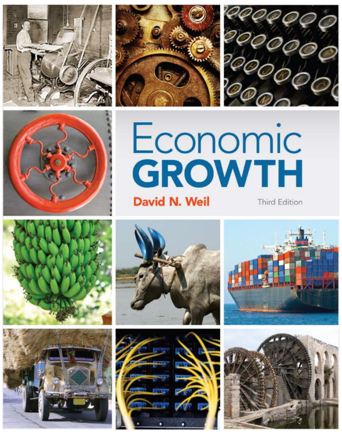
Chapter 8

THE ROLE OF TECHNOLOGY IN GROWTH



Productivity

Recall

Country	Output per Worker, y	Physical Capital per Worker, k	Human Capital per Worker, h	Factors of Production, $k^{1/3}h^{2/3}$	Productivity, A
United States	1.00	1.00	1.00	1.00	1.00
Norway	1.12	1.32	0.98	1.08	1.04
United Kingdom	0.82	0.68	0.87	0.80	1.03
Canada	0.80	0.81	0.96	0.91	0.88
Japan	0.73	1.16	0.98	1.04	0.70
South Korea	0.62	0.92	0.98	0.96	0.64
Turkey	0.37	0.28	0.78	0.55	0.68
Mexico	0.35	0.33	0.84	0.61	0.56
Brazil	0.20	0.19	0.78	0.48	0.42
India	0.10	0.089	0.66	0.34	0.31
Kenya	0.032	0.022	0.73	0.23	0.14
Malawi	0.018	0.029	0.57	0.21	0.087

Sources: Output per worker: Heston, Summers, and Aten (2011); physical capital: author's calculations; human capital: Barro and Lee (2010). The data set used here and in Section 7.3 is composed of data for 90 countries for which consistent data are available for 1975 and 2009.

Enormous differences in A across countries.

2/ 44

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.

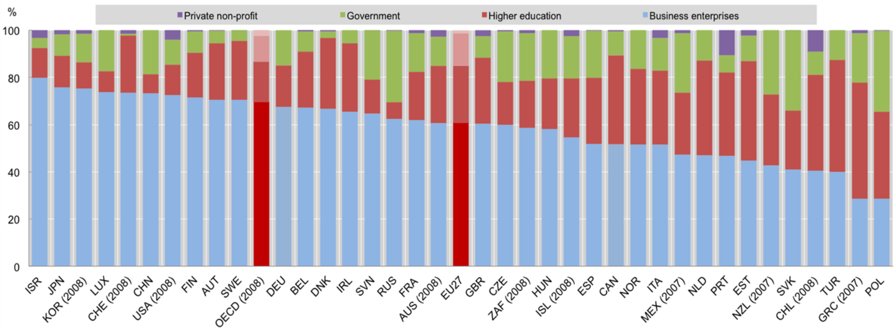
Researchers and Research Spending, 2009

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.

8/44

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

9 / 44

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).

10 / 44

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.

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

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

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

16/44

Growth

Recall output is

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

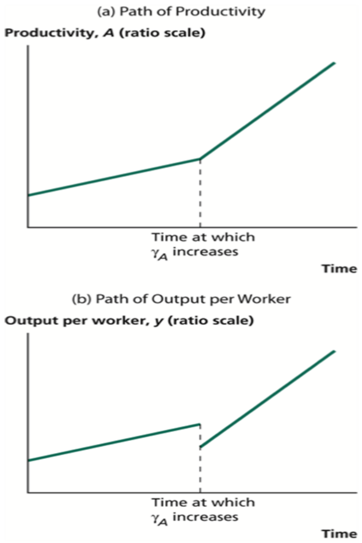
If no change in γ_A, then growth is

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

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.

Open economy

Countries 1 & 2.

$L_1 = L_2 = L$, $\gamma_{A1} > \gamma_{A2}$ and $A_1 > A_2$.

Technological progress through innovation (country 1) or imitation (country 2).

Production functions

$$y_1 = A_1(1 - \gamma_{A1})$$

$$y_2 = A_2(1 - \gamma_{A2})$$

Innovation and imitation

Assumptions:

The cost of imitation is

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

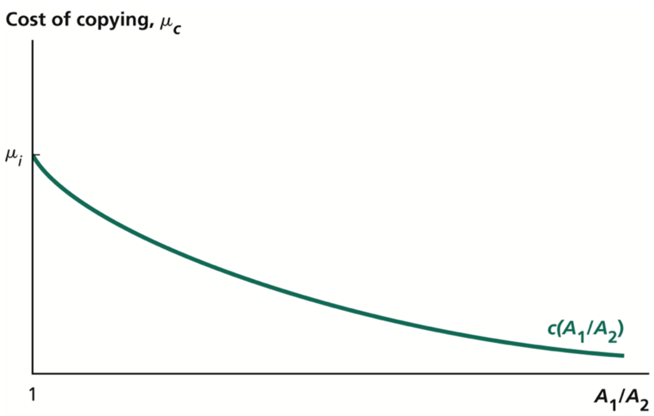
(recall $\hat{A} = (\gamma_A/\mu)\,L$)

$\mu_2 < \mu_1$ (imitation cheaper than innovation).
$c' < 0$ (imitation cheaper if the technology gap is large).

Boundary conditions:

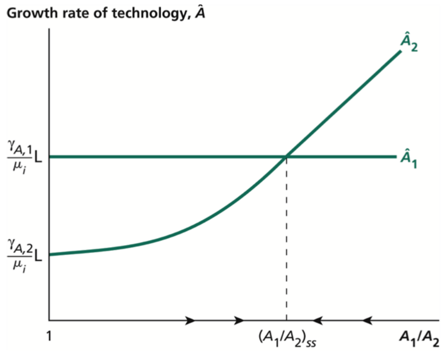
- $\mu_2 \rightarrow 0$ when $A_1/A_2 \rightarrow \infty$.
- $\mu_2 \rightarrow \mu_1$ when $A_1/A_2 \rightarrow 1$.

Imitation costs



20 / 44

Steady state



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

In steady state

$\hat{A}_1=\hat{A}_2$

then

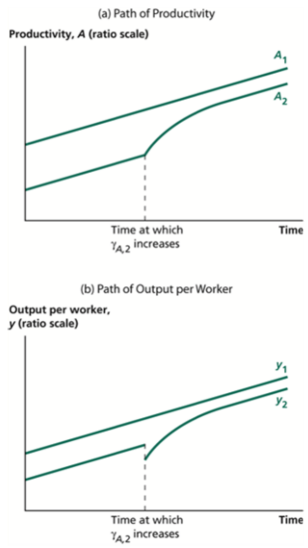
$\mu_c = (\gamma_{A2} / \gamma_{A1})\ \mu_i$

2 far behind (A_2 low): 2 growing faster than 1 $\dashrightarrow$ $A_1/A_2 \downarrow$.

2 close to frontier (A_2 high): 2 growing slower than 1 $\dashrightarrow$ $A_1/A_2 \uparrow$.

SS: Identical growth rates.

More R&D workers in follower country



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

$\gamma_{A2} \uparrow \dashrightarrow$ Short-term fall in 2's output.

24 / 44

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

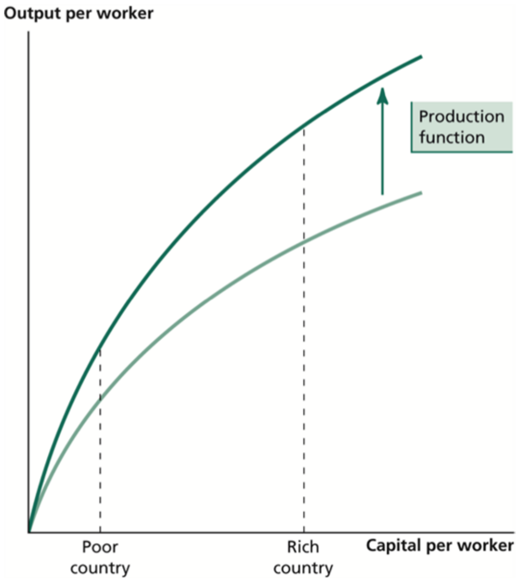
Description of patents not always

sufficient. Learning by doing.

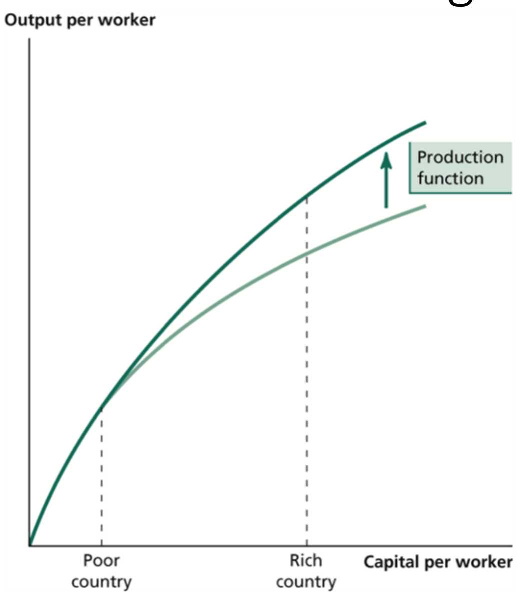
Michael Polanyi (1958): light bulb factory in Hungary vs Germany.

� Enormous productivity differences with same technology and capital.

Neutral technical change



Capital-biased technical change



Higher A only benefits high k and h countries

Let us have a look at Romer's model

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 among the frontier.

Growth accounting

Using historical data, calculate $\hat{A}$ before and after the industrial revolution.

Focus on Europe, which was the frontier.

Production function

$$Y = AX^{\beta} L^{1-\beta},$$

where X is land.

Intensive form:

$$y = A \left(\frac{X}{L} \right)^{\beta}$$

Growth rates:

$$\hat{y} = \hat{A} + \beta \left(\hat{X} - \hat{L} \right) \implies$$

$$\hat{A} = \hat{y} + \beta \hat{L}$$

if $\hat{X} = 0$.

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).

Assume population = workforce (L).

Growth accounting

Annual growth of 0.033% −→ over the 500-1500 period increase is

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

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

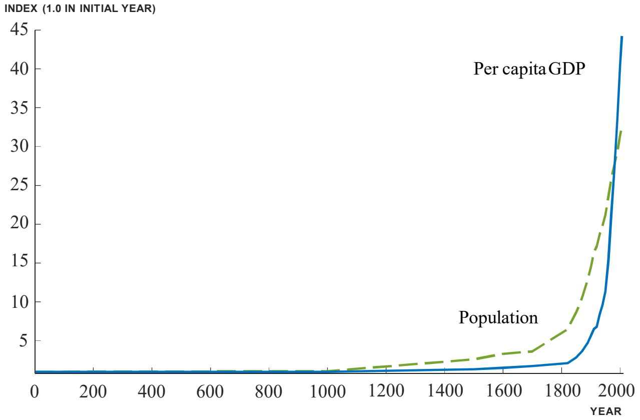
Annual growth of 0.166% −→ over the 1500-1700 period, increase is

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

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

But still minuscule growth rates compared to today.

Growth over the very long run



Note: Data are from Maddison (2008) for the "West," i.e. Western Europe plus the United States. A similar pattern holds using the "world" numbers from Maddison.

Living standards doubled from year 1 to 1820.

Living standards rose by 20x over the next 200 years.

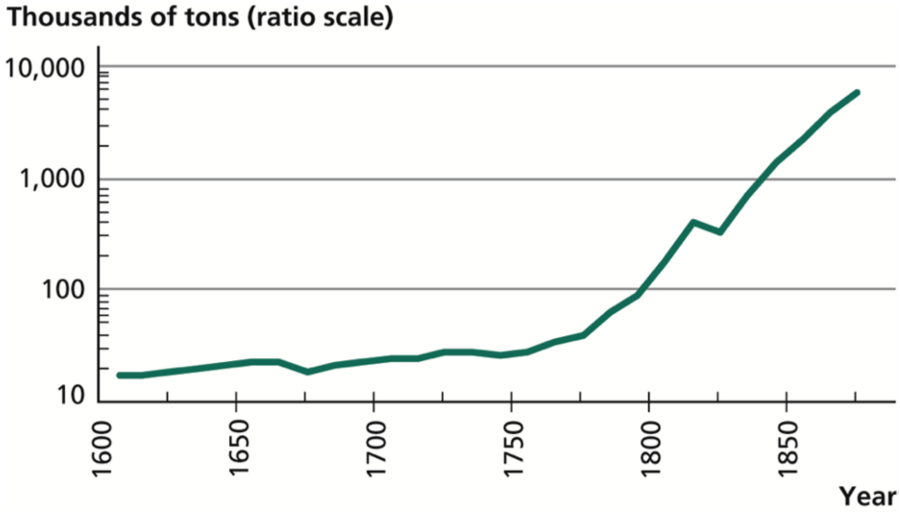
The industrial revolution

The period 1760-1830 in Great Britain and later continental Europe and North America.

Rapid technological change across a wide range of industries. In particular:

- Efficiency improvements in
  - textiles production
  - iron production
- Invention of the steam engine.
- Energy: Switch from wood to coal as source of energy.

Britith iron production



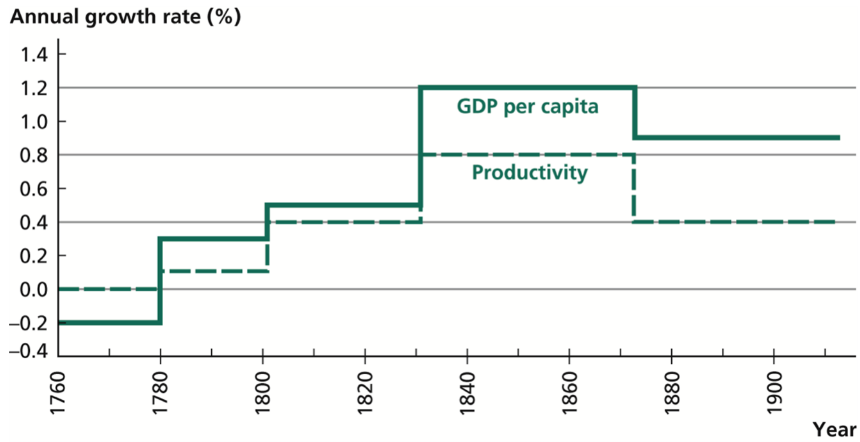
1760: 34,000 tons. 1830: 680,000 tons. 1870: 5,960,000 tons. Made possible by vast increase in coal production.

Structural change

Structural change in the British economy:

- Employment share in agriculture down from 48% to 25%.
- Employment share in manufacturing up from 22% to 44% (1760-1831).
- Urban population share up from 17% to 50% (1700-1850).
- Infrastructure: 4000km new canals.

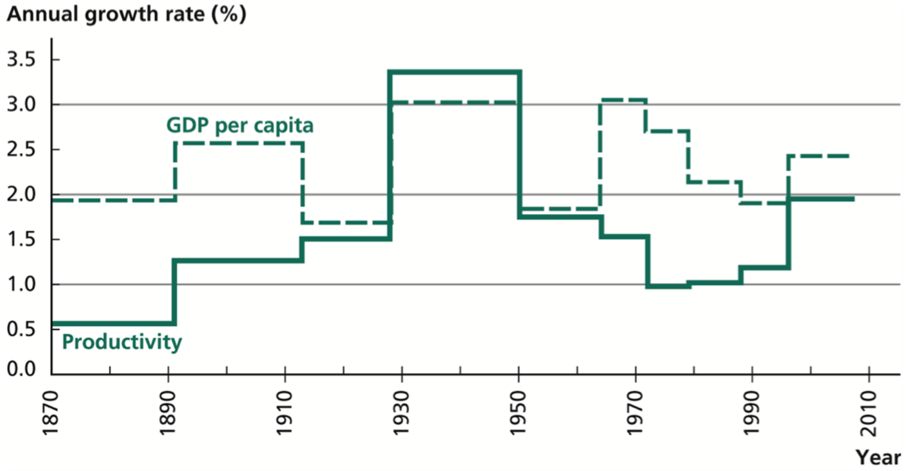
British output and productivity



By modern standards, relatively low growth rates.

- Industrial revolution confined to a few industries.
- IR was the beginning.

U.S. output and productivity



Remarkable productivity growth from 1890-1970.

Diffusion of technologies to the whole economy: electric lights, refrigeration, telephone, cars, air travel, radio, TV, plumbing.

The production of technology

Recall

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

Not satisfactory because

As technology becomes more advanced, new innovation becomes increasingly more difficult ("fishing out effect").

Decreasing returns to scale: a doubling of L_A does not double the growth rate $\hat{A}$.

Extensions

$$\hat{A} = \frac{L_A^{\lambda}}{\mu} A^{-\varphi}, \quad 0 < \varphi < 1, \quad 0 < \lambda < 1$$

$\hat{A}$ is less than proportional to the # of R&D workers L_A. $\hat{A}$ falls with the level of productivity A.

This captures the fishing out and decreasing returns mechanism.

Extensions

$$\hat{A} = \frac{L_A^{\lambda}}{\mu} A^{-\varphi}$$

Consider steady state where growth $\hat{A}$ is constant.

If so, $x \equiv L_A^{\lambda} A^{-\varphi}$ must be constant. Or

$$\hat{x} = 0$$
$$\lambda \hat{L}_A - \varphi \hat{A} = 0$$
$$\hat{A} = \frac{\lambda}{\varphi} \hat{L}_A$$

Growth can only occur with continuous expansion of the R&D sector.

Magnitudes depend on λ and φ.

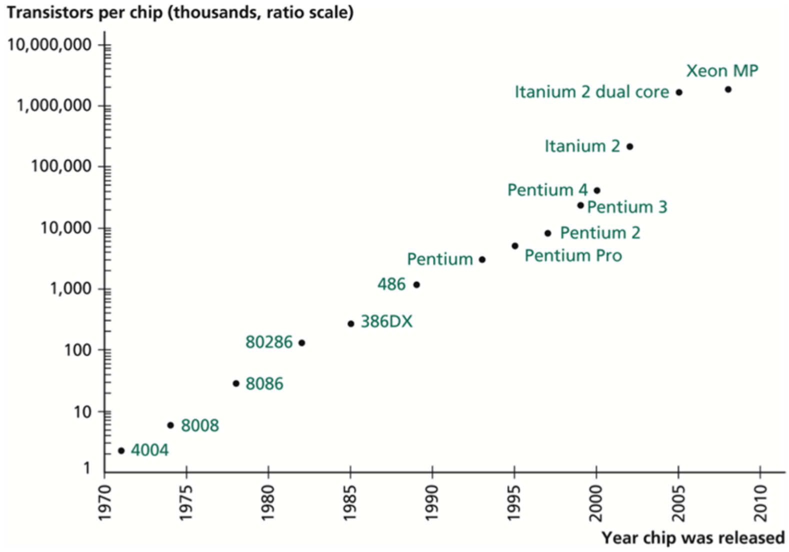
Is technological stagnation inevitable?

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.

Still scope for higher R&D employment and spending.

Is technological stagnation inevitable?



Moore's law: the number of transistors in a dense integrated circuit doubles approximately every two years.

43 / 44

Is technological stagnation inevitable?

Enormous productivity growth in manufacturing

- Cars, machinery, textiles.

Much less so in sevices

- Health care, hairdressers, entertainment.

Advanced economies spend more and more on services and less on goods.

- Less scope for aggregate productivity growth?

44 / 44

Chapter 10

EFFICIENCY

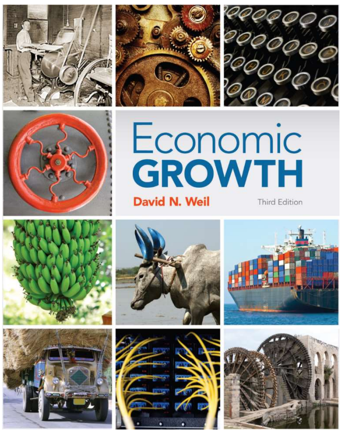
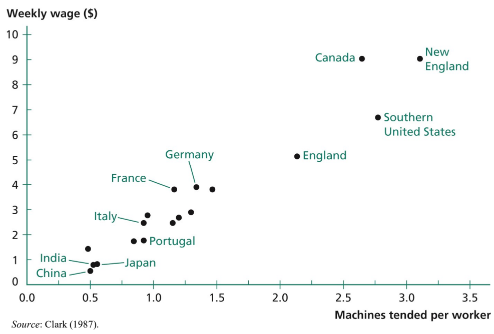


Table 10.1 Decomposition of Productivity Gap Between India and the United States

$A = T * E, \quad A_{india}/A_{usa} = 0.35$

Years India Lags United States in Technology (*G*)	Level of Technology in India Relative to United States (*T*)	Level of Efficiency in India Relative to United States (*E*)
10	0.95	0.33
20	0.90	0.35
30	0.85	0.36
40	0.81	0.38
50	0.76	0.41
75	0.67	0.46
100	0.58	0.53
125	0.51	0.61

Figure 10.1 Wages and Machines in the Textile Industry, 1910



Source: Clark (1987).

Table 10.2 Productivity in Selected Industries in the Early 1990s

	United States	Japan	Germany
Automobiles	100	127	84
Steel	100	110	100
Food Processing	100	42	84
Telecommunications	100	51	42
Aggregate Productivity	100	67	89

Types of inefficiencies

- Unproductive activities
  - Rent seeking phenomena (licences)
- Idle resources
  - Unemployment
  - Under participation to labour force
- Misallocation of factors among sectors and firms
  - Barriers to mobility
  - Wages not equal to marginal product

Figure 10.3 Efficient Allocation of Labor between Sectors

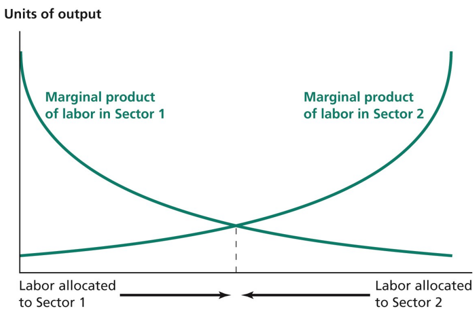


Figure 10.4 Overallocation of Labor to Sector 1

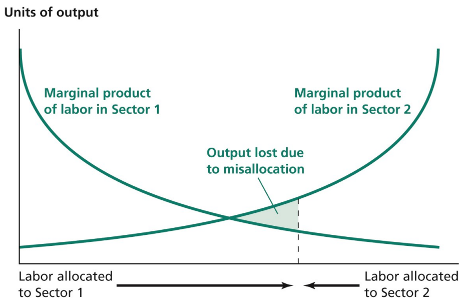
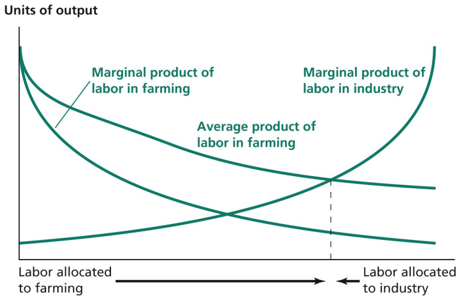
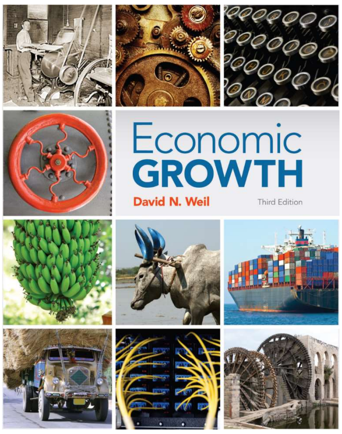


Figure 10.5 Overallocation of Labor to Farming When Farmworkers Are Paid Their Average Product



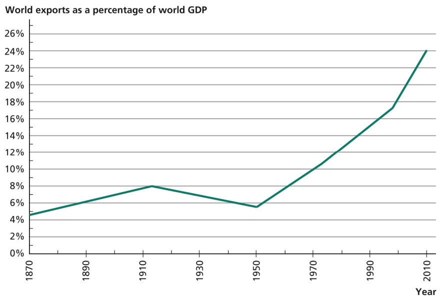
Chapter 11



GROWTH IN THE OPEN ECONOMY

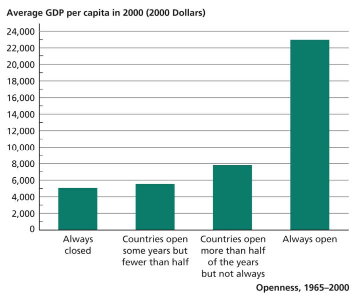
Figure 11.1 Growth of World Trade, 1870–2010

Thanks to:
•Decreasing transport costs
•Easier diffusion of information
•Trade policy



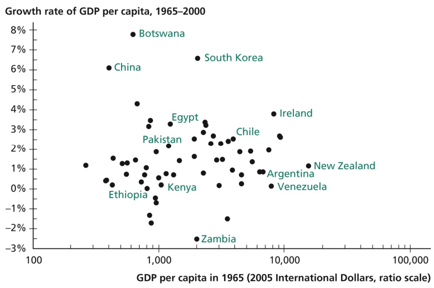
Sources: Maddison (2001), World Bank (2007a).

Figure 11.2 Relationship between Economic Openness and GDP per Capita



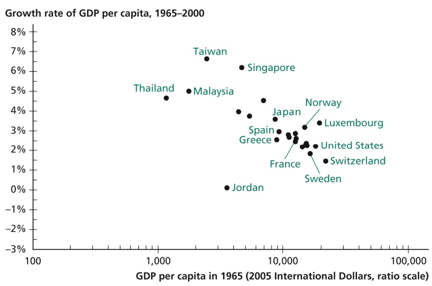
Sources: Sachs and Warner (1995), Wacziarg and Welch (2008).

Figure 11.3 Growth in Closed Economies



Sources: Sachs and Warner (1995), Wacziarg and Welch (2008), Heston et al. (2011).

Figure 11.4 Growth in Open Economies



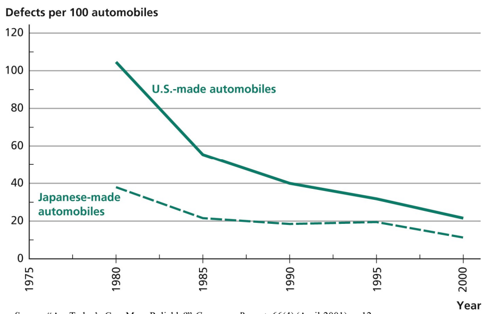
Sources: Sachs and Warner (1995), Wacziarg and Welch (2008), Heston et al. (2011).

Table 11.1 Prices in Japan before and after Opening to Trade

	Price Before Opening (U.S. cents per pound)	Price After Opening (U.S. cents per pound)
Tea	19.7	28.2
Sugar	22.7	11.2

Source: Huber (1971).

Figure 11.6 Quality of U.S.- and Japanese-made Automobiles



Source: "Are Today's Cars More Reliable?" *Consumer Reports* 66(4) (April 2001), p. 12.

Effects of openess

- Specialisation
- More competition
- Better allocation of factors across countries
- …