Chapter 9:
Economic Growth II:
Technology, Empirics, and Policy

Learning objectives

- Technological progress in the Solow model
- Policies to promote growth
- Growth empirics:
  Confronting the theory with facts
- Endogenous growth:
  Two simple models in which the rate of technological progress is endogenous

Introduction

In the Solow model of Chapter 8,

- the production technology is held constant
- income per capita is constant in the steady state.

Neither point is true in the real world:

- for instance U.S. real GDP per person grew by a factor of 8.3 between 1900 and 2013, or 1.9% per year.
- examples of technological progress abound *(see next slide)*

Examples of technological progress

- U.S. farm sector productivity nearly tripled from 1950 to 2012.
- The real price of computer power has fallen an average of 30% per year over the past three decades.
- 2000: 361 million Internet users, 740 million cell phone users
  2015: 3.1 billion Internet users, 4.9 billion cell phone users
- 2001: iPod capacity = 5gb, 1000 songs. Not capable of playing episodes of *Game of Thrones*.

  2015: iPod touch capacity = 64gb, 16,000 songs. Can play episodes of *Game of Thrones*.

Tech. progress in the Solow model

- A new variable: ***E*** = labor efficiency (劳动效率）
- Assume:
  Technological progress is **labor-augmenting** （劳动扩张型技术进步）: it increases labor efficiency at the exogenous rate ***g****:*

$$\boldsymbol{g} = \frac{\Delta \boldsymbol{E}}{\boldsymbol{E}}$$

Tech. progress in the Solow model

- We now write the production function as:

$$\boldsymbol{Y = F(K, L \times E)}$$

- where $\boldsymbol{L \times E}$ = the number of effective workers （效率工人）.
  - Hence, increases in labor efficiency have the same effect on output as increases in the labor force.

Tech. progress in the Solow model

- Notation:

  $y = Y/LE$ = **output per effective worker**

  $k = K/LE$ = **capital per effective worker**

- Production function per effective worker:

  $$y = f(k)$$

- Saving and investment per effective worker:

  $$s\,y = s\,f(k)$$

Tech. progress in the Solow model

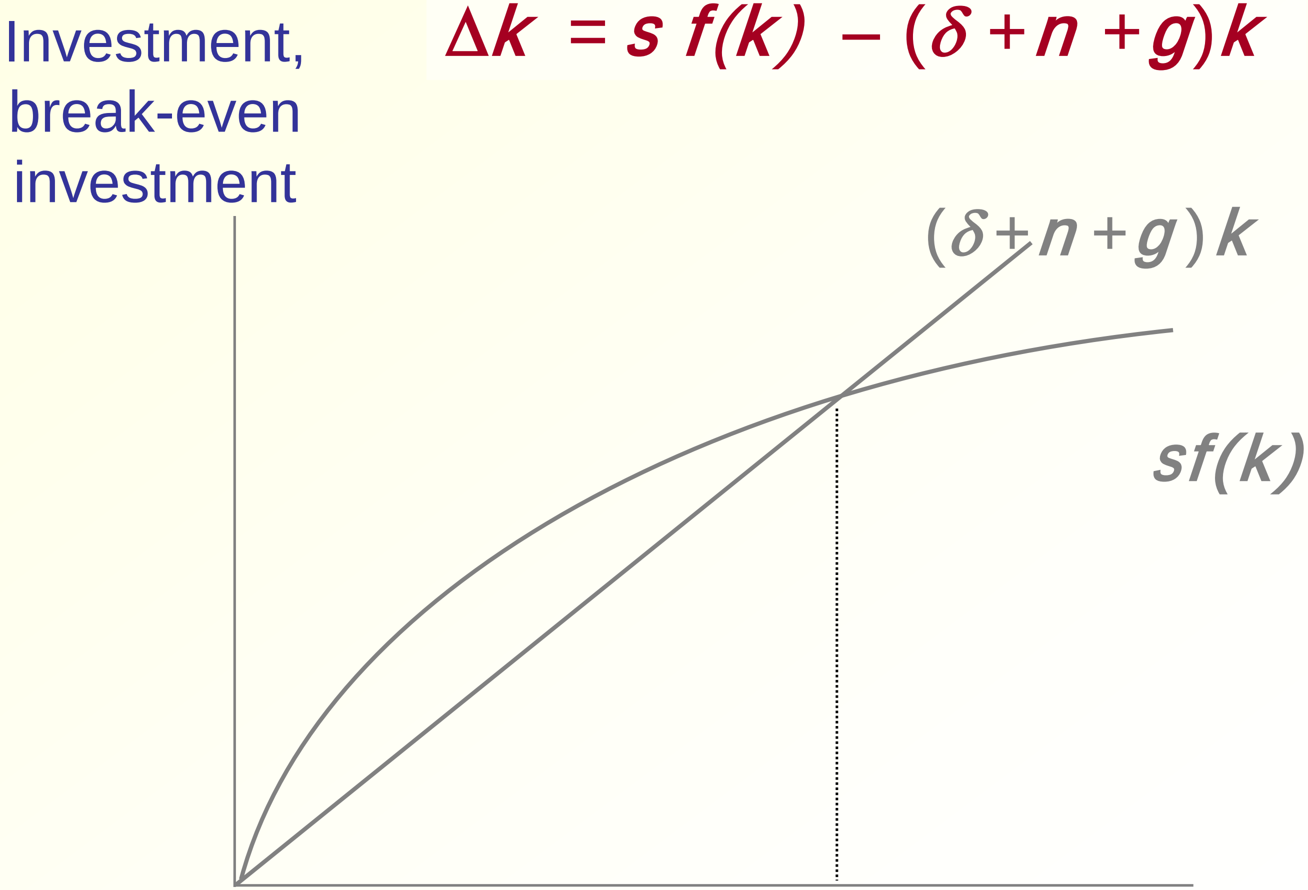
$(\delta + \boldsymbol{n} + \boldsymbol{g})\boldsymbol{k}$ = break-even investment: the amount of investment necessary to keep $\boldsymbol{k}$ constant.

Consists of:

- $\delta \boldsymbol{k}$ to replace depreciating capital
- $\boldsymbol{n}\,\boldsymbol{k}$ to provide capital for new workers
- $\boldsymbol{g}\,\boldsymbol{k}$ to provide capital for the new "effective" workers created by technological progress

Tech. progress in the Solow model

$$\Delta k = s\,f(k) - (\delta + n + g)k$$



Steady-State Growth Rates in the Solow Model with Tech. Progress

Variable	Symbol	Steady-state growth rate
Capital per effective worker	$k = K/(L \times E)$	0
Output per effective worker	$y = Y/(L \times E)$	0
Output per worker	$(Y/L) = y \times E$	g
Total output	$Y = y \times E \times L$	$n + g$

The Golden Rule

To find the Golden Rule capital stock,
express c^* in terms of k^*:

$$c^* = y^* - i^*$$
$$= f(k^*) - (\delta + n + g)k^*$$

c^* is maximized when

$$\text{MPK} = \delta + n + g$$

or equivalently,

$$\boxed{\text{MPK} - \delta = n + g}$$

In the Golden Rule Steady State, the marginal product of capital net of depreciation equals the pop. growth rate plus the rate of tech progress.

Policies issues

1. Are we saving enough? Or too much?
2. What policies might change the saving rate?
3. How should we allocate our investment between privately owned physical capital, public infrastructure, and “human capital”?
4. How do a country’s institutions affect production efficiency and capital accumulation?
5. What policies might encourage faster technological progress?

1. Evaluating the Rate of Saving

- Use the Golden Rule to determine whether our saving rate and capital stock are too high, too low, or about right.
- To do this, we need to compare $(\text{MPK} - \delta)$ to $(\boldsymbol{n} + \boldsymbol{g})$.
- If $(\text{MPK} - \delta) > (\boldsymbol{n} + \boldsymbol{g})$, then we are below the Golden Rule steady state and should increase ***s***.
- If $(\text{MPK} - \delta) < (\boldsymbol{n} + \boldsymbol{g})$, then we are above the Golden Rule steady state and should reduce ***s***.

1. Evaluating the Rate of Saving

To estimate ($MPK - \delta$), we use three facts about the economy of the U.K.:

1. $\boldsymbol{k} = 2.5\, \boldsymbol{y}$
   The capital stock is about 2.5 times one year's GDP.
2. $\delta \boldsymbol{k} = 0.1\, \boldsymbol{y}$
   About 10% of GDP is used to replace depreciating capital.
3. $MPK \times \boldsymbol{k} = 0.3\, \boldsymbol{y}$
   Capital income is about 30% of GDP

1. Evaluating the Rate of Saving

1. $\boldsymbol{k} = 2.5\,\boldsymbol{y}$
2. $\delta\boldsymbol{k} = 0.1\,\boldsymbol{y}$
3. $\text{MPK} \times \boldsymbol{k} = 0.3\,\boldsymbol{y}$

To determine δ, divide 2 by 1:

$$\frac{\delta\boldsymbol{k}}{\boldsymbol{k}} = \frac{0.1\,\boldsymbol{y}}{2.5\,\boldsymbol{y}} \quad \Rightarrow \quad \delta = \frac{0.1}{2.5} = 0.04$$

1. Evaluating the Rate of Saving

1. $\boldsymbol{k} = 2.5\,\boldsymbol{y}$
2. $\delta\,\boldsymbol{k} = 0.1\,\boldsymbol{y}$
3. $\text{MPK} \times \boldsymbol{k} = 0.3\,\boldsymbol{y}$

To determine MPK, divide 3 by 1:

$$\frac{\text{MPK} \times \boldsymbol{k}}{\boldsymbol{k}} = \frac{0.3\,\boldsymbol{y}}{2.5\,\boldsymbol{y}} \quad \Rightarrow \quad \text{MPK} = \frac{0.3}{2.5} = 0.12$$

Hence, $\text{MPK} - \delta = 0.12 - 0.04 = 0.08$

1. Evaluating the Rate of Saving

- From the last slide: MPK – δ = 0.08
- U.K. real GDP grows an average of 2.5%/year,
  so $\boldsymbol{n + g} = 0.025$
- Thus, in the U.K.,

$$\text{MPK} - \delta = 0.08 > 0.025 = \boldsymbol{n + g}$$

The U.K. is below the Golden Rule steady state: if we increase our saving rate, we will have faster growth until we get to a new steady state with higher consumption per capita.

2. Policies to increase the saving rate

- Reduce the government budget deficit (or increase the budget surplus)
- Increase incentives for private saving:
  - reduce capital gains tax, corporate income tax, inheritance tax as they discourage saving
  - replace income tax by consumption tax
  - expand tax incentives for savings through retirement pension funds and other retirement savings accounts

3. Allocating the economy's investment

- In the Solow model, there's one type of capital.
- In the real world, there are many types, which we can divide into three categories:
  - private capital stock
  - public infrastructure
  - **human capital**: the knowledge and skills that workers acquire through education
- How should we allocate investment among these types?

Allocating the economy's investment: *two viewpoints*

1. Equalize tax treatment of all types of capital in all industries, then let the market allocate investment to the type with the highest marginal product.
2. **Industrial policy**: Gov't should actively encourage investment in capital of certain types or in certain industries, because they may have *positive externalities* (by-products) that private investors don't consider.

Possible problems with industrial policy （产业政策）

- Does the gov’t have the ability to “pick winners” (choose industries with the highest return to capital or biggest externalities)?
- Would politics (e.g. campaign contributions) rather than economics influence which industries get preferential treatment?

4. Establishing the right institutions

- Creating the right institutions is important for ensuring that resources are allocated to their best use.   Examples:
  - Legal institutions, to protect property rights.
  - Capital markets, to help financial capital flow to the best investment projects.
  - A corruption-free government, to promote competition, enforce contracts, etc.

5. Encouraging technological progress

- Patent laws:
  encourage innovation by granting temporary monopolies to inventors of new products
- Tax incentives for R&D
- Grants to fund research at universities
- Industrial policy:
  encourage specific industries that are key for rapid tech. progress
  (subject to the concerns on the preceding slide)

CASE STUDY:

Is free trade good for economic growth?

- Since Adam Smith, economists have argued that free trade can increase production efficiency and living standards.
- Research by Sachs & Warner:

Average annual growth rates, 1970–89		
	open	closed
developed nations	2.3%	0.7%
developing nations	4.5%	0.7%

CASE STUDY:
Is free trade good for economic growth?

- To determine causation, Frankel and Romer exploit geographic differences among countries:
  - Some nations trade less because they are farther from other nations, or landlocked.
  - Such geographical differences are correlated with trade but not with other determinants of income.
  - Hence, they can be used to isolate the impact of trade on income.
- Findings: increasing trade/GDP by 2% causes GDP per capita to rise 1%, other things equal.

CASE STUDY: The Productivity Slowdown

	Growth in output per person (percent per year)	
	1948–72	1972–95
Canada	2.9	1.8
France	4.3	1.6
Germany	5.7	2.0
Italy	4.9	2.3
Japan	8.2	2.6
U.K.	2.4	1.8
U.S.	2.2	1.5

Explanations?

- *Measurement problems*
  Increases in productivity not fully measured.
  - But: Why would measurement problems be worse after 1972 than before?
- *Oil prices*
  Oil shocks occurred about when productivity slowdown began.
  - But: Then why didn't productivity speed up when oil prices fell in the mid-1980s?

Explanations?

- *Worker quality*
  1970s - large influx of new entrants into labor force (baby boomers, women).
  New workers are less productive than experienced workers.

- *The depletion of ideas* (思想枯竭）

The bottom line:

We don’t know which of these is the true explanation, it’s probably a combination of several of them.

CASE STUDY: I.T. and the “new economy”

	Growth in output per person (percent per year)		
	1948-72	1972-95	1995-2000
Canada	2.9	1.8	2.7
France	4.3	1.6	2.2
Germany	5.7	2.0	1.7
Italy	4.9	2.3	4.7
Japan	8.2	2.6	1.1
U.K.	2.4	1.8	2.5
U.S.	2.2	1.5	2.9

CASE STUDY: I.T. and the “new economy”

Apparently, the computer revolution didn’t affect aggregate productivity until the mid-1990s.

Two reasons:

1. Computer industry’s share of GDP much bigger in late 1990s than earlier.
2. Takes time for firms to determine how to utilize new technology most effectively

The big questions:

- Will the growth spurt of the late 1990s continue?

Growth empirics: Confronting the Solow model with the facts

Solow model's steady state exhibits **balanced growth** - many variables grow at the same rate.

- Solow model predicts ***Y/L*** and ***K/L*** grow at same rate (***g***), so that ***K/Y*** should be constant.
- This is true in the real world.
- Solow model predicts real wage grows at same rate as ***Y/L***, while real rental price is constant.

  Also true in the real world.

Convergence （趋同）

- Solow model predicts that, other things equal, "poor" countries (with lower ***Y/L*** and ***K/L***) should grow faster than "rich" ones.
- If true, then the income gap between rich & poor countries would shrink over time, and living standards "converge."
- In real world, many poor countries do NOT grow faster than rich ones. Does this mean the Solow model fails?

Convergence

- No, because "other things" aren't equal.
  - In samples of countries with similar savings & pop. growth rates, income gaps shrink about 2%/year.
  - In larger samples, if one controls for differences in saving, population growth, and human capital, incomes converge by about 2%/year.
- What the Solow model *really* predicts is **conditional convergence** - countries converge to their own steady states, which are determined by saving, population growth, and education.

  And this prediction comes true in the real world.

Factor accumulation vs. Production efficiency

Two reasons why income per capita are lower in some countries than others:

1. Differences in capital (physical or human) per worker
2. Differences in the efficiency of production (the height of the production function)

Studies:

- both factors are important
- countries with higher capital (physical or human) per worker also tend to have higher production efficiency

Endogenous Growth Theory

- Solow model:
  - sustained growth in living standards is due to tech progress
  - the rate of tech progress is exogenous
- Endogenous growth theory:
  - a set of models in which the growth rate of productivity and living standards is endogenous

A basic model

- Production function: $\boldsymbol{Y = A\,K}$
  where $\boldsymbol{A}$ is the amount of output for each unit of capital ($\boldsymbol{A}$ is exogenous & constant)
- Key difference between this model & Solow: MPK is constant here, diminishes in Solow
- Investment: $\boldsymbol{s\,Y}$
- Depreciation: $\boldsymbol{\delta\,K}$
- Law of motion for total capital:

$$\Delta \boldsymbol{K} = \boldsymbol{s\,Y} - \boldsymbol{\delta\,K}$$

A basic model

$$\Delta K = s\,Y - \delta K$$

- Divide through by K and use $Y = A\,K$, get:

$$\frac{\Delta Y}{Y} = \frac{\Delta K}{K} = sA - \delta$$

- If $s\,A > \delta$, then income will grow forever, and investment is the "engine of growth."
- Here, the permanent growth rate depends on s. In Solow model, it does not.

Does capital have diminishing returns or not?

- Depends on definition of capital.
- Yes, if "capital" is narrowly defined (plant & equipment).
- Perhaps not, with a broad definition of "capital" (physical & human capital, knowledge).
- Some economists believe that knowledge exhibits <u>increasing</u> returns.

A two-sector model

- Two sectors:
  - manufacturing firms produce goods
  - research universities produce knowledge that increases labor efficiency in manufacturing
- $\boldsymbol{u}$ = fraction of labor in research

  ($\boldsymbol{u}$ is enogenous)
- Mnf prod func: $\boldsymbol{Y} = \boldsymbol{F}[\boldsymbol{K}, (1-\boldsymbol{u})\boldsymbol{E}\boldsymbol{L}]$
- Res prod func: $\Delta \boldsymbol{E} = \boldsymbol{g}(\boldsymbol{u})\boldsymbol{E}$
- Cap accumulation: $\Delta \boldsymbol{K} = \boldsymbol{s}\boldsymbol{Y} - \delta \boldsymbol{K}$

A two-sector model

- In the steady state, mnf output per worker and the standard of living grow at rate
  $\Delta \boldsymbol{E}/\boldsymbol{E} = \boldsymbol{g}\,(\boldsymbol{u})$.
- Key variables:
  s: affects the level of income, but not its growth rate (same as in Solow model)
  u: affects level <u>and</u> growth rate of income
- Question:
  Would an increase in ***u*** be unambiguously good for the economy?

Three facts about R&D (研发）in the real world

1. Much research is done by firms seeking profits.
2. Firms profit from research because
   - new inventions can be patented, creating a stream of monopoly profits until the patent expires
   - there is an advantage to being the first firm on the market with a new product
3. Innovation produces externalities that reduce the cost of subsequent innovation.

   Much of the new endogenous growth theory attempts to incorporate these facts into models to better understand tech progress.

Is the private sector doing enough R&D?

- The existence of positive externalities in the creation of knowledge suggests that the private sector is not doing enough R&D.
- But, there is much duplication of R&D effort among competing firms.
- Estimates: The social return to R&D is very large (sometimes above 40% per year). Thus, many believe gov't should encourage R&D

Economic growth as “creative destruction”

- Schumpeter (1942) coined term “creative destruction” to describe displacements resulting from technological progress:
  - the introduction of a new product is good for consumers but often bad for incumbent producers, who may be forced out of the market.
- Examples:
  - Luddites (1811–12) destroyed machines that displaced skilled knitting workers in England.
  - Walmart displaces many mom-and-pop stores.

Chapter summary

1. Key results from Solow model with tech progress
    - steady state growth rate of income per person depends solely on the exogenous rate of tech progress
    - most economies have much less capital than the Golden Rule steady state

2. Ways to increase the saving rate
    - increase public saving (reduce budget deficit)
    - tax incentives for private saving

Chapter summary

3. Productivity slowdown & "new economy"
   - Early 1970s: fall in productivity growth in the U.K. and other countries.
   - Mid 1990s: productivity growth increased, probably because of advances in I.T.
4. Empirical studies
   - Solow model explains balanced growth, conditional convergence
   - Cross-country variation in living standards due to differences in capital accumulation and in production efficiency

Chapter summary

5. Endogenous growth theory: models that
   - examine the determinants of the rate of tech progress, which Solow takes as given
   - explain decisions that determine the creation of knowledge through R&D