The Role of Technology in Growth

References: Weil, Chapter 8

2 fundamental questions:

- what explains productivity differences between countries? $\rightarrow$ later
- what explains productivity growth? $\rightarrow$ now

Compare: growth through Factor Accumulation:

- naturally diminishing returns
- bounded by physical entitities
- neoclassical theory $\rightarrow$ growth will be finite
- infinite growth (Ak model)?

growth through Productivity Growth:

- accumulation of something non-physical:
  - knowledge (how to (re-) combine physical factors)
  - blueprints (for new goods and technologies)
  - ideas
- naturally increasing returns
- infinite growth?

2 fundamental characteristics of ideas:

- (i) Non-rivalry: my use of an idea does not preclude anybody else's use of the same idea.
- (ii) Non-excludability: I cannot prevent that somebody else uses the idea.

Observe the trade-off:

- from (i): increasing returns
- from (ii): disincentive to create ideas.

Thus, it's desirable to have *partly* excludable ideas/knowledge

- tacit knowledge (Coca Cola).
- patents

Conclude: new scope for government activity

- from (i) subsidies for $R\&D$
- from (ii) patent law, law enforcement

Compare:

- most of world history: ideas are created by tinkerers (alchemists)
- since about 1850: creation of ideas is a big business.

Creation of ideas as a market activity

- we can explain how technological change / productivity growth is created
- we cannot solve the model with standard (neo-classical) theory.

The problem of having increasing returns. Homogenous production function:

$$F(\lambda K, \lambda L, \lambda A) = \lambda^{\epsilon} F(K, L, A).$$

ϵ: degree of homogeneity, $\epsilon = 1$: constant returns to scale, $\epsilon > 1$: increasing returns to scale.

Applying Euler's Theorem:

$$\epsilon \cdot \underbrace{F(K, L, A)}_{\text{production, ie. GDP}} = \underbrace{\left[\frac{\partial F}{\partial K} K + \frac{\partial F}{\partial L} L + \frac{\partial F}{\partial A} A\right]}_{\text{factor income if factors are paid according to marginal product}}$$

Conclude:

- naturally c.r.s in the physical factors (K, L, ...)
- i.r.s. in all factors (including A)
- R&D as a market activity is incompatible with the national accounting identity if factors are paid according to the marginal product.

$\rightarrow$ an unsolved problem until Paul Romer's article (1990).

Another way to see this:

- rivalrous goods must be produced each time they are sold (e.g. a CD)
  $\rightarrow$ constant average costs
- ideas are produced only once (e.g. a song, MS Windows)
  $\rightarrow$ large fix costs & almost no variable costs $\rightarrow$ decreasing average costs $\rightarrow$ increasing returns to scale.

Implying: not all factors can be paid according to marginal product.

Firms create ideas in order to produce/increase profits. Important aspects:

- protection from imitation (monopoly)
- size of the market (globalization, TRIPS)
- obsolescence (Schumpeter: creative destruction)
- uncertainty: how likely is it that R&D pays off? (joint venture funds).

Introduction: A toy model (3 Equations)

2 sectors of production: goods, ideas (R&D)

Workers produce either goods or ideas:

$$L = L_Y + L_A \tag{1}$$

Linear production function for goods (no capital involved):

$$Y = A \cdot L_Y \tag{2}$$

Linear production function for new ideas:

$$dA = \frac{1}{\mu} \cdot A \cdot L_A \cdot dt \tag{3}$$

i.e. an input of L_A researchers over a time interval dt produces dA new, productivity enhancing ideas. μ: a productivity parameter.

Observe the double linearity: the amount of new ideas dA depends linearly on

- input of researchers
- on the amount of already existing ideas A

$=>$ Why?

- knowledge spillovers
- once a piece of knowledge is created, it can be used freely (i.e. with negligible cost) in the production of new knowledge
- knowledge is non-excludable on R&D level
- we don't have to re-invent the wheel to invent a car.

Let the share of workers in R&D be given by the constant γ_A
(Why? $\rightarrow$ it's a toy model)

$$\gamma_A = \frac{L_A}{L} \quad \Rightarrow \quad L_Y = (1-\gamma_A)L \quad \Rightarrow \quad Y = A(1-\gamma_A)L.$$

And thus output per capita

$$y = \frac{Y}{L} = A \cdot (1-\gamma_A).$$

Log.-differentiate this w.r.t. time to get growth rates

$$\frac{\dot{y}}{y} = \frac{\dot{A}}{A} \quad \text{i.e.} \quad \hat{y} = \hat{A}$$

Output grows with the rate of technological progress (productivity growth).

And thus with (3)

$$\hat{y} = \frac{\gamma_A}{\mu} \cdot L \tag{4}$$

Conclude: endogenous growth increasing in

- share of workers in R&D
- productivity level of R&D
- population size

Comparative Dynamics: Is it desirable to have a higher share of workers in R&D?

[Insert: Impulse Response paths for higher γ_A]

Observe from (4):

- a higher level L leads to a permanently higher growth rate
- we say: the model implies a Scale Effect (of first order).

This is obviously wrong (compare Germany vs. Luxembourg).
$\rightarrow$ 2 possibilities to "repair" the model...

A Two-Country Model

Notion:

- an idea created in Germany can also be used in Luxembourg
- international diffusion of ideas/technological progress
- national boundaries and population sizes (L) are meaningless.
- Yet, societies must be "somehow" connected.

In a simplified world of 2 countries of same size (L)

- country 1 (the leader) creates the idea
- country 2 (the follower) adopts/copies the idea. It imitates countries 1.
- For example
  - China vs. Europe
  - England vs. Continental Europe
  - US vs. Japan

As before, per capita production:

$$y_1 = A_1(1 - \gamma_{A,1}), \qquad y_2 = A_2(1 - \gamma_{A,2}) \tag{5}$$

As before for the innovating country 1:

$$\hat{A}_1 = \frac{1}{\mu_i} \cdot \gamma_{A,1} \cdot L. \tag{6}$$

And for the imitating country 2:

$$\hat{A}_2 = \frac{1}{\mu_c} \cdot \gamma_{A,2} \cdot L. \tag{7}$$

Yet, the cost of adopting a technology is a function c of the technology gap:

$$\mu_c = c\left(\frac{A_1}{A_2}\right), \qquad c' < 0, \tag{8}$$

i.e. the larger the technological gap the less costly it is to implement new ideas.

Furthermore we assume

- $c(A_1/A_2) \to \mu_i$ for $A_2 \to A_1$. As technologies converge so do costs.
- For $A_1/A_2 \to \infty \lim c(A_1/A_2) = 0$.

[Insert: Cost of copying for the follower country]

Dynamics:

- steady-state where A_1/A_2 is something constant
- i.e. where A_1 and A_2 grow at equal rates.

Equating $\hat{A}_1$ and $\hat{A}_2$:

$$\frac{\gamma_{A,1}}{\mu_i} = \frac{\gamma_{A,2}}{c\left(\frac{A_1}{A_2}\right)}.$$

Thus a steady-state is where

$$\mu_c = c\left(\frac{A_1}{A_2}\right) = \mu_i \cdot \frac{\gamma_{A,2}}{\gamma_{A,1}}.$$

i.e. if it exists it is at unique.

Observe:

- lower μ_c for A_1/A_2 above steady-state level.
- growth of A_1 is given
- A_2 grows at higher rate for for A_1/A_2 above steady-state level.

$\rightarrow$ the steady-state is stable.

[Insert: Phase diagram for 2 country model]

Conclude

- Convergence of growth rates for A_1 and A_2
- Convergence of income growth rates y_1 and y_2.
- Yet, income levels may differ depending on the parameters.
- Even the copying country can be richer:
  - low copying costs
  - only a little fraction of people has to work in R&D. Many produce goods.

Comparative statics and dynamics:

- Suppose country 2 allocates a higher fraction of people to R&D ($\gamma_{A,2} \uparrow$).
- temporary loss of output
- temporary higher rate of technology advancements (adoption)
- in the end growth is determined by the (given) rate of the leader country.

[Insert: Phase diagram and Impulse Response paths]

Conclude: elimination of the scale effect (for follower):

- more people in R&D leads to temporary higher growth and permanently higher income
- but no change of long-run growth rate.

Note

- If $\gamma_{A,2} > \gamma_{A,1}$ the equilibrium does not exist.
- Starting with imitation at some point we reach $A_2 = A_1$
- Complete catch up $\rightarrow$ country 2 becomes the leader.

Normally among the developed countries

- some countries/firms lead with some technology others with others
- capital embodied technological change
- R&D productivity is higher at younger vintages of capital (e.g. PC's)

$\rightarrow$ Leapfrogging.

But then, if this is true: why seem many LDC's not to converge

- Patents expire after about 20 years
- Many LDC's are lagging much more than 20 years behind.

2 possible explanations (more later)

1. Tacit knowledge
   - it is not enough to have the blueprint for a new technology (e.g. a nuclear power plant)
   - one needs the (tacit) knowledge of people to operate it.
   - knowledge that is not written down but in the mind of engineers.

2. Technological change is capital biased
   - according to our simple theory where $y = Ak^{\alpha}$ a shift of A increases productivity at all levels of capital accumulation (proportional to k^{α}).

[Insert: Neutral technological change]

But think, for example, of technological change in agriculture (the tractor, the combine harvester, ...)

- In many instances technological progress is capital-biased
- It benefits only those who operate a sufficiently capital intensive technology.
- It has no/little effects in countries with low capital per capita.

[Insert: Capital-biased technological change]

Economic development in stages

- Accumulation of sufficient capital and education per person before imitating the technologically advanced countries.
- Imitating before operating a cutting-edge technology and creating knowledge.

Sadly, its easy to get stuck at the first stage.

Problem:

- Firms in developed countries could invent new technologies designed for LDC's.
- But the incentive is low because of low protection of intellectual property rights.
- The problem of bad institutions $\rightarrow$ later.