Technological Progress and Economic Growth

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:

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

Introduction (2)

- How should we consider human capital and education ?
- How to measure the unobservable technological progress ?

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 *True Blood*.
  2009: iPod capacity = 120gb, 30,000 songs. Can play episodes of *True Blood*.

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

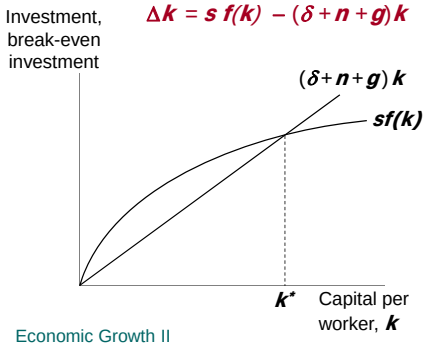
$(\delta + n + g)k$ = break-even investment: the amount of investment necessary to keep k constant.

Consists of:

- δk to replace depreciating capital
- nk to provide capital for new workers
- gk 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 with technological progress

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.
    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: 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 saving rate and capital stock are too high, too low, or about right.
  - If $(MPK - \delta) > (n + g)$, capital stock is below the Golden Rule steady state and should increase s.
  - If $(MPK - \delta) < (n + g)$, capital stock is above the Golden Rule steady state and should reduce s.

Policy issues: How to increase the saving rate

- Reduce the government budget deficit (or increase the budget surplus).
- Moving from PYGO social security to Funded Social security system
- 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.

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 can we increase the incentive for human capital accumulation ?

Human capital accumulation

- Lower the cost of education
- Lower the adult mortality rate
- Correct capital market distortion (make educational loan available)
- Generate an incentive for employer to make investment on employee human capital accumulation. (lower minimum wage.)

Measureing technologial progress

- Assume the Cobb-Douglas Production Function

$$Y_t = K^{\alpha}(L_t E_t)^{1-\alpha}$$

- Take a long and take a derivative on both sides

$$\frac{\Delta Y}{Y} = \alpha\frac{\Delta K}{K} + (1-\alpha)\frac{\Delta L}{L} + (1-\alpha)\frac{\Delta E}{E}$$

$$\frac{\Delta E}{E} = \frac{\Delta Y}{Y} - \frac{\alpha}{1-\alpha}\frac{\Delta K}{K} - \frac{\Delta L}{L}$$

- Thus, we can measure the technological progress
- This is also called Solow's residual (see grapth)
- Research found that the half of the grow of GDP comes from the technological progress.

Total factor productivity in the world