CHAPTER 8

Economic Growth II: Technology, Empirics, and Policy

In this chapter, you will learn…

- how to incorporate technological progress in the Solow model
- about policies to promote growth
- about growth empirics: confronting the theory with facts
- two simple models in which the rate of technological progress is endogenous

Introduction

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:

- 1904-2004: U.S. real GDP per person grew by a factor of 7.6, or 2% per year.
- examples of technological progress abound *(see next slide).*

Examples of technological progress

- 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.
- Percentage of U.S. households with ≥ 1 computers: 8% in 1984, 62% in 2003
- 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 *Grey's Anatomy*.
  2006: iPod capacity = 80gb, 20,000 songs. Can play episodes of *Grey's Anatomy*.

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***:

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

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:
  $y = Y/LE$ = 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:
  $sy = sf(k)$

Technological progress in the Solow model

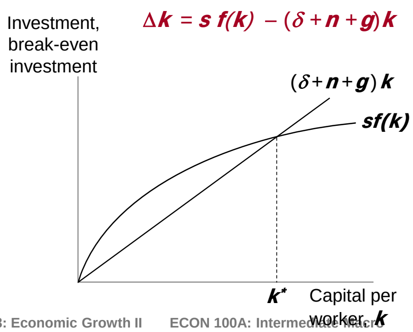
$(\delta + n + g)k$ = break-even investment: the amount of investment necessary to keep k constant.

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

Technological 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

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

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.

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), so 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.
  - This is also true in the real world.

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

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%

Growth empirics: Production efficiency and free trade

- 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.

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

- Use the Golden Rule to determine whether the U.S. saving rate and capital stock are too high, too low, or about right.
  - If $(MPK - \delta) > (\boldsymbol{n} + \boldsymbol{g})$, U.S. 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

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

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. $MPK \times \boldsymbol{k} = 0.3\,\boldsymbol{y}$

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

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:

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**:
   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.

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:
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

Possible explanations for the productivity slowdown

- *Measurement problems:*
  Productivity increases 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?

Possible explanations for the productivity slowdown

- *Worker quality:*
  1970s - large influx of new entrants into labor force (baby boomers, women).
  New workers tend to be less productive than experienced workers.
- *The depletion of ideas:*
  Perhaps the slow growth of 1972-1995 is normal, and the rapid growth during 1948-1972 is the anomaly.

Which of these suspects is the culprit?

All of them are plausible,
but it's difficult to prove
that any one of them is guilty.

CASE STUDY:
I.T. and the "New Economy"

	Growth in output per person (percent per year)		
	1948-72	1972-95	1995-2004
Canada	2.9	1.8	2.4
France	4.3	1.6	1.7
Germany	5.7	2.0	1.2
Italy	4.9	2.3	1.5
Japan	8.2	2.6	1.2
U.K.	2.4	1.8	2.5
U.S.	2.2	1.5	2.2

CASE STUDY:
I.T. and the "New Economy"

Apparently, the computer revolution did not 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, open question:

- How long will I.T. remain an engine of growth?

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: $Y = AK$
  where A is the amount of output for each unit of capital (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:
  $\Delta K = sY - \delta K$

A 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: $Y = F[K, (1\text{-}u)EL]$
- 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 $\Delta E/E = g(u)$.
- 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
- Question: Would an increase in ***u*** be unambiguously good for the economy?

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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.

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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.

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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.

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Lecture 5, Part II 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

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Lecture 5, Part II Summary

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

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Lecture 5, Part II 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.