation condition

$$P^m(c_1) < c_0 \quad \Leftrightarrow \quad \frac{A + c_1}{2} < c_0 \quad \Leftrightarrow \quad A + c_1 < 2c_0$$

Numeric check: drastic or non-drastic?

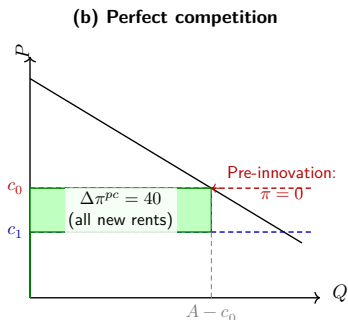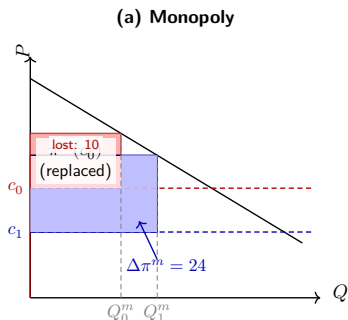Take $A = 20$, $c_0 = 10$, and $c_1 = 6$.

▶ **Drastic condition**: $A + c_1 = 26 > 2c_0 = 20 \rightarrow$ **non-drastic**
▶ Innovator limit-prices at $p = c_0 = 10$, sells $Q = A - c_0 = 10$
▶ Competitive innovator profit: $(c_0 - c_1)(A - c_0) = 4 \times 10 = 40$
▶ Recall monopoly WTP: $\Delta \pi^m = \frac{(14)^2 - (10)^2}{4} = \frac{196 - 100}{4} = 24$

> **i** Replacement effect preview
>
> The competitive innovator earns $40 > 24$ (the monopolist's WTP). The monopolist gains less because it already earns $\pi^m(c_0) = 25$ before innovating — it is partly **replacing** existing rents.

Replacement effect: visual comparison

▶ Left panel: the incumbent monopolist already earns $\pi^m(c_0)$ before innovating.

▶ Innovation raises monopoly profit only by the increment $\pi^m(c_1) - \pi^m(c_0)$.

▶ Right panel: under competitive pre-innovation conditions, the innovation mostly **creates** rents.

(a) Monopoly

lost: 10
(replaced)

$\Delta \pi^m = 24$

$Q_0^m \quad Q_1^m$

(b) Perfect competition

Pre-innovation: $\pi = 0$

$\Delta \pi^{pc} = 40$
(all new rents)

$A - c_0$

Replacement effect (Arrow 1972)

▶ Under perfect competition, pre-innovation profits are approximately zero.

▶ Under monopoly, pre-innovation profits are positive.

▶ So the same innovation has a larger incremental private value in competitive settings.

Appropriability and imitation

▶ If the innovation cannot be protected (instant diffusion / perfect imitation), competition drives price to c_1 and the innovator's WTP is zero.

▶ Most IO policy questions start from the fact that appropriability is imperfect but positive (patents, secrecy, lead time).

Replacement effect: a one-line comparison (drastic case)

If the innovation is drastic and grants exclusive rights:

$$\Delta\pi^{pc} = \pi^m(c_1), \qquad \Delta\pi^m = \pi^m(c_1) - \pi^m(c_0)$$

$$\Delta\pi^{pc} - \Delta\pi^m = \pi^m(c_0) > 0$$

▶ The wedge equals pre-innovation monopoly rents, $\pi^m(c_0)$.
▶ The replacement effect is strongest when baseline monopoly rents are high.

# Replacement effect: intuition

> **!** Takeaway
>
> Holding everything else fixed, an incumbent monopolist has **weaker** incentives to innovate than a competitive industry because it is "replacing" its own pre-innovation rents.

Empirical example: competition and innovation

▶ Low competition: firms have little pressure to "escape."

▶ Intermediate competition: innovation incentives are strongest for neck-and-neck firms.

▶ Very high competition: post-innovation rents are compressed, reducing innovation incentives.

> **i** Inverted-U evidence (QJE)
>
> Aghion et al. (2005) document an **inverted-U** relationship between product-market competition and innovation (patents/citations) in UK firms, consistent with "escape competition" incentives for neck-and-neck firms and a **replacement effect** for laggards.
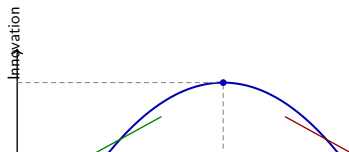
Social Value of Innovation

Social planner: value of a cost reduction

Efficient output (price equals marginal cost)

$$Q^{sp}(c) = A - c$$

Total surplus (welfare):

$$W(c) = \int_0^{A-c} (A - Q - c)\, dQ = \frac{(A-c)^2}{2}$$

> **i** Interpretation
>
> In this linear example, $\Delta W = 2\,\Delta\pi^m$: the planner values the
> output expansion that the monopolist does not internalise.

Max WTP for innovation (social planner):

$$\Delta W = W(c_1) - W(c_0) = \frac{(A - c_1)^2 - (A - c_0)^2}{2}$$

▶ This is the full increase in total surplus from lowering marginal cost.

▶ In the linear benchmark, it is exactly twice the monopoly incremental profit.

Putting the benchmarks side-by-side

Environment	What the innovator captures	WTP / value
Monopoly (incumbent)	Incremental rents	$\Delta\pi^m = \pi^m(c_1) - \pi^m(c_0)$
Perfect competition (pre) + exclusive rights (post)	Mostly created rents	$\Delta\pi^{pc} = \pi^m(c_1)$ if drastic; otherwise limit pricing profit
Social planner	Full surplus gain	$\Delta W = W(c_1) - W(c_0)$

! Policy interpretation

Private incentives and social value need not align: ΔW **can exceed** $\Delta\pi$, but market power created by IPRs also generates static distortions. This is the basic patents trade-off.

Empirical example: private vs social returns

▶ Measured producer gains capture only part of innovation's value.

▶ Consumer surplus from quality improvements can be very large.

▶ This gap motivates policy tools that raise private appropriability.

ℹ Welfare gains from product innovation (JPE)

Trajtenberg (1989) estimates consumer and producer surplus gains from quality improvements in computed tomography (CT) scanners, illustrating that the **social value** of innovation can greatly exceed the innovator's private returns.

Quick numeric check (optional)

Take $A = 20$, $c_0 = 10$, and $c_1 = 6$.

▶ Monopoly: $\pi^m(c_0) = 25$, $\pi^m(c_1) = 49$, so $\Delta\pi^m = 24$
▶ Planner: $W(c_0) = 50$, $W(c_1) = 98$, so $\Delta W = 48$ (twice the monopoly gain)

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i Discussion question

In what sense is this "too little" innovation from a welfare perspective? What policy instruments could close the gap?

Innovation with Rivals and Entry

Incentives to innovate in oligopoly

Takeaway

▶ Innovation incentives need not be monotone in "competition intensity"

▶ They depend on:
  ▶ Number of firms (n)
  ▶ Product differentiation
  ▶ Mode of competition (price vs quantity)
  ▶ Whether innovation is **protectable** (patents/lead time) and whether there are **spillovers**

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i Rule of thumb

More rivals reduces baseline profits (hurting incentives), but can increase the value of being the low-cost firm (helping incentives).

Impact of number of firms (Cournot intuition)

Linear Cournot with n firms: incentives can follow an **inverse-U** as n increases.

Two opposing effects as $n \uparrow$:

▶ **Competition effect**: profits for all firms fall (discourages innovation)

▶ **Competitive advantage effect**: cost advantage becomes more valuable when there are more inefficient rivals (encourages innovation)

Monopoly threatened by entry: setup

Incumbent monopoly faces potential entrant:

▶ Both can acquire innovation reducing MC from c_0 to $c_1 < c_0$
▶ Entrant can enter profitably **only if** it gets innovation
▶ Let $\pi^d(c_i, c_j)$ denote firm i's profit in the post-entry **duopoly** when own cost is c_i and the rival's cost is c_j

Timing/game structure:

We compare the **willingness to pay** for innovation (e.g., in a patent auction or R&D race). The innovation is awarded to whichever firm values it more highly. Entry happens *after* the innovation is allocated.

Entry threat: payoff structure

Payoffs:

▶ **If incumbent gets innovation**: entrant stays out
   ▶ Incumbent: $\pi^m(c_1)$; Entrant: 0
▶ **If entrant gets innovation**: entrant enters
   ▶ Incumbent: $\pi^d(c_0, c_1)$; Entrant: $\pi^d(c_1, c_0)$

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i Strategic value

Innovation can change market structure (monopoly vs duopoly),
so incentives are not only about production efficiency.

Entry threat: pre-emption incentives (Gilbert and Newbery 1982)

Per-period value of innovation

$$V_I = \pi^m(c_1) - \pi^d(c_0, c_1)$$

$$V_E = \pi^d(c_1, c_0)$$

Incumbent has stronger incentives if:

$$V_I > V_E \quad \Leftrightarrow \quad \pi^m(c_1) > \pi^d(c_1, c_0) + \pi^d(c_0, c_1)$$

This typically holds when products are close substitutes (entry is very harmful).

! Interpretation

The incumbent may innovate **more** than an entrant because

Discussion: when does pre-emption fail?

> **i** Discussion question
>
> Under what market conditions might an entrant have stronger innovation incentives than the incumbent? What features would reverse the pre-emption result?

Empirical example: strategic incentives and market share

> **i** Pre-emptive innovation patterns (ReStud)
>
> Blundell et al. (1999) find that higher market share and market value predict more patenting/innovations in UK manufacturing firms, consistent with **strategic** incentives (including pre-emptive innovation) in oligopolistic industries.

Endogenous R&D and Market Structure: Dasgupta and Stiglitz (1980)

Setup and key result

The Dasgupta and Stiglitz (1980) model treats R&D as an **endogenous sunk cost**: firms spend on R&D to reduce marginal cost, and entry adjusts endogenously.

The key result is a clean link between:

▶ **Demand conditions** (elasticity, market size)
▶ **Innovative opportunities** (how effective R&D is at lowering costs)
▶ **Equilibrium concentration** (how many firms survive under free entry)

The linear model gave us clean closed-form comparisons. The D-S framework sacrifices tractability for generality — but delivers a structural result linking innovation to concentration.

Notation for this section

Symbol	Type	Meaning
x	Choice	R&D expenditure per

Planner benchmark

Question: Do more firms imply more innovation?

Primitives:

- $U(Q) =$ gross social benefit
- $c = c(x) =$ constant marginal cost depending on R&D expenditure x
- Assumption: $c'(x) < 0$ (R&D reduces cost)

Social optimum:

$$\max_{x,Q} V(x,Q) = U(Q) - c(x)Q - x$$

First-order condition in x:

$$-c'(x)Q = 1$$

Planner benchmark: interpretation

▶ Optimal R&D increases with scale Q: a larger market makes cost reduction more valuable

Empirical example: market size and innovation

i Pharmaceutical innovation responds to demand

Acemoglu and Linn (2004) show that larger potential markets
lead to
- ▶ more pharmaceutical innovation (new drugs/new
  molecular entities)
- ▶ → consistent with models where the return to innovation
  rises with **scale**.

Firm's problem

Assumptions: Firms engage in **Cournot (quantity) competition** with symmetric costs. Each firm chooses R&D expenditure x_i and output q_i simultaneously.

Firm i's problem:

$$\max_{x_i, q_i} \pi(x_i, q_i) = [P(q_i + q_{-i}) - c(x_i)]q_i - x_i$$

Symmetric equilibrium:

▶ $q_1^* = \cdots = q_N^* = Q^*/N$ and $x_1^* = \cdots = x_N^* = x^*$

Intuition check: What determines N^*?

What forces at work here?

- ▶ **Entry incentive:** If industry profits are positive, more firms want to enter
- ▶ **R&D cost:** Each firm must spend x^* to achieve low cost $c(x^*)$
- ▶ **Market power:** More firms $\rightarrow$ lower mark-ups $\rightarrow$ lower operating profits
- ▶ **Zero-profit equilibrium:** Entry stops when operating profits just cover R&D outlays

Key insight: Equilibrium concentration (N^*) balances these forces. We'll derive the precise formula by combining the pricing and free-entry conditions.

Reminder: Cournot perceived elasticity

From Lecture 1: Under Cournot competition, firm i perceives the demand elasticity facing its own output as $N\varepsilon$, where ε is the market demand elasticity.

This gives the markup formula:

$$\frac{P-c}{P} = \frac{1}{N\varepsilon}$$

Rearranging:

$$P\left(1 - \frac{1}{N\varepsilon}\right) = c$$

We'll use this to link pricing to R&D in the Dasgupta–Stiglitz model.

Equilibrium pricing

First-order condition in q_i:

$$P(Q^*)\left(1 - \frac{1}{N\varepsilon}\right) = c(x^*)$$

where $\varepsilon = -\frac{\partial Q}{\partial P}\frac{P}{Q}$ is the demand elasticity.

Interpretation:

▶ The term $\left(1 - \frac{1}{N\varepsilon}\right)$ captures market power via the perceived demand elasticity under Cournot

   ▶ More firms ($N \uparrow$) $\rightarrow$ perceived demand becomes more elastic $\rightarrow$ mark-ups fall

Free entry condition

Zero profit condition (free entry):

$$\pi = 0 \quad \Rightarrow \quad (P - c)\frac{Q^*}{N^*} - x^* = 0$$

Rearrange:

$$P - c = N^* \frac{x^*}{Q^*}$$

Deriving the concentration formula (I): Setup

Combine the two conditions:

▶ From pricing FOC: $P - c = \frac{P}{N\varepsilon}$
▶ From free entry: $P - c = \frac{Nx}{Q}$

Equating the two expressions:

$$\frac{P}{N\varepsilon} = \frac{Nx}{Q}$$

(We solve for N on the next slide.)

Deriving the concentration formula (II): Solution

Introduce the R&D cost elasticity $\alpha = -\frac{dc(x)}{dx}\frac{x}{c}$ (from firm's R&D FOC).

This implies: $\frac{x}{cq} = \alpha$, so $\frac{Nx}{Q} = \frac{Nx}{Nq} = \frac{x}{q} = \alpha c$

Substitute into our equation:

$$\underbrace{\frac{P}{N\varepsilon}}_{\text{markup}} = \underbrace{\alpha c}_{\text{R\&D cost per unit}}$$

Divide by P **and use** $c/P = 1 - 1/(N\varepsilon)$ **from the pricing FOC:**

$$\frac{1}{N\varepsilon} = \alpha\left(1 - \frac{1}{N\varepsilon}\right) \quad \Rightarrow \quad \frac{1}{N^*} = \frac{1}{\varepsilon} \cdot \frac{\alpha}{1+\alpha}$$

Equilibrium concentration

Equilibrium concentration satisfies:

$$\frac{1}{N^*} = \frac{1}{\varepsilon} \cdot \frac{\alpha}{1+\alpha}$$

> **i** Interpretation
>
> Concentration and research intensity are jointly determined: entry expands N until operating surplus covers R&D outlays x^*. Higher R&D cost elasticity (α) supports higher concentration; more elastic demand lowers concentration.

Numerical illustration

Using the concentration formula with specific values:

$$\frac{1}{N^*} = \frac{1}{\varepsilon} \cdot \frac{\alpha}{1+\alpha}$$

▶ If $\varepsilon = 2$ and $\alpha = 1$: $\frac{1}{N^*} = \frac{1}{2} \cdot \frac{1}{2} = \frac{1}{4}$, so $N^* = 4$ firms
▶ If $\varepsilon = 2$ and $\alpha = 3$: $\frac{1}{N^*} = \frac{1}{2} \cdot \frac{3}{4} = \frac{3}{8}$, so $N^* \approx 2.7$ firms

> **ℹ** Discussion question
>
> If a government subsidy increases the R&D cost elasticity (α, making R&D more effective), what does the model predict for market structure? Is this welfare-improving?

Key comparative statics (I)

With $P(Q) = \sigma Q^{-\varepsilon}$ and $c(x) = \beta x^{-\alpha}$:

Dynamic vs static efficiency trade-off:

▶ $x^*(N+1) < x^*(N)$ (more firms → less R&D per firm)
▶ $Q^*(N+1) > Q^*(N)$ (more firms → higher output)

Research intensity:

▶ Often maximized at moderate concentration (Scherer-style inverse-U)

Interpretation:

▶ Market structure affects both static outcomes (Q) and dynamic investment incentives (x)

Key comparative statics (II)

Greater R&D effectiveness (higher α) associated with higher concentration:

$$\frac{\partial(1/N^*)}{\partial\alpha} > 0$$

Demand growth stimulates R&D:

$$\frac{\partial x^*}{\partial\sigma} > 0$$

Interpretation:

- ▶ Larger markets (higher σ) increase the return to cost reduction
- ▶ More effective R&D (higher α) can support higher concentration in equilibrium

Summary and next week

Summary

▶ Innovation value depends on the objective: $\Delta \pi$ **(private)** versus ΔW **(social)**

▶ Replacement effect: pre-innovation rents reduce the incumbent's incremental gain from innovation

▶ With entry threat, innovation can be worth more because it changes **market structure** (monopoly vs duopoly)

▶ In oligopoly, incentives reflect competing forces (competition effect vs competitive advantage effect)

Next week: patents and IPRs

▶ Patents as incentives: monopoly rights vs. dynamic efficiency

▶ Patent races and timing

▶ Disclosure, licensing, and welfare

▶ Horizontal and vertical innovation (brief)

References

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