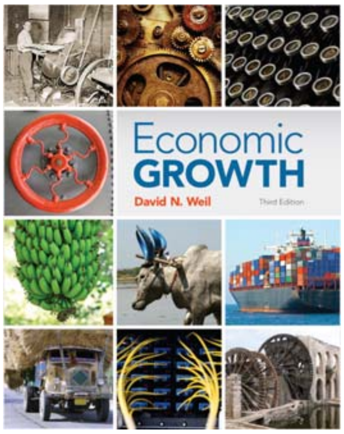
Chapter 8

THE ROLE OF TECHNOLOGY IN GROWTH



Productivity

Country	Output per Worker, y	Physical Capital per Worker, k	Human Capital per Worker, h	Factors of Production, [illegible]	Productivity, A
United States	[illegible]	1.00	[illegible]	[illegible]	[illegible]
Norway	1.12	[illegible]	[illegible]	[illegible]	[illegible]
United Kingdom	[illegible]	0.68	0.87	[illegible]	[illegible]
Canada	[illegible]	0.81	[illegible]	0.91	[illegible]
Japan	0.73	1.16	[illegible]	1.04	0.70
South Korea	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Turkey	0.37	0.25	[illegible]	[illegible]	[illegible]
Mexico	[illegible]	[illegible]	0.84	0.61	[illegible]
Brazil	0.28	0.19	[illegible]	[illegible]	0.42
India	[illegible]	[illegible]	[illegible]	0.34	0.31
Kenya	0.032	0.022	0.73	0.23	0.14
Malawi	0.018	[illegible]	0.57	0.21	[illegible]

[illegible]

Enormous differences in A across countries.

Technology

A varies because of differences in technology?

What determines the level/adoption of technology in a country?

- Human capital
- R&D.
- Cross-country spillovers.
- Barriers to technology transfer.

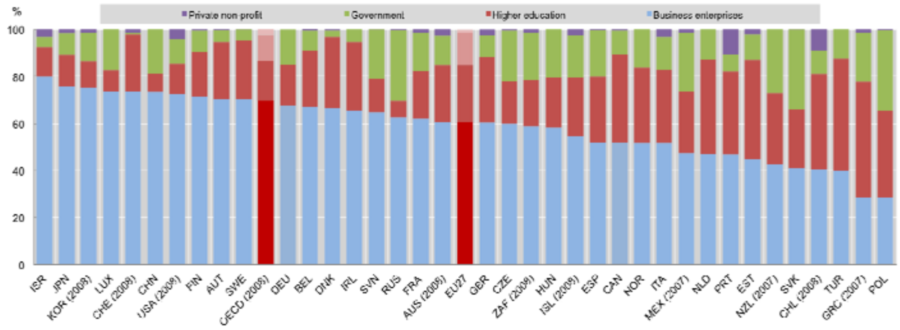
Researchers and Research Spending, 2009

And Italy?

Country	Number of Researchers	Researchers as a Percentage of the Labor Force	Research Spending ($ billions)	Research Spending as a Percentage of GDP
United States	1,412,639	0.89%	398.2	2.8%
Japan	655,530	1.00%	137.9	3.4%
Germany	311,519	0.74%	82.7	2.8%
France	229,130	0.80%	48	2.2%
Korea	236,137	0.96%	43.9	3.3%
OECD Total	4,199,512	0.70%	965.6	2.4%

Source: OECD Main Science and Technology Indicators database.

Determinants: R&D



The majority of R&D is performed by the private sector (but not in all countries and regions). But the goverment is important

- To provide the right incentives: The patent system.
- Publicly funded research and linkages to private sector.

What is technology?

How is technology different than physical and human capital?

Technology is (mostly) about ideas and knowledge.

Instructions for mixing together raw materials (labor and capital).

- Can be used over and over again by many people at the same time (non-rival).
- Partly non-excludable.

} Public good nature

Implications:

No diminishing returns.

Without legal framework, zero or negligible private incentives to innovate despite the large returns for society.

The nature of technological progress

- Technology creation
  - Invention
    - The creation of something new, or a "breakthrough" technology. This is often included in the process of product development and relies on research.
  - Innovation
    - generation, application and realization of new ideas, products, services and processes
  - Diffusion
    - generalised adoption of an innovation, it is with diffusion that non rivarly and non excludability come to action

Patents

A patent gives the owner the right to produce, use and sell the **invention for a period of time (typically 20 years)** –→**Temporary** monopoly.

The patent office requires:

- That the invention is novel and non-obvious.
- Have technical characteristics (not abstract ideas, laws of nature, etc.)

Examples: incandescent lamp, computer technology, zippers, cheese slicer, fertilizer.

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Challenges

Monopoly.

- Firm charges too high prices - limiting benefits of new technology.
- May reduce R&D incentives: Costly to copy and build on existing technology.
  - Patent wars between Apple, Nokia, Microsoft, Google, Samsung
  - E.g. Apple suing Samsung for similar icons for apps.

Patent may have very different value

- Firms collecting patents with no intention of using them.
- Sealed crustless sandwich

Solution: citation counts

Alternatives to patents

- Secrecy (e.g. Coca Cola has maintained exclusivity since 1886).
- Open source (Linux, fashion design).
- Brand
- More public R&D (e.g. for global problems such as AIDS or more generally to create basic knowledge instead of applied knowledge).

Determinants of R&D spending

- Schumpeter identified innovation as the critical dimension of economic change. He argued that economic change revolves around innovation, entrepreneurial activities, and market power. He sought to prove that innovation-originated market power can provide better results than the invisible hand and price competition.
- He argued that technological innovation often creates temporary monopolies, allowing abnormal profits that would soon be competed away by rivals and imitators. These temporary monopolies were necessary to provide the incentive for firms to develop new products and processes
- R&D expenditure therefore depends on profit considerations, which are a function of
  - How much advantage with respect to followers
  - How long does the advantage last
  - Size of the market
  - Uncertainty

- Concept of creative distruction…

Technology → Growth

Questions:

What is the effect of more R&D on growth?

If technology is (partly) non-rival and non-excludable, what are the consequences for poor countries?

We will look at two frameworks:

- Closed economy
- Open economy (2 countries)
  potential for technology
  transfer.

But let's start recalling the Solow model

One country model

- Only factor of production is labor L (no human or physical capital).
- Labour can be used either in production or in the R&D
- Its function in R&D is similar to the saving rate in the Solow model

Closed economy: TC as the result of a deliberate effort

Definitions:

L_Y workers employed in manufacturing.

L_A workers employed in R&D.

$$L = L_Y + L_A$$

Define $\gamma_A = L_A/L$ - the share employed in R&D.

$1 - \gamma_A$ is the share employed in manufacturing.

Output

- The production function given by

$$Y = AL_Y = A(1 - \gamma_A)L$$

$$y = A(1 - \gamma_A) \text{ (intensive, per capita form)}$$

Higher $A \rightarrow$ higher GDP per capita.
Higher γ_A (more R&D workers) $\rightarrow$ Lower GDP per capita

Technological change

Assume that A grows,

$$\hat{A} = \frac{L_A}{\mu}$$

More R&D workers $\rightarrow$ higher growth.

Parameter $1/\mu$ determines how effective R&D is.

Rewrite

$$\hat{A} = \frac{L_A}{\mu} = (\gamma_A L)/\mu$$

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Growth

Recall output is

$$y = A(1 - \gamma_A)$$

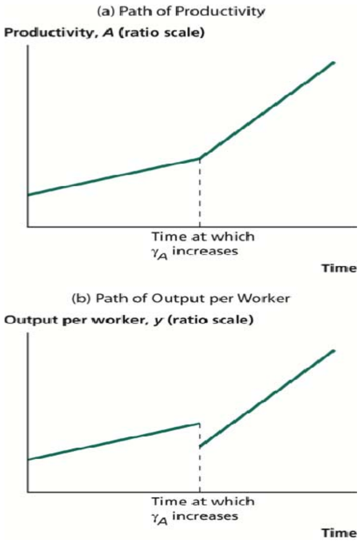
If no change in γ_A, then growth is

$$\hat{y} = \hat{A} = \frac{\gamma_A L}{\mu}$$

Higher growth when

- Higher share R&D workers γ_A.
- Higher R&D efficiency $1/\mu$.
- Larger population.

Effect of shifting labor into R&D



An increase in γ_A: (1) Short run: y ↓, (2) Long run: y ↑

Transitory and permanent effects

Recall Solow model:

- More physical investment boosts the level of GDP/capita.
- During the transition process, higher growth rates.

Here:

- More R&D investment permanently boosts the growth rate.
- Who decide how many workers employ in the labs instead of in the factories?

Two country model/1

- γ and μ are now different among countries
- One country invests more in R&D and it is the leader (country 1) the other one is the follower (country 2)
- $Y_1=A_1(1-\gamma_{A1})L_1$ …. $y_1=A_1(1-\gamma_{A1})$
- $Y_2=A_2(1-\gamma_{A2})L_2$ …. $y_2=A_2(1-\gamma_{A2})$
- where $\gamma_{A1} > \gamma_{A2}$

Two country model/2

- Country 1 invents and innovates
- Country 2 imitates and/or does incremental innovation
- $\hat{A}_1 = (\gamma_{A1}/\mu_i)L$ where μ_i is the cost of invention
- μ_c is the cost of copying for country 2 and it is given by a function of A_1/A_2
- $\mu_c = c(A_1/A_2)$ and $\hat{A}_2 = (\gamma_{A2}/\mu_c)L_2$

Innovation and imitation

Assumptions:

The cost of imitation is

$$\mu_2 = c\left(\frac{A_1}{A_2}\right)$$

(recall $\hat{A} = (\gamma_A/\mu)L$)

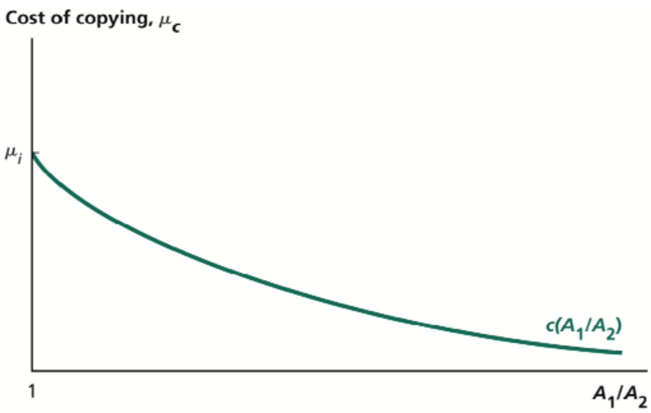
$\mu_2 < \mu_1$ (imitation cheaper than innovation).

$c' < 0$ (imitation cheaper if the technology gap is large).

Boundary conditions:

- $\mu_2 \to 0$ when $A_1/A_2 \to \infty$.
- $\mu_2 \to \mu_1$ when $A_1/A_2 \to 1$.

Imitation costs



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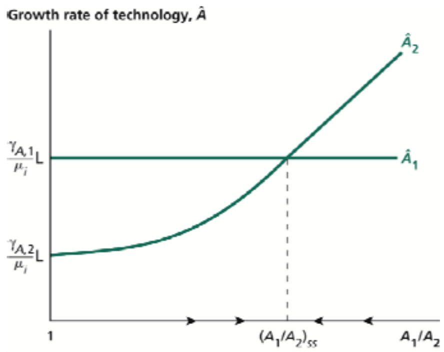
Steady state

When $A_1=A_2$ then $\mu_i=\mu_c$



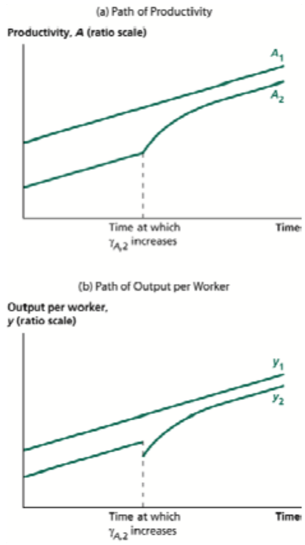
In steady state $\hat{A}_1=\hat{A}_2$ then $\mu_c = (\gamma_{A2} / \gamma_{A1})\, \mu_i$

2 far behind (A_2 low): 2 growing faster than 1 −→ A_1/A_2 ↓.

2 close to frontier (A_2 high): 2 growing slower than 1 −→ A_1/A_2 ↑.

In SS: Identical growth rates.

More R&D workers in follower country



$\gamma_{A2} \uparrow -\rightarrow$ Short-term increase in 2's productivity growth rate.
$\gamma_{A2} \uparrow -\rightarrow$ Short-term fall in 2's output.

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Technology transfer

In the model, imitation is cheap if you are far behind the frontier –→

- We should experience rapid technological catching-up.
- In practice, many barriers to technology transfer:
  - � Tacit knowledge: Not all knowledge can be codified.
  - � Skill/capital-biased technical change.

Tacit knowledge

Description of patents is not always sufficient for imitation

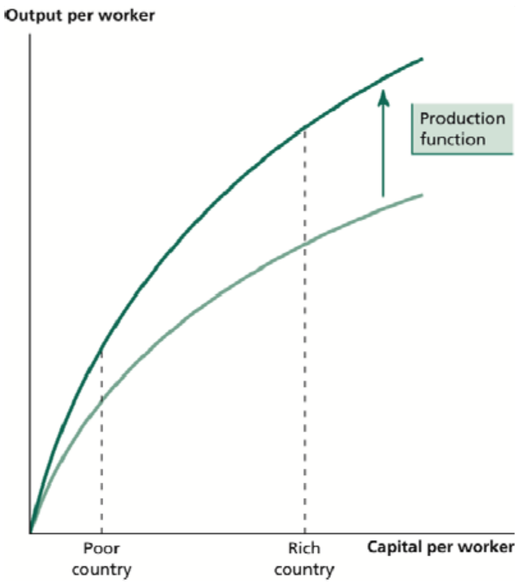
Learning by doing phenomenon

Michael Polanyi (1958): light bulb factory in Hungary vs Germany.

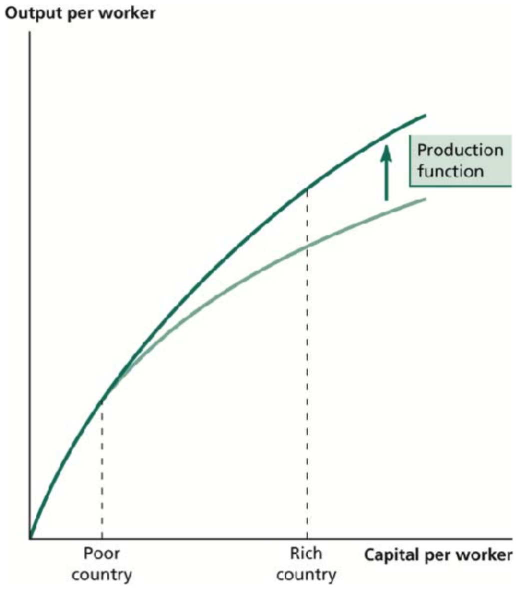
- Enormous productivity differences with same technology and capital.

Efficiency gap… see below

Neutral technical change



Capital-biased technical change



Higher A only benefits high k and h countries

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Cutting edge technology

Technological progress thought to be the main source behind economic growth the last 250 years.

We will

- Document the pace of technological change.
- Ask what determines innovation near the frontier.

Growth accounting

Period	Annual Growth Rate of come per Capita, $\hat{Y}$	Annual Growth Rate of Population, $\hat{L}$	Annual Growth Rate of Productivity, $\hat{A}$
500–1500	0.0%	0.1%	0.033%
1500–1700	0.1%	0.2%	0.166%

Assume $\beta = 1/3$ (share of land in production).

Land and Labour are factors of prodution, land does not grow

Assume population = workforce (L).

Growth accounting

Annual growth of 0.033% $-\rightarrow$ over the 500-1500 period increase is

$$1.00033^{1000} = 1.39,$$

i.e. just 39% increase over a **millenium**.

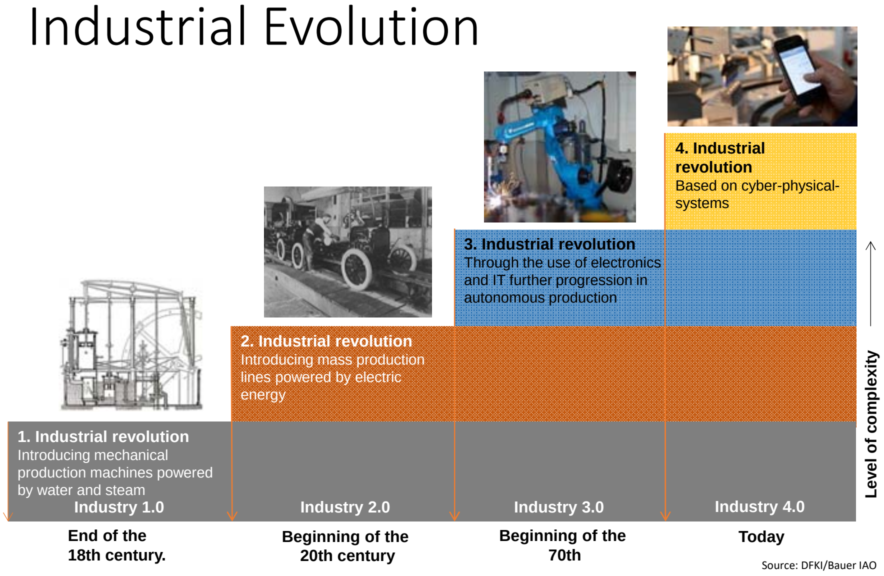
Annual growth of 0.166% $-\rightarrow$ over the 1500-1700 period, increase is

$$1.00166^{200} = 1.39,$$

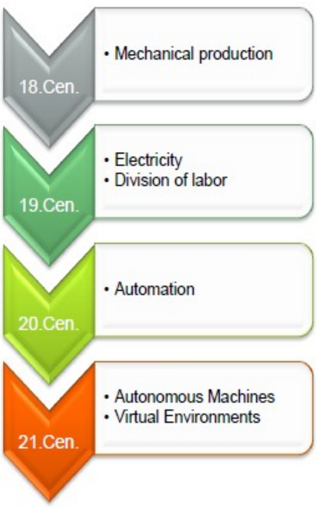
i.e. same growth over just **200 years**.

But still minuscule growth rates compared to today.

Industrial Evolution



The Industrial Revolution



- 1. Implementation of mechanical production plants
  - 1712 Invention of the steam engine
- 2. Mass production based on the division of labor and electricity
  - 1840 Telegraphy and from about1880 Telephony
  - 1920ies Taylorism
- 3. Automation of production processes
  - 1971 first microcomputer (Altair 8800)
  - 1976 Apple I (S. Jobs und S. Wozniak)
- 4. Autonomous Machines and Virtual Environments
  - 1998 Spring Meeting AutoID (IML) + AutoID Labs (MIT)
  - 2000er The Internet of Things
  - 2010 e.g. Cellular Transport systems
  - 2020 Autonomous Interaction and Virtualization

I. An Historical Perspective on Growth

- **What precipitated periods of high growth?**
  - **Industrial Revolution #1** (1750- 1830): steam engine and cotton gin Railroads even though they didn't have full effect until 1850-1900

    E.g. no indoor plumbing, no window screens, horses used for local transportation (leads to manure in streets)

    ***
  - **Industrial Revolution #2** (1870-1900): electricity, internal combustion engine, indoor plumbing , motor power replaces animal power.
    - No need to carry water inside
    - Travel and communications became quicker
    - Telephone, phonograph, and motion pictures all invented in 1880s
    - US went from 75 percent rural to 80 percent urban

I. An Historical Perspective on Growth

- **What precipitated periods of high growth?**

  ***
  - **Industrial Revolution #3** (1960+): computers and Internet
    - Internet begins 1995, but fast computing began in 1960s
    - However, benefits don't appear in productivity statistics until 1990s
    - Moreover benefits go away by mid2000s
  - Note the general nature of many of these technologies (e.g. **general purpose technologies**).
    - Takes time for their impact to diffuse throughout the economy

And now....

Industry 4.0 optimizes the computerization of Industry 3.0

- When computers were introduced in Industry 3.0, it was disruptive thanks to the addition of an entirely new technology. Now, and into the future as Industry 4.0 unfolds, computers are connected and communicate with one another to ultimately make decisions without human involvement.
- A combination of cyber-physical systems, the Internet of Things and the Internet of Systems make Industry 4.0 possible and the smart factory a reality. As a result of the support of smart machines that keep getting smarter as they get access to more data, our factories will become more efficient and productive and less wasteful.
- Ultimately, it's the network of these machines that are digitally connected with one another and create and share information that results in the true power of Industry 4.0.

Industry 4.0

- In short, it is the idea of smart factories in which machines are augmented with web connectivity and connected to a system that can visualise the entire production chain and make decisions on its own.
- It includes cyber-physical systems, the Internet of things, cloud computing and cognitive computing.
- Industry 4.0 creates what has been called a "smart factory". Within the modular structured smart factories, cyber-physical systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions.
- Over the Internet of Things, cyber-physical systems communicate and cooperate with each other and with humans in real time, and via the Internet of Services, both internal and cross-organizational services are offered and used by participants of the value chain.

Industry 4.0 applications today

- Here are just a few of the possible applications:
- Identify opportunities: Since connected machines collect a tremendous volume of data that can inform maintenance, performance and other issues, as well as analyze that data to identify patterns and insights that would be impossible for a human to do in a reasonable timeframe, Industry 4.0 offers the opportunity for manufacturers to optimize their operations quickly and efficiently by knowing what needs attention.
- http://senseable.mit.edu/MinimumFleet/
- http://roboat.org/
- https://amfg.ai/2019/03/28/industry-4-0-7-real-world-examples-of-digital-manufacturing-in-action/