# Lecture 2
# What is Innovation?

## E5104 – Economics of Innovation

**Bernhard Ganglmair**

UNIVERSITY OF MANNHEIM

Leibniz Gemeinschaft

ZEW

Innovation = creation of something new

the conversion of an idea for a new product or process into reality, putting the idea or invention into practice.

# Three Stages of Innovation

1. **Invention** – creation of an idea of how to do or make something
   - “an increment in the set of total technical knowledge of a given society" (Mokyr 1992)
   - “prescription for a producible product or operable process so new as not to have been obvious to one skilled in the art at the time the idea was put forward" (Schmookler 1966)

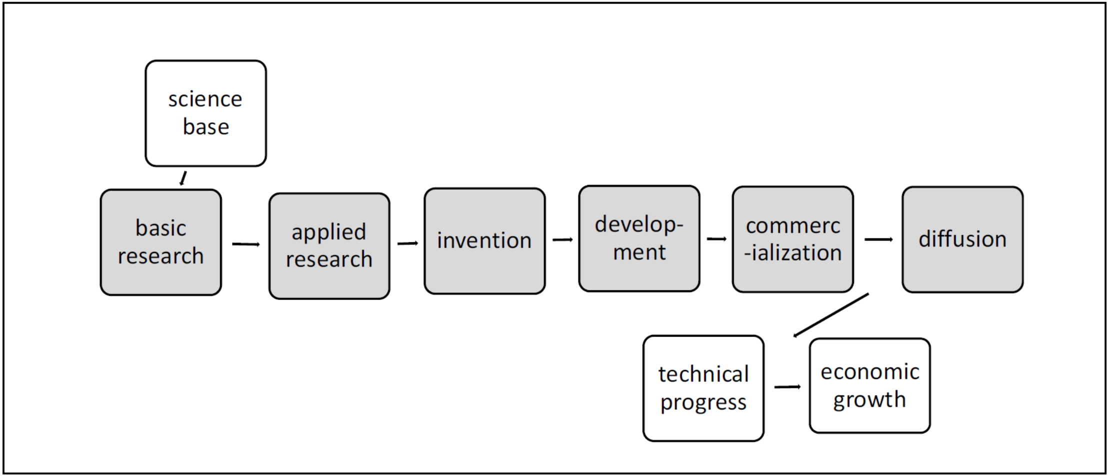
2. **Innovation** – making an idea for a new product or process real, putting it into practice (incl. development and commercialization)

3. **Diffusion** – spread of a new invention/innovation throughout society (or relevant part of society)

# Key Features of Innovation

- Economics factors: yes; but **chance** and **unpredictability** are often seen in the process
- Innovation is often modeled as a linear process from science to the end product, **feedback** in the other direction is important to eventual success
- Innovation needs the right **environment** where factors, such as consumer demand and capabilities of necessary complementary products, come together
- Some innovations are made **before** the relevant science is completely understood

# Linear Model of the Innovative Process




Source: Hall & Helmers (2022)

# Example: Pharmaceutical Innovation

- **Science base**: accumulated knowledge in biology, organic chemistry, and biomedicine
- Pharma firms conduct **basic research** to ensure researchers have access to frontier; but also rely on basic research done at universities and government laboratories (often in cooperation)
- **Applied research** directed at particular disease involves screening of likely compounds
- An **invention** is successfully identifying an effective compound

# Example: Pharmaceutical Innovation

- **Development** consists of clinical trials (leading to regulatory approval)
  - Phase I: *safety* checks on a few healthy volunteers
  - Phase II: *effectiveness* (and dosage) on few hundred people with the disease
  - Phase III: *treatment benefits* (and safety data) on few thousand subject (treatment and control/placebo)
- **Commercialization**: packaging, dosage, scaling the manufacturing process, marketing
- **Diffusion**: spread through out relevant doctor and patient population

nature



NEWS | 18 June 2021

# CureVac COVID vaccine let-down spotlights mRNA design challenges

Scientists are searching for explanations to disappointing final-stage trial results. These insights could help guide the future development of mRNA vaccines.

Elie Dolgin

# Invention $\neq$ Innovation

- Successful invention by no means leads (with certainty) to a successful innovation
- Clinical trial success is highly uncertain
- Wong et al. (2019):
  - Out of 400,000 candidate drug components (“inventions”) only 20% made it through Phase III trials
  - Only 5% in case of oncology/cancer drugs

# Innovative Processes Differ!

- Timing of costs
  - *Pharma:* costs probably highest in the development phase
  - *Software:* success is achieved via investment at the diffusion phase
- Uncertainty
  - *Pharma:* uncertainty about feasibility (Phase III!)
  - *Software:* uncertainty about whether the app gets to market before a competing product appears
- Modularity
  - *Pharma:* new drugs builds on prior knowledge, but not a large number of pieces (*"discrete"*)
  - *Software:* often/almost always involves combination of many pieces, some of which are patented (*"complex"*)
- Learning
  - *Pharma:* much of the learning done during original development phase
  - *Software:* continuous development, responding to experience of users

# Science *to* vs. *from* Technology

- Not all innovative processes are linear or follow a simple path: feedback or accidental discoveries
- The drive for new technology can be the driver of science
  - drive to understand why something works leads to new science
  - deliberate attempt to improve a technology requires further understanding of the science behind it
- Example: Louis Pasteur
  - tried to improve the fermentation process of beetroot wine
  - traced the source of contamination to micro-organisms that could be eliminated by heating the liquid
  - invented pasteurization (a commercial **invention**) but also led to the germ theory of disease (**science**)
- Another example, the laser: technology grounded in basic scientific research in physics, then contributing to further scientific advance in science of optics

People also ask

What does beetroot wine taste like?

Beetroot pairs well with a lot of spices because it has a **rounded, earthy flavour**. A small amount of cinnamon or nutmeg along with the beetroot makes a great winter warming wine. Alternatively, coriander and orange zest, much like in a weisse beer can really work well with that earthy tone. 10 Dec 2019

https://homebrewanswers.com › beetroot-wine-recipe

Beetroot Wine Recipe - Home Brew Answers

# Science from Technology

| Years | Technological source | Scientific field developed |
| --- | --- | --- |
| 1600s | Torricelli designing an improved pump | Atmospheric/pressure science |
| 1830s | Carnot – understanding the efficiency of steam engines | Thermodynamics |
| 1850s | Pasteur – studies in the wine industry | Bacteriology/germ theories |
| 1850-1900s | Bessemer process for steel; age-hardening of Duralumin | Metallurgy/materials science |
| 1932 | Jansky/Bell labs – identifying sources of radio noise and static | Radio astronomy |
| 1920s | Davisson – looking for improvements in vacuum tubes | Wave nature of matter |
| 1950s | Laser technology for cables, increasing capacity while reducing size | Optics |
| 1940s | Early semiconductors used as rectifiers (AC-DC converters) | Solid state physics of free electrons |

Source: Hall & Helmers (2022) [Rosenberg (1982)]

# Learning

- How does innovation use result in learning that feeds back into the innovative process?
- Learning by doing
  - associated with process innovation
- Learning by using
  - associated with product innovation

# Learning by Doing

- Production cost falls as experience is gained in producing a particular good
- Captured by a learning curve (or progress curve) and considered an empirical regularity in, e.g., shipbuilding and airframe industries
- Where is this learning curve coming from?
  - Accumulation of experience on the part of the workers
  - Learning by management (better organization of productive tasks, better timing in ordering parts,...)
  - Improvements in design or material

# Learning or Scale?

- Learning: Production process becomes more efficient as it is repeated.
- $\Rightarrow$ higher output associated with lower costs?
- Then, how does learning differ from economies of scale?

# Learning by Doing

- Learning curve:
  - Relates the cost $c$ of producing the next unit of a product to the number of such products previously produced ($y$)

- Simple model:

$$c = c_0 y^{-b} \qquad \text{or} \qquad \log(c) = \log(c_0) - b\log(y)$$

- Here, $b$ is the elasticity of unit cost with respect to past output; $c_0$ is the cost of producing the first (well, really second) unit

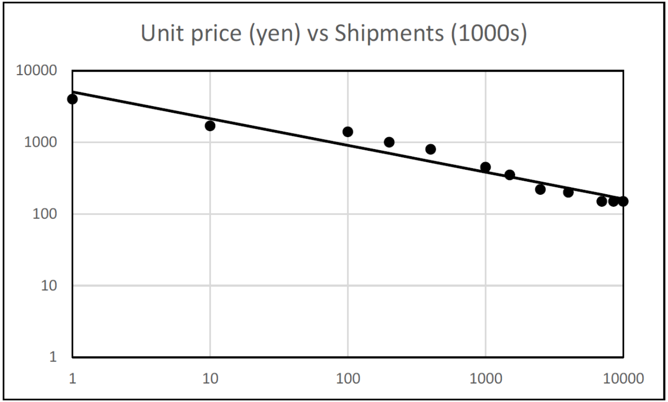
$$c = c_0 1^{-b} = c_0$$

- Elasticity $b$ measures the percent reduction in unit cost from a one-percent increase in output:

$$b = -\frac{d\log c}{d\log y} = -\frac{y}{c}$$

# Learning Curve: Sony Laser Diode Manufacturing Costs

$$\log(\mathit{price}) = \log(5038) - 0.373\log(\mathit{shipments})$$




Source: Hall & Helmers (2022) [Lipman and Sperling (1999)]

# Learning by Using

- Learning is the result of experience when using a new innovative product
- Technological change does not end when the technology is diffused to users, but products continue to improve due to feedback from users
- Often in complex capital goods where performance is not fully understood until they are used

# Boeing 747

**Table 2: Example: Stretching the Boeing 747**

| Model | Year introduced | Number of passengers |
|---|---|---|
| **747-100** | 1969 | 366 |
| **747-200** | 1971 | NA |
| **747-300** | 1983 | 400; stretched upper deck |
| **747-400** | 1989 | 416-524 |
| **747-8** | 2005 | 467 |

Source: Hall & Helmers (2022)

# Boeing 737 MAX

- This process can also go south
- Upgrades of 737 to 737 MAX with more efficient engines, aerodynamic changes, and airframe modifications
- One troubling change: Maneuvering Characteristics Augmentation System (MACS) was automated without pilot control, appears to have increase the accident rate

# User Innovation

- Users themselves innovate and modify a product
- Shah (2006) on windsurfing, skateboarding, and snowboarding equipment
  - Users developed original model by modifying a piece of equipment in related sports
  - Major improvements: 57% by users; 27% by manufacturers
- von Hippel (2006) studies user innovation in scientific instruments, semiconductors, industrial gases and thermoplastics
- When (Why) do users innovate?
  - When they expect to capture profits from the innovation

# Open Source Software as User Innovation

- Examples: Linux, Apache Web server, Netscape (open source in 1998), Mozilla Firefox (built using Netscape source code)
- Lerner and Tirole (2002) observe that open source where primary users are other programmers
- Again, why do users innovate?
- Lerner and Tirole argue: career concerns
  - signing contributions via comments in the code is highly encouraged
  - contributors can be easily identified

“There is no reason anyone would
want a computer in their home."

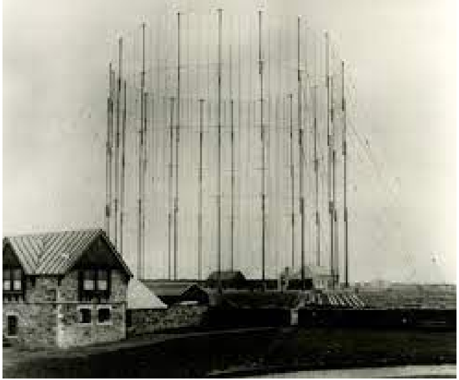
(Ken Olson, Digital Equipment Corporation, 1977)

# Uncertainty

- Not anticipating the impact of the innovation
- Thomas Watson, CEO of IBM in 1943: worldwide demand for their computers would be 5!
- We know the rest of the story!

# Uncertainty

- Not anticipating the best use
- Guglielmo Marconi, pioneer in the development of radio
- Focused on “narrowcasting:" wireless communication where cables are not possible
- Not seeing the potential of radio for “broadcasting"



# Complementary Innovation

- Availability of complementary innovation is often necessary
- The length of time between invention and larger-effect innovation can vary and depends on this availability
- Internet:
  - ARPANET networks were linked to create a primitive internet in the 1970s
  - Tim Berners-Lee at CERN put together that technology with hypertext to create the world wide web
- Computers:
  - Prior to semiconductors, computers were massive and heavy
  - Invention of semiconductors reduced size and weight and enabled modern PCs.

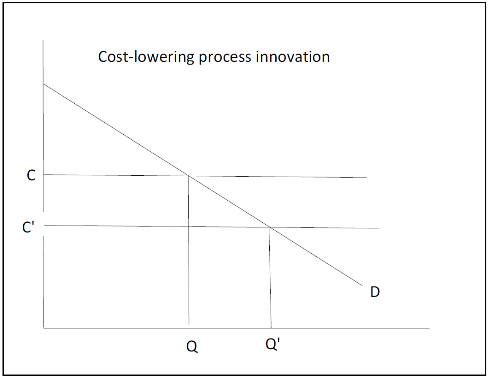
# Types of Innovation: Incremental and Radical

- **Incremental innovation**: improvements in an existing product or process
- **Radical innovation**: often viewed as those creating entire new markets
  - more often serendipitous rather than due to conscious research
  - more frequently made by new entrants to an industry
  - radical innovations have the tendency to threaten existing firms; with an impact on the nature of competition

# Types of Innovation: Process and Product Innovation

- **Process innovation** is a new way of doing something
- Typically thought to be cost-reducing for the firm

**Figure 3: Process innovation**

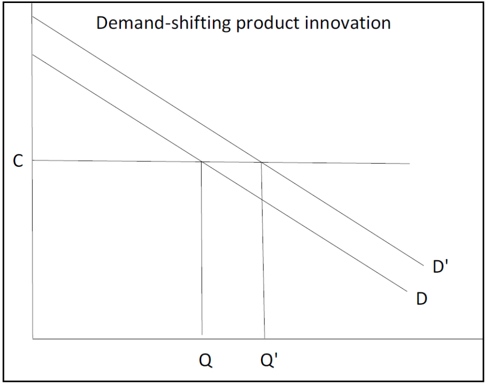



Source: Hall & Helmers (2022)

# Types of Innovation: Process and Product Innovation

- **Product innovation** is the creation of a new good or service for sale
- Is likely to increase demand

**Figure 4: Product innovation**




Source: Hall & Helmers (2022)

# How Much is Process? How Much is Product

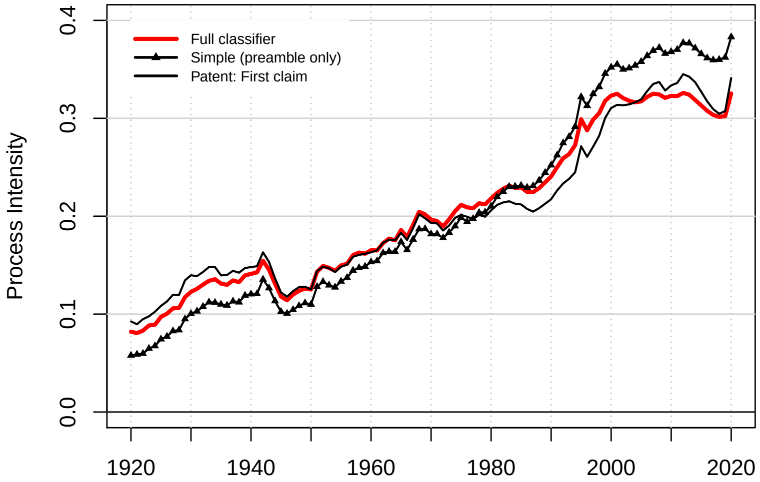
- Italian manufacturing firms, 1996–2005

**Table 3: Distribution of innovation types for Italian manufacturing firms**

| Type of innovation | Share of firms |
|---|---|
| No innovation | 32.1% |
| Process innovation only | 24.0% |
| Product innovation only | 12.0% |
| Both process and product innovation | 26.9% |

Source: Hall & Helmers (2022) [Hall et al., 2012]

# Process Intensity in U.S. Patents




Source: Ganglmair, Robinson, and Seeligson (2022)

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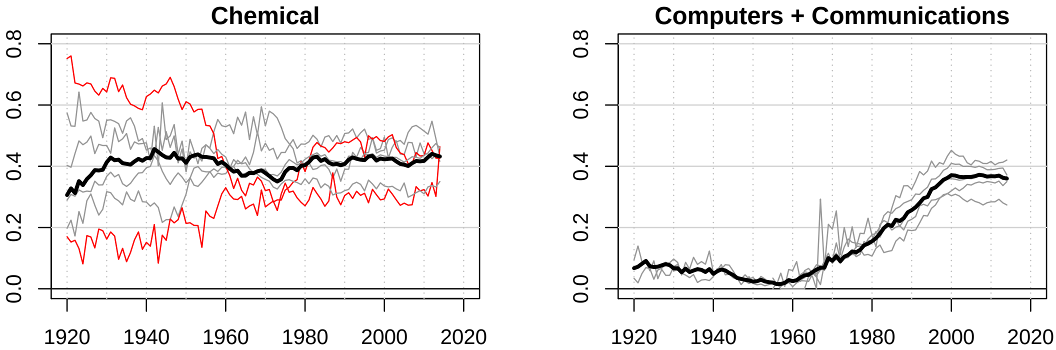


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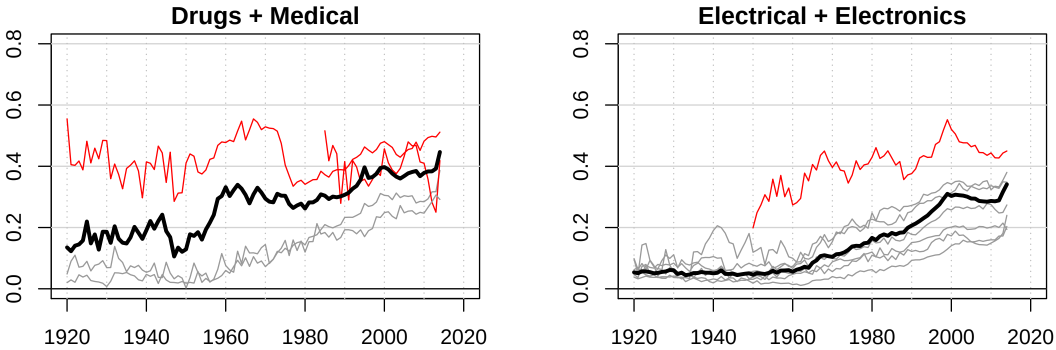


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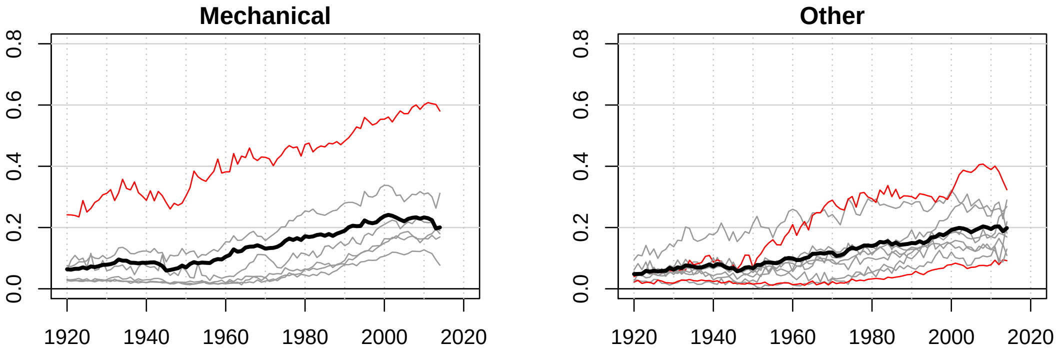


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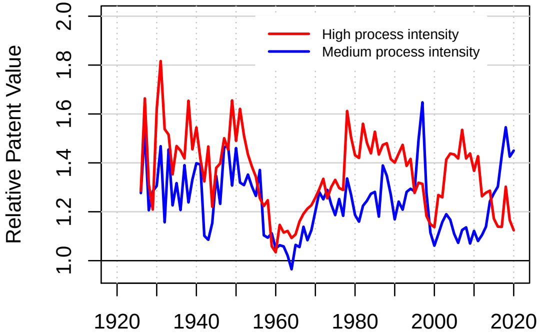
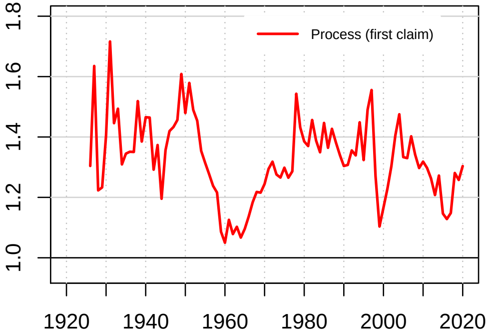
# Value of Process Patents

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