EC569 Economic Growth
Technological Progress
Lecture 8

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Overview

- Finish covering the two-country model of technology creation and growth
- Relax some unrealistic assumptions on the growth rate of technology
- Analyze the motives and consequences of R&D in a market economy
- Understand why might the level of R&D in market economy not be socially optimal
- Last lecture and this one are about understanding the sustained economic growth in advanced economies.

Last week, we left at...

Two-country model of technology creation and growth

- Draws on Barro and Sala-i Martin (1997)
- Two countries: country 1 and country 2

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

$$y_2 = A_2(1 - \gamma_{A,2})$$

- Two means of acquiring a technology
  - **Innovation:** the invention of a new technology
  - **Imitation:** copying of a technology from elsewhere, available only to *technology follower*
- Suppose, country 1 is the **technology leader:** $A_1 > A_2$
- Country 2 is the **technology follower:** $A_1 > A_2$
- Assume $\gamma_{A,1} > \gamma_{A,2}$
  - This assumption along with equal labor force sizes guarantees that country 1 is the technology leader in the model's steady state.

Productivity Growth Rates

- Productivity growth rate in the leader country

$$\hat{A}_1 = \frac{\gamma_{A,1}}{\mu_i} L_1,$$

where μ_i is the cost of *invention*.

- Productivity growth rate in the follower

$$\hat{A}_2 = \frac{\gamma_{A,2}}{\mu_c} L_2,$$

where μ_c is cost of *copying* (or *imitation*)

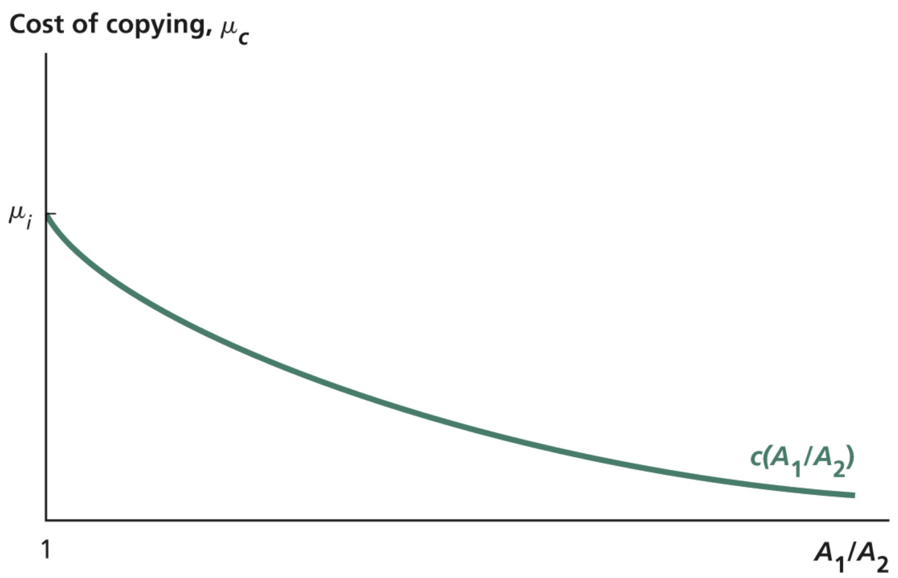
Cost of Copying for the Follower Country

- Cost of *copying* is a function of technology gap between leader and follower:

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

- As technology gap widens, cost of copying decreases

- As $\frac{A_1}{A_2} \to \infty$, $\mu_c = c\left(\frac{A_1}{A_2}\right) \to 0$

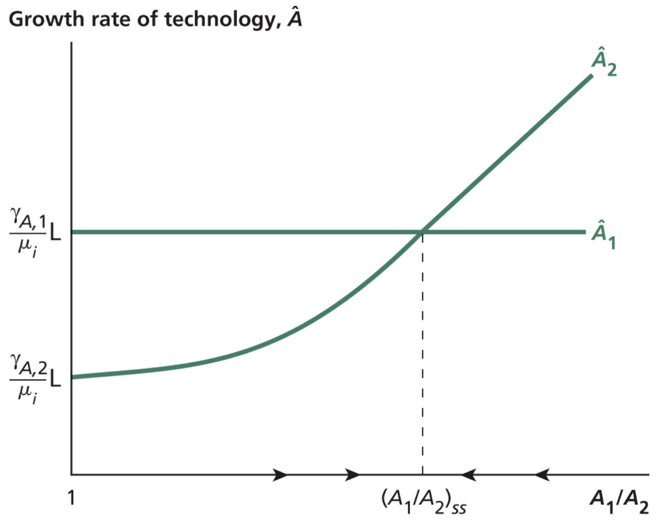


Graphics from: Weil (2013)

Steady State in the Two-Country Model

- If $A_1/A_2 = 1$, then cost of invention would be the same, and country 1 will grow faster since $\gamma_{A,1} > \gamma_{A,2}$
- If $A_1/A_2 = \infty$, then cost of copying would be 0 for country 2, and it will grow much faster than country 1
- At some point $1 < A_1/A_2 < \infty$ the countries will grow at the same rate
- Steady state is stable:
  - If $A_1/A_2 > (A_1/A_2)_{ss}$, A_2 will grow faster and $A_1/A_2 \downarrow$
  - If $A_1/A_2 < (A_1/A_2)_{ss}$, A_1 will grow faster and $A_1/A_2 \uparrow$

- Remember that $\hat{A}_2 = \frac{\gamma_{A,2}}{\mu_c} L_2$, $\mu_c \downarrow$ as $A_1/A_2 \uparrow$



Graphics from: Weil (2013)

Steady state

- In the steady state, countries grow at the same rate

$$\frac{\gamma_{A,1}}{\mu_i} L = \hat{A}_1 = \hat{A}_2 = \frac{\gamma_{A,2}}{\mu_c} L$$

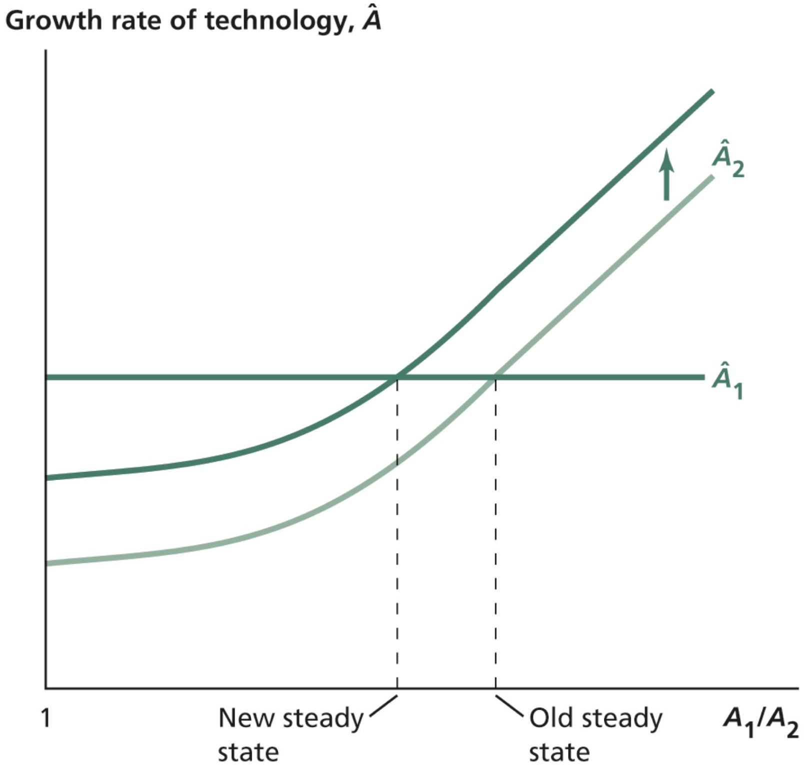
- Cost of copying:

$$\mu_c = \frac{\gamma_{A,2}}{\gamma_{A,1}} \mu_i$$

- Country 2 has lower cost of technology acquisition
- Once we know μ_c, we can solve for A_1/A_2 s.t. $c(A_1/A_2) = \mu_c = \frac{\gamma_{A,2}}{\gamma_{A,1}} \mu_i$
- Is the technology-leading country necessarily better off than the follower?

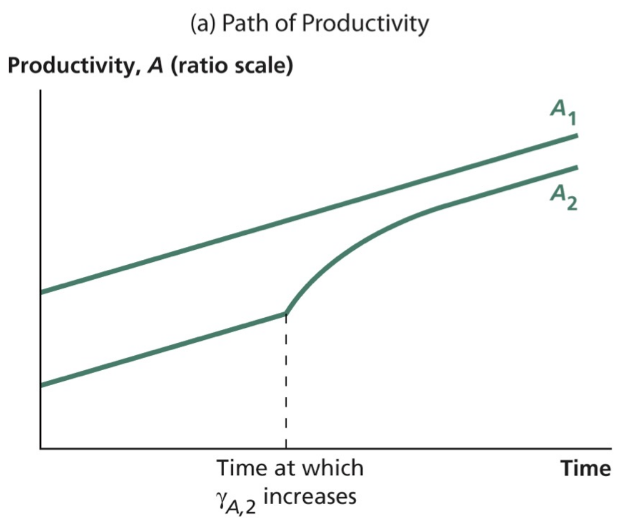
Effects of an increase in R&D in the follower country on the steady state

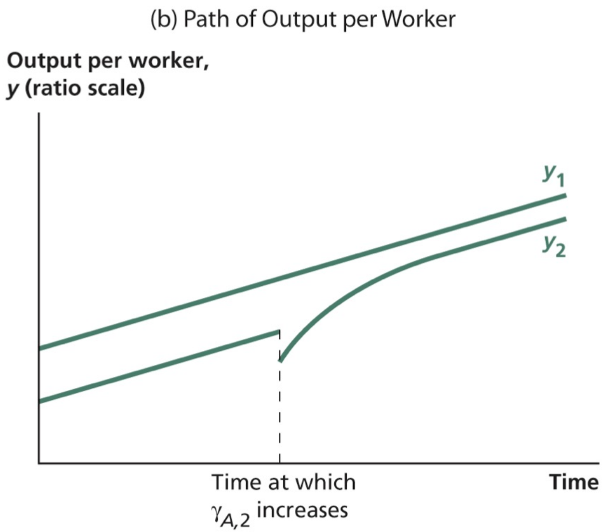
- Increase $\gamma_{A,2}$ but still lower than $\gamma_{A,1}$
- Technology level of the follower country come closer to the technology level of the leader country
- Since $\gamma_{A,2} < \gamma_{A,1}$, $A_1 > A_2$ in the long run



Graphics from: Weil (2013)

Effect of an increase in $\gamma_{A,2}$ on productivity and output





Graphics from: Weil (2013)

- Increase in $\gamma_{A,2}$ causes a temporary increase in growth rates, in contrast to permanent increase in one-country model
    - Similar to increase in investment rate in the Solow model
- In contrast, an increase in $\gamma_{A,1}$ leads to permanent changes in the growth rates

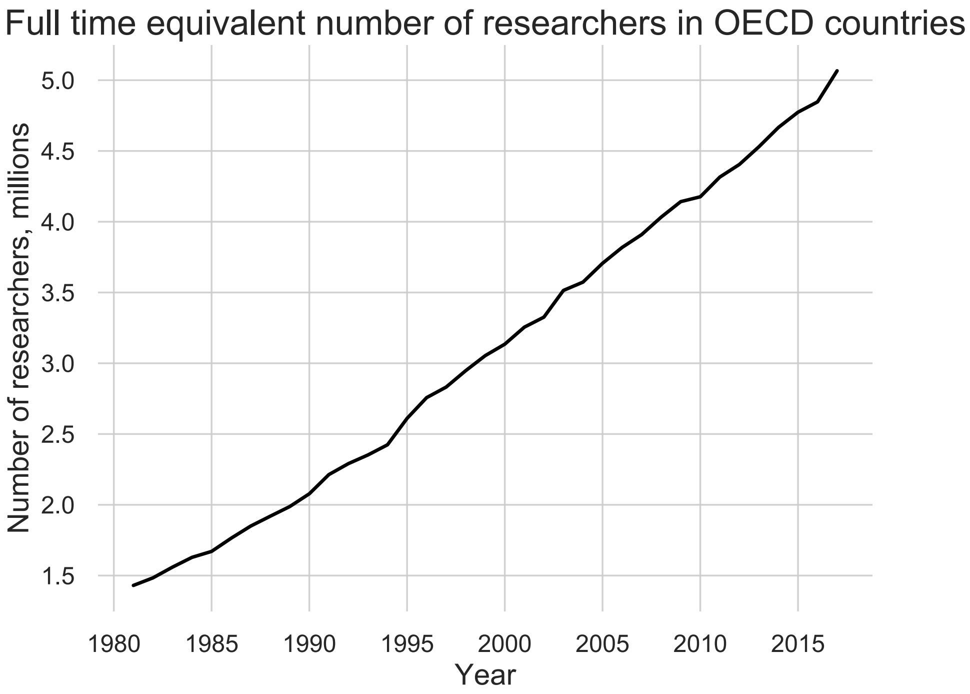
Technology production function

Technology production function

- So far, we assumed technology growth rate is independent of current technology level:

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

- However, technology is cumulative:
    - Researchers begin their investigations where those who came before them left off.
- Considering the increse in the research efforts, growth should have skyrocketed.



Data source: OECD

Cumulative nature of technology development

Instead of assuming $\hat{A} = \frac{L_A}{\mu}$ assume $\hat{A} \equiv \frac{\dot{A}}{A} = \frac{L_A^\lambda}{\mu} A^{\phi - 1}$, then

$$\dot{A} = \frac{L_A^\lambda}{\mu} A^\phi$$

- If $\phi > 0$: **standing on shoulders**

  Isaac Newton:

  > If I have seen farther than others, it is because I have stood on *the shoulders of giants*.

  - Larger base of knowledge
  - Larger set of tools
- If $\phi < 0$: **fishing out**
  - Fishing out effect: easiest discoveries have already been made
  - More is known today, more effort for a researcher to learn everything required

Stepping on toes effect

- If $\lambda < 1$
- Efforts of most of the researchers will be wasted if many are working at the same project
    - Charles Darwin came up earlier with *natural selection* than Alfred Wallace
    - Two teams completed the sequencing of human genome simultaneously

Long-run growth rate

- How do we calculate long-run economic growth if $\dot{A} = \frac{L_A^\lambda}{\mu} A^\phi$?
- Growth rate of A, $g_A \equiv \frac{\dot{A}}{A} = \frac{(\gamma_A L)^\lambda}{\mu} A^{\phi-1} = \frac{(\gamma_A L)^\lambda}{\mu A^{1-\phi}}$
- For g_A to be constant, $(\gamma_A L)^\lambda$ and $\mu A^{1-\phi}$ should grow at the same rate.
- Growth rate of $(\gamma_A L)^\lambda$ is λn, where n is the population growth rate.
- Growth rate of $\mu A^{1-\phi}$ is equal to $(1-\phi) g_A$
- $(1-\phi) g_A = \lambda n$
- Growth rate of technology: $g_A = \frac{\lambda n}{(1-\phi)}$ if $\phi < 1$.
- g_A is positively correlated with λ and n, and negatively correlated with ϕ

Determinants of productivity growth

Recall that $g_A \equiv \frac{\dot{A}}{A} = \frac{(\gamma_A L)^\lambda}{\mu} \frac{A^\phi}{A}$

In the long-run: $g_A = \frac{\lambda n}{(1-\phi)}$

To understand the intuition, suppose $\lambda = 1$ and $\phi = 0$

Then $g_A = \frac{(\gamma_A L)}{\mu} \frac{1}{A}$ all the time, $g_A = n$ in the long run

- If population does not grow, g_A will converge to 0
- Hence the only source of growth is from population growth
- $g_A = n$ if $\lambda = 1$ and $\phi = 0$
- Larger population generates more ideas
- Since ideas are non-rivalrous, everyone benefits

Determinants of productivity growth, cont'd

- Now suppose $\lambda = 1$ and $\phi = 1$
- Then, $g_A = \frac{(\gamma_A L)}{\mu} \frac{A}{A} = \frac{(\gamma_A L)}{\mu}$ all the time
- Notice that this formulation is equivalent to our assumption in the last lecture
- We see sustained growth even if research effor is contant, i.e. even if $\gamma_A L$ is constant.
- Rejected by the data

Determinants of productivity growth, cont'd (2)

If $\phi > 0$ but $\phi < 1$:

- still positive spillovers from research

$g_A = \frac{(\gamma_A L)^\lambda}{\mu} \frac{A^\phi}{A}$ all the time

g_A at the steady state (or balanced growth path): $g_A = \frac{\lambda n}{(1-\phi)}$

- Unaffected by the fraction of population engaging in R&D
  - Intuitively, higher γ_A leads to higher $\hat{A}$ in the short run
  - In the long-run, because of diminishing marginal product of idea stock in idea creation, γ_A does not affect the long-run economic growth.

However, short-run growth rate of productivity is a still function of fraction of labor force engaging in R&D.

Income per capita in the long run

- Fraction of labor force engaging in R&D impacts income per capita
  - Positively: high level of productivity in the long run
  - Negatively: smaller fraction of workers in the production
- Size of labor force, $L(t)$, impacts income per capita positively (**scale effect**):
  - **demand effect:** $L \uparrow \Rightarrow$ larger market for an idea $\Rightarrow \uparrow$ return to research
  - **supply effect:** $L \uparrow \Rightarrow$ more potential creators of ideas

How is the level of innovation determined in a market economy?

2-models of innovation

Romer Model

- Developed by Paul Romer
- Technological progress in Romer:
  - increase in the number of differentiated intermediate goods
  - steam engines and electric motors are used alongside each other
- To produce a differentiated intermediate good,
  - one needs to own the blueprints of production
- Monopolistic competition in the intermediate goods
  - Economic profit is the motive to innovate

Schumpeterian model

- Developed by Aghion and Howitt (1992) and Grossman and Helpman (1991)
- Insights of Joseph Schumpeter, creative destruction
- Technological progress in the Schumpeterian model:
  - Technological progress: an innovation replaces an existing intermediate good
  - Walking $\rightarrow$ horse cart $\rightarrow$ the Model T Ford $\rightarrow$ modern cars
  - Hence the term **creative destruction**

What motivates entrepreneurs to innovate?

Return to innovation: expected discounted sum of future profits

Fraction of labor force working in R&D depends

- negatively on the distcount rate
    - the lower the value of future consumption, the lower the incentive to give up current consumption to have higher future consumption
- positively on the probability of innovation
    - The higher the chance of a successful innovation, the higher the incentives to innovate
- Negatively on the probability of innovation
    - The higher the chance of being replaced by subsequent innovators, the lower the incentives to innovate
    - Notice that this motive is missing in the Romer model.

Comparison of the Romer model and the Schumpeterian model

- In both models, long-run **growth** is independent of the fraction of labor force engaging in research
- In both models, **level** of income per capita in the long run is impacted by the fraction of labor force engaging in research
- If the discount rate applied to monopoly profits is large, the Schumpeterian model imply a larger fraction of labor force engaging in innovation
  - because relative importance of being replaced by others is small
- If the discount rate is relatively small, the Schumpeterian model imply a smaller fraction of labor force engaging in research
  - because people are sensitive to the future destruction of profits

Socially optimal R&D

Because of the externalities in the innovation process, competitive equilibrium R&D level is not socially optimal.

Three distortions:

Remember that $\dot{A} = \frac{L_A}{\mu} A^{\phi}$

- if $\phi > 0$: "standing on shoulders"
  - Researchers do not benefit from the positive impact on the subsequent innovators
- if $\lambda < 1$: "stepping on toes"
  - Researchers do not take into account potential duplication of research efforts
- Consumer surplus effect
  - Private gain of an innovation = profit < Consumer surplus = Social gain
- Ground for government interference to correct for the externalities

Summary

- Analyzed the technology growth rates of different countries are interrelated.
- Analyzed how current level of technology, and number of researchers determine rate of technological progress.
- Analyzed the motives of innovation
- Analyzed the consequences of innovation
- Analyzed externalities in the innovation process, and justified the role of government intervention

To review this lecture

Read

- Chapter 8.3 of Economic Growth by David Weil
- Mathematical appendix to Cahpter 9 of Economic Growth by David Weil
- Chapter 5 of Introduction to Economic Growth by Jones and Vollrath