



# CHAPTER 8

## Economic Growth II: Technology, Empirics, and Policy

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## **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  $\geq 1$  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:

- $\delta k$  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

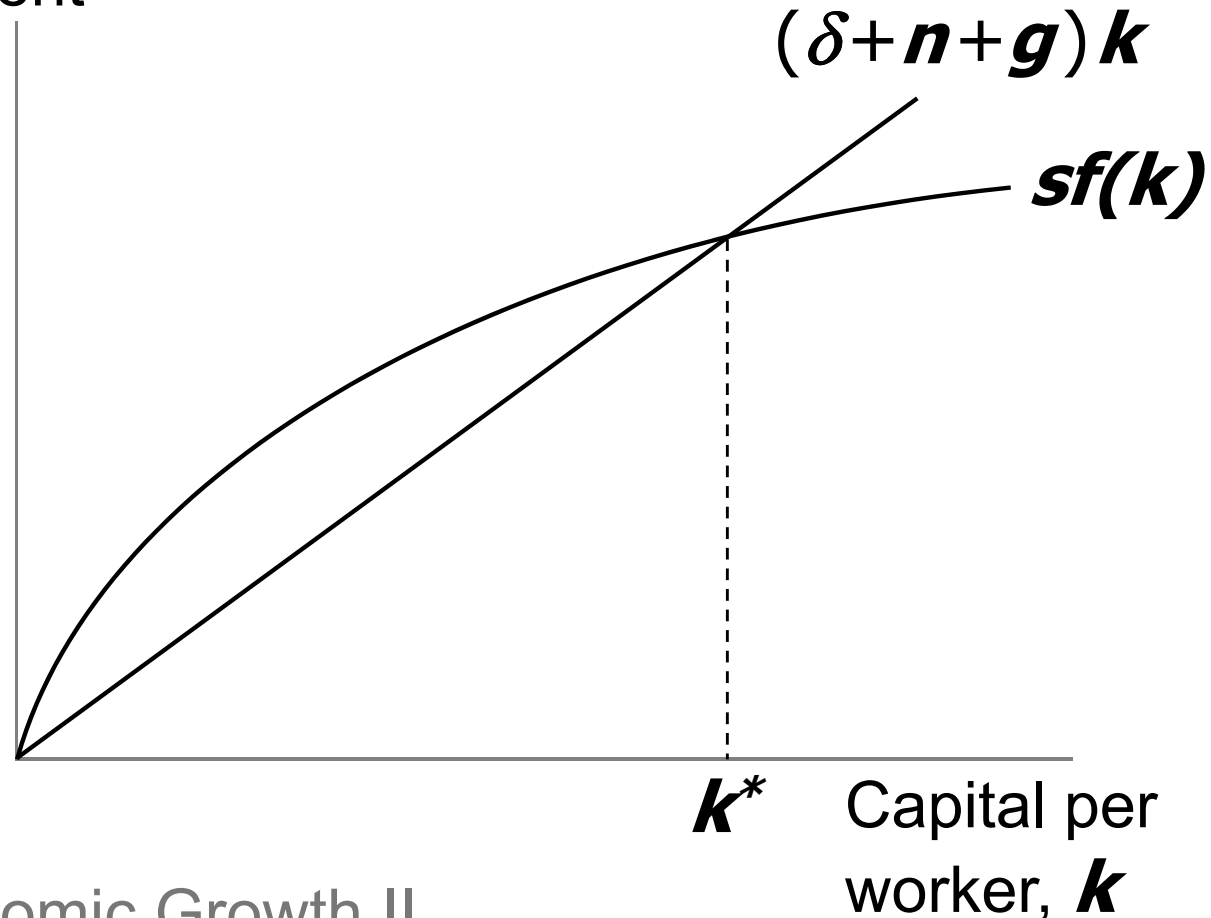




# Technological progress in the Solow model

Investment,  
break-even  
investment

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





## 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  $k^*$ :

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

$c^*$  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:

<b>Average annual growth rates, 1970-89</b>		
	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  $(MPK - \delta) > (n + g)$ ,  
U.S. is below the Golden Rule steady state and should increase  $s$ .
  - If  $(MPK - \delta) < (n + g)$ ,  
U.S. economy is above the Golden Rule steady state and should reduce  $s$ .



## Policy issues:

### Evaluating the rate of saving

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

1.  $k = 2.5 y$

The capital stock is about 2.5 times one year's GDP.

2.  $\delta k = 0.1 y$

About 10% of GDP is used to replace depreciating capital.

3.  $MPK \times k = 0.3 y$

Capital income is about 30% of GDP.



# Policy issues: Evaluating the rate of saving

1.  $k = 2.5 y$
2.  $\delta k = 0.1 y$
3.  $MPK \times k = 0.3 y$

To determine  $\delta$ , divide **2** by **1**:

$$\frac{\delta k}{k} = \frac{0.1 y}{2.5 y} \implies \delta = \frac{0.1}{2.5} = 0.04$$



# Policy issues: Evaluating the rate of saving

1.  $k = 2.5 y$
2.  $\delta k = 0.1 y$
3.  $MPK \times k = 0.3 y$

To determine  $MPK$ , divide **3** by **1**:

$$\frac{MPK \times k}{k} = \frac{0.3 y}{2.5 y} \implies MPK = \frac{0.3}{2.5} = 0.12$$

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





# 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  $n + g = 0.03$
- Thus,  
$$MPK - \delta = 0.08 > 0.03 = n + g$$
- 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
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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:  $\delta K$
- 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:  $Y = F[K, (1-u)EL]$
- 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?



## 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.*



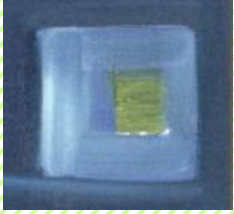
# Is the private sector doing enough R&D?

- 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  $\geq$  40% per year.
- Thus, many believe govt should encourage R&D.



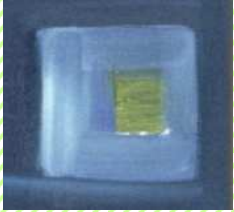
# Economic growth as “creative destruction”

- 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. 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





# 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.