Macroeconomics

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CHAPTER 9

Economic Growth II: Technology, Empirics, and Policy

Presentation Slides

IN THIS CHAPTER, YOU WILL LEARN:

- how to incorporate technological progress in the Solow model
- about growth empirics: confronting the theory with facts
- about policies to promote 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:

- 1900–2016: U.S. real GDP per person grew by a factor of 8.58, 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*.

  2018: iPod touch capacity = 64gb, 30,000 songs. Can play episodes of *Game of Thrones*.

9.1 Technological Progress in the Solow Model

Technological progress in the Solow model

- A new variable: ***E*** = labor efficiency
- Assume:
  Technological progress is **labor-augmenting**: it increases labor efficiency at the exogenous rate ***g***:

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

Solow Model

$$sf(k) = (\delta + n + g)k$$

Technological progress in the Solow model

- We now write the production function as:

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

- where $L \times E$ = the number of effective workers.
  - Increases in labor efficiency have the same effect on output as increases in the labor force.

Technological progress in the Solow model

- Notation:

  $\boldsymbol{y} = \boldsymbol{Y/LE}$ = output per effective worker

  $\boldsymbol{k} = \boldsymbol{K/LE}$ = capital per effective worker

- Production function per effective worker:

  $$\boldsymbol{y} = \boldsymbol{f(k)}$$

- Saving and investment per effective worker:

  $$\boldsymbol{sy} = \boldsymbol{sf(k)}$$

Technological progress in the Solow model

$k = \frac{K}{L \cdot E}$

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

$$0 = \frac{dk}{dt} = \frac{d\left(\frac{K}{LE}\right)}{dt} = \frac{1}{LE}\underbrace{\frac{dK}{dt}}_{I-\delta K} - \underbrace{\frac{1}{L}\cdot\frac{K}{LE}}_{k}\cdot\underbrace{\frac{dL}{dt}}_{n=\frac{\Delta L}{L}} - \underbrace{\frac{1}{E}\cdot\frac{K}{LE}}_{k}\cdot\underbrace{\frac{dE}{dt}}_{g=\frac{\Delta E}{E}}$$

$\Rightarrow i - \delta k - nk - gk = 0$

$\Rightarrow sf(k) = (\delta + n + g)k$

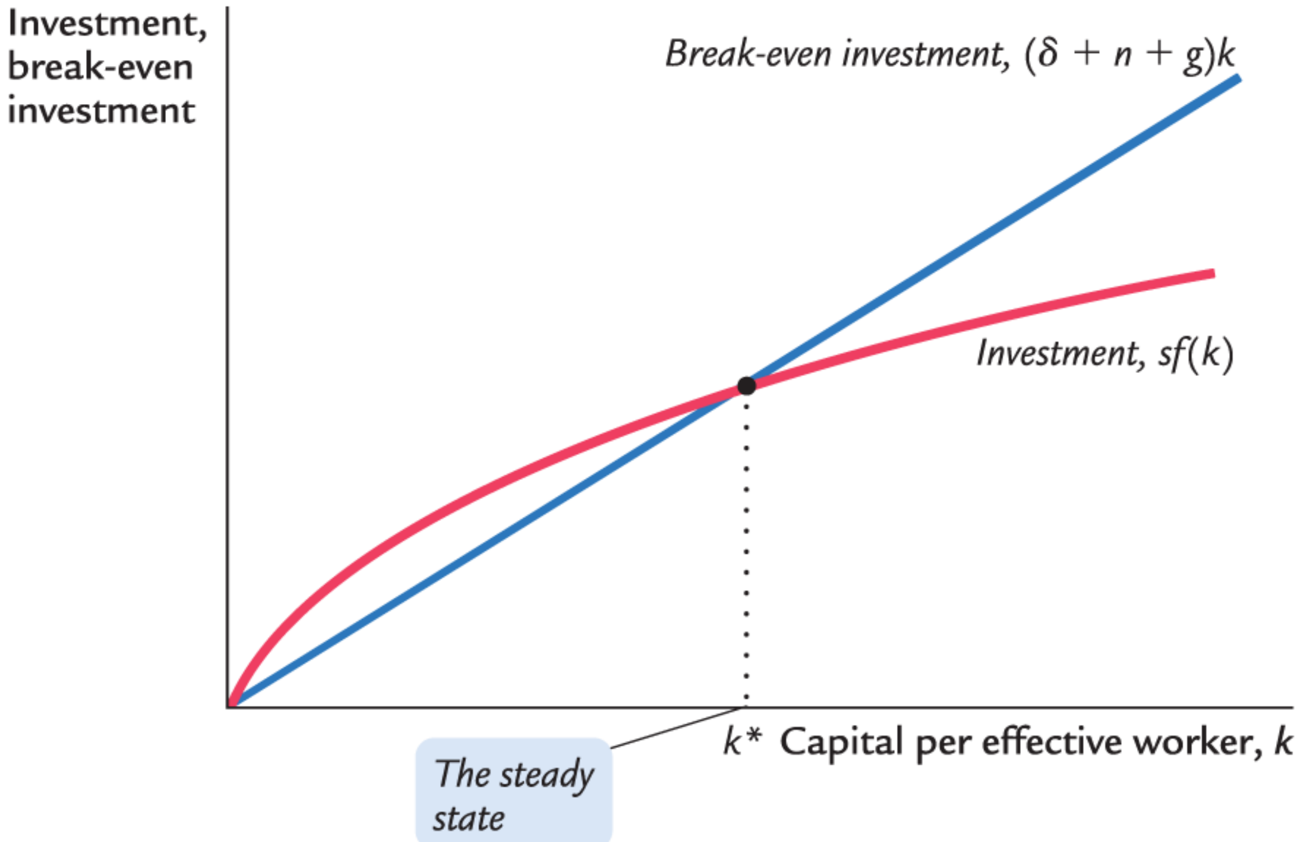
Solow Model

Consists of:

- δk to replace depreciating capital
- $n k$ to provide capital for new workers
- $g k$ to provide capital for the new "effective" workers created by technological progress

Technological progress in the Solow model

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



Mankiw, *Macroeconomics*, 10e, © 2019 Worth Publishers

Steady-state growth rates in the Solow model with tech. progress

$sf(k) = (\delta + n + g)k$

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	$(Y/L) = y \times \overset{g}{\boxed{E}}$	g
Total output	$Y = y \times \overset{g}{E} \times \overset{n}{L}$	$n + g$ 3% in China

The Golden Rule with technological progress

To find the Golden Rule capital stock, express $\boldsymbol{c}^*$ in terms of $\boldsymbol{k}^*$:

$$\begin{aligned} c^* &= \quad y^* \quad - \quad i^* \\ &= f(k^*) - (\delta + n + g)k^* \end{aligned}$$

$\boldsymbol{c}^*$ is maximized when

$$MPK = \delta + n + g$$

or equivalently,

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

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.

9.2 From Growth Theory to Growth Empirics

Growth empirics: Balanced growth

$sy = (\delta+n+g)k$

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

  stock → flow → $\frac{K}{Y} = \frac{K/L}{Y/L} = \frac{K/LE}{Y/LE} = \frac{k}{y} = \boxed{\frac{s}{\delta+n+g}}$

  - Solow model predicts ***Y***/***L*** and ***K***/***L*** grow at the same rate (***g***), so ***K***/***Y*** should be constant.

    $\frac{K}{Y} = 2$ in China

    This is true in the real world. $sy = (\delta+n+g)k$

  - Solow model predicts real wage grows at same rate as ***Y***/***L***, while real rental price is constant. (why?)

    Also true in the real world.

$MPK = \text{Const.}$

- **4.** Prove each of the following statements about the steady state of the Solow model with population growth and technological progress.

- **a.** The capital–output ratio is constant. $\frac{K}{Y} = \frac{s}{\delta+n+g}$ ✓

$Y = MPK \cdot K + MPL \cdot L$ $MPK \cdot K = \alpha Y$

- **b.** Capital and labor each earn a constant share of an economy's income.

$MPL \cdot L = (1-\alpha) Y$. Cobb-Douglas Production func.

- **c.** Total capital income and total labor income both grow at the rate of population growth plus the rate of technological progress, *n*+*g*.

$\% Y = n+g$, +(b.)

人均产出增速：技术进步

- **d.** The real rental price of capital is constant, and the real wage grows at the rate of technological progress *g*.

稳态不变 $MPK = \text{Const}$ (Steady state)

$$MPL = \frac{MPL \cdot L}{L} = \frac{(1-\alpha)\cdot Y \xrightarrow{} n+g}{L \xrightarrow{} n} \xrightarrow{} g.$$

Growth empirics: Convergence

- 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, causing living standards to *converge*.
- In real world, many poor countries do NOT grow faster than rich ones. Does this mean the Solow model fails?

Growth empirics: Convergence

- Solow model predicts that, other things equal, poor countries (with lower ***Y***/***L*** and ***K***/***L***) should grow faster than rich ones.
- No, because "other things" aren't equal:
  - In samples of countries with similar savings & pop. growth rates, income gaps shrink about 2% per year.
  - In larger samples, after controlling for differences in saving, pop. growth, and human capital, incomes converge by about 2% per year.

Growth empirics: Convergence

- 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.~~
- This prediction comes true in the real world.

Growth empirics: Factor accumulation vs. production efficiency

- Differences in income per capita among countries can be due to differences in:
  1. capital—physical or human—per worker
  2. the efficiency of production
     (the height of the production function)
- Studies:
  - Both factors are important.
  - The two factors are correlated: countries with higher physical or human capital per worker also tend to have higher production efficiency.

Growth empirics: Factor accumulation vs. production efficiency

- Possible explanations for the correlation between capital per worker and production efficiency:
  - Production efficiency encourages capital accumulation.
  - Capital accumulation has externalities that raise efficiency.

    外部性
  - A third, unknown variable causes capital accumulation and efficiency to be higher in some countries than others.

9.3 Policies to Promote Growth

Policy issues

- Are we saving enough? Too much?
- What policies might change the saving rate?
- How should we allocate our investment between privately owned physical capital, public infrastructure, and human capital?
- How do a country's institutions affect production efficiency and capital accumulation?
- What policies might encourage faster technological progress?

Policy issues: Evaluating the rate of saving

n+g: rate of Y

- Use the Golden Rule to determine whether the U.S. saving rate and capital stock are too high, too low, or about right. K↓ → MPK↑
  - If $(MPK - \delta) > (\boldsymbol{n} + \boldsymbol{g})$, U.S. economy is below the Golden Rule steady state and should increase $\boldsymbol{s}$.
  - If $(MPK - \delta) < (\boldsymbol{n} + \boldsymbol{g})$, U.S. economy is above the Golden Rule steady state and should reduce $\boldsymbol{s}$.

Policy issues: Evaluating the rate of saving

MPK− δ pk n+g

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

(stock) (flow)

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.

Policy issues: Evaluating the rate of saving

1. $\boldsymbol{k} = 2.5\,\boldsymbol{y}$
2. $\delta \boldsymbol{k} = 0.1\,\boldsymbol{y}$
3. $MPK \times \boldsymbol{k} = 0.3\,\boldsymbol{y}$ MPK=0.12

To determine δ, divide **2** by **1**:

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

Policy issues: Evaluating the rate of saving

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

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

Policy issues: Evaluating the rate of saving

- From the last slide: $MPK - \delta = 0.08$
- U.S. real GDP grows an average of 3% per year, so $\boldsymbol{n} + \boldsymbol{g} = 0.03$
- Thus,

$$MPK - \delta = 0.08 > 0.03 = \boldsymbol{n} + \boldsymbol{g}$$

MPK > n+g+δ   k too small
⟺ MPK too big

- Conclusion:

The U.S. is below the Golden Rule steady state: Increasing the U.S. saving rate would increase consumption per capita in the long run.

How about China? An estimate

1. $\boldsymbol{k} = 2\,\boldsymbol{y}$
2. $\delta \boldsymbol{k} = 0.14\,\boldsymbol{y}$
3. $MPK \times \boldsymbol{k} = 0.5\,\boldsymbol{y}$

$MPK - \delta = 0.18 > n + g \approx 0.03$

$Y = AK^{\alpha}L^{1-\alpha}$

$$\delta = \frac{0.14}{2} = 0.07$$

$$\text{MPK} = \frac{0.5}{2} = 0.25$$

Policy issues:
How 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, estate tax, as they discourage saving.
  - Replace federal income tax with a consumption tax.
  - Expand tax incentives for IRAs (individual retirement accounts) and other retirement savings accounts.

Policy issues: 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?

Policy issues:
Allocating the economy's investment

Two viewpoints: 张维迎

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**: 林毅夫
   Govt should actively encourage investment in capital of certain types or in certain industries, because they may have positive externalities that private investors don't consider.

Possible problems with industrial policy

- The govt may not have the ability to "pick winners" (choose industries with the highest return to capital or biggest externalities).
- Politics (*e.g.*, campaign contributions) rather than economics may influence which industries get preferential treatment.

Policy issues: 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.

Establishing the right institutions:
North vs. South Korea

After WW2, Korea split into:

- North Korea with institutions based on authoritarian communism
- South Korea with Western-style democratic capitalism

Today, GDP per capita is over 10x higher in S. Korea than N. Korea

Policy issues: Encouraging tech. progress

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

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.

9.4 Beyond the Solow Model: Endogenous Growth Theory 内生增长模型

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.

The basic model

MPK=A

- Production function: $Y = AK$
  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: sY
- Depreciation: δK
- Equation of motion for total capital:
  $$\Delta K = sY - \delta K$$

The basic model

$$\Delta K = sY - \delta K$$

- Divide through by K and use $Y = AK$ to get:

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

- If $sA > \delta$, 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.
- If capital is narrowly defined (only plant & equipment), then yes.
- Advocates of endogenous growth theory argue that knowledge is a type of capital.
- If so, then constant returns to capital is more plausible, and this model may be a good description of economic growth.

A two-sector model

- Two sectors:
  - manufacturing firms produce goods.
  - research universities produce knowledge that increases labor efficiency in manufacturing.
- u = fraction of labor in research
  (u is exogenous)
- Mfg prod func: $Y = F[K, (1-u)EL]$
- Res prod func: $\Delta E = g(u)E$
- Cap accumulation: $\Delta K = sY - \delta K$

A two-sector model

- In the steady state, mfg 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 and growth rate of income

DISCUSSION QUESTION

The merits of raising *u*

Question:

In what ways would raising ***u*** (*i.e.* devoting more labor to research) benefit the economy? What are the costs of raising ***u***?

Facts about R&D

1. Much research is done by firms seeking profits.
2. Firms profit from research:
   - Patents create a stream of monopoly profits.
   - Extra profit from being first 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 technological 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:
  Social return to R&D ≥ 40% per year.
- Thus, many believe govt 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
   - The U.S. has 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. Empirical studies
   - Solow model explains balanced growth, conditional convergence.
   - Cross-country variation in living standards is due to differences in cap. accumulation and in production efficiency.
4. 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.