Chapter 8: Growth, continued

In the basic Solow model:
- the production technology is held constant
- income per capita is constant in the steady state.

In the real world:
- 1929-2001: U.S. real GDP per person grew by 2.2% pa
- examples of technological progress
  1970: 50,000 computers in the world
  2000: 51% of U.S. households have 1 or more computers

Tech. progress in the Solow model

- $E =$ labor efficiency
- Assume technological progress is labor-augmenting: it increases labor efficiency at the exogenous rate:
  $$ g = \frac{\Delta E}{E} $$

- 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.

Tech. 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:
  $$ sy = sf(k) $$
Tech. progress in the Solow model

\[(\delta + n + g)k = \text{break-even investment: the amount of investment necessary to keep } k \text{ constant.}\]

Consists of:
- \(\delta k\) to replace depreciating capital
- \(nk\) to provide capital for new workers
- \(gk\) to provide capital for the new “effective” workers created by technological progress.

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Steady-State Growth Rates in the Solow Model with Tech. Progress

<table>
<thead>
<tr>
<th>Variable</th>
<th>Symbol</th>
<th>Steady-state growth rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital per effective worker</td>
<td>(k = K(L \times E))</td>
<td>0</td>
</tr>
<tr>
<td>Output per effective worker</td>
<td>(y = Y(L \times E))</td>
<td>0</td>
</tr>
<tr>
<td>Output per worker</td>
<td>((Y/L) = y \times E)</td>
<td>(g)</td>
</tr>
<tr>
<td>Total output</td>
<td>(Y = y \times E \times L)</td>
<td>(n + g)</td>
</tr>
</tbody>
</table>
The Golden Rule

To find the Golden Rule capital stock, express \( c' \) in terms of \( k' \):
\[
c' = y' - r = f(k') - (\delta + n + g)k'
\]
\( c' \) is maximized when
\[
\text{MPK} = \delta + n + g
\]
or equivalently,
\[
\text{MPK} - \delta = n + g
\]

Policies to promote growth

Four policy questions:
1. Are we saving enough? Too much?
2. What policies might change the saving rate?
3. How should we allocate our investment between privately owned physical capital, public infrastructure, and "human capital"?
4. What policies might encourage faster technological progress?

1. Evaluating the Rate of Saving

- Use the Golden Rule to determine whether \( s \) and \( K \) are too high, too low, or about right.
- Need to compare (MPK – \( \delta \)) to \( (n + g) \).
- If (MPK – \( \delta \)) > \( (n + g) \), then we are below the Golden Rule steady state and should increase \( s \).
- If (MPK – \( \delta \)) < \( (n + g) \), then we are above the Golden Rule steady state and should reduce \( s \).
1. Evaluating the Rate of Saving

In the US:
1. $k = 2.5y$: Capital stock is 2.5 times one year's GDP.
2. $\delta k = 0.1y$: 10% of GDP used to replace depreciating capital.
3. $MPK \times k = 0.3y$: Capital income is 30% of GDP.

- Use (2) / (1) $\rightarrow \delta = 0.1 / 2.5 = 0.04$
- Use (3) / (1) $\rightarrow MPK = 0.3 / 2.5 = 0.12$
- In the U.S, $n + g = 0.03$
- Thus $MPK - \delta > n + g$

- Hence we are below the golden rule! If we save more now, we will have higher consumption in the new steady state.

2. Policies to increase the saving rate

- Reduce the government budget deficit.
- 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.

3. Allocating the economy's investment

- In the real world, there are many types of $K$:
  - private capital stock
  - public infrastructure
  - human capital: the knowledge and skills that workers acquire through education.

- How should we allocate investment among these types?
1. Equalize tax treatment of all $K$, then let market forces work.
2. Industrial policy: Encourage investment in certain industries, because they may yield positive externalities. Problems:
   - Does the government have the ability to "pick winners"?
   - Would politics influence which industries are preferred?
4. 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:
  encourage specific industries that are key for rapid tech. progress
  (subject to the concerns on the preceding slide)

CASE STUDY: The Productivity Slowdown

<table>
<thead>
<tr>
<th></th>
<th>Growth in output per person (percent per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1948-72</td>
</tr>
<tr>
<td>Canada</td>
<td>2.9</td>
</tr>
<tr>
<td>France</td>
<td>4.3</td>
</tr>
<tr>
<td>Germany</td>
<td>5.7</td>
</tr>
<tr>
<td>Italy</td>
<td>4.9</td>
</tr>
<tr>
<td>Japan</td>
<td>8.2</td>
</tr>
<tr>
<td>U.K.</td>
<td>2.4</td>
</tr>
<tr>
<td>U.S.</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Explanations?

- Problem with measuring productivity
  But: Why would measurement problems worsen after '72?

- Oil prices
  Oil shocks occurred about when slowdown began.
  But: Why didn't productivity speed up when oil prices fell in the '80s?

- Worker quality
  1970s - large influx into labor force (baby boomers, women).
  New workers are less productive than experienced workers.

- The depletion of ideas
  Perhaps the slow growth of 1972-1995 is normal and the true anomaly was the rapid growth from 1948-1972.
Growth empirics: Solow vs the facts

<table>
<thead>
<tr>
<th>SOLOW MODEL</th>
<th>REAL WORLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{Y}{L}$ and $\frac{K}{L}$ grow at same rate</td>
<td>TRUE</td>
</tr>
<tr>
<td>$\frac{K}{Y}$ should be constant.</td>
<td>TRUE</td>
</tr>
<tr>
<td>real wage grows at same rate as $\frac{Y}{L}$</td>
<td>TRUE</td>
</tr>
<tr>
<td>real rental price is constant.</td>
<td>TRUE</td>
</tr>
<tr>
<td>other things equal, “poor” countries (low $\frac{Y}{L}$ and $\frac{K}{L}$) should grow faster than “rich” ones. (convergence)</td>
<td>OTHER THINGS ARE NOT EQUAL</td>
</tr>
</tbody>
</table>

if one controls for differences in saving, population growth, and human capital, incomes converge by about 2%/year.

Endogenous growth model

- Production function: $Y = AK$
- Investment: $sY$, Depreciation: $\delta K$
- Equation of motion for capital: $\Delta K = sY - \delta K$
- Rearrange to obtain:
  $$\frac{\Delta Y}{Y} = \frac{\Delta K}{K} = sA - \delta$$
- If $sA > \delta$ then income will grow forever, and investment is the "engine of growth."
- Here, income growth in endogenous

Does capital have diminishing returns?

- Yes, if “capital” is narrowly defined (plant & equipment).
- Perhaps not, with a broad definition of “capital” (physical & human capital, knowledge).
- Some economists believe that knowledge exhibits increasing returns.
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: \( \Delta K = sY - \delta K \)

In the steady state, mfg output per worker and the standard of living grow at rate \( \frac{\Delta E}{E} = g(u) \).

- 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?

1. higher \( u \)\( \rightarrow \) means faster growth.
2. higher \( u \)\( \rightarrow \) less labor is devoted to the production of goods & services.

- Increase \( u \), output of goods & services per capita will fall in the near term.
- But, with faster growth, output per capita will eventually be higher than it would have.
- There must be some “golden rule” for \( u \), \( u \) that maximizes well-being per capita in steady state.
Three facts about R&D in the real world

1. Much research is done by firms seeking profits.
2. Firms profit from research because
   - new inventions can be patented, creating a stream of monopoly profits until the patent expires
   - there is an advantage to being the first firm 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 tech 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: The social return to R&D is at least 40% per year.
  Thus, many believe govt should encourage R&D