Chapter 8: Economic Growth II

### Technology, Empirics, and Policy

- 8-1 Technological Progress in the Solow Model
- 8-2 From Growth Theory to Growth Empirics
- 8-3 Policies to Promote Growth
- 8-4 Endogenous Growth Theory

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### 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).

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### Technological progress in the Solow model

- A new variable: $E = \text{labor efficiency}$
- Assume: Technological progress is **labor-augmenting**:
  - It increases labor efficiency at the exogenous rate $g$:
  
  $$ g = \frac{\Delta E}{E} $$

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### 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
  - 2006: iPod capacity = 80gb, 20,000 songs. Can play episodes of Grey’s Anatomy.

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### 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:
  \[ y = \frac{Y}{LE} \] = output per effective worker
  \[ k = \frac{K}{LE} \] = capital per effective worker
- Production function per effective worker:
  \[ y = f(k) \]
- Saving and investment per effective worker:
  \[ sy = sf(k) \]

**The Golden Rule**

To find the Golden Rule capital stock, express \( c' \) in terms of \( k' \):

\[
c' = y' - i'
\]

\[ = f(k') - \delta + n + g \]

\( c' \) 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.

**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 deprecating capital
- \( nk \) to provide capital for new workers
- \( gk \) to provide capital for the new “effective” workers created by technological progress

**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 = \frac{K}{LE} )</td>
<td>0</td>
</tr>
<tr>
<td>Output per effective worker</td>
<td>( y = \frac{Y}{(L}\times E) )</td>
<td>0</td>
</tr>
<tr>
<td>Output per worker</td>
<td>( \frac{Y}{L} = \frac{Y}{E}\times L )</td>
<td>( g )</td>
</tr>
<tr>
<td>Total output</td>
<td>( Y = \frac{Y}{E}\times L )</td>
<td>( n + g )</td>
</tr>
</tbody>
</table>

**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?

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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.

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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.

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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.

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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.

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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%  |

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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 \( s \).

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

1. \( k = 2.5y \)  
   The capital stock is about 2.5 times one year’s GDP.
2. \( \delta k = 0.1y \)  
   About 10% of GDP is used to replace depreciating capital.
3. \( MPK \times k = 0.3y \)  
   Capital income is about 30% of GDP.

To determine \( MPK \), divide 3 by 1:

\[
\frac{MPK \times k}{k} = \frac{0.3y}{2.5y} \quad \Rightarrow \quad MPK = \frac{0.3}{2.5} = 0.12
\]

Hence, \( MPK - \delta = 0.12 - 0.04 = 0.08 \)
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).

**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 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: 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>
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 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: \( Y = F [K, (1-u)E] \)

- Res prod func: \( \Delta E = g(u)E \)

- Cap accumulation: \( \Delta K = sY - \delta K \)

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**

- 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 $\geq 40\%$ 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
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
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.