Chapter 6: Long-Run Economic Growth

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Chapter Outline

- Discuss the sources of economic growth and the fundamentals of growth accounting.
- Explain the factors affecting long-run living standards in the Solow model.
- Endogenous Growth Theory.
- Discuss government policies for raising long-run living standards.
Countries have grown at very different rates over long spans of time (Table 6.1).

We want to explain why this happens:

- What determines growth?
- What is the role of capital accumulation?
- What is the role of technological progress?
**Table 6.1** Economic Growth in Eight Major Countries, 1870–2008

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</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>3,273</td>
<td>5,157</td>
<td>7,412</td>
<td>25,301</td>
<td>1.5%</td>
</tr>
<tr>
<td>Canada</td>
<td>1,695</td>
<td>4,447</td>
<td>7,291</td>
<td>25,267</td>
<td>2.0</td>
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<tr>
<td>France</td>
<td>1,876</td>
<td>3,485</td>
<td>5,186</td>
<td>22,223</td>
<td>1.8</td>
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<tr>
<td>Germany</td>
<td>1,839</td>
<td>3,648</td>
<td>3,881</td>
<td>20,801</td>
<td>1.8</td>
</tr>
<tr>
<td>Japan</td>
<td>737</td>
<td>1,387</td>
<td>1,921</td>
<td>22,816</td>
<td>2.5</td>
</tr>
<tr>
<td>Sweden</td>
<td>1,359</td>
<td>3,073</td>
<td>6,769</td>
<td>24,409</td>
<td>2.1</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>3,190</td>
<td>4,921</td>
<td>6,939</td>
<td>23,742</td>
<td>1.5</td>
</tr>
<tr>
<td>United States</td>
<td>2,445</td>
<td>5,301</td>
<td>9,561</td>
<td>31,178</td>
<td>1.9</td>
</tr>
</tbody>
</table>

*Note:* Figures are in U.S. dollars at 1990 prices, adjusted for differences in the purchasing power of the various national currencies.

The Sources of Economic Growth

• The production function:

\[ Y = AF(K, N), \] (1)

where \( F \) tells us how much output is produced for given quantities of capital and labor. The production function depends on the state of technology, \( A \). The higher the state of technology, the higher output \( Y \) for a given \( K \) and a given \( N \).

• Decompose into growth rate form (the growth accounting equation):

\[ \frac{\Delta Y}{Y} = \frac{\Delta A}{A} + a_K \frac{\Delta K}{K} + a_N \frac{\Delta N}{N}, \] (2)

where the \( a \) terms are the elasticities of output with respect to the inputs (capital and labor).

• Interpretation: An increase of 10% in \( A \) raises output by 10%. An increase of 10% in \( K \) raises output by \( a_K \) times 10%. An increase of 10% in \( N \) raises output by \( a_N \) times 10%.

• Both \( a_K \) and \( a_N \) are less than 1 due to diminishing marginal productivity.
Growth accounting

Four steps in breaking output growth into its causes (productivity growth, capital input growth, labor input growth):

1. Get data on $\frac{\Delta Y}{Y}$, $\frac{\Delta K}{K}$, and $\frac{\Delta N}{N}$, adjusting for quality changes.
2. Estimate $a_K$ and $a_N$ from historical data.
3. Calculate the contributions of $K$ and $N$ as $a_K \frac{\Delta K}{K}$ and $a_N \frac{\Delta N}{N}$, respectively.
4. Calculate productivity growth as the residual:

$$\frac{\Delta A}{A} = \frac{\Delta Y}{Y} - a_K \frac{\Delta K}{K} - a_N \frac{\Delta N}{N}. \quad (3)$$
### Table 6.2 The Steps of Growth Accounting: A Numerical Example

**Step 1.** Obtain measures of output growth, capital growth, and labor growth over the period to be studied.

Example:

- Output growth: \( \frac{\Delta Y}{Y} = 40\% \)
- Capital growth: \( \frac{\Delta K}{K} = 20\% \)
- Labor growth: \( \frac{\Delta N}{N} = 30\% \)

**Step 2.** Using historical data, obtain estimates of the elasticities of output with respect to capital and labor, \( a_K \) and \( a_N \).

Example: \( a_K = 0.3 \) and \( a_N = 0.7 \).

**Step 3.** Find the contributions to growth of capital and labor.

Example:

- Contribution to output growth of growth in capital: \( a_K \frac{\Delta K}{K} = 0.3 \times 20\% = 6\% \)
- Contribution to output growth of growth in labor: \( a_N \frac{\Delta N}{N} = 0.7 \times 30\% = 21\% \)

**Step 4.** Find productivity growth as the residual (the part of output growth not explained by capital or labor).

Example:

- Productivity growth: \( \frac{\Delta A}{A} = \frac{\Delta Y}{Y} - a_K \frac{\Delta K}{K} - a_N \frac{\Delta N}{N} \)

\[
= 40\% - 6\% - 21\% = 13\%.
\]
Denison’s results for 1929 – 1982 (Table 6.3):

- Entire period output growth 2.92%; due to labor 1.34%; due to capital 0.56%; due to productivity 1.02%.
- Pre-1948 capital growth was much slower than post-1948.

Productivity growth is major difference


Productivity growth slowdown occurred in all major developed countries.
Application: the post-1973 slowdown in productivity growth

- What caused the decline in productivity?
  - The legal and human environment—regulations for pollution control and worker safety, crime, and declines in educational quality.
  - Oil prices—huge increase in oil prices reduced productivity of capital and labor, especially in basic industries.
Table 6.3  Sources of Economic Growth in the United States (Denison) (Percent per Year)

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Labor growth</td>
<td>1.42</td>
<td>1.40</td>
<td>1.13</td>
<td>1.34</td>
<td>0.99</td>
</tr>
<tr>
<td>Capital growth</td>
<td>0.11</td>
<td>0.77</td>
<td>0.69</td>
<td>0.56</td>
<td>1.18</td>
</tr>
<tr>
<td>Total input growth</td>
<td>1.53</td>
<td>2.17</td>
<td>1.82</td>
<td>1.90</td>
<td>2.17</td>
</tr>
<tr>
<td>Productivity growth</td>
<td>1.01</td>
<td>1.53</td>
<td>–0.27</td>
<td>1.02</td>
<td>1.06</td>
</tr>
<tr>
<td>Total output growth</td>
<td><strong>2.54</strong></td>
<td><strong>3.70</strong></td>
<td><strong>1.55</strong></td>
<td><strong>2.92</strong></td>
<td><strong>3.23</strong></td>
</tr>
</tbody>
</table>

Application: the recent surge in U.S. productivity growth

- Labor productivity growth increased sharply in the second half of the 1990s.
- Labor productivity and TFP grew steadily from 1982 to 2008 (Fig. 6.1).
Figure 6.1  Productivity Levels, 1948-2011

Labor productivity growth has generally exceeded TFP growth since 1995 (Fig. 6.2).

How can we relate this graph to our model?

Use equations to relate the differing productivity concepts:

\[
\frac{\Delta Y}{Y} - \frac{\Delta N}{N} = \frac{\Delta A}{A} + aK \left( \frac{\Delta K}{K} - \frac{\Delta N}{N} \right). \tag{4}
\]

So, labor productivity growth exceeds TFP growth because of faster growth of capital relative to growth of labor.

ICT growth (information and communications technology) may have been a prime reason.
**Figure 6.2** Productivity Growth, 1949-2011

(Conti.) Why did ICT growth contribute to U.S. productivity growth, but not in other countries?

- Government regulations.
- Lack of competitive pressure.
- Available labor force.
- Ability to adapt quickly.

Why was there such a lag between investment in ICT and growth in productivity?

- Intangible capital: R&D, Firm reorganization, Worker training.
(Conti.) Similar growth in productivity experienced in past:
- Steam power, railroads, telegraph in late 1800s.
- Electrification of factories after WWI.
- Transistor after WWII.

What matters most is ability of economy to adapt to new technologies.
Two basic questions about growth

- What's the relationship between the long-run standard of living and the saving rate, population growth rate, and rate of technical progress?
- How does economic growth change over time? Will it speed up, slow down, or stabilize?
The Solow Model

- Basic assumptions and variables:
  - Population and work force grow at same rate $n$.
  - Economy is closed and $G = 0$:

  $$C_t = Y_t - I_t$$  \hspace{1cm} (5)

- Rewrite everything in per-worker terms:

  $$y_t = \frac{Y_t}{N_t}; c_t = \frac{C_t}{N_t}; k_t = \frac{K_t}{N_t}$$

  where $k_t$ is also called the capital-labor ratio. The per-worker production function:

  $$y_t = f(k_t).$$  \hspace{1cm} (6)

- Assume no productivity growth for now (add it later). Plot of per-worker production function (Fig. 6.3). Same shape as aggregate production function.
Figure 6.3  The per-worker production function

![Graph showing the per-worker production function with output per worker, $y_t$, on the y-axis and capital-labor ratio, $k_t$, on the x-axis. The function is $y_t = f(k_t)$, and there is a point marked $y_1$ and $k_1$.](image-url)
Steady states

- Steady state: $y_t$, $c_t$, and $k_t$ are constant over time.

- Gross investment must:
  - Replace worn out capital, $dK_t$.
  - Expand so the capital stock grows as the economy grows, $nK_t$:

$$I_t = (n + d)K_t.$$  \hfill (7)

- 

$$C_t = Y_t - I_t = Y_t - (n + d)K_t \hfill (8)$$

- In per-worker terms, in steady state:

$$c = f(k) - (n + d)k$$

Plot of $c$, $f(k)$, and $(n + d)k$ (Fig. 6.4).
Figure 6.4 The relationship of consumption per worker to the capital–labor ratio in the steady state
Some Interpretations

- Increasing $k$ will increase $c$ up to a point.
  - This is $k_G$ in the figure, the Golden Rule capital-labor ratio.
  - For $k$ beyond this point, $c$ will decline. But we assume henceforth that $k$ is less than $k_G$, so $c$ always rises as $k$ rises.

- Suppose saving is proportional to current income:
  \[ S_t = sY_t, \]  
  where $s$ is the saving rate, which is between 0 and 1.

- Equating saving to investment gives:
  \[ sY_t = (n + d)K_t. \]  
  The higher the output, the higher are saving and investment.
(Conti.) Putting this in per-worker terms gives:

\[ sf(k) = (n + d)k \]

Plot of \( sf(k) \) and \( (n + d)k \) (Fig. 6.5).

The only possible steady-state capital-labor ratio is \( k^* \). Output at that point is \( y^* = f(k^*) \); consumption is \( c^* = f(k^*) - (n + d)k^* \).

If \( k \) begins at some level other than \( k^* \), it will move toward \( k^* \):

- For \( k \) below \( k^* \), saving > the amount of investment needed to keep \( k \) constant, so \( k \) rises.
- For \( k \) above \( k^* \), saving < the amount of investment needed to keep \( k \) constant, so \( k \) falls.
Figure 6.5 Determining the capital–labor ratio in the steady state
(Conti.) Putting this in per-worker terms gives:

\[ sf(k) = (n + d)k \]

Plot of \( sf(k) \) and \( (n + d)k \) (Fig. 6.5).

The only possible steady-state capital-labor ratio is \( k^* \). Output at that point is \( y^* = f(k^*) \); consumption is \( c^* = f(k^*) - (n + d)k^* \).

If \( k \) begins at some level other than \( k^* \), it will move toward \( k^* \):

- For \( k \) below \( k^* \), saving > the amount of investment needed to keep \( k \) constant, so \( k \) rises.
- For \( k \) above \( k^* \), saving < the amount of investment needed to keep \( k \) constant, so \( k \) falls.
Take a poor country (one with low $k$) and a rich country (that has a high $k$).

The poor country will probably be farther away from $k^*$ than the rich country.

Then the poor country should grow faster than the rich country and catch up.

Given the same level of technology and human capital, same institutions, etc.

This model says that all countries should converge to the same level.
Consider the following specific production function:

\[ Y = \sqrt{K} \sqrt{N}. \quad (11) \]

- What are the steady state capital stock and output?
- What is the golden rule consumption?
Summary

- With no productivity growth, the economy reaches a steady state, with constant capital-labor ratio, output per worker, and consumption per worker.

- The fundamental determinants of long-run living standards
  - The saving rate.
  - Population growth.
  - Productivity growth.
The saving rate

- Higher saving rate \((s)\) means higher capital-labor ratio \((k^*)\), higher output per worker \((y^*)\), and higher consumption per worker \((c^*)\) (Fig. 6.6).

- The saving rate has no effect on the long run growth rate of output per worker, which is equal to zero.
  - Output per worker and capital per worker are constant in the steady state.
  - If an economy wanted to increase the steady state \(k^*\) every year it would have to increase savings/output every year.

- Nonetheless, the saving rate determines the level of output per worker in the long run. Other things equal, countries with a higher saving rate will achieve higher output per worker in the long run.

- Should a policy goal be to raise the saving rate?
  - Not necessarily, since the cost is lower consumption in the short run.
  - There is a trade-off between present and future consumption.
Figure 6.6 The effect of an increased saving rate on the steady-state capital–labor ratio
Higher population growth means a lower capital-labor ratio, lower output per worker, and lower consumption per worker (Fig. 6.7).

Should a policy goal be to reduce population growth?
  - Doing so will raise consumption per worker.
  - But it will reduce total output and consumption, affecting a nation’s ability to defend itself or influence world events.

The Solow model also assumes that the proportion of the population of working age is fixed.
  - But when population growth changes dramatically this may not be true.
  - Changes in cohort sizes may cause problems for social security systems and areas like health care.
Figure 6.7  The effect of a higher population growth rate on the steady-state capital–labor ratio
Productivity growth

- The key factor in economic growth is productivity improvement.
- Productivity improvement raises output per worker for a given level of the capital-labor ratio (Fig. 6.8).
- In equilibrium, productivity improvement increases the capital-labor ratio, output per worker, and consumption per worker:
  - Productivity improvement directly improves the amount that can be produced at any capital-labor ratio.
  - The increase in output per worker increases the supply of saving, causing the long-run capital-labor ratio to rise (Fig. 6.9).
- Can consumption per worker grow indefinitely?
  - The saving rate can’t rise forever (it peaks at 100%) and the population growth rate can’t fall forever.
  - But productivity and innovation can always occur, so living standards can rise continuously.
- Summary: The rate of productivity improvement is the dominant factor determining how quickly living standards rise.
**Figure 6.8** An improvement in productivity
Figure 6.9  The effect of a productivity improvement on the steady-state capital–labor ratio
### The Fundamental Determinants of Long-Run Living Standards

<table>
<thead>
<tr>
<th>An increase in</th>
<th>Causes long-run output, consumption, and capital per worker to</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>The saving rate, $s$</td>
<td>Rise</td>
<td>Higher saving allows for more investment and a larger capital stock.</td>
</tr>
<tr>
<td>The rate of population growth, $n$</td>
<td>Fall</td>
<td>With higher population growth more output must be used to equip new workers with capital, leaving less output available for consumption or to increase capital per worker.</td>
</tr>
<tr>
<td>Productivity</td>
<td>Rise</td>
<td>Higher productivity directly increases output; by raising incomes, it also raises saving and the capital stock.</td>
</tr>
</tbody>
</table>
Application: The growth of China

- China is an economic juggernaut.
  - Population 1.4 billion people.
  - Real GDP per capita is low but growing (Table 6.4).
  - Starting with low level of GDP, but growing rapidly (Fig. 6.10).

- Fast output growth attributable to
  - Huge increase in capital investment.
  - Fast productivity growth (in part from changing to a market economy).
  - Increased trade.
**Table 6.4** Economic Growth in China, Japan, and the United States

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</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>530</td>
<td>552</td>
<td>448</td>
<td>6,725</td>
<td>1.9%</td>
</tr>
<tr>
<td>Japan</td>
<td>737</td>
<td>1,387</td>
<td>1,921</td>
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</tr>
</tbody>
</table>

*Note: Figures are in U.S. dollars at 1990 prices, adjusted for differences in the purchasing power of the various national currencies.*

Figure 6.10  Real GDP growth in China and the United States, 2001-2011

Will China be able to keep growing rapidly?

- Rapid growth because of
  - use of underemployed resources.
  - using advanced technology developed elsewhere.
  - making transition from centrally-planned economy to market economy.

- Such gains may not last. So, it may take China a long time to catch up with the rest of the developed world.
Endogenous growth theory—explaining the sources of productivity growth. Aggregate production function:

\[ Y = AK \]  

Constant \( MPK \): Human capital
- Knowledge, skills, and training of individuals.
- Human capital tends to increase in the same proportion as physical capital.

Research and development programs.
Increases in capital and output generate increased technical knowledge, which offsets decline in \( MPK \) from having more capital.
Implications of endogenous growth

- Suppose saving is a constant fraction of output:
  \[ S = sAK. \] (13)

- Since investment = net investment + depreciation:
  \[ I = \Delta K + dK \] (14)

- Setting investment equal to saving implies:
  \[ \Delta K + dK = sAK, \] (15)
  \[ \frac{\Delta K}{K} = sA - d. \] (16)

- Since output is proportional to capital, \( \frac{\Delta Y}{Y} = \frac{\Delta K}{K} \), so
  \[ \frac{\Delta Y}{Y} = sA - d, \]

which means that the saving rate affects the long-run growth rate (not true in Solow model).
Endogenous growth theory attempts to explain, rather than assume, the economy’s growth rate. The growth rate depends on many things, such as the saving rate, that can be affected by government policies.
Policies to affect the saving rate

If the private market is efficient, the government shouldn’t try to change the saving rate:

- The private market’s saving rate represents its trade-off of present for future consumption.
- But if tax laws or myopia cause an inefficiently low level of saving, government policy to raise the saving rate may be justified.

How can saving be increased?

- One way is to raise the real interest rate to encourage saving; but the response of saving to changes in the real interest rate seems to be small.
- Another way is to increase government saving: The government could reduce the deficit or run a surplus. But under Ricardian equivalence, tax increases to reduce the deficit won’t affect national saving.
Policies to raise the rate of productivity growth

- Improving infrastructure:
  - Infrastructure: highways, bridges, utilities, dams, airports.
  - Empirical studies suggest a link between infrastructure and productivity.
  - U.S. infrastructure spending has declined in the last two decades.

- Would increased infrastructure spending increase productivity?
  - There might be reverse causation: Richer countries with higher productivity spend more on infrastructure, rather than vice versa.
  - Infrastructure investments by government may be inefficient, since politics, not economic efficiency, is often the main determinant.
(Conti.) Building human capital:

- There’s a strong connection between productivity and human capital.
- Government can encourage human capital formation through educational policies, worker training and relocation programs, and health programs.
- Another form of human capital is entrepreneurial skill.
- Government could help by removing barriers like red tape.
(Conti.) Encouraging research and development:

- Support scientific research.
- Fund government research facilities.
- Provide grants to researchers.
- Contract for particular projects.
- Give tax incentives.
- Provide support for science education.