Chapter 8: Economic Growth II: Technology, Empirics, and Policy*

MACROECONOMICS

Seventh Edition

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* Slides based on Ron Cronovich's slides, adjusted for course in Macroeconomics for International Masters Program at the Wang Yanan Institute for Studies in Economics at Xiamen University.

Learning Objectives

This chapter introduces you to understanding:

- technological progress in the Solow model
- the connection between growth theory and growth empirics
- policies to promote growth
- endogenous growth theory

8.1) Technological Progress (TP)

➔ SGM: So Far Assumed Constant Technology

In the Solow model of Chapter 7,

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

Neither point is true in the real world:

- examples of technological progress abound (see next slide).
- 1908-2008: U.S. real GDP per person grew by a factor of 7.8, or 2.05% per year.

8.1) Technological Progress (TP)

➔ Examples For TP

- From 1950 to 2000, U.S. farm sector productivity nearly tripled.
- The real price of computer power has fallen an average of 30% per year over the past three decades.
- 1981: 213 computers connected to the Internet
  2000: 60 million computers connected to the Internet
- 2001: iPod capacity = 5gb, 1000 songs. Not capable of playing episodes of television shows.
  2009: iPod capacity = 120gb, 30,000 songs. Can play episodes of television shows.

8.1) Technological Progress (TP)

➔ SGM: Including TP

A new variable: ***E*** = labor efficiency

Assume:
Technological progress is **labor-augmenting**:
it increases labor efficiency at the exogenous rate ***g***:

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

8.1) Technological Progress (TP)

➔ SGM: Including TP

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.

8.1) Technological Progress (TP)

➔ SGM: Including TP (ctd.)

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:

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

8.1) Technological Progress (TP)

➔ SGM: Including TP (ctd.)

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

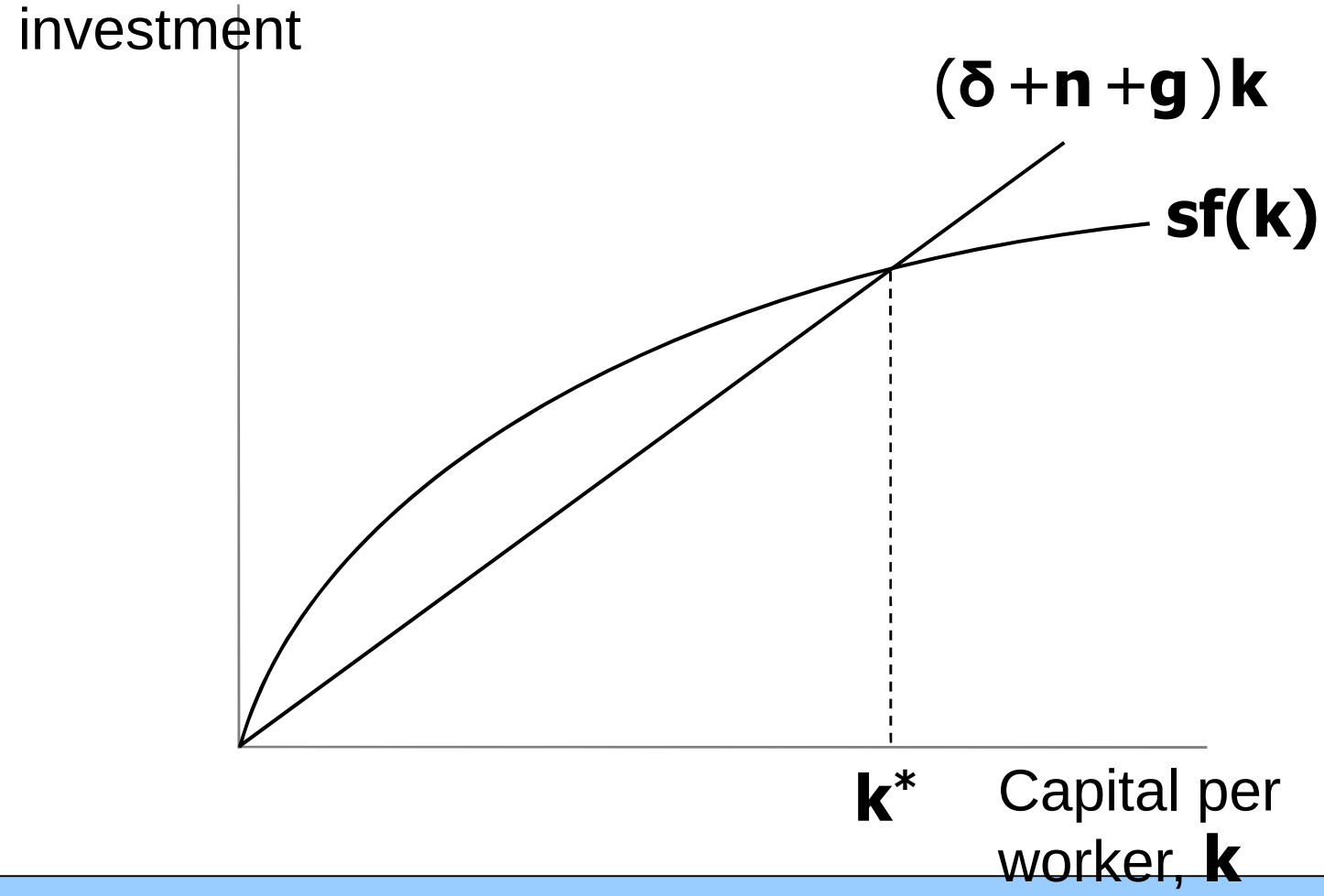
Consists of:

- 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

8.1) Technological Progress (TP)

➔ SGM: Including TP (ctd.)

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



8.1) Technological Progress (TP)

➔ SGM with TP: Steady-State Growth Rates

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	$Y = y \times E \times L$	$n + g$

8.1) Technological Progress (TP)

➔ SGM with TP: 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

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

or equivalently,

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

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.

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8.2) Growth Empirics

➔ Balanced Growth

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 the same rate (g).

➔ 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.

8.2) 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?

8.2) Growth Empirics

➔ Convergence (ctd.)

- Solow model predicts that, other things equal, “poor” countries (with lower ***Y*/*L*** and ***K*/*L***) should grow faster than “rich” ones.
- Solow model does not fail, because “other things” aren’t equal.
- In samples of countries with similar savings & population growth rates, income gaps shrink about 2% per year.
- In larger samples, after controlling for differences in saving, population growth, and human capital, incomes converge by about 2% per year.

8.2) Growth Empirics

➔ Convergence (ctd.)

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.

8.2) Growth Empirics

➔ Factor Accumulation vs. 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:
  1. Both factors are important.
  2. The two factors are correlated: countries with higher physical or human capital per worker also tend to have higher production efficiency.

8.2) Growth Empirics

➔ Factor Accumulation vs. Efficiency (ctd.)

Possible explanations for the correlation between capital per worker and production efficiency:

1. Production efficiency encourages capital accumulation.

2. Capital accumulation has externalities that raise efficiency.

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

8.2) Growth Empirics

➔ Production Efficiency and Free Trade

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%

Learning Objectives

This chapter introduces you to understanding:

- technological progress in the Solow model ✓
- the connection between growth theory and growth empirics ✓
- policies to promote growth: SELF-STUDY ⇦
- endogenous growth theory

BREAK I/III
(7 minutes)

8.3) 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?

8.3) Policy Issues

➔ How to Increase the Savings 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.

8.3) 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?

8.3) Policy Issues

➔ 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**:
   Govmt 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.
   ➔But: Do Govmts really have the ability to pick winners?
   ➔Danger of politics being captured by interest groups

8.3) 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.

8.3) Policy Issues

➔ Encouraging Technological 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).*

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8.4) 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.

8.4) Endogenous Growth Theory

➔Basic Model

- Production function: $Y = AK$
  where A is the amount of output for each unit of capital
  (A is exogenous & constant)
- Key difference between this model & the SGM: *MPK* is constant here, diminishes in SGM
- Investment: sY
- Depreciation: δK
- Equation of motion for total capital: $\Delta K = sY - \delta K$

8.4) Endogenous Growth Theory

➔Basic Model (ctd.)

- $\Delta K = s\,Y - \delta\,K$
- Divide through by K and use $Y = A\,K$ to 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.

8.4) Endogenous Growth Theory

➔Basic Model: Has Capital Diminishing Returns?

- 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.

8.4) Endogenous Growth Theory

➔ 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)
- Manufacturing production function: $Y = F[K, (1-u)EL]$
- Research production function: $\Delta E = g(u)E$
- Capital accumulation: $\Delta K = sY - \delta K$

8.4) Endogenous Growth Theory

➔ Two-Sector Model (ctd.)

- In the steady state, manufacturing output per worker and the standard of living grow at rate
  $\Delta E/E = g(u)$.
- 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

8.4) Endogenous Growth Theory

➔ 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 ('innovation encourages innovation').

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

8.4) Endogenous Growth Theory

➔ Research in the Private Sector

- Estimates:
  Though there is a lot of duplication of R&D among competing firms, social return to R&D ≥ 40% per year.

  ➔Thus, many believe government should encourage R&D.

BREAK II/III
(7 minutes)

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

Summary (ctd.)

3. Productivity slowdown & “new economy”
   - Early 1970s: productivity growth fell in the U.S. 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 is due to differences in cap. accumulation and in production efficiency

Summary (ctd.)

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.