Economics 680
Economic Growth

Professor Keating

Output measurement

- Aggregate Output is measured by

  Gross Domestic Product

  GDP is:

  - The market value
  - Of currently produced goods and services
  - For final use
  - In a particular economy
  - Over a particular period of time

  – Real output is the preferred measure

Movements in output

- Growth
  - output (Y) trends upward over time – it grows!
  - on average, output growth has been about 3% per year in the US
  - Definition of the growth rate of Y:

$$\frac{Y_t - Y_{t-1}}{Y_{t-1}}$$

- Business Cycles
  - output fluctuates, it does NOT grow at a constant rate over time
  - a decline in output, a.k.a. a contraction, is called a recession
  - a rise in output is called an expansion

Average Labor Productivity

- Defined as the ratio of output to labor input.
  - Output is typically measured by real GDP
  - Labor input is usually measured by:
    - total hours worked

      OR

    - number of workers

An equation for:
Average Labor Productivity

$$\text{Average Labor Productivity} = \frac{Y}{N}$$

Where Y=output
N=labor input

Output-per-capita

- Equals: Output (Y) divided by Population
- This is typically used to measure the ***Standard of Living*** for the average person in an economy (usually a single country)
- Output-per-capita must always be less than output-per-worker
  - This is because population is always greater than the number of workers
    - Population includes the Unemployed and also people who are: Not In The Labor Force
    - If you have no job and are not seeking one, then you considered Not In The Labor Force

Comparing income across countries

- Income in different countries is measured in different currencies
- To make a cross-country comparison, we need to put output in terms of a common currency
- Problem: Exchange rates are sometimes subject to enormous fluctuations over a short period of time. Output can not be changing as rapidly as the change in exchange rates. Thus we can't use actual exchange rates to compare output across countries.
- A Purchasing Power Parity exchange rate is used to put things in a common currency and to control for the wide swings that market exchange rates often exhibit.

Various ways to rank the size of the world's countries

- Rankings can be based on
  – The amount of output (GDP) produced
  – The population in a country
  – The amount of GDP per capita (which is the ratio of output to population)

Table 1.1 Top Eleven Countries in Year 2009 According to Three Different Measures

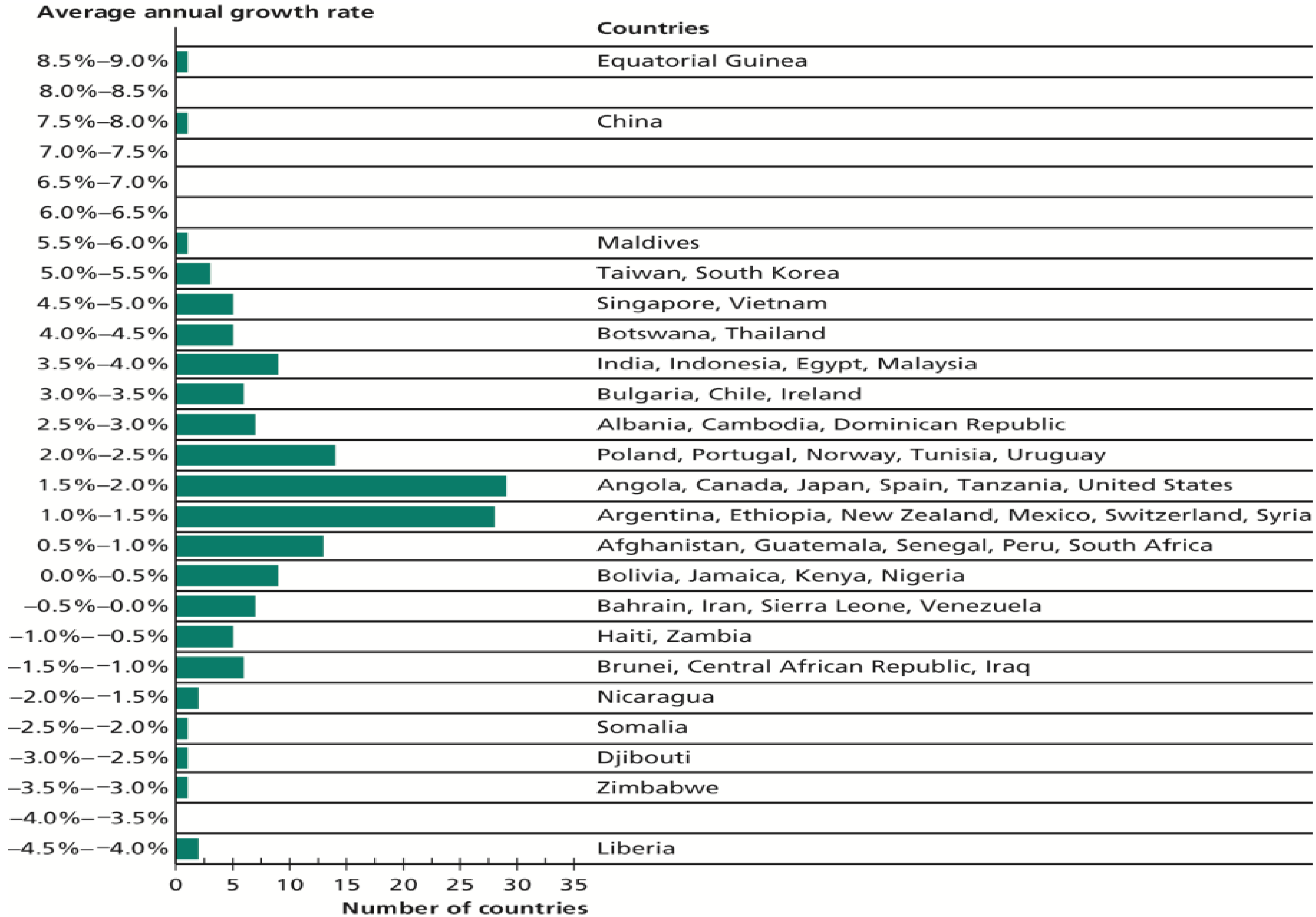
Rank	Highest GDP per Capita		Largest Economies		Most Populous Countries	
	Country	GDP per Capita ($)	Country	Total GDP ($ trillions)	Country	Population (millions)
1	Qatar	159,469	United States	12.62	China	1,320
2	Luxembourg	84,525	China	10.08	India	1,160
3	United Arab Emirates	52,946	Japan	3.81	United States	307
4	Bermuda	52,090	India	3.76	Indonesia	240
5	Macao	51,057	Germany	2.66	Brazil	199
6	Norway	49,945	United Kingdom	2.07	Pakistan	181
7	Singapore	47,373	Russia	2.05	Bangladesh	154
8	Kuwait	46,639	France	1.98	Nigeria	149
9	Brunei	46,229	Italy	1.68	Russia	140
10	Australia	41,304	Brazil	1.62	Japan	127
11	United States	41,099	Mexico	1.29	Mexico	111

- The US has ranked 1st in the economy's size and 3rd in population for some time
- After the recent recession, we fell to 11th in terms of output per capita (typically the US has ranked no lower than 3rd)
  - This recent decline, in 2009, stems from
    - The severe financial crisis that hurt the US more in 2009 than most other countries
    - Nations that produce oil primarily did quite well, relative to the US, after the world price of oil reached record highs (in both nominal and real values in 2008)

What has happened to country growth rates in recent decades?

- The next graph examines the distribution of growth rates of GDP over the period from 1975 to 2009.
  - Countries are grouped according to average growth rate
  - One or more examples, are given for each growth rate grouping

The Distribution of Country Growth Rates,1975–2009



- Definition: A cross section measures a variable across different groups
- We have plotted a cross sectional graph that examines how average growth rate of GDP has varied across countries

- Over the last 3 to 4 decades many countries have grown much faster than the US
  - China leads all major countries in growth rate
  - Two tiny countries have grown rapidly based on oil production (Equatorial Guinea) and tourism (Maldives)
  - Countries formerly known as “Asian Tigers”, Hong Kong, which in 1997 became a part of China, along with Singapore, Taiwan and South Korea, have continued to grow fast for many years
  - Other Asian countries have more recently grown rapidly (Vietnam and Thailand, in particular, with Malaysia and Indonesia doing almost as well)
  - Botswana has grown rapidly due to a rich supply of diamonds. Acemoglu and Robinson argue this country has also made important changes to political and economic institutions that will allow it to sustain this fast economic growth

- If these countries can maintain this more rapid growth rate for long enough they will catch-up to the US and possibly surpass the US economy as the largest economy in the world
  – Given China’s large economy and rapid growth rate, China is very close to becoming the world’s largest economy

- Quite a few countries have grown at roughly the same rate as the US
  - If a country has the same growth in output as the US, and a lower initial level of output, its output level will never catch up to the US level

- Even more countries have grown slower than the US since 1975
  - If they maintain this slower growth, they will fall farther and farther behind the US
- Some of the very poorest countries in the world have experienced the slowest growth
  - The slowest growing countries have had negative growth rates of output per capita which means that output per capita is falling, not rising over the period
    - Most of these countries with negative growth rates are found in Africa

- Acemoglu and Robinson argue that all these countries with negative growth rates have serious institutional problems.
  - Some countries are so politically divided that the civil war seems never ending (e.g. Somalia)
  - Some countries have government elites that impose harsh rules on the rest and destroy the incentives for productive economic activity. (e.g. Zimbabwe)
    - Examples of productive activities include saving, investing, getting an education, and trying to be an innovator or an entrepreneur

A Very Useful Tool: "The Rule of 70"

- Suppose GDP is growing at a rate of g
- The rule of 70 says that the level of GDP will double in
- $\dfrac{70}{g}$ years
  - If g=3.5, then 70/3.5 = 20, and therefore it takes 20 years for the level of output to double in size.
  - Alternatively, if you knew it took 20 years to double, this equation tells us that the growth rate (g) is 3.5 percent
  - Mathematical note: 3.5 means 3.5 percent per year which is not written in decimal form for a percentage which would be .035
- Can use this rule with any variable, not just GDP

TABLE 1.1 STATISTICS ON GROWTH AND DEVELOPMENT

	GDP per capita, 2008	GDP per worker, 2008	Labor force participation rate, 2008	Average annual growth rate, 1960–2008	Years to double
"Rich" countries					
United States	$43,326	$84,771	0.51	1.6	43
Japan	33,735	64,778	0.52	3.4	21
France	31,980	69,910	0.46	2.2	30
United Kingdom	35,345	70,008	0.51	1.9	36
Spain	28,958	57,786	0.50	2.7	26
"Poor" countries					
China	6,415	10,938	0.59	5.6	13
India	3,078	7,801	0.39	3.0	24
Nigeria	1,963	6,106	0.32	0.6	114
Uganda	1,122	2,604	0.43	1.3	52
"Growth miracles"					
Hong Kong	37,834	70,940	0.53	4.3	16
Singapore	49,987	92,634	0.54	4.1	17
Taiwan	29,645	62,610	0.47	5.1	14
South Korea	25,539	50,988	0.50	4.5	16
"Growth disasters"					
Venezuela	9,762	21,439	0.46	−0.1	−627
Haiti	1,403	3,164	0.44	−0.4	−168
Madagascar	810	1,656	0.49	−0.1	−488
Zimbabwe	135	343	0.40	−1.5	−47

Another way to examine economic performance is on a time scale

- Below we plot the output per capita over time from 1960 to 2000 for a number of countries
  - These data are called “time series” because they can vary over time

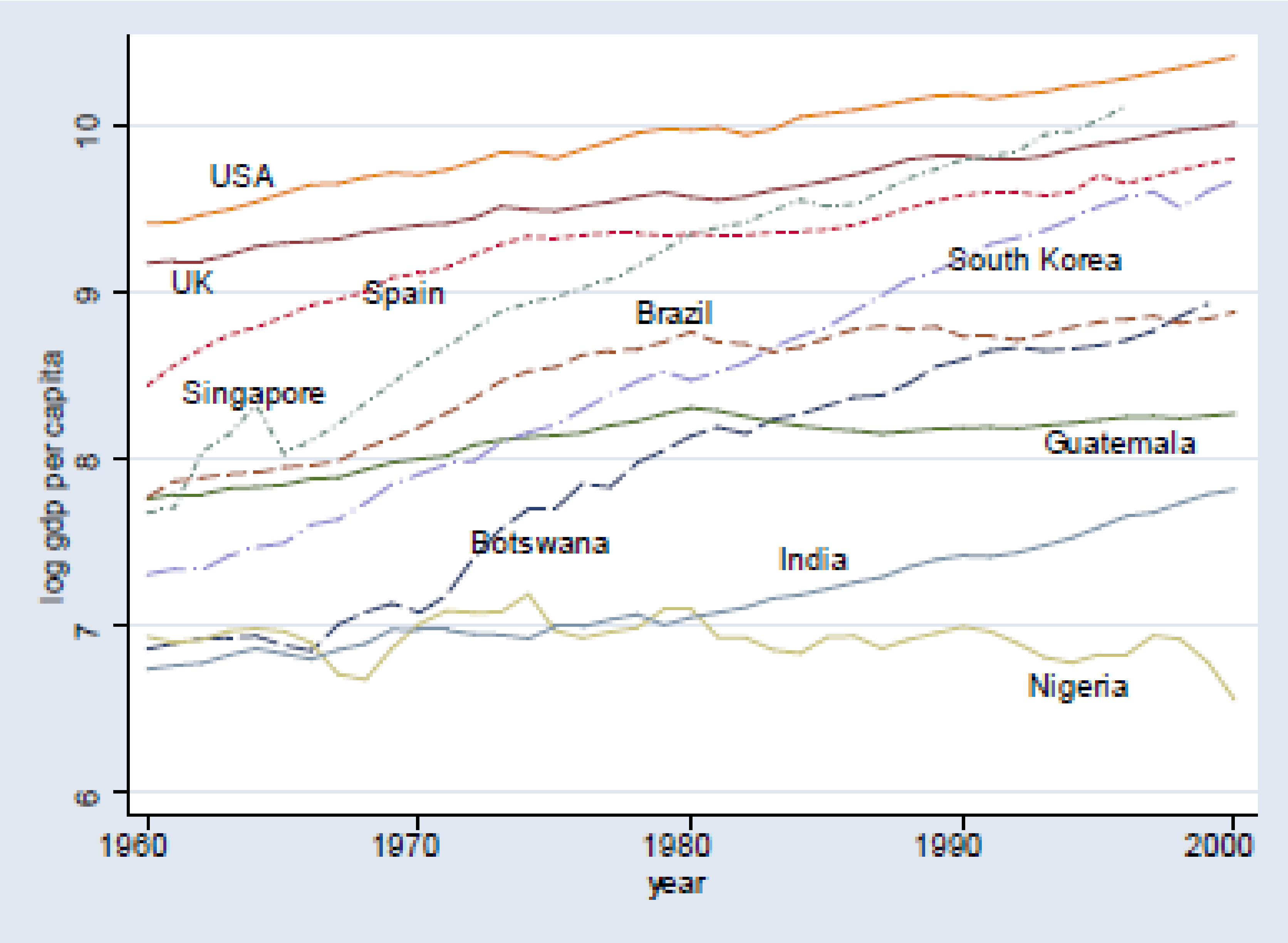


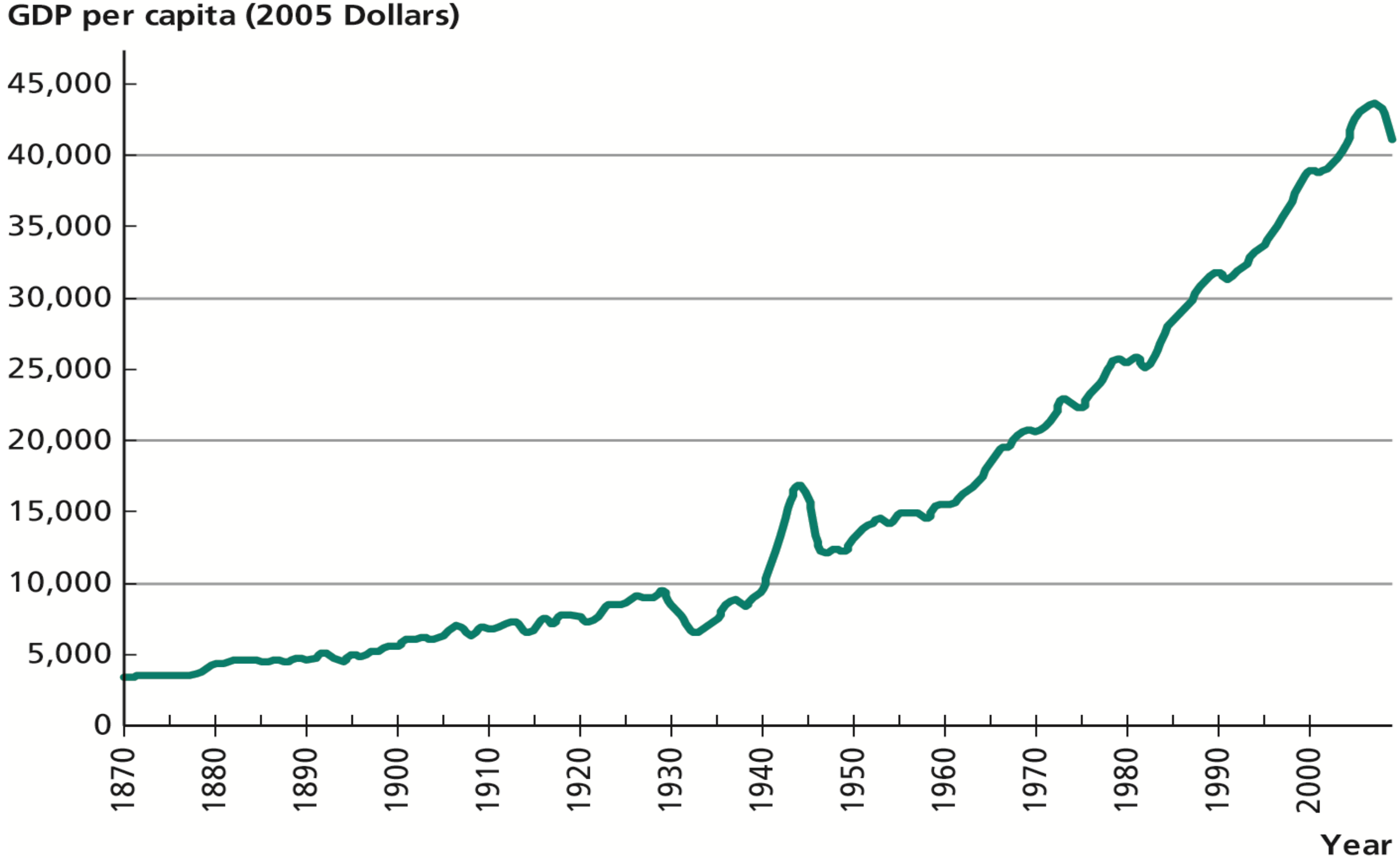
Figure: The evolution of income per capita 1960-2000.

- This provides an interesting way of seeing how countries have grown at different rates for a period of time.
- This graph also shows the growth rate for some countries has varied (increased or decreased) at different points in times in that period
  – To tell differences in growth rates we have used the logarithm (or ratio) scale for the data not the level scale – the slope of the line when using logs is approximately equal to the growth rate
  – We soon will show why this is so

US income-per-capita, since 1870

- Now lets examine the time series data for a particular country, the US
  - In the next picture we examine how US GDP per capita varies over time

Figure 1.2 GDP per Capita in the United States, 1870–2009



- The advantage of this type if graph - It jointly illustrates two key features observed in all measures of output
  - Growth
    - The tendency for output per capita to trend upward over time
  - Cycles
    - The tendency for output per capita to fluctuate around this upward trend

- Question: Can you tell from the previous graph whether or not US GDP-per-capita is growing faster after 1960 that it did before 1929?

- The answer is no, or at least not very easily.
- Growth differences are NOT plotted by that graph
  - That graph plots the level of output-per-capita on the vertical axis
    - therefore you can easily compare changes in the level of output per capita over time
    - but comparing changes in growth rates over time is not easily done because a growth rate is the percentage change in a variable.
      - Recall our definition of output growth

$$\frac{Y_t - Y_{t-1}}{Y_{t-1}}$$

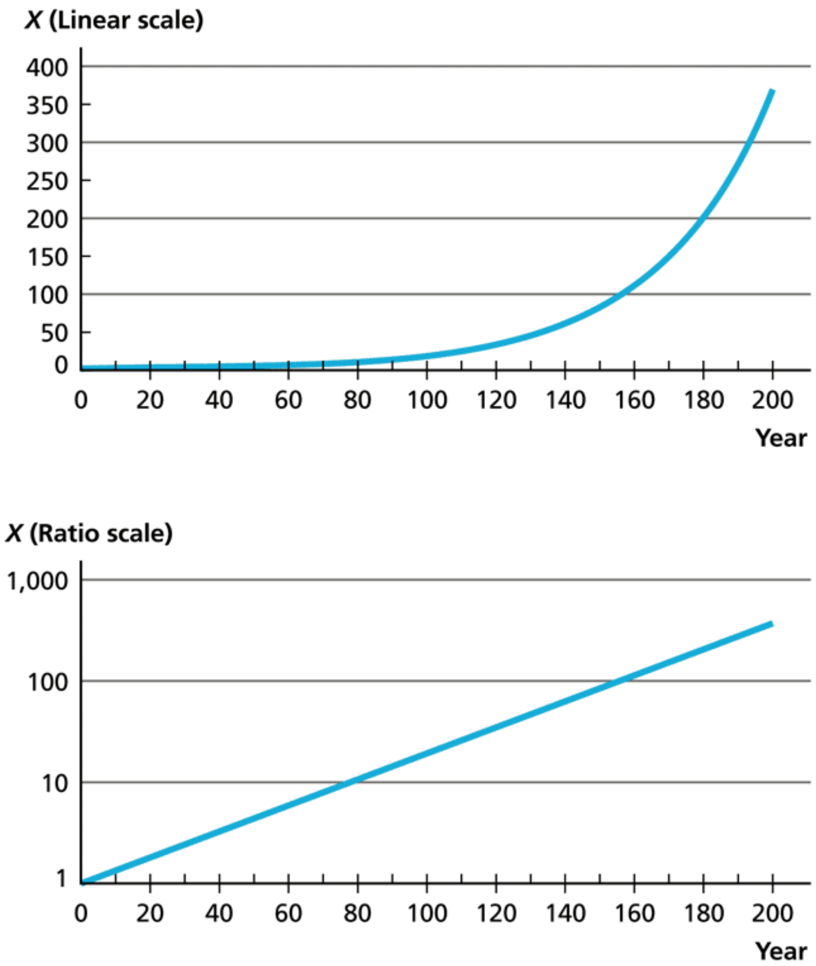
- To illustrate the main points, we use the next two graphs to plot a variable X that is growing at a fixed rate over time

  First Graph: Plots X on a Linear Scale (the level of X as it varies over time)

  Second Graph: Plots X on the Ratio Scale (the logarithm of X as it varies over time)

  - We see how easily output growth rates at different points in time are compared using the Ratio Scale

Figure 1.3 The Effect of Using a Ratio Scale

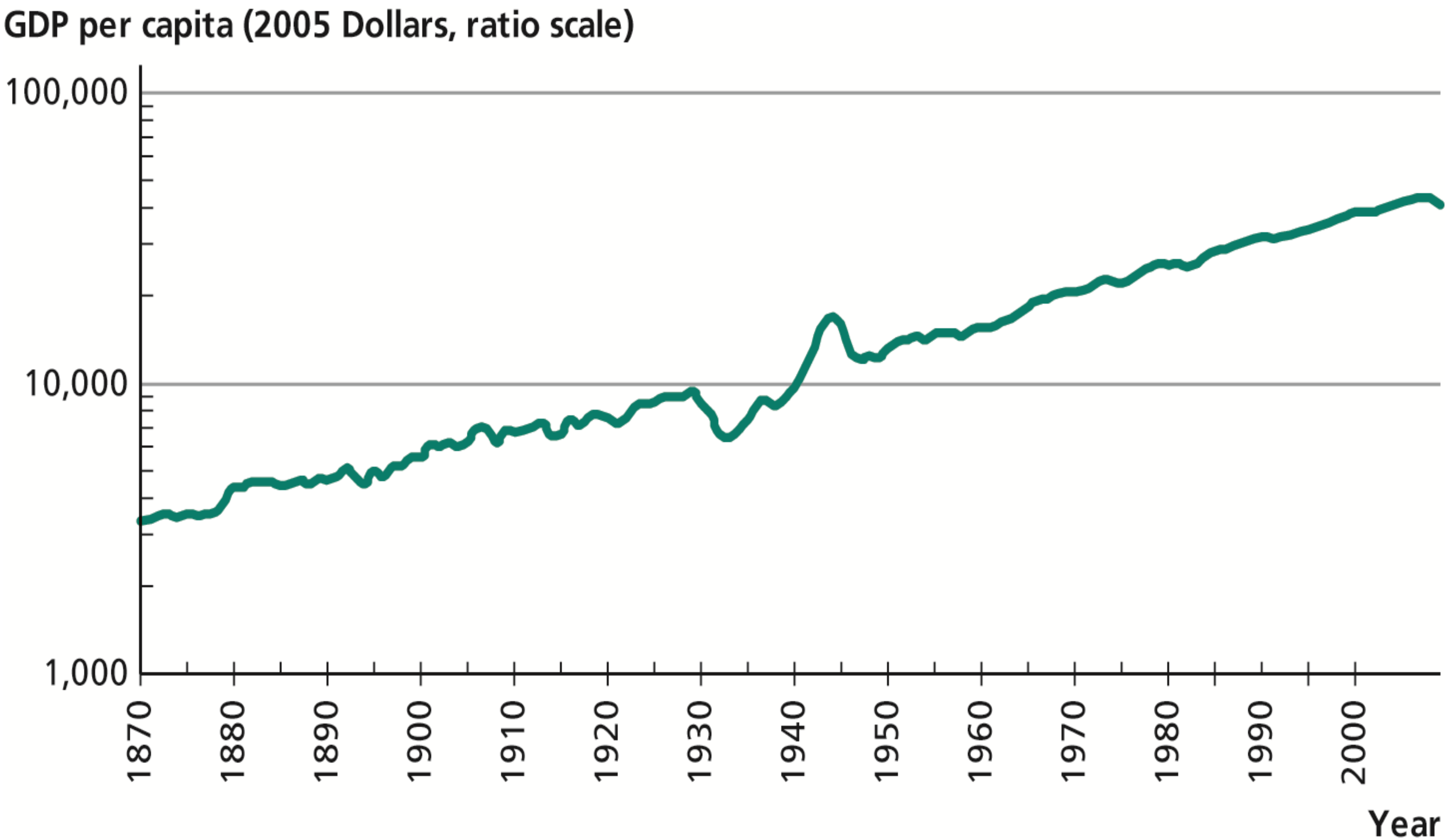


- In the Ratio Scale, the slope indicates growth rate. So two lines that have the same slope indicate the same growth rate

- Therefore, we can use the ratio plot for making easy visual comparisons of growth rates over time
  - Such comparisons are not easily done when a variable is plotted on a linear scale

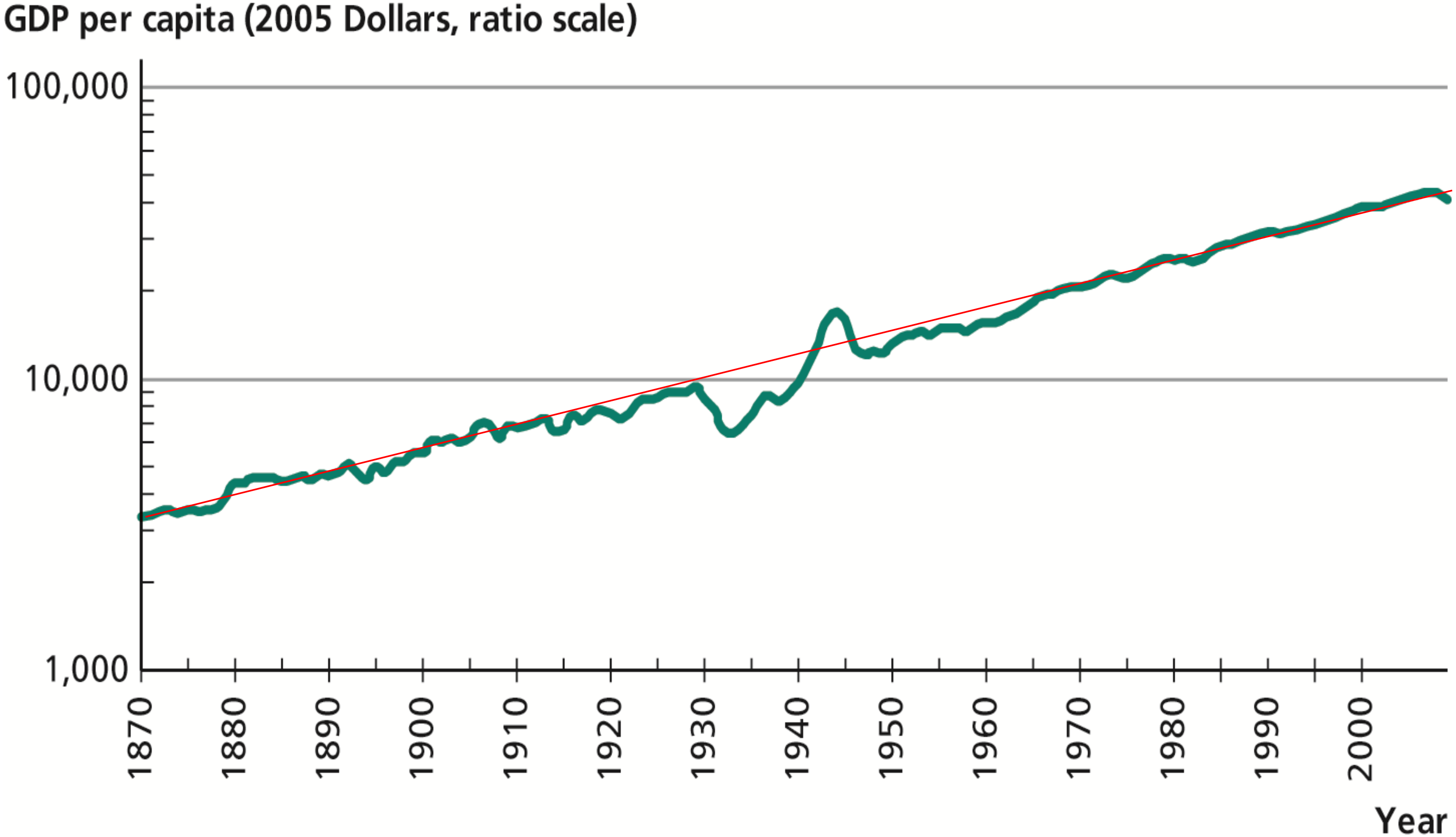
- Now we return to the US output-per-capita data and plot that on a ratio scale

Figure 1.4 GDP per Capita in the United States, 1870–2009 (Ratio Scale)



- As we saw, a straight line indicates a constant growth rate in a Ratio Scale
- In fact, we can draw a straight line through this output per capita plot
  - This supports the idea that growth is a persistent feature in US data
    - Over long periods of time, GDP per capita (or per worker) has tended to grow at a constant rate
      - The slope of this straight line is equal to the average growth rate of output in the US over the period of time used in the graph

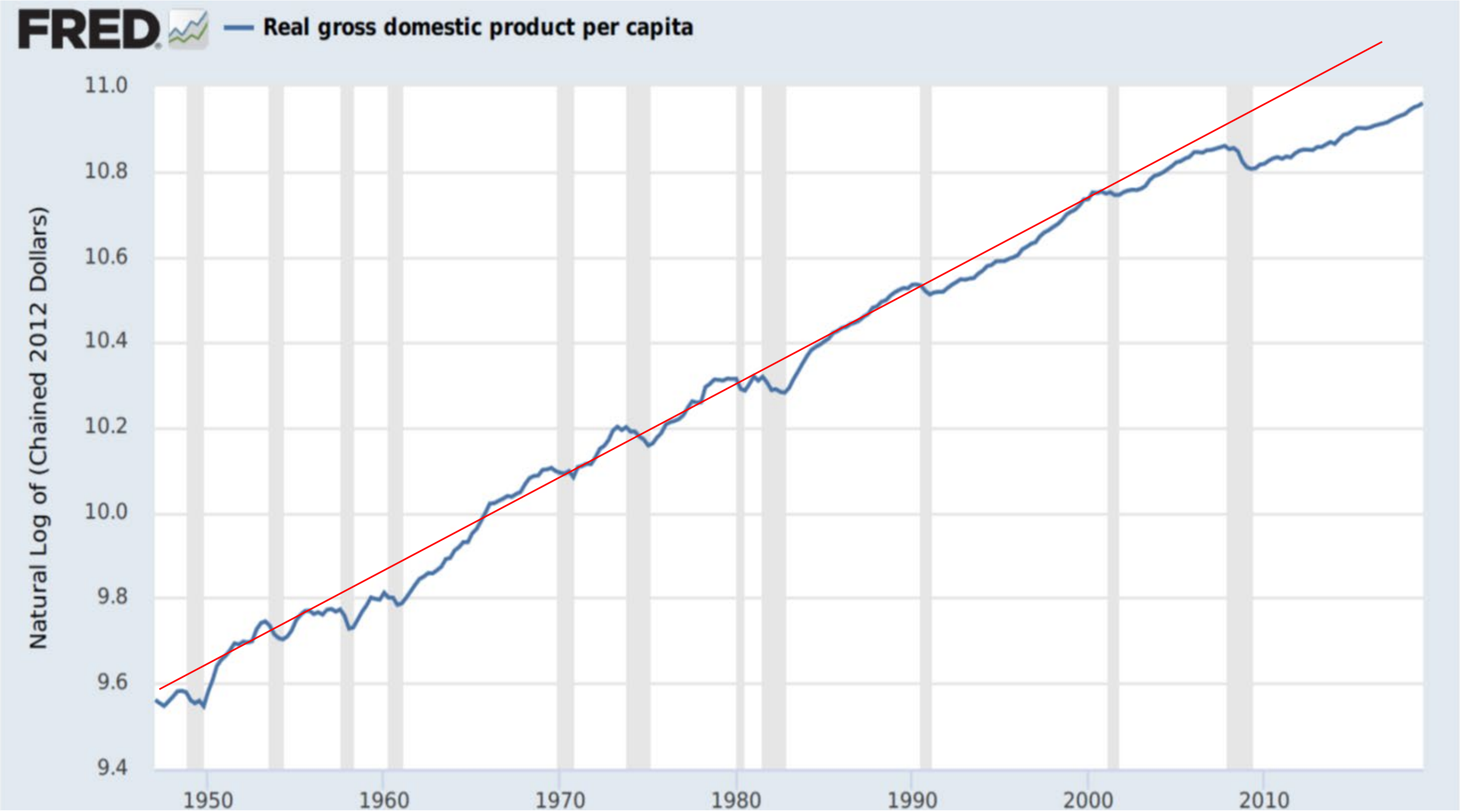
Figure 1.4 GDP per Capita in the United States, 1870–2009 (Ratio Scale)

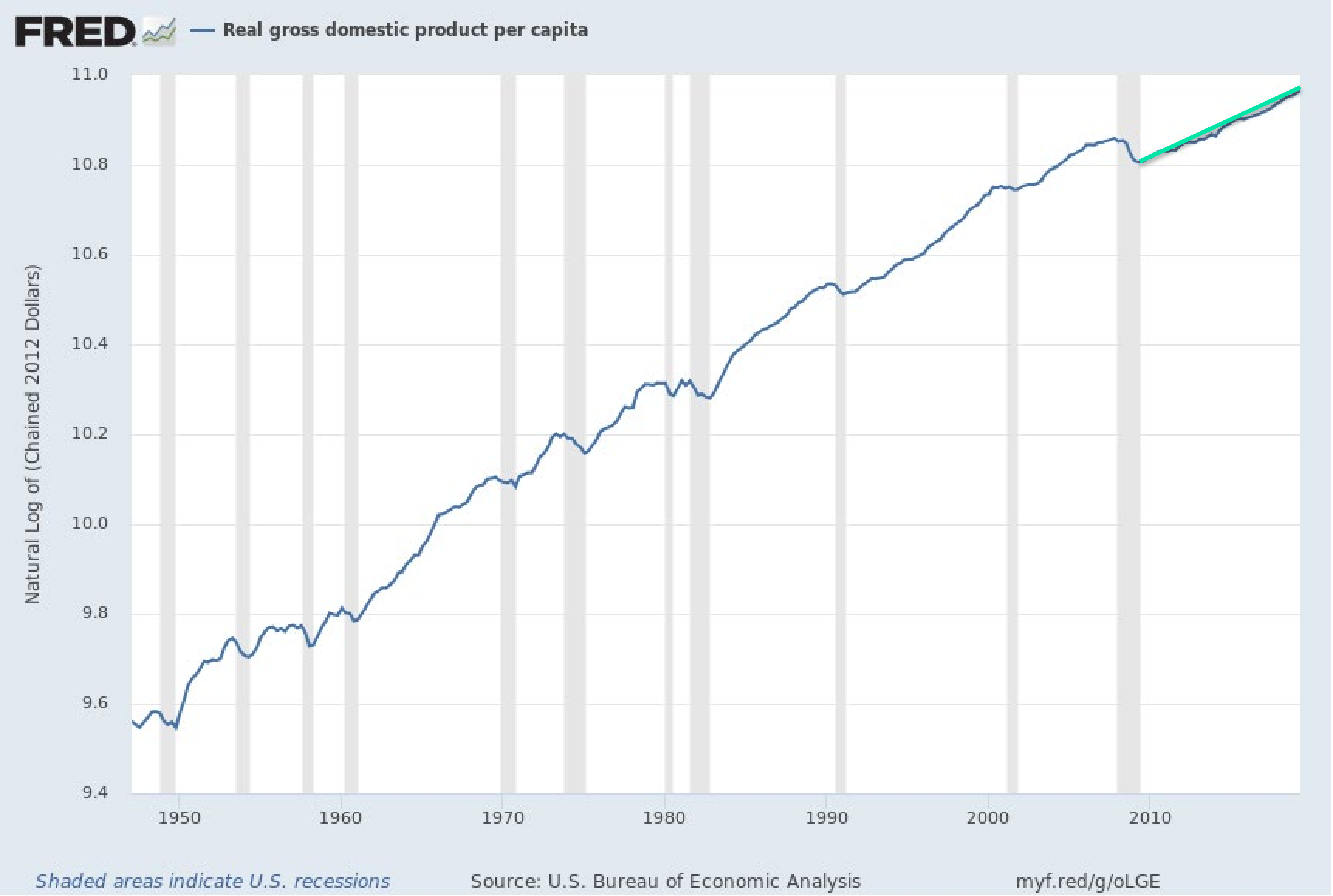


- Output per capita tracks this straight line fairly well over the long haul. And there are some notable deviations from that line, for example during WWII and the Great Depression
  - This suggests that
    - US GDP per-capita has tended to grow at roughly a constant rate over the long run
    - While over shorter time periods it has sometimes grown notably faster or slower.
  - Output per worker and total output exhibit similar tendencies

Extending the sample of US data

- Unfortunately, the US economy has not been performing as well since the last recession
- One particular problem is that Real GDP per Capita has been growing at a slower rate since the last recession


FRED
Real gross domestic product per capita
Natural Log of (Chained 2012 Dollars)
11.0
10.8
10.6
10.4
10.2
10.0
9.8
9.6
9.4
1950
1960
1970
1980
1990
2000
2010


FRED
Real gross domestic product per capita
Natural Log of (Chained 2012 Dollars)
11.0
10.8
10.6
10.4
10.2
10.0
9.8
9.6
9.4
1950
1960
1970
1980
1990
2000
2010
Shaded areas indicate U.S. recessions
Source: U.S. Bureau of Economic Analysis
myf.red/g/oLGE

- US GDP per-capita experienced a serious decline when the 2007-9 recession was over.
- And since then, US real GDP has been growing at a slower rate

We can compare GDP per capita for a variety of countries

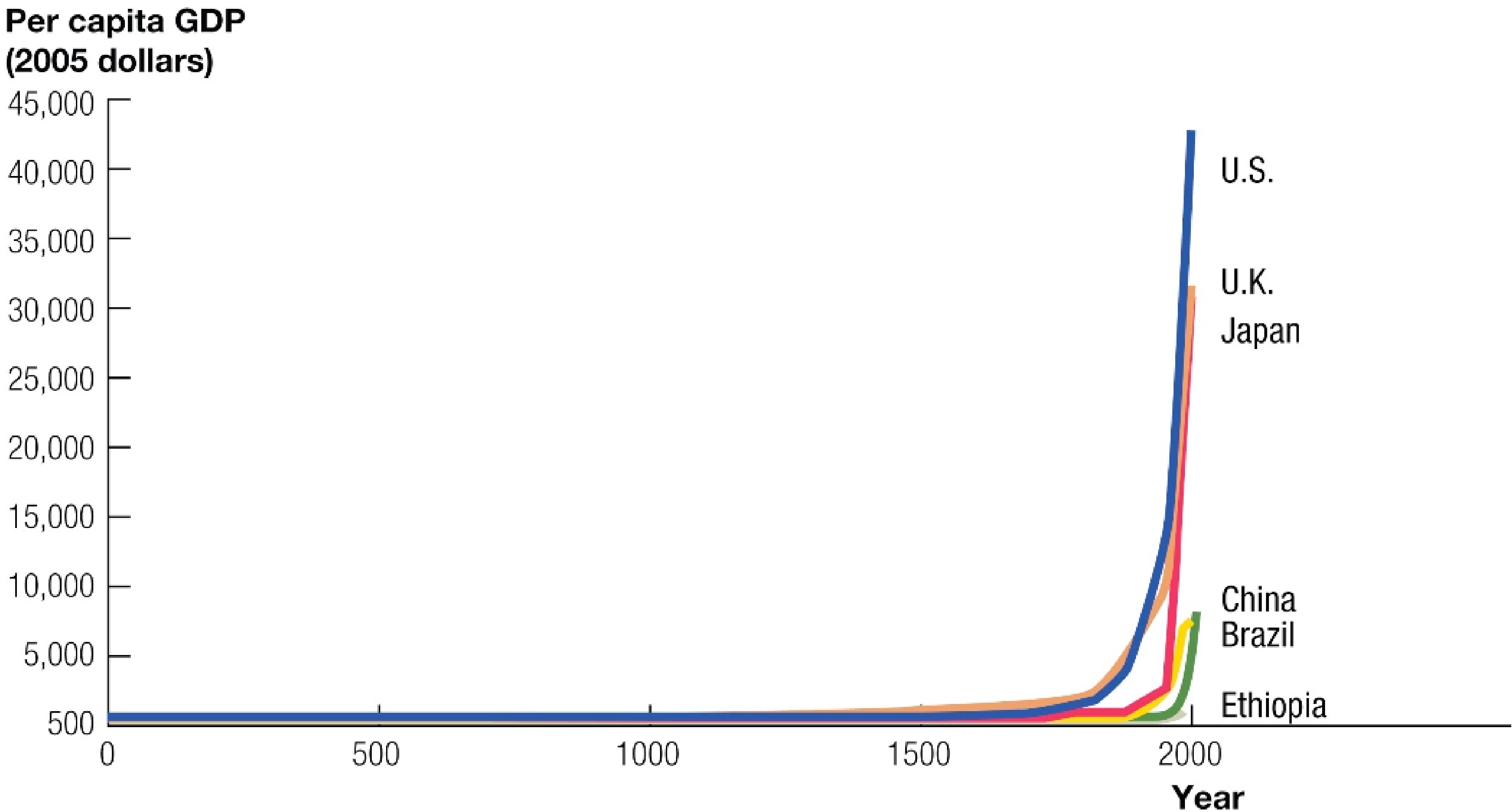
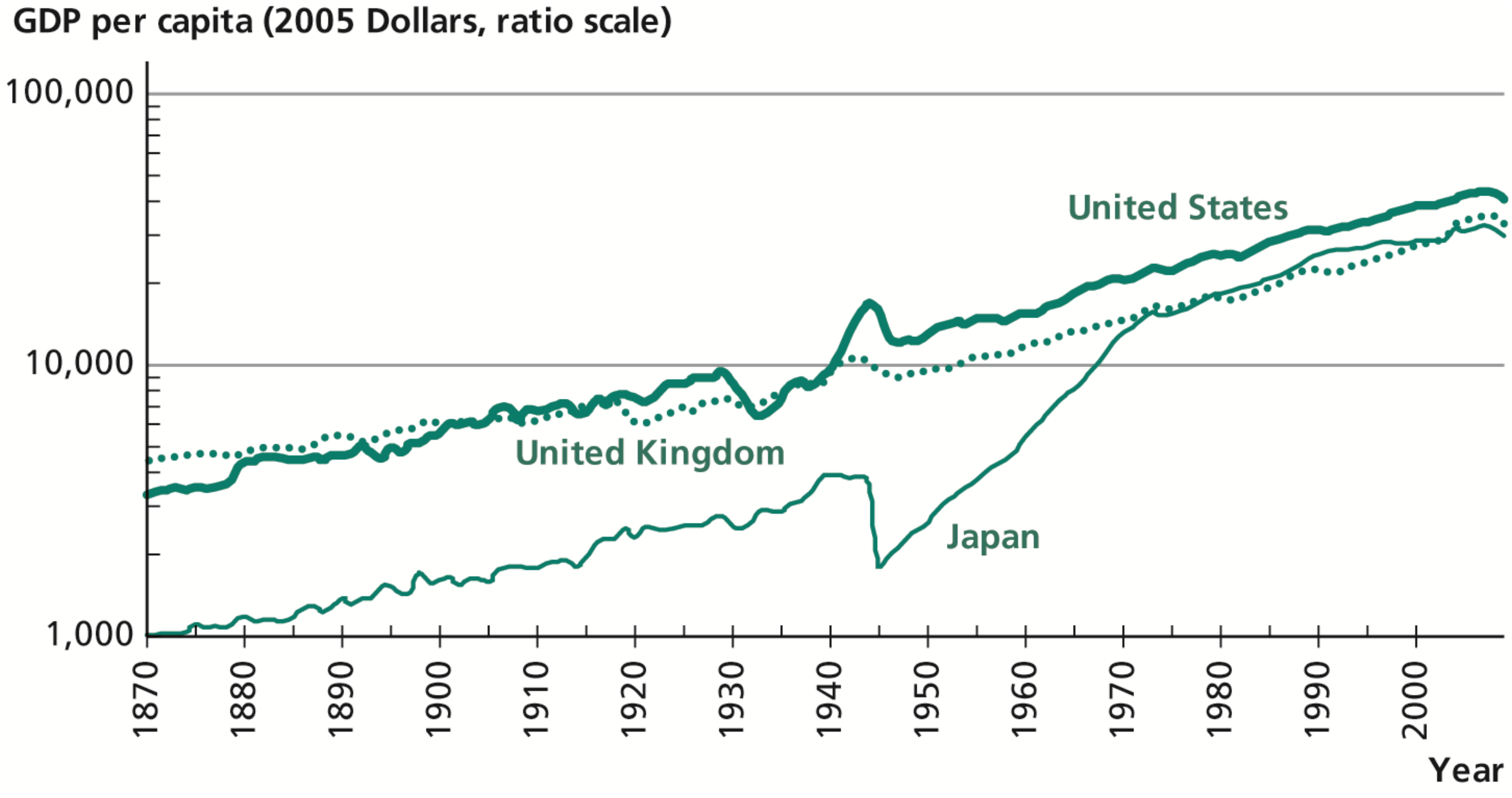


FIGURE 3.1 Economic Growth over the Very Long Run in Six Countries

- This plot of the level of a series has the same problem we have with any data that are growing over time
- However, this picture makes two important points
  - Up to 1750:
    - Output per capita showed no growth
    - Output levels were very similar across countries
  - After 1750:
    - Output levels diverged –countries grew at very different rates (some not at all)
    - What happened? The Industrial Revolution began for a small group of countries.
      - For most countries the Industrial Revolution was delayed or it never fully materialized.

- Now lets look at the ratio scale (i.e. the logarithm of a quantity)

Figure 1.5 GDP per Capita in the United States, the United Kingdom, and Japan, 1870–2009



- In the late 1800’s the UK was the world leader in output per capita.
  - The Industrial Revolution began in Britain giving the UK a head start over the rest of the world
- The US surpassed the UK in the early 1900s
  - Except for a brief period of time during the Great Depression, the US has since produced more output per capita than the UK
  - Since 1950, US and UK have grown at roughly the same rate
- Until 1930, Japan grew roughly the same rate as the US and a little faster than UK
  - But by the end of World War II, output per capita for Japan fell to a much lower level compared with the US or in the UK
- After WWII, Japan started growing at a faster rate than any other country
  - In the late 70s Japan’s output per capita surpassed that of the UK
  - Japan’s growth rate slowed somewhat in the 1970s, but it was still growing faster than the US and the UK. So it appeared Japan would soon also surpass the US in terms of output per capita
  - However, starting in 1990 Japan’s growth rate fell below the US rate and Japan’s output per capita began to fall relative to the US measure and is now about the same as the UK

Adding other countries to the discussion

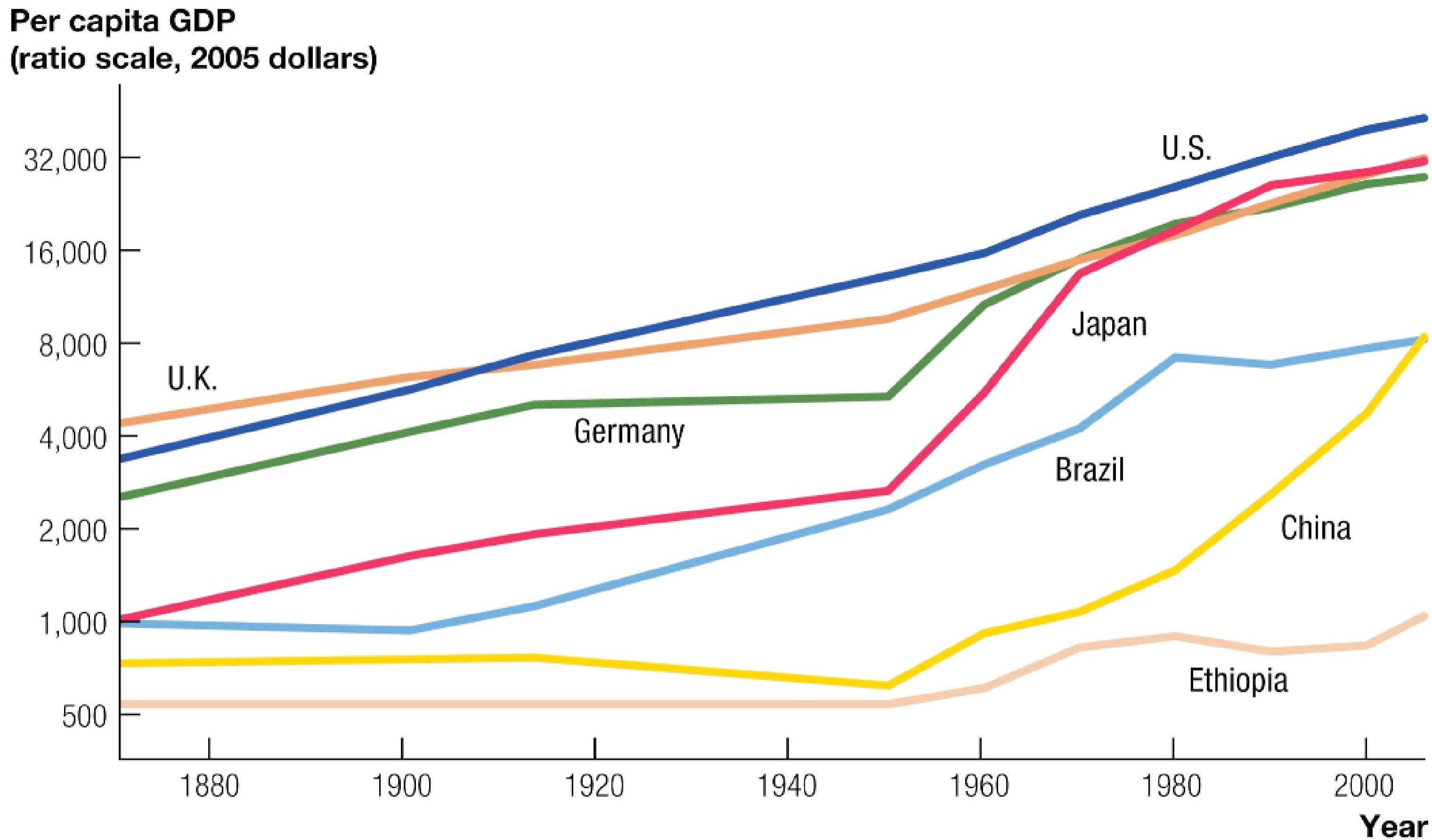


FIGURE 1.1 Per Capita GDP in Seven Countries, 1870–2006

- The US , UK and Japan results don't change (and shouldn't given our interest in long-term trends).
  – However the series are much smoother because data are decadal averages
- Germany's experience parallels Japan's
  – Germany was also predicted by some to be on the verge of passing the US
- China
  – grew faster after the Communist Revolution ended
  – and grew extremely fast after Chairman Mao died.
- Two examples of economies that have not done as well. Brazil was doing great until the 1980s; Ethiopia has stayed very poor

Next we examine data for different regions of the world

- Why?
  - We have data for broad regions going back farther in time than we do for many countries individually
    - The trade-off is that we have less frequent observations as we go further back in time
      - For some of the broad categories we are only able to obtain an estimate of average GDP over a decade (not even annually)
  - Often, economic performance is fairly similar for countries in a particular region, so grouping may be reasonable
    - Other Asia is an exception. While it excludes Japan, China, India and the former USSR countries, it combines the 4 Asian Tigers and Thailand along with many less prosperous Asian nations
  - Western Offshoots consists of the US, Canada, Australia and New Zealand
  - The other groupings are self explanatory

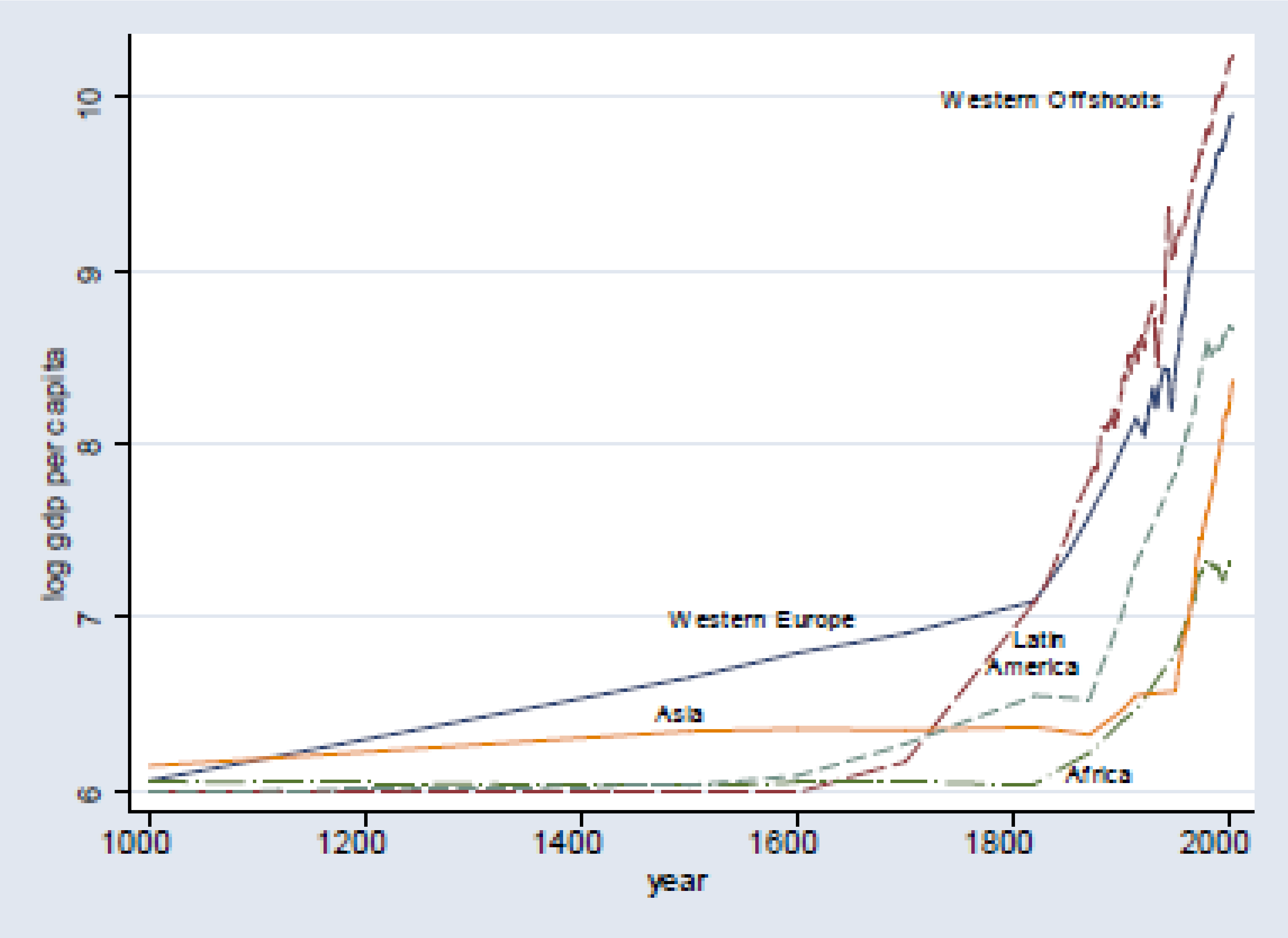
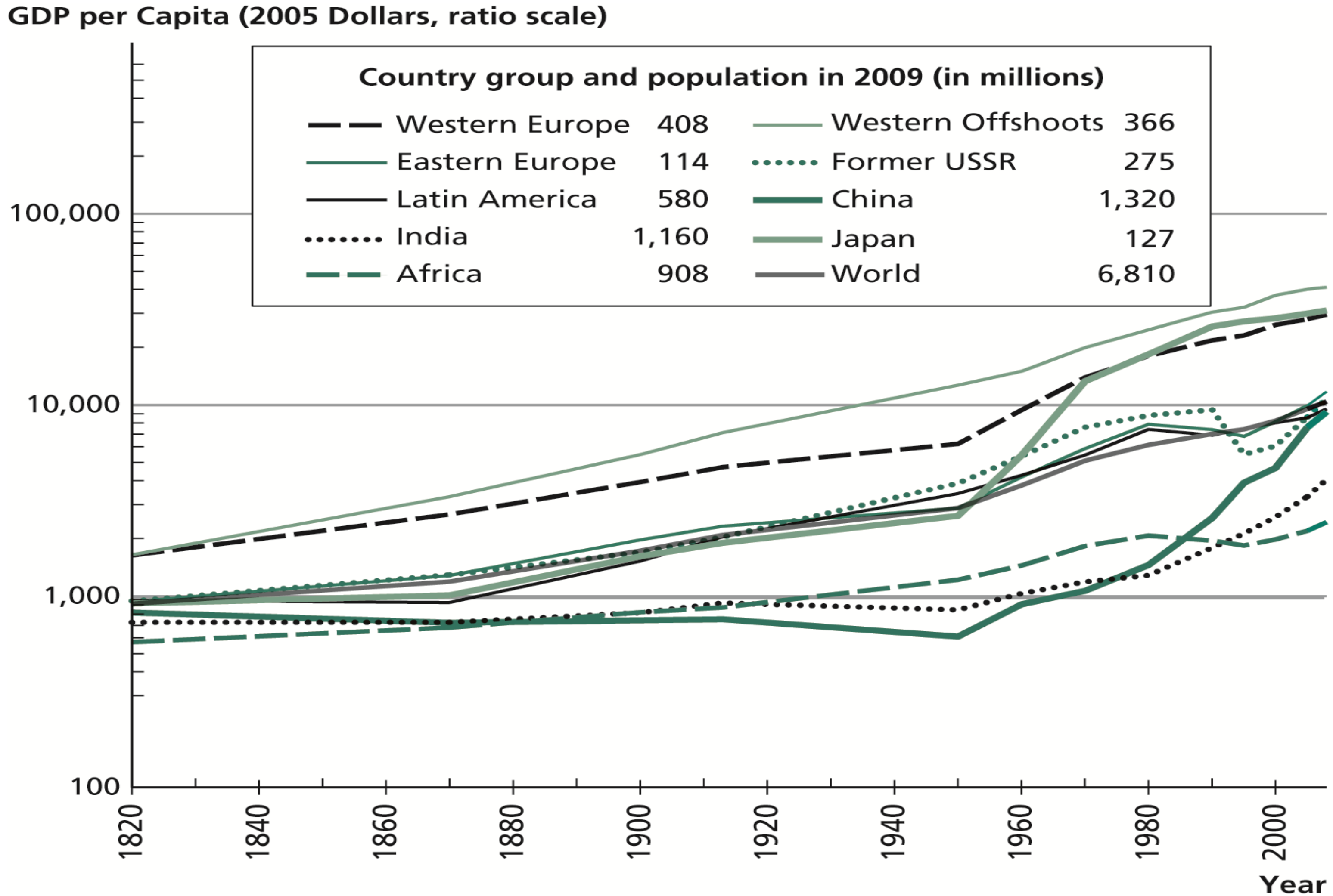


Figure: Evolution of GDP 1000-2000.

Figure 1.7 GDP per Capita by Country Group, 1820–2008



- Western Offshoots have been world leaders since about 1820
- Western Europe lost its lead shortly after 1820 and fell further behind until about 1950.
  - Then it closed some of the gap it had with Western Offshoots until about 1970.
  - Since then Western Europe has maintained a roughly constant gap relative to the Western Offshoots
- Japan was an average economy until WWII ended
  - Then it grew rapidly to surpass Western Europe some time in the 1970s
- The former USSR was lagging in growth compared to most countries of the world, until recently. The recent pick-up is due to oil prices rising and the USSR being a major oil producer
  - But China has now surpassed the USSR

- China was close to the average in 1820. But it fell further below the mean until it started turning things around after WWII
  - Over most of the 1820 to 1950 period, China's standard of living was stagnant or declined
  - Since 1970 China has grown the fastest of any of these groups and over the last few decades China has grown faster than any other nation
- India has experienced qualitatively similar changes as China,
  - India's standard of living and growth were superior to China's for most of the time, until WWII ended.
  - Since then, China's growth rate has surpassed India's growth and consequently China's standard of living has surpassed India's
- Africa has always been below the average, and this gap has been widening since 1970
  - In 1950 Africa was doing almost as well as Other Asia and was significantly ahead of India and China
  - Since then Africa has stagnated and fallen way behind

- As you can see from the picture the world growth rate has shown a tendency to rise since 1820

- Throughout most of human history there was no growth in output per capita
  - Hunter-Gathering economies
    - (200,000 BC to 10,000 BC),
    - no upward trend in output per capita
  - Agricultural economies
    - (10,000 BC to 1700 AD),
    - the Neolithic Revolution sowed the seeds for growth but there was very little growth until the latter stages of the period
  - Industrial economies
    - (since 1700 AD)
    - have experienced long periods of sustained growth

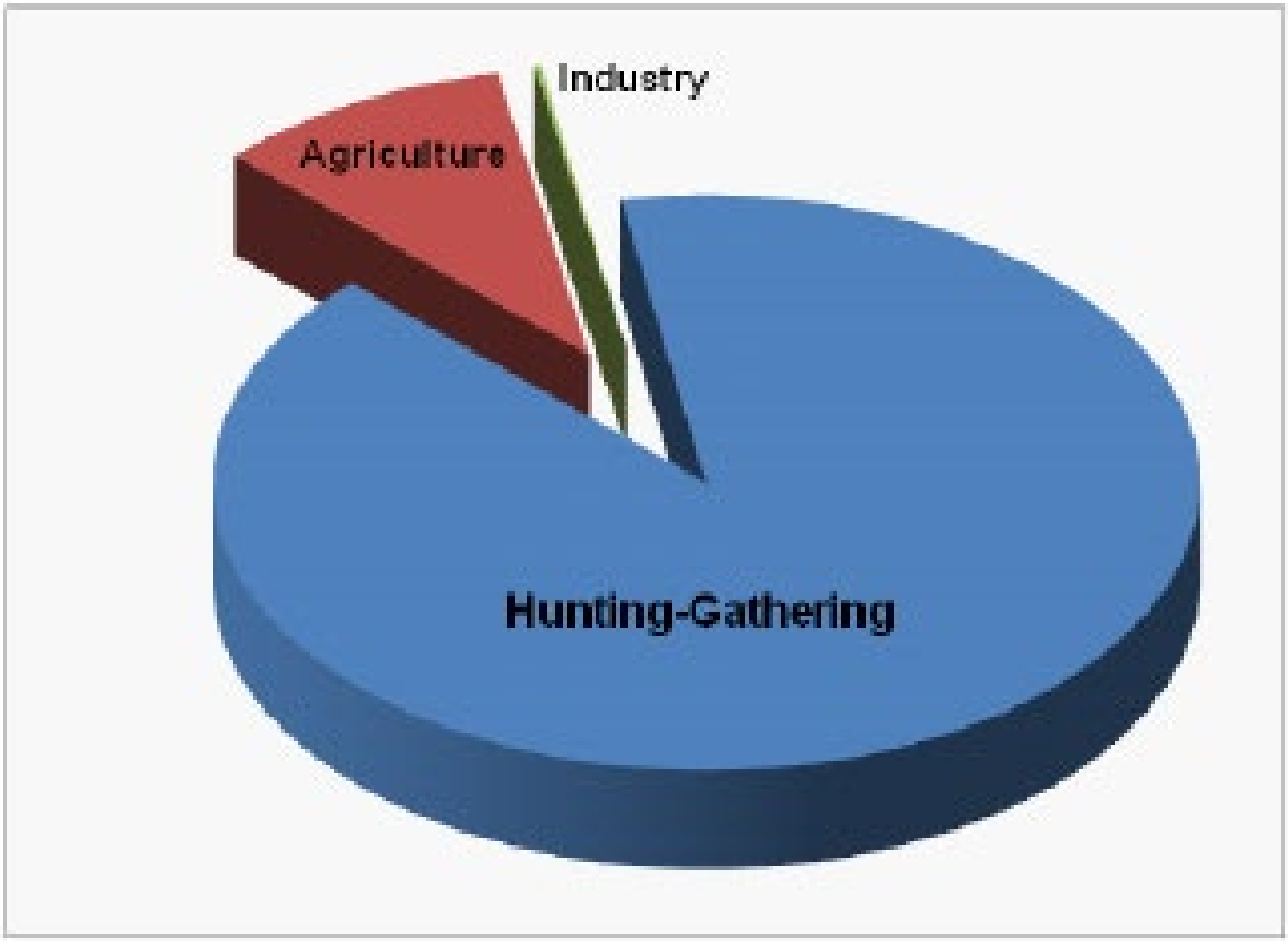
Major Periods: World Economy

- The Malthusian Epoch
  – Developed Countries 100,000 BCE - 1750
  – LDCs 100,000 BCE – 1900

- The Post Malthusian Regime
  – Developed Countries 1750 - 1870
  – LDCs 1900 -

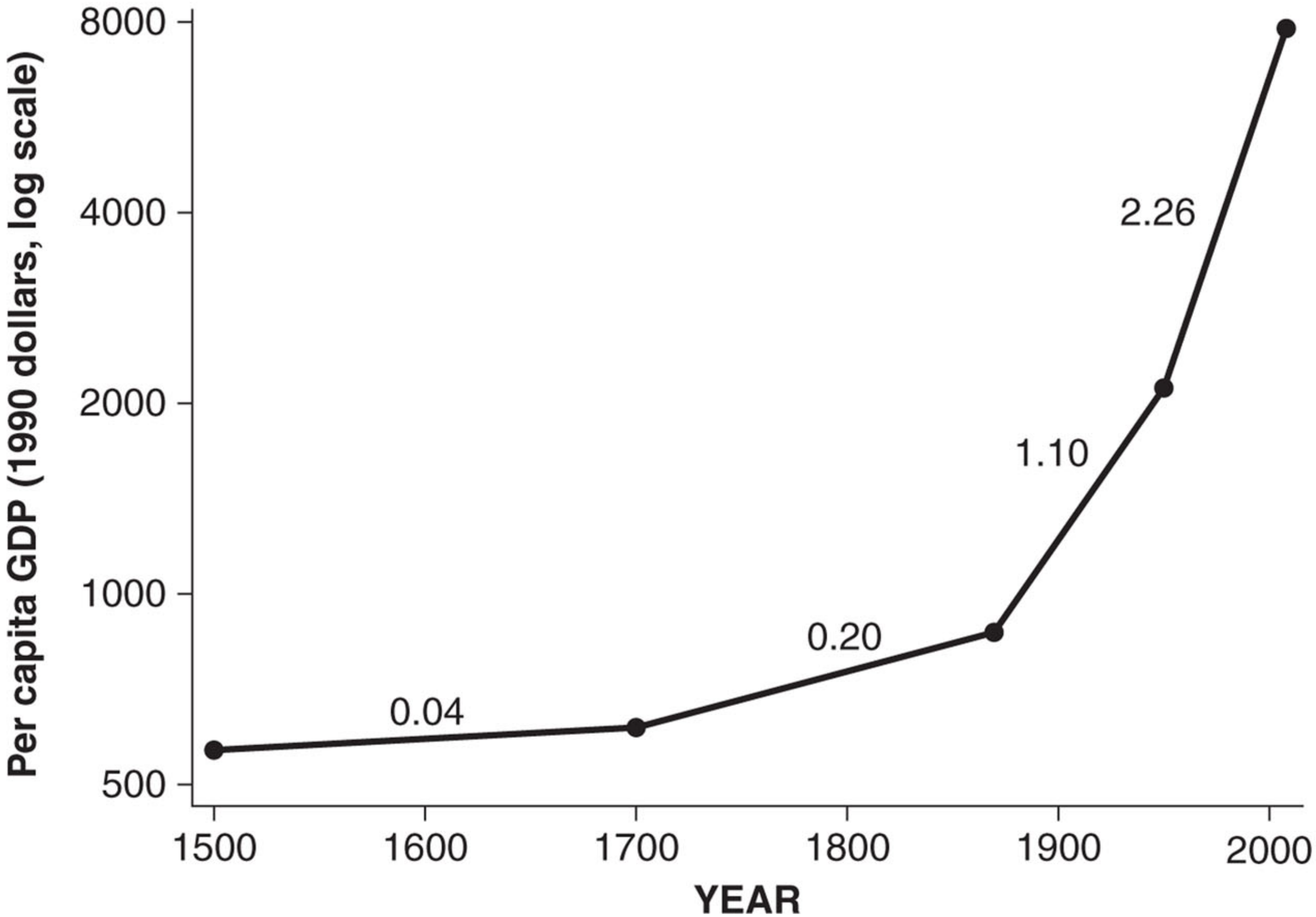
- The Modern Growth Regime
  – Developed Countries 1870 - present
  – LDCs

Human Time Line



- Looking at estimates of world output per capita we see that
  - The **“level”** of GDP per-capita has been trending upward
  - BUT EVEN MORE IMPRESSIVE: the **“growth rate”** has been rising over time!

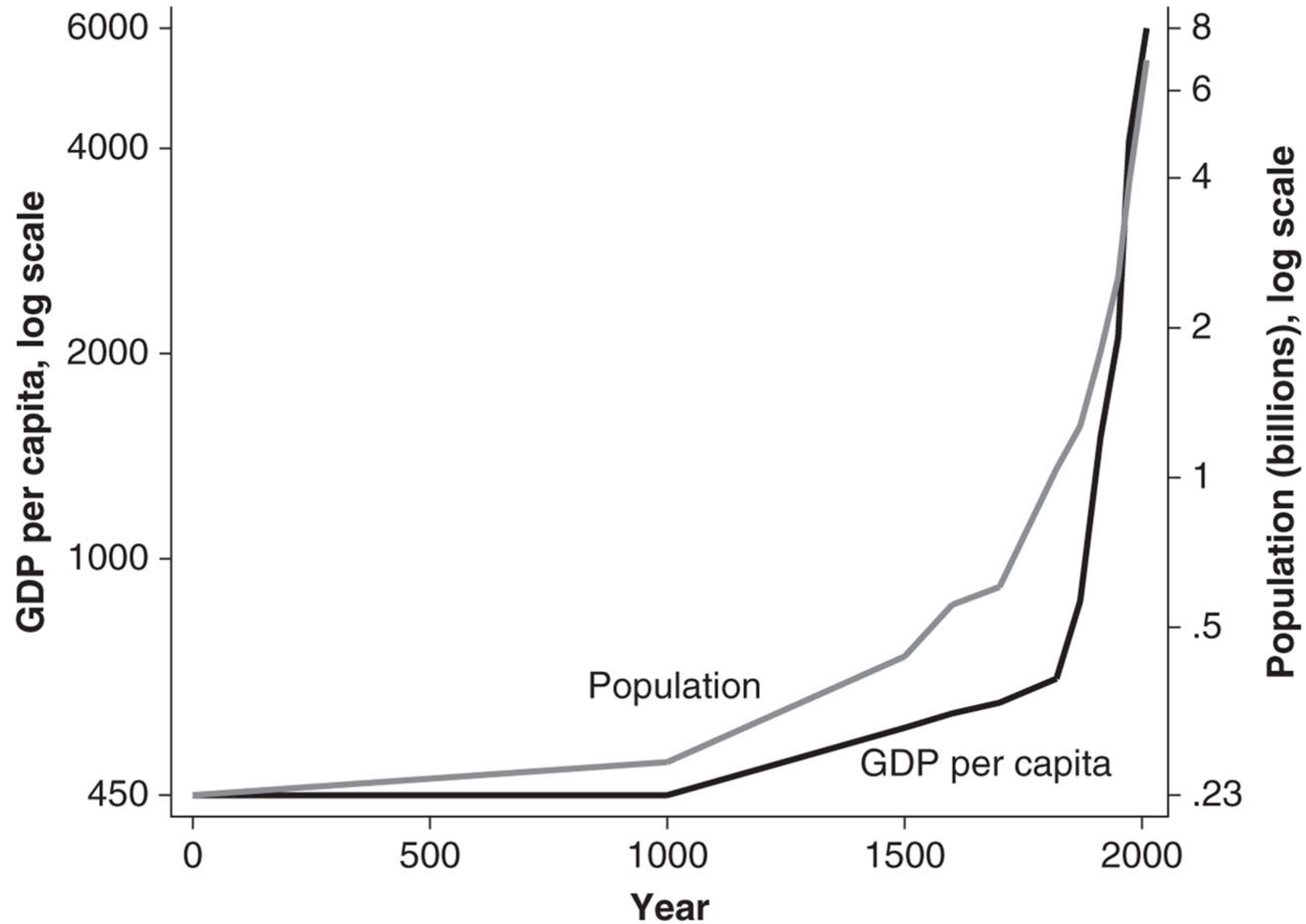
FIGURE 1.3 WORLD PER CAPITA GDP AND GROWTH RATES, 1500–2000



- The World’s growth rate of income per capita was very small from 1500 to the early1700s
  - In fact, Keynes speculated that there was at best a doubling of the world standard of living in the 4000 years that ended in 1700
    - HOMEWORK: What is the annual growth rate if it takes 4000 years for GDP per capita to double?
- The Industrial Revolution coincides with a notable increase in growth. The mid-1700s is sometimes called the First Industrial Revolution. Growth rate still not very large
- The more substantial mid-1800s increase is associated with what some call a Second Industrial Revolution
- The World growth rate increased still further after WWII

- We also observe another interesting empirical relationship:
- the **growth rate** of population **increases** around the time that World GDP per capita **growth increases**

FIGURE 8.1 WORLD INCOME PER CAPITA AND POPULATION

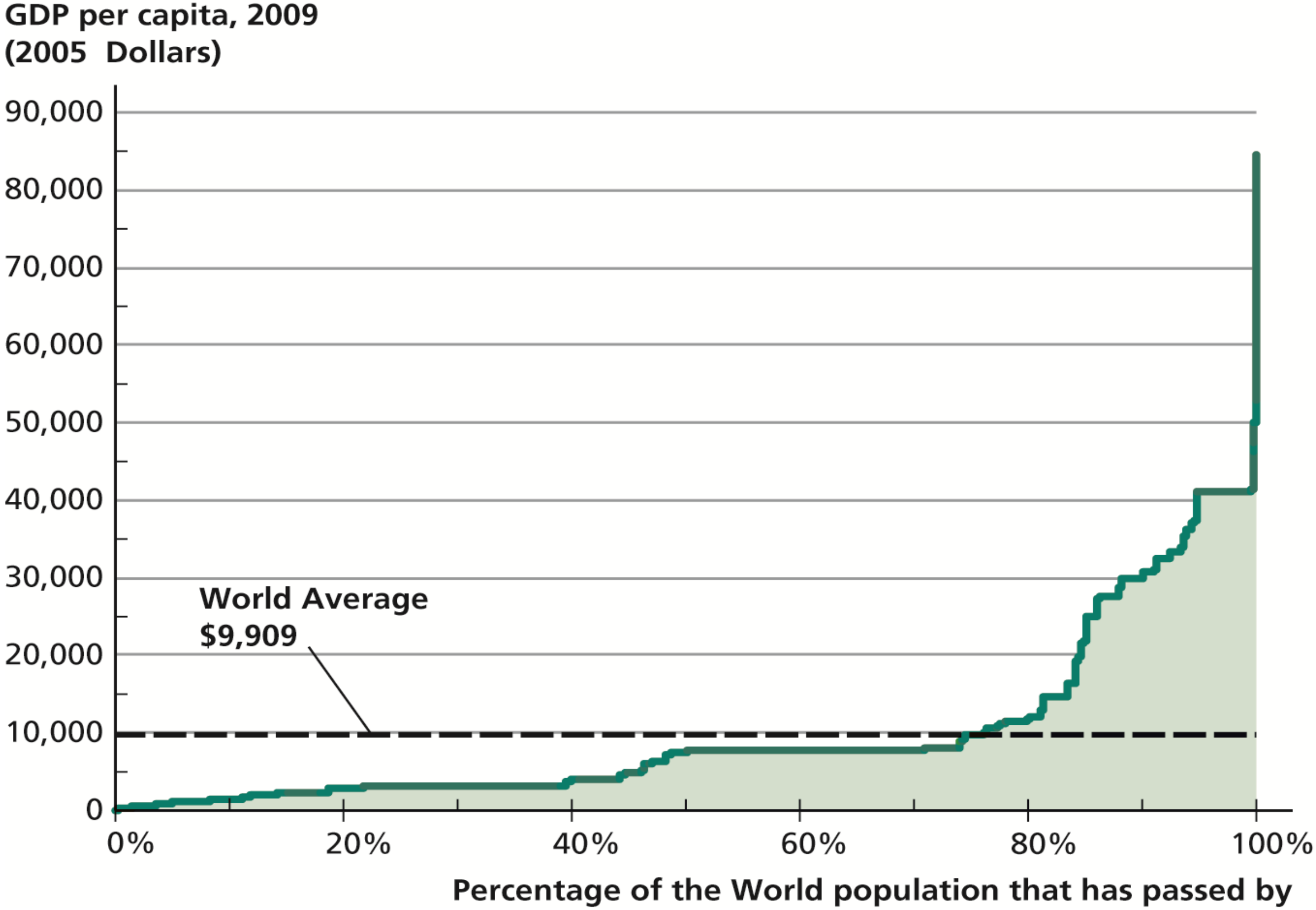


Introduction to Economic Growth, 3rd Edition

The World Income Distribution

- Standard of living differs widely across the world
  - Most of the world has significantly less income per capita than the US
    - Roughly half of the world has an income per capita that is 20% or less of the US level
  - A small fraction of the world has income per capita that is nearly as high as the US
    - Roughly 10% or the world has income per-capita of about 75% or more of the US

Figure 1.1 The Parade of World Income



- A similar pattern is observed if we would look at output per worker, instead of output per capita.
  - A large fraction of the world has much less output per worker than the US while a small fraction of the world has output per worker that is not too much less

The Income Distribution is Shifting over time

- Most of the world’s economies are getting richer over time
- This shifts the entire distribution to the right over time

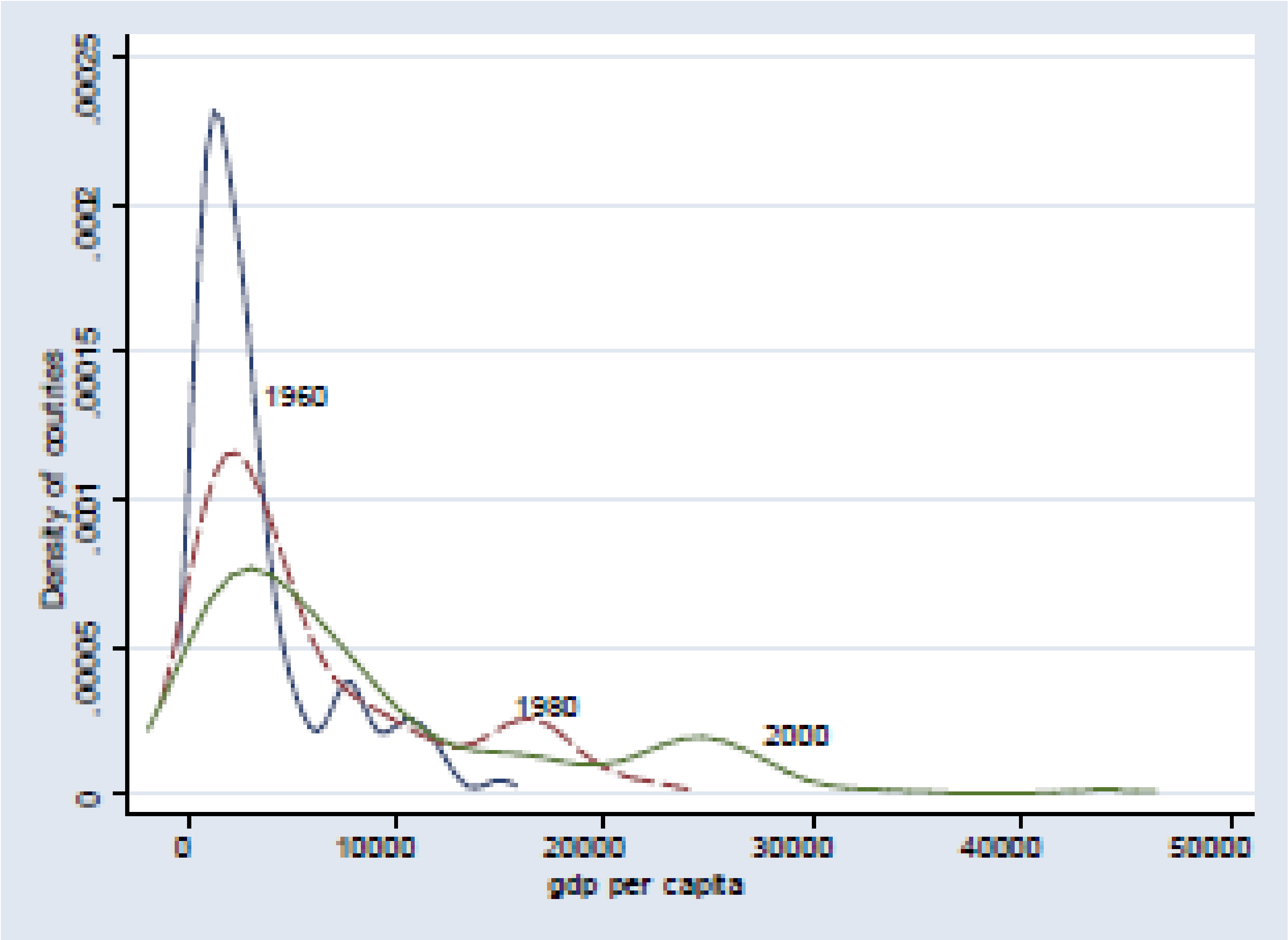


Figure: Distribution of PPP-adjusted GDP per capita.

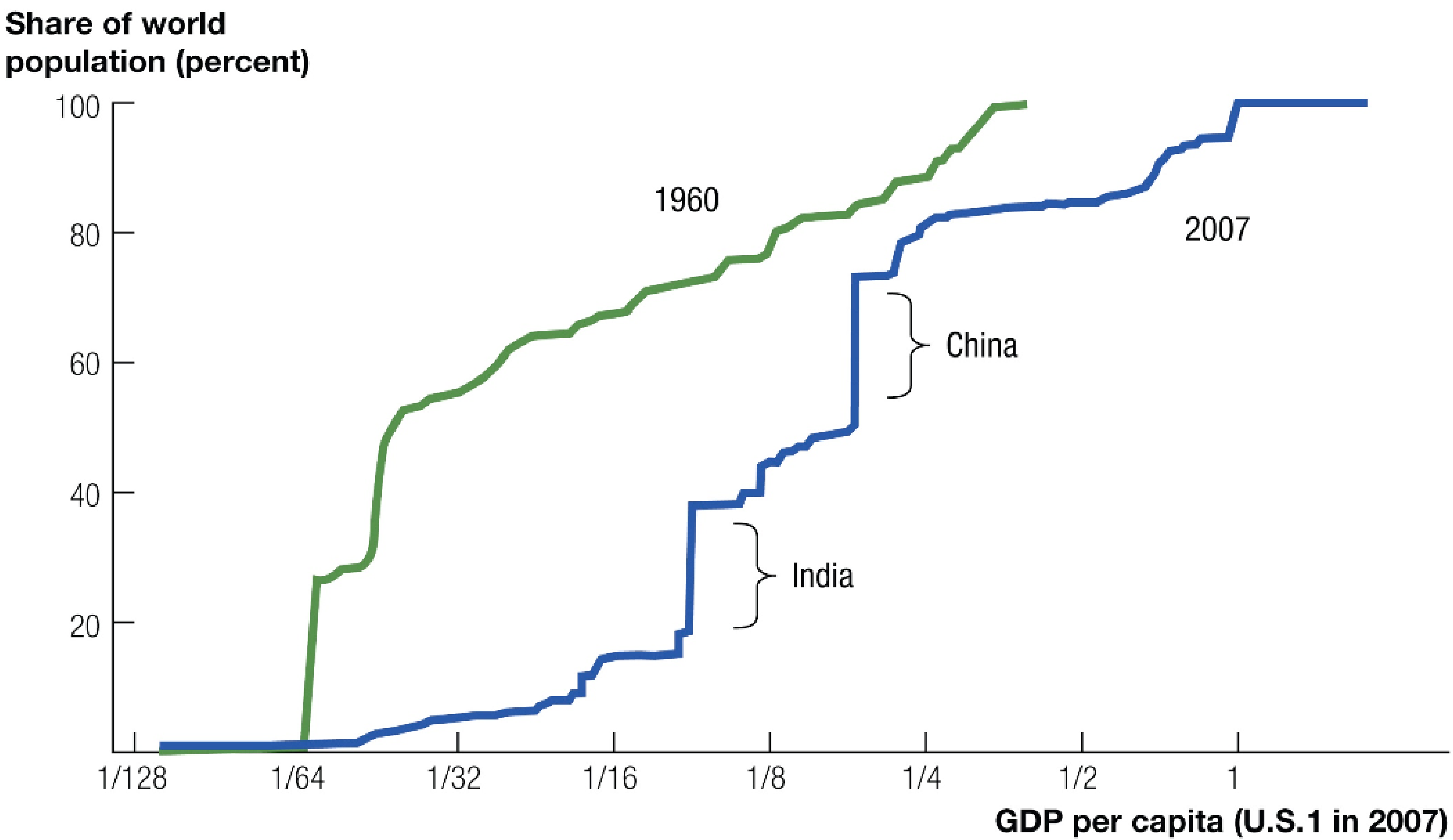


FIGURE 3.8 The Distribution of World Population by Per Capita GDP, 1960 and 2007

- Does this mean there have been major changes in the relative World Distribution?
- In other words, has the relative position of poor and rich countries changed?

- Recall that levels data may make it difficult to appreciate relative position and relative growth rates

- So lets look at logarithms of output per capita and output per worker in separate graphs (logs as were used previously in the ratio scale)

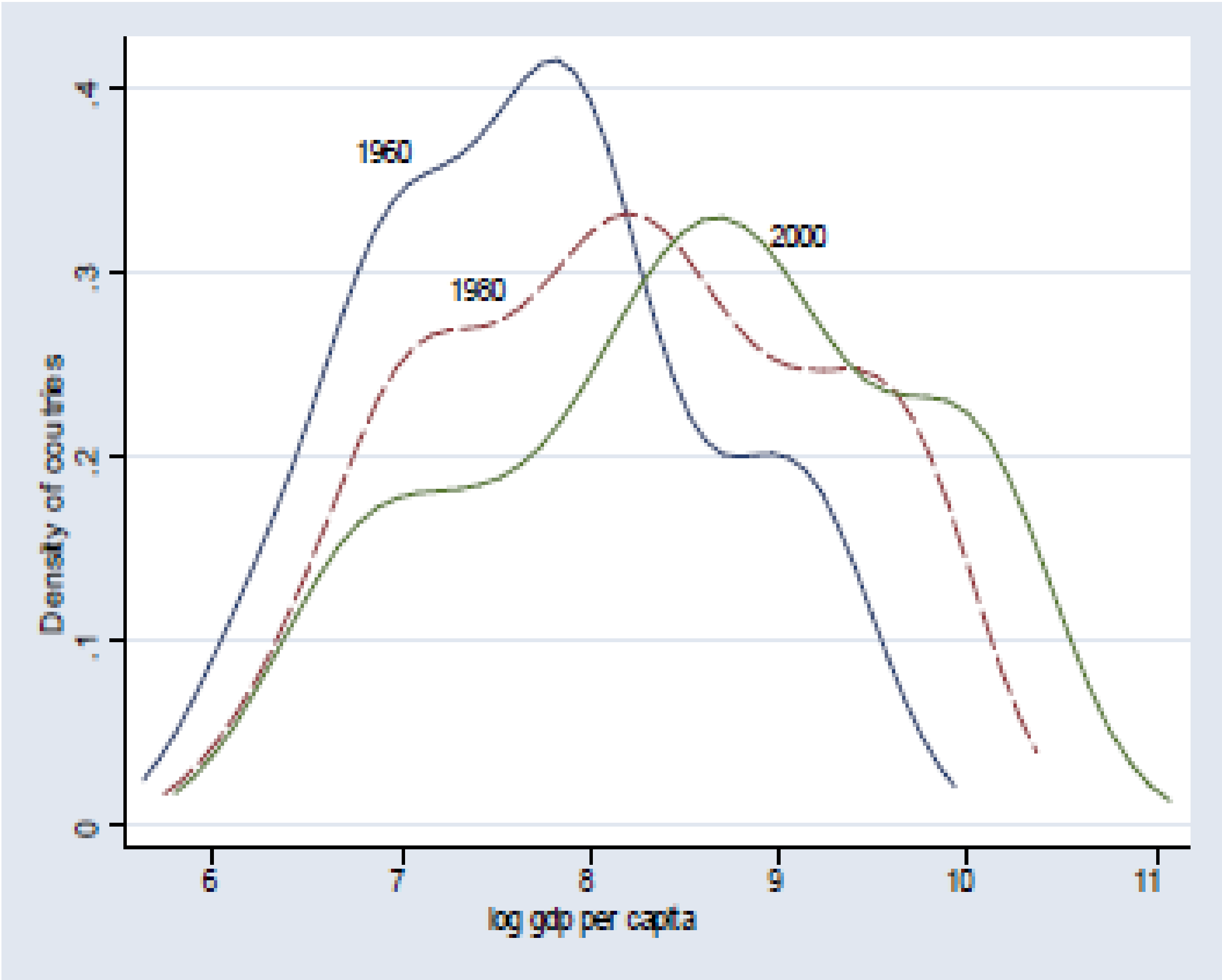


Figure: Estimates of the distribution of countries according to log GDP per capita (PPP-adjusted) in 1960, 1980 and 2000.

Figure: Distribution of log GDP per worker (PPP-adjusted).

- Changes in the world distribution are observed
  - The entire distribution shifts from 1960 to 1980 as economies of all levels are improving
    - Some of the poorest countries improved the most, e.g. China
  - But from 1980 to 2000 we see the distribution being stretched
    - This is evidence of many very poor countries staying very poor while moderate income and wealthy countries have mostly improved

Income Inequality: Measurement, Results and Implications

- Income inequality has accompanied the increasing growth rate of the world's economy
- Bourguignon & Morrison (2002, AER) measure income inequality by:

  the mean logarithmic deviation,

- which is given by:

$$\frac{1}{n}\sum_{i=1}^{n}\ln\left(\frac{\bar{X}}{X_i}\right)$$

where: $\bar{X}$ is the mean of X

and n is number of

observations on X

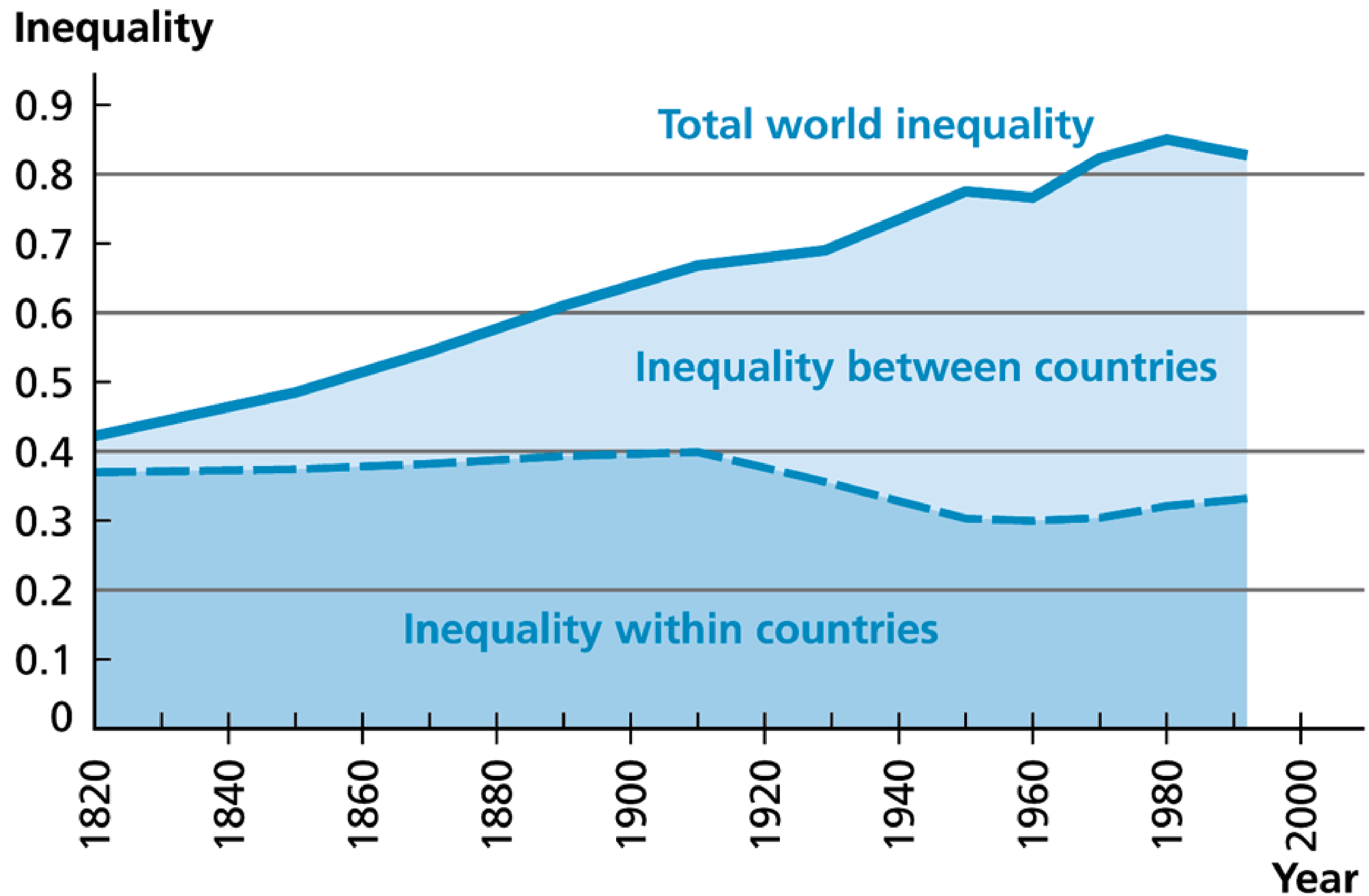
X=Real GDP

- Do not be too concerned about how this equation works
  - It is one of the ways to explain the dispersion in a sample of data
  - Technical note: dispersion means “cross sectional variance”

- To get some idea about how this measure of dispersion works, consider the following:
  - if each value of X_i is equal to the mean of X, then this measure is equal to zero
    - Because the logarithm of 1 is zero
  - As the dispersion – i.e. variation around the mean increases so will this measure
    - For this example, “dispersion” means the cross-sectional variation in income for a given year

- The measure is applied to each year’s data from 1820 to 1992
  – First, the inequality measure is calculated over the entire world
  – Then, the measure of inequality between countries is calculated
  – If world inequality exceeds within country inequality, the difference is attributable to inequality within countries

FIGURE 1.8
World Inequality and Its Components, 1820–1992



Source: Bourguignon and Morrison (2002).

- World inequality has been rising over time
- Within country inequality rose very slightly from 1820 to the early 1900s, declined somewhat until the 1950s and began a very slow rise after that
- In 1820 almost all of world income inequality is explained by inequality within countries and little inequality across countries.

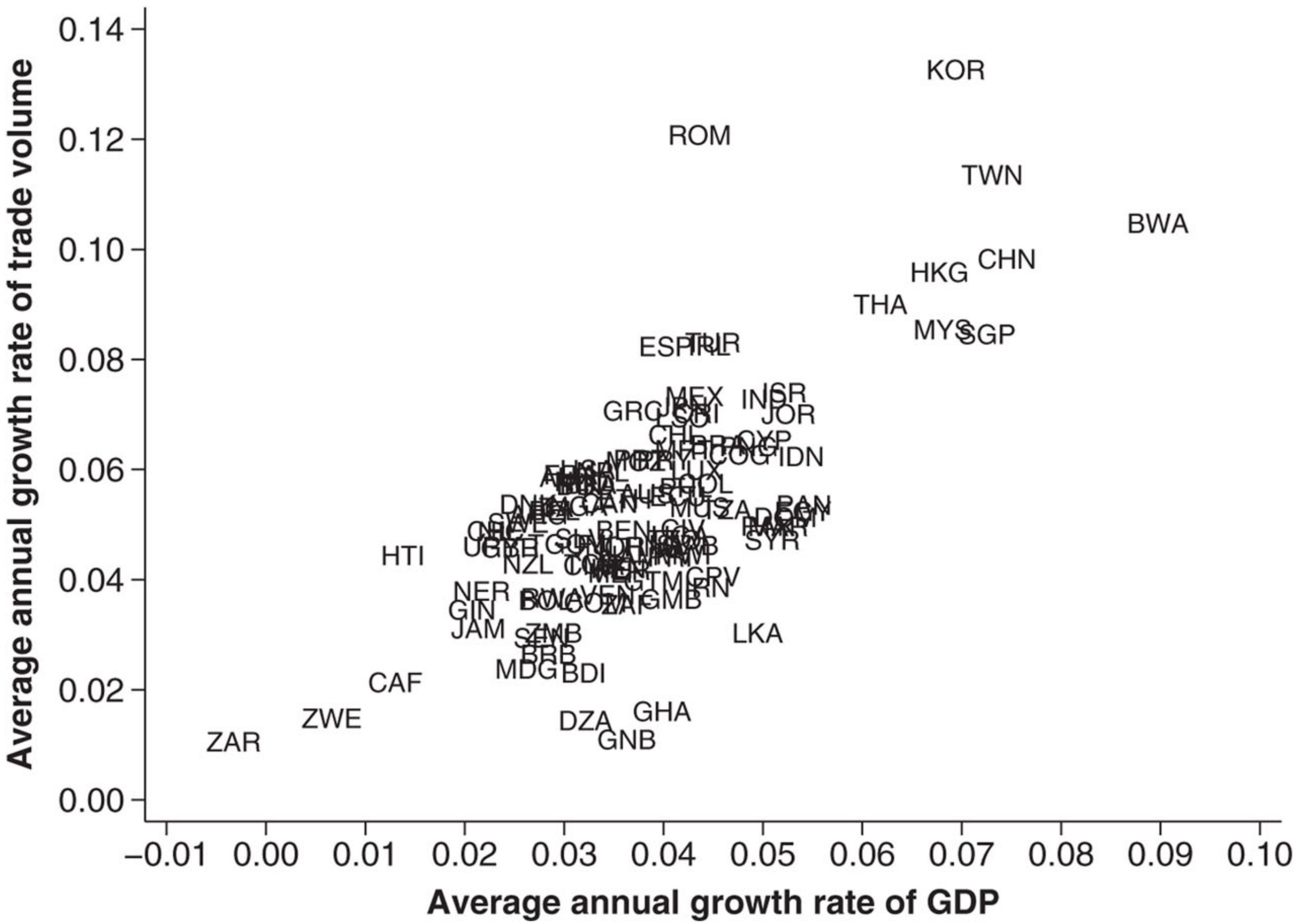
- Over time inequality across countries has come to explain most of the world income inequality as well as the upward trend in world inequality
  - But, inequality within countries is still an important factor in inequality
- In other words,
  - differences in income across countries used to account for very little of the income differences in the world.
  - But over time cross country differences have become more important for explaining income differences.

Trade and Growth

- Now we examine how trade and economic performance are related across countries
  - There is a strong positive relationship between the growth rate of trade and the growth rate of the national economy
    - The relationship holds if we measure trade by
      - export growth,
      - import growth or
      - growth in trade volume

        Defined here as the sum of exports and imports

FIGURE 1.5 GROWTH IN TRADE AND GDP, 1960–2008



- Why might growth in trade and growth in output be related?

- Lots of possible explanations

- One possible explanation: Increased growth in trade promotes greater economic growth
  – E.g. Increased trading may allow us to learn from another country how to produce new goods or how to make goods better than we used to or how to make goods more productively , causing output to increase at a faster rate

- Another possible explanation: Faster economic growth makes trade volume grow at a faster rate
  - Faster economic growth will always make imports grow faster
    - As our national income increases the amount we spend on goods rises – we buy more foreign produced goods – imports increase
      - We also will buy more domestically produced goods when income increases
  - If we produce more goods than US residents will buy, then we are forced to look for foreign markets to export things we can not sell domestically

- It is possible that a third factor causes two variables to be have some empirical relationship
  - E.g. technological improvements can make output grow faster. Higher incomes make us import more. Technological improvements may also make our goods more attractive than foreign produced goods, and so we will export more to foreign countries
  - So its not that one variable causes another, but that they are both caused by some other factor

Two Important and Very General Insights from this discussion

- This discussion about the relationship between growth in trade and output highlights two very important points about economics more generally that you should always keep in mind
  - Multiple cause-and-effect explanations are common in economics
  - “Correlation does not imply causation”

How do we compare GDP across different countries?

- If the two countries share the same currency then the comparison is easy
  - Make a direct comparison in GDP, GDP per capita OR GDP per worker
    - E.g. All of the European countries that use the Euro have GDP measured in the same currency. Thus we do not need to adjust for differences in currency valuation
  - But, most of the time countries do not use the same currency
- When countries do not use the same currency, we need to convert GDP to a common currency

- Selecting the common currency
  - Any currency will work
  - The US dollar is the typical choice. Why?
    - The dollars has been the dominant currency in international trade for a long time
    - Historically, the US has been the leader in economic research and so most economic studies have chosen the dollar
    - But the Euro and Renminbi are catching up to the dollar in terms of relevance for international trading.
      - Despite the dollar losing its dominance in trade and the US losing its dominance in economic research, though still strong in both cases, most people in the US and the world continue to use the dollar for currency comparison

- Using the exchange rate to convert foreign currency into dollars
  - E.g. Suppose
    - exchange rate is 1.25 $/Euro
    - GDP per-capita in Germany is 40,000 Euro
    - Then, in terms of dollars,

    German GDP per capita is 50,000 dollars:

    1.25 $/Euro * 40,000 Euro = $50,000

– Of course exchange rates can be reported in two equivalent ways:
  - the number of foreign currency units a unit of domestic currency is worth

    OR

  - The number of domestic currency units a unit of foreign currency is worth

– Returning to our earlier example:

1.25 \$/Euro is equivalent to an exchange rate of 0.8 Euro/\$ (0.8 = 1/1.25), and German GDP per capita is:

$$40{,}000 \text{ Euro} / (0.8 \text{ Euro}/\$) = \$50{,}000$$

- Two Major Problems with using exchange rates to compare GDP

  1. Market exchange rates can fluctuate widely in a short period of time
     - A 20% depreciation of some currency relative to the dollar in a short period of time, say a month, sometimes occurs
       - That would make foreign country's GDP in dollar terms fall by 20% in that short span of time.
         - A country's output has never fallen by that much in such a short span of time. In fact, output changes on the order of 20% over the course of a whole year almost never occur and have never occurred in the course of a month

2. Exchange rates don’t reflect the prices of non tradable goods, and non-tradables typically sell for relatively low prices in poorer countries while tradable goods do not. Why?

- Competition tends to push the prices of traded goods closer to one another across different countries
- A prime reason why non-tradable goods are relatively inexpensive in poorer countries is that these goods tend to be labor intensive (e.g. non-tradable services like haircuts) and labor tends to be relatively cheap in poorer countries
- The relatively low prices for non-traded goods in poor countries means that GDP will tend to be undervalued in these countries when we use a market exchange rate to convert GDP to a common currency,

Calculating PPP corrected GDP

- Doing a Purchasing Power Parity (PPP) correction for cross country GDP comparison

- A simple example
  - Two goods
    - TVs (which are tradable)
    - Haircuts (which are non-tradable)
  - Two countries
    - Richland
    - Poorland
  - Each country has its own currency
    - Richland has the Richland Dollar
    - Poorland has the Poorland Dollar
  - The following Table shows the data on production and prices in each country

TABLE 1.2

Production and Prices in Richland and Poorland

Country	Production of Televisions per Capita	Production of Haircuts per Capita	Price of Televisions in Local Currency	Price of Haircuts in Local Currency	GDP per Capita in Local Currency
Richland	4	40	10	2	120
Poorland	1	10	10	1	20

- According to the Table
  - Each country produces goods in the same proportion
    - 1 TV for every 10 Haircuts
  - Richland produces 4 times as many TVs and 4 times as many Haircuts as Poorland,
    - Thus we would expect Richland GDP to be 4 times as great as in Poorland

- Given the data in the table we can calculate GDP in each country's own currency by multiplying the quantity times the price for each good and then summing these up over all the goods
  - Richland GDP: 4•10 + 40•2 = 120 Richland Dollars
  - Poorland GDP: 1•10 + 10•1 = 20 Poorland Dollars

- To compare output across countries with different currencies, we need to know the exchange rate

- What is the exchange rate here?

- To figure out the exchange rate we will use the law of one price.

- The Law of One Price states:

If,

  - Goods are identical across countries,
  - Goods markets are perfectly competitive,
  - There are no trade barriers, and
  - There is no cost to transporting a good from one country to another;

then the goods from each country will cost the same when priced in a common currency

- The Law of One Price is a strong version of another concept called Purchasing Power Parity

- Return to our example:

- If TVs are traded and they satisfy the Law of One Price assumptions, then they must sell for the same price when put into a common currency

  - Since a TV sell for 10 Richland dollars in Richland and for 10 Poorland dollars in Poorland, that means:

    10 Richland Dollars is worth 10 Poorland Dollars

    Or that the exchange rate is:

    1 Richland Dollar per Poorland Dollar

- But based on this 1 to 1 exchange rate, Richland has 6 times the GDP per capita of Poorland when we convert output to a common currency

- That doesn’t make sense because Richland produces 4 times as much of each good as Poorland

- This example illustrates how market exchange rates may not necessarily be good for comparing output across different countries

- In practice, this problem with using regular exchange rates arises because of the relatively low price of non-tradables in poorer countries

- The solution (resembling somewhat the calculation of a Consumer Price Index) is to construct the PPP exchange rate:
  - Select a standardized basket of goods and services
    - In our example that is easy: 1 TV and 10 Haircuts
    - This is because each country uses 10 haircuts for every TV
  - Calculate what this basket (1 TV and 10 Haircuts) costs in each country
    - In Richland the basket costs:

      1•10 + 10•2 = 30 Richland Dollars
    - In Poorland the basket costs:

      1•10 + 10•1 = 20 Poorland Dollars
  - Obtain the PPP exchange rate
    - 30 Richland Dollars = 20 Poorland Dollars
  - Use this ratio to convert output from one currency into the other currency
    - (120 Richland Dollars) * (20/30 Poorland Dollars per Richland Dollar)

    equals 80 Poorland Dollars
      - Which is 4 times the GDP per capita of Poorland when measured in Poorland Dollars. THIS MAKES ECONOMIC SENSE!

Homework: Using the numbers from the previous Table, calculate Poorland's GDP in terms of Richland Dollars based on the PPP exchange rate. Does the ratio of GDP for these two countries make sense?

- Homework: In this example, what would the market exchange rate be if TVs cost 10 Richland dollars in Richland, but only 5 Poorland dollars in Poorland?

- Remember we are assuming the Law of One Price holds?

- Problems with our simple analysis:
  - In the real world, we don’t find that each country produces the same ratio of haircuts to TVs
    - Thus selecting a bundle of goods is more difficult
  - The assumptions that generate the Law of One Price are rarely, if ever, exactly true
    - Goods are NOT ALWAYS identical across countries,
    - markets are RARELY perfectly competitive,
    - there ARE often serious trade barriers,
    - costs of transportation are NOT ZERO
- Consequently, real-world calculations are considerably more complicated
  - The actual methods use aggregation theory
  - We shall stick with our simpler assumptions

- Examples of what correcting the exchange rate for PPP does to the comparison of GDP per capita across actual economies

Table 1.3 The Effect of Using PPP on Comparisons of GDP

Country	GDP per Capita in 2009 Using Market Exchange Rates (dollars)	GDP per Capita in 2009 Using PPP Exchange Rates (dollars)
United States	41,099	41,099
Japan	36,651	30,008
Germany	36,702	32,488
Argentina	6,519	11,961
Mexico	7,257	11,629
India	1,041	3,239

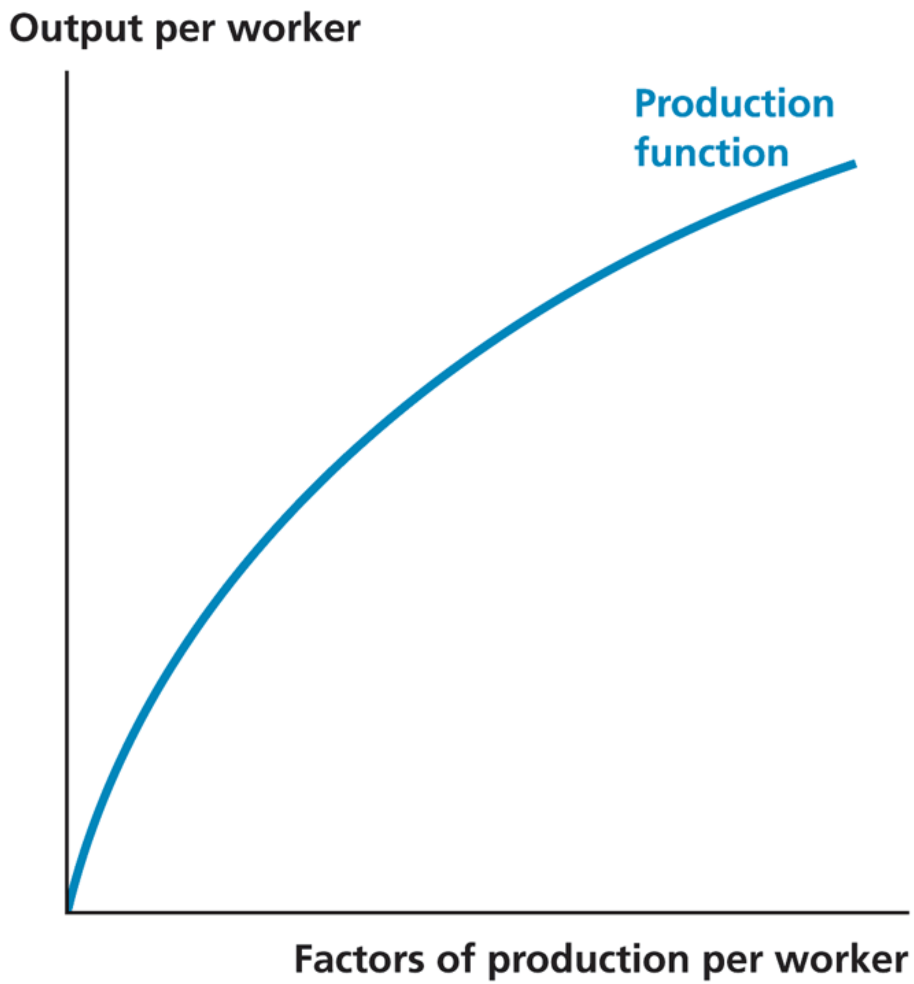
- We see that PPP corrections tend to raise GDP for poorer countries relative to the GDP obtained using market exchange rates
  - Poor countries tend to have a larger percentage effect from a PPP correction
    - India's GDP is roughly 3 times greater when we use PPP exchange rate
    - Mexico, a somewhat wealthier country than India, sees its GDP go up by over 50% (a.k.a. ½) when PPP exchange rates are used.
  - Using market exchange rates, the relatively less expensive labor in a relatively poorer country will make the price of non-tradables lower and therefore make measured output lower
  - Note that some richer countries actually have output fall when PPP exchange rates are used because the non-tradable goods are relatively expensive in those countries
    - Japan's GDP is 1/6-th lower when we use PPP exchange rates.

An introduction to theory

- A production function describes the way we can use inputs to produce outputs.
- It conceptualizes the technological constraint on what we are able to produce with our inputs (e.g. factories, capital equipment, labor, …)
  - technically speaking, a production function tells us the maximum amount of output we could produce for any combination of inputs we might choose

- When we graph the production function we sometimes focus attention on one input at a time by holding all others constant
    - This is the *ceteris paribus* (Latin phrase) assumption: Holding other factors fixed
  - We are sometimes able to make a wise choice of variables and with that summarize the major inputs by a single quantity
    - Later, we will write the production function as an equation
    - But for now we will use a graph

Figure 2.1
The Production Function



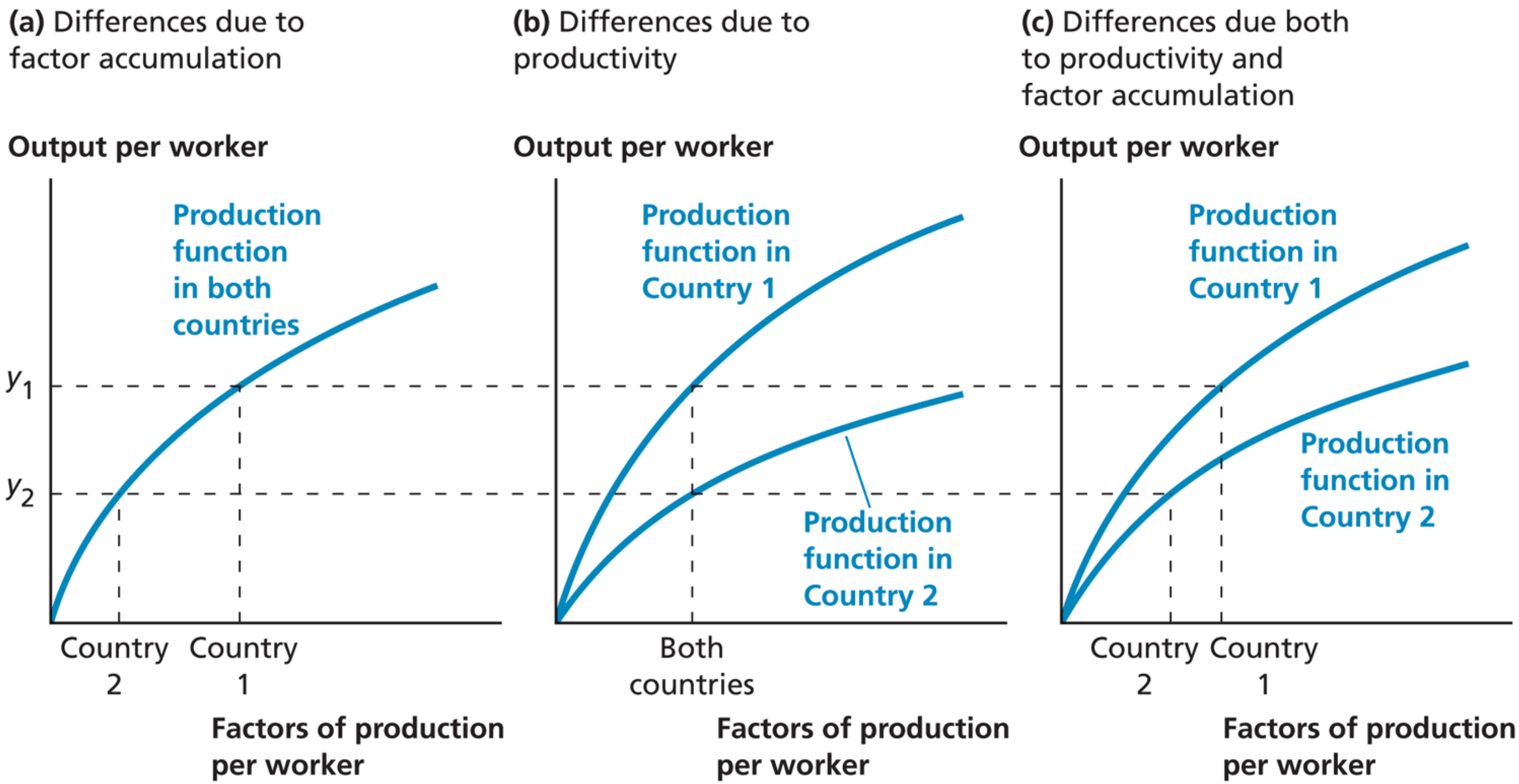
- This graph illustrates two important properties of most production functions
  - Positive marginal product
    - If we use more factors we are able to produce more output
      - This is because the line has a positive slope
  - Diminishing marginal product
    - As a factor increases, we get a smaller and smaller increase in the amount of additional output produced
      - The slope decreases as the factors increase
        - In other words, the production function is concave

- Suppose we observed that two countries differ in terms of output per capita.
- Could we conclude anything about the reason for this difference on the basis of the production function?

- Answer:
  - Maybe, but we would need to know more that simply there is a difference in output per capita.

- The following graphs illustrate this point

Figure 2.2
Possible Sources of Differences in Output per Worker



(a) If both countries are operating on the same production function, then this difference in output per capita would be solely due to different amounts of factors being used

– the country with less output per capita would have less factors of production

(b) If both countries are utilizing the same amount of factors, different output per capita is explained by different production functions

– The country with higher output has a production function that is higher than the other country

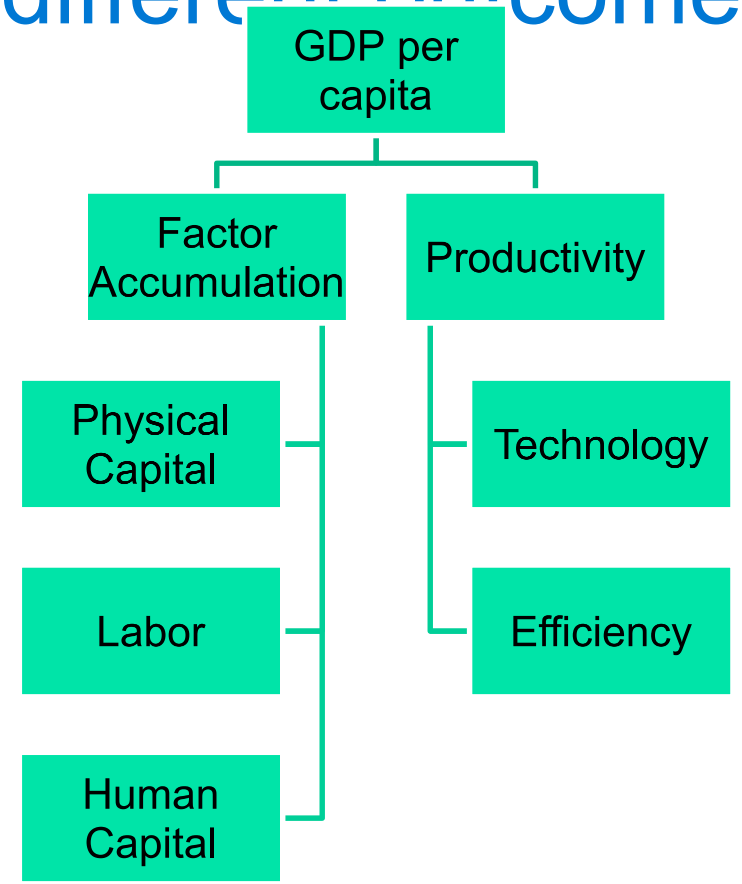
  - This means that the country with higher output is more productive – it can produce more output for any given level of inputs

(c) In general, differences in productivity and factor accumulation could both be causing output per capita to differ across countries

– In the 3rd diagram, we see that country 1 has higher output per capita because it has more factors and because it is more productive

  - We will later see that this situation is quite common - Countries with higher per capita tend to be more productive and better endowed with factors of production

Explaining different outcomes:



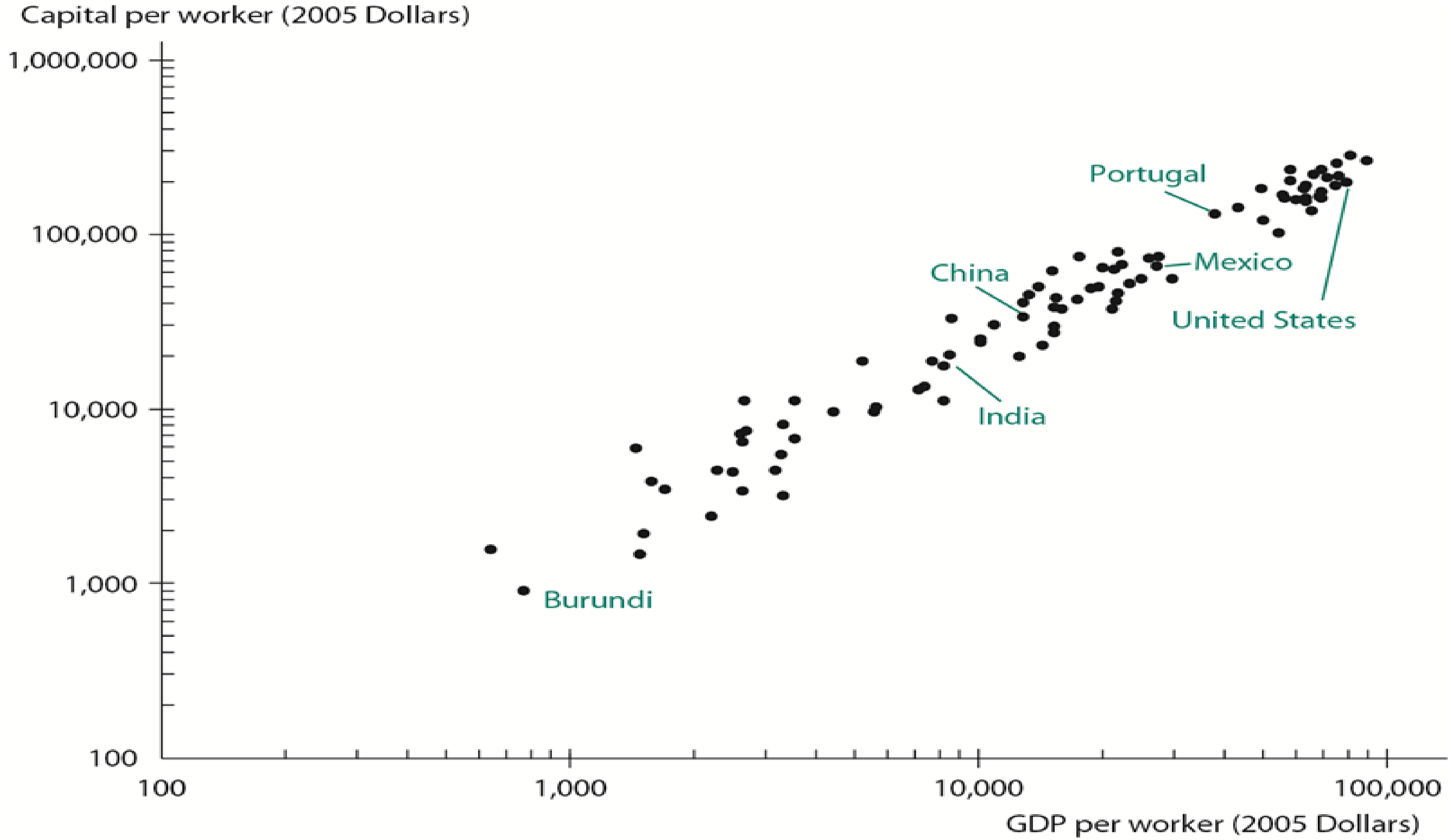
Here, we outline the direct (proximate) causes of change in GDP per capita.

The important question that we'll then deal with is: What are the fundamental causes of economic growth and in what way(s) do they work through these proximate causes?

A Model of Physical Capital

- A capital based theory of economic performance is supported by some of the empirical evidence
  – Country’s with more capital per worker produce more output-per-worker

Figure 3.1 GDP and Capital per Worker, 2009



- As mentioned before, empirical evidence may be consistent with 3 possibilities.
- The positive relationship between capital and income is consistent with:

1. More capital causing more output to be produced
    - If the only factor is capital, our production function is consistent with this hypothesis
2. More output causing an increase in capital
    - As incomes rise 2 things may occur simultaneously: savings increases and the demand for investment may also increase. Either of these should cause an increase in the amount of capital that is built
3. Some other factor causing both capital and output to move together

- What are the important features of physical capital in an economy?

- Capital is used to produce output
- Capital must be built
- Capital has a rate of return
- Capital wears out over time
- Capital is subject to certain limitations. For example, capital is a rival good
  - If some thing is a rival good, your use of it precludes someone else from using it (a cell phone)
  - Something is not a rival good if your use does not inhibit someone else from using it (for example, a technology such as calculus)

- We often think of capital as the factories and equipment firms use to produce the goods they sell.
- But there are other important types of capital
  - The stock of housing
  - Government capital
    - Tangible government capital: roads, bridges, schools, train tracks, airports, etc.
    - Intangible government capital: rule of law, property rights, public safety, national security, etc.

- Again we know capital is used to produce output
- First we examine a production function

$$Y=F(K,L)$$

where :

F is some function of K and L,

K is the stock of capital,

L is the labor

- We like to assume F(K,L) has positive and diminishing marginal products for K and for L separately
  - Positive marginal product means that as K goes up Y goes up
  - Diminishing marginal product of K means that the amount Y goes up for a given increase in K becomes smaller as K increases
- Similarly
  - Positive marginal product means that as L goes up Y goes up
  - Diminishing marginal product of L means that the amount Y goes up for a given increase in L becomes smaller as L increases

- A common assumption in economics is that the production function has constant returns to scale (CRS) for all factors taken together
- That means if we double the inputs – capital and labor - we will double the amount of output that we can produce

CRS has an intuitive appeal:

- Suppose we own one factory and employ a group of workers and with these produce a certain amount of output. If we build a second factory that has precisely the same facilities and we employ identical workers in both factories, we should be able to produce twice as much output as before
- Sometimes this is known as the replication argument – if we perfectly replicate the factory and workers we should be able to double production

- More generally, CRS means that a given percentage change in every input will change the amount of output we can produce by precisely that same percentage
- We will combine this idea with our production function to develop a very useful and interesting result

- Assume that the production function, F(), is a CRS production function
- Suppose z indicates how much we change each of the factors
- CRS means that if Y=F(K,L) for particular values of K, L and Y, then

$$F(zK,zL)=zY$$

- For example, if z=2, this shows that doubling K and L yields a doubling of Y!
- This is true for any positive number z

- So if CRS means that if $Y=F(K,L)$ for particular values of K, L and Y, then

$$F(zK,zL)=zY$$

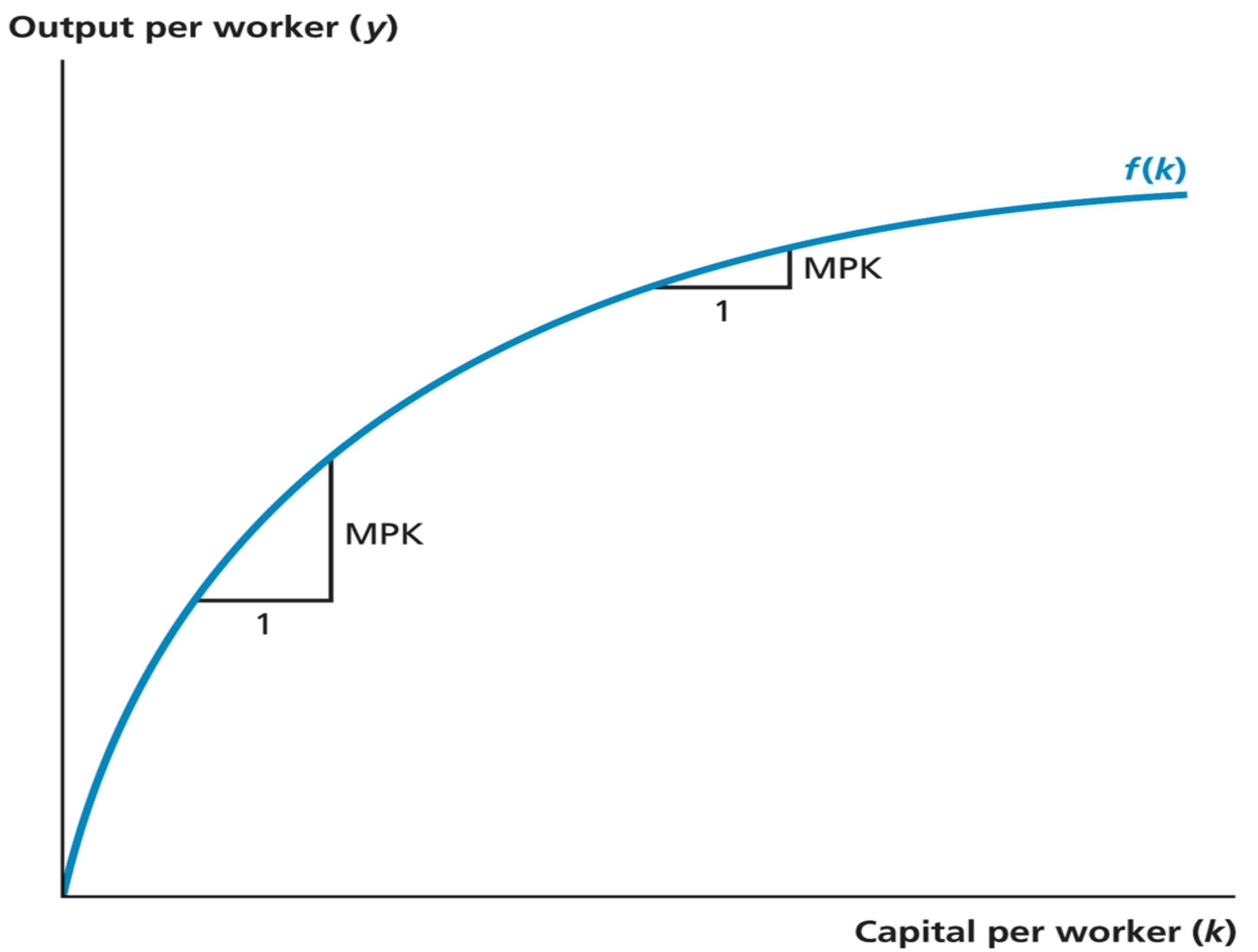
- We could let $z=(1/L)$, and in that case, the previous equation becomes:

$$(Y/L) = F(\,(K/L),\, 1\,)$$

- So now it is really convenient to redefine variables in per capita terms
- $y=Y/L$ output per capita
- $k=K/L$ capital per capita
- And to use f to represent the new function
- $y = F(k,1) = f(k)$

- A graphical version of the production function

Figure 3.2
A Production Function with Diminishing Marginal Product of Capital



- Properties of the new production function f(k)
  - Positive marginal product with respect to k
    - Increased k raises the maximum amount of output that can be produced
      - The curve is upward sloping
  - Diminishing marginal product of k
    - Increased k raises the amount of y that can be produced, but does so at a diminishing rate
      - The curve has a concave shape

- The properties for f(k) resemble the production function we started with, F(K,L).

- We will see that while F(K,L) has constant returns to scale (CRS) for K and L, f(k) will not generally have CRS for k

- This is a good time to either teach you a little bit of calculus, or hopefully, refresh your memory about some rudimentary elements of differential calculus

- Derivatives are useful for many reasons.

- We can use derivatives:

1. To determine the shape of a function

- E.g. A production function is assumed to have:
  - positive marginal product
    - For f(k) this means that the derivative of f(k) is positive
    - the function is increasing as k increases, and so our graph slopes upward
    - If the derivative of f(k) is negative, that would be a negative marginal product of k which does not make intuitive sense
  - decreasing marginal product
    - For f(k) this means the derivative of the marginal product is negative
      - this is also called the second derivative of f(k)
    - In that case, the slope of the function is decreasing as k increases
      - In our graph, a positively sloped function that has its slope decreasing in k is a concave function

2. To maximize a function

– E.g. Suppose firms maximize profits

  - To maximize profits, they would take the derivative of their profit function and set that derivative to zero

    – A condition on the second derivative is also required – more on this later

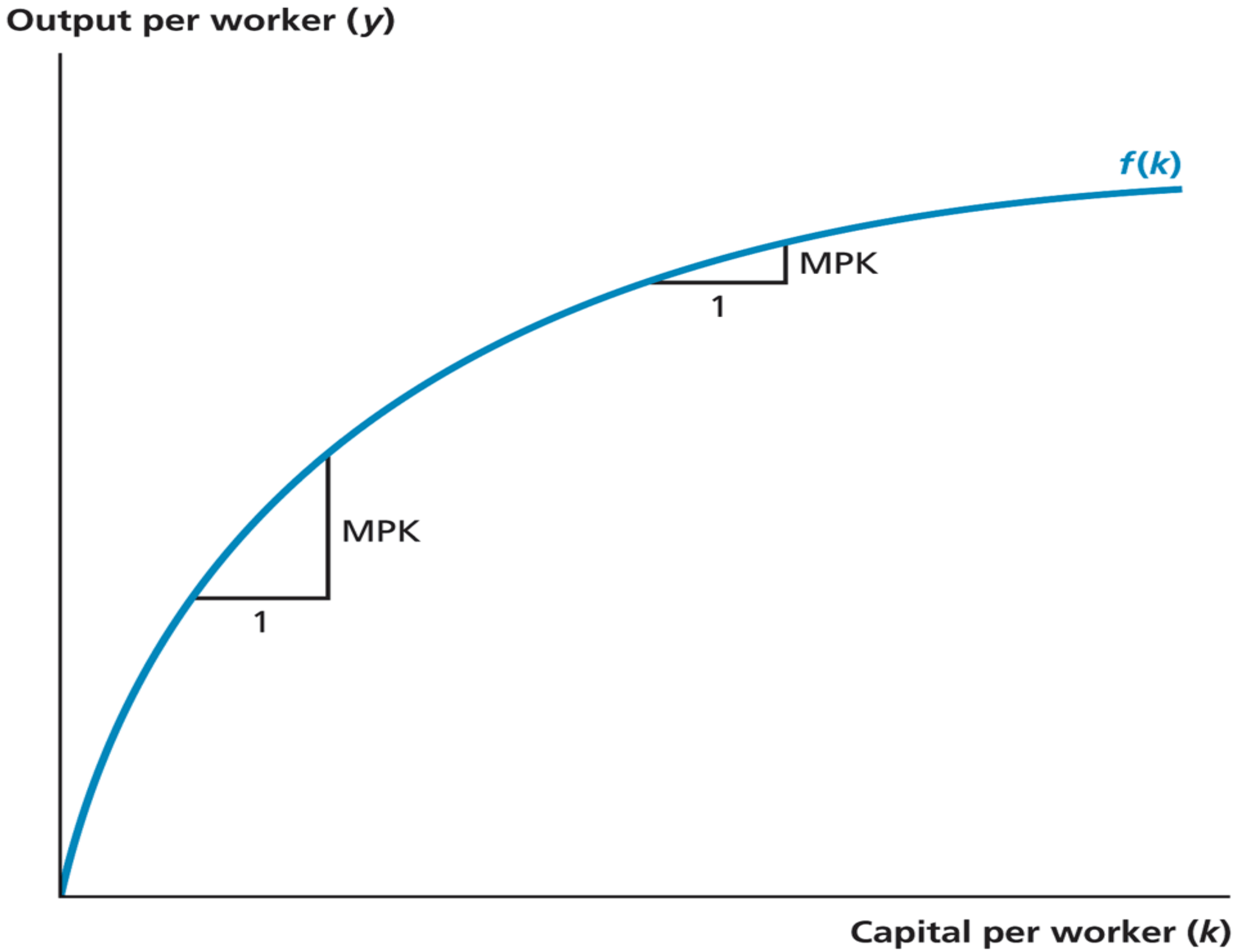
    – From this equation we can determine how much K or N a firm would want to use

3. To calculate the total effect of some change in a variable on other variables in a model of the economy (if the model can be written as a system of equations)

- Taking the derivative of a function provides a way to calculate the slope of that function at any point on the function
  - Derivatives tells us how much one variable changes when there is a small change in some other variable
  - E.g. We can answer the question: How much more output can we produce if we use a little more capital?
  - Returning to Figure 3.2 ….

FIGURE 3.2

A Production Function with Diminishing Marginal Product of Capital



- The change in y for a unit change in k is depicted on the graph for two cases
  - MPK is positive in both cases
  - and MPK is smaller when k is larger
    - Both of these ideas generalize to any combination of points on the graph of f(k)

- More generally, we could change k by an arbitrarily amount and calculate how much y changes as a result
  - using fancy Greek notation, we write this general case as

$$\frac{\Delta y}{\Delta k}$$

with Δk meaning the change in k and Δy meaning the change in y that results from this change in k

Dividing Δy by Δk is a way of writing how much y changes for a unit change in k

- To calculate the derivative, we let the change in k get smaller and smaller
- Specifically, the derivative of y with respect to k is:
  - the limit of $\frac{\Delta y}{\Delta k}$ as Δk approaches zero
  - A limit is a value some variable will converge to as some other variable approaches a particular value

- The derivative is the slope of the line
  - As Δk approaches zero we obtain the slope of the straight line that is tangent to the curve at a particular point

- Some simple examples of derivatives
  - Suppose a is not a function of k – to simplify think of it as a constant parameter
  - If y=a, then y is not a function of k
    - In this case, the derivative of y with respect to k is zero because y is unrelated to k

- We can write any linear equation as:

$$y = a + bk$$

  - With neither a and b a function of k, and so we can again think of them as constant parameters
  - We know from previous math classes (pre-calculus) that the slope of a line is constant and given by b
  - Since the derivative of y with respect to k is the slope of function, in this case it must equal b

- A useful rule for derivatives
-
- The derivative of a power function
  - Suppose $y = c \cdot k^d$

    where c and d are parameters

    Then the derivative of y with respect to k is:

    $$d \cdot c \cdot k^{d-1}$$

- The derivative of a sum is equal to the sum of the derivatives
  - For example, suppose $y = c \cdot k^d + e \cdot k^f$

    Then the derivative of y with respect to k is:

    $$d \cdot c \cdot k^{d-1} + f \cdot e \cdot k^{f-1}$$

  - This idea generalizes to a polynomial with any number of terms in k

- Homework: Use these two rules to prove that derivatives on the two pages before last page. Specifically, show that the derivative of a constant is zero (Hint: $k^0=1$) and that the derivative of a linear equation is equal to the slope of that line

- There are different rules for taking derivatives of more complicated functions, but we will only be concerned with power functions

- A popular example of a production function
  - The Cobb-Douglas production function

$$Y = A \cdot K^{\alpha} \cdot L^{1-\alpha} \quad \text{with} \quad 0 < \alpha < 1$$

where Y = output, K = capital, L = labor,

$F(K,L) = K^{\alpha} \cdot L^{1-\alpha}$ and A is productivity.

We need this productivity term in a production function since there are times when two economies use essentially the same amount of the factors of production, K and L, and yet produce substantially different amounts of Y

- We will see that the assumption that α is bounded between zero and one comes from the assumption that marginal products are positive and diminishing

- This production function can be converted into y as a function of k by dividing it by L

$$
\begin{aligned}
y = Y/L &= (1/L) \bullet A \bullet K^{\alpha} \bullet L^{1-\alpha} \\
&= L^{-1} \bullet A \bullet K^{\alpha} \bullet L^{1-\alpha} \\
&= A \bullet K^{\alpha} \bullet L^{1-\alpha} \bullet L^{-1} \\
&= A \bullet K^{\alpha} \bullet L^{1-\alpha-1} \\
&= A \bullet K^{\alpha} \bullet L^{-\alpha} \\
&= A \bullet K^{\alpha} \bullet (1/L)^{\alpha} \\
&= A \bullet (K/L)^{\alpha}
\end{aligned}
$$

- Therefore, we get $y = A \bullet k^{\alpha}$

- Use the power rule to calculate the derivative of y with respect to k: $\alpha \cdot A \cdot k^{\alpha-1}$
  - Only non-negative values of A and k make sense
    - If A=0 or k=0 then y=0 (from the production function)
  - Assuming A and k are positive means that in order for marginal product of y with respect to k to be positive, α must be a positive number
- The derivative of y with respect to k tells us how y changes with k – in other words the slope of the function of k
- This slope is called the marginal product of k
- We are also interested in how this slope changes with k
  - If this slope gets smaller as k gets larger we have diminishing marginal product of k or diminishing returns to k.

- By analogy to our earlier derivative, we can determine how the slope changes with k by taking the derivative of the slope with respect to k
  - This is called a second derivative
    - the second derivative of y with respect to k determines if the marginal product of k is decreasing
- The marginal product of y with respect to k is equal to the derivative of y with respect to k:

$$\alpha \bullet A \bullet k^{\alpha-1}$$

- Using our rules for taking derivatives, the derivative of this marginal product with respect to k is:

$$(\alpha-1) \bullet \alpha \bullet A \bullet k^{\alpha-1-1}$$

OR $(\alpha-1) \bullet \alpha \bullet A \bullet k^{\alpha-2}$

- Recall that A, k and α are positive numbers
  - That means the only way for marginal product to be diminishing is if

$$(\alpha - 1) < 0$$

  - Which means $\alpha < 1$
- This means for marginal product of k to be positive and diminishing requires that

$$0 < \alpha < 1$$

in the Cobb-Douglas production function

Homework: Assume a Cobb-Douglas production function:

$$Y = A \cdot K^{\alpha} \cdot L^{1-\alpha} \quad \text{with} \quad 0 < \alpha < 1.$$

Suppose the economy starts at some initial levels of capital, labor and output: K_0, L_0 and Y_0.

After a year goes by the levels of capital, labor and output become: K_1, L_1 and Y_1.

Assume K_1 and L_1 each have grown by the same rate g from their initial levels:

$$K_1 = (1+g)K_0 \quad \text{and} \quad L_1 = (1+g)L_0$$

How is Y_1 related to Y_0? Does this production function have constant returns to scale?

- Can we determine the value of the parameter α?
  - Yes, under a specific set of structural assumptions
  - Assume firms maximize profits. Soon we will show how this can lead firms to choose the amount of labor to employ such that:

real wage rate = marginal product of labor:

$$W/P = MPL$$

Recall: the MPL is equal to the derivative of $A \cdot K^{\alpha} \cdot L^{1-\alpha}$ with respect to L (because $Y = A \cdot K^{\alpha} \cdot L^{1-\alpha}$)

thus $MPL = (1-\alpha) \cdot A \cdot K^{\alpha} \cdot L^{1-\alpha-1}$

- So the condition for profit maximization (W/P=MPL) yields:

$$W/P = (1-\alpha) \cdot A \cdot K^{\alpha} \cdot L^{-\alpha}$$

- Note that: $A \cdot K^{\alpha} \cdot L^{-\alpha} = Y/L$ based on our production function
- Insert this result into the profit maximizing condition:

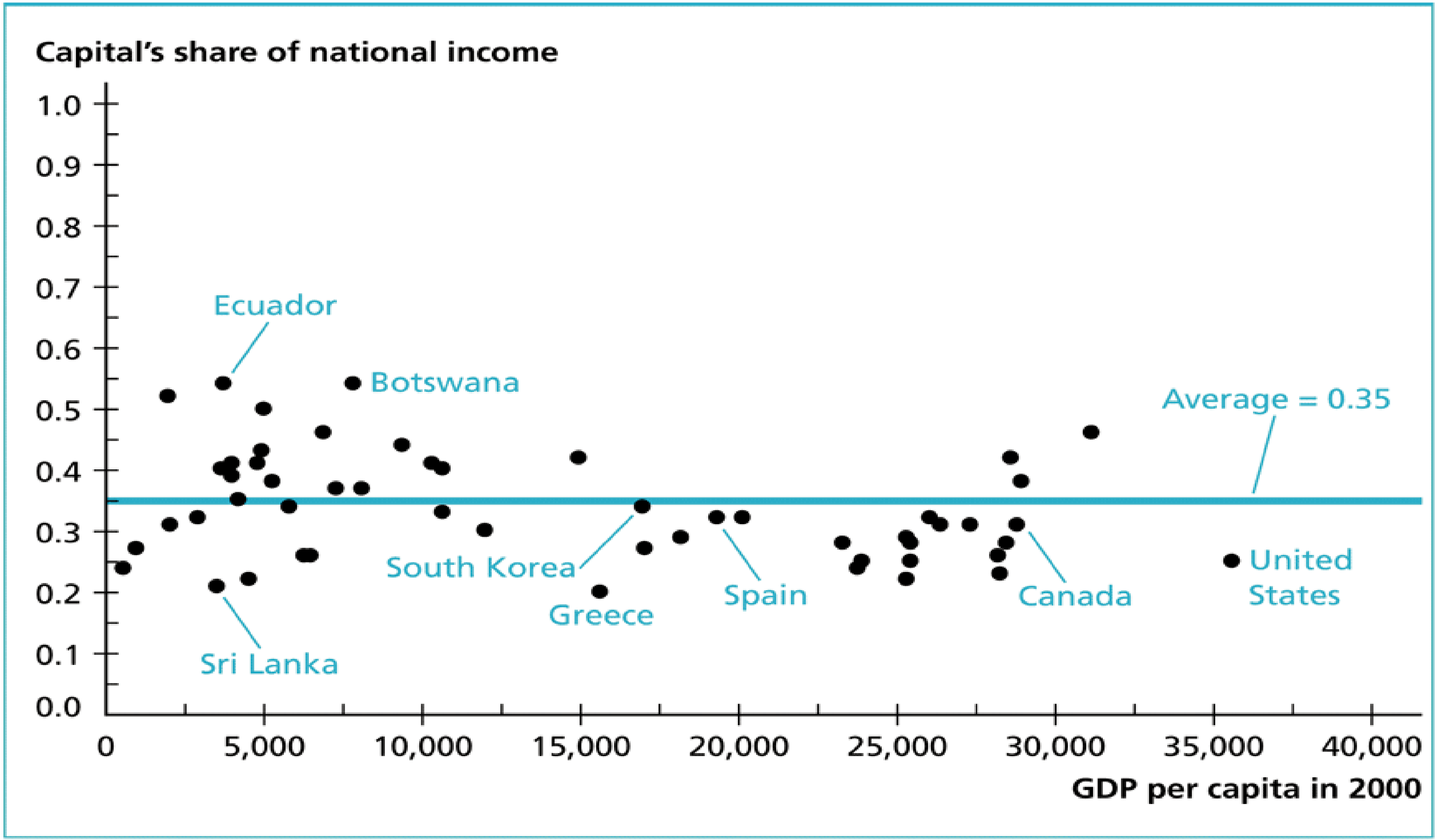
$$W/P = (1-\alpha) \cdot Y/L$$

hence

$$(W \cdot L)/(P \cdot Y) = (1-\alpha)$$

- This says that the labor share of income = 1-α (a constant)
- Similarly we can show that the capital share of income = α
- Therefore, since we can measure the share of income going to labor we can use that information to estimate the α parameter in the production function

Figure 3.3 Capital's Share of Income in a Cross-Section of Countries



Source: Bernanke and Gürkaynak (2002), table 10 and note 18.

- The cross-country average of capital’s share of income is: .35
- There is wide variation in this share:
  - Highest number, Ecuador: .55
  - Lowest number, Greece: .20
  - The US number: .25

- One explanation for wide variation in these estimates is that we have noisy measurements of this share

- This will be our assumption, and we will usually assume that the share is about 1/3 (i.e. .333333) as that is roughly the cross-country average and it turns out a value of 1/3 makes many calculations a little easier

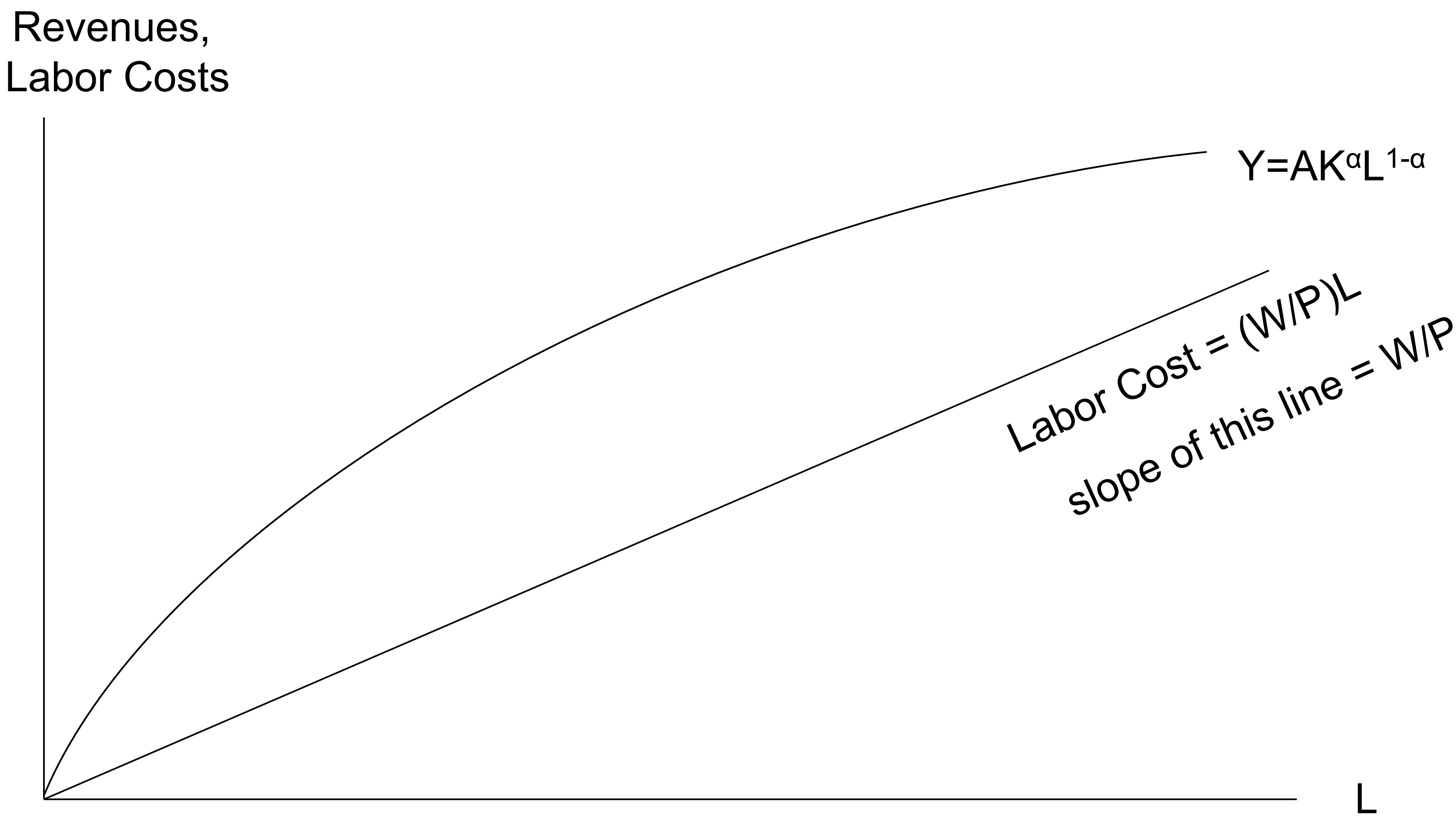
- Are there alternative structural explanation for this cross-country variation in capital share?
- Perhaps countries use different production functions that have a different value for α
- Why might this be?
  - Some economists argue that poorer countries use more labor intensive technologies
  - In that case, poorer countries will have smaller income shares going to capital and larger income shares going to labor
- In this case, our theory says that the α parameter should be smaller in poorer countries than in richer countries
- And that is why this explanation doesn't fit the facts: The previous figure shows that there is NOT a positive relationship between capital's income share and income per capita (it might be a modestly negative relationship but not positive)

Profit Maximization

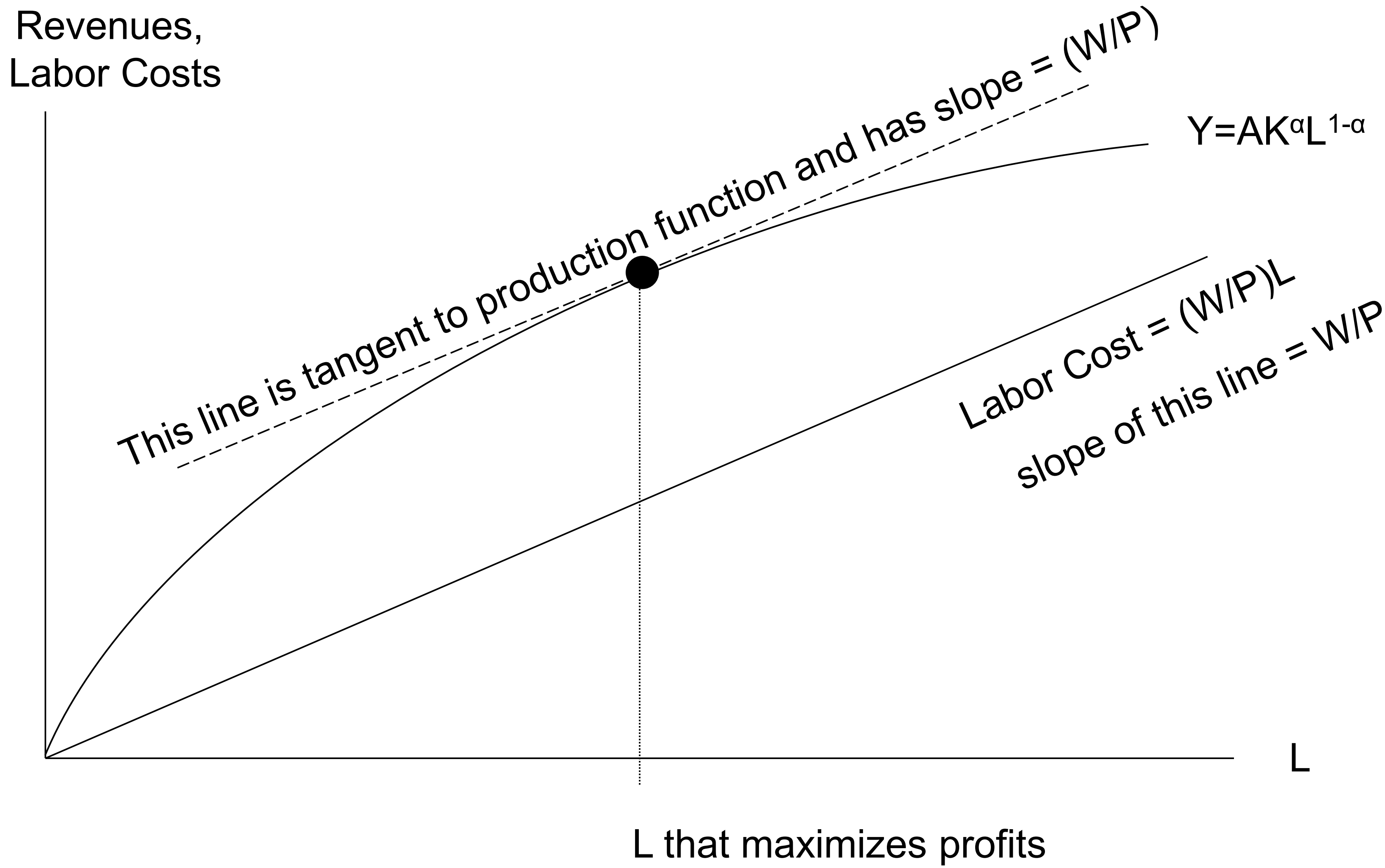
- Profits = Revenues - Costs
- Revenues, in real terms, is equal to Real Output: Y
- Costs, in real terms:
  - Real labor costs: $\left(\frac{W}{P}\right)$ where W=nominal wage rate
  - Real cost of capital: $uc=(r+\delta)\frac{P_k}{P}$ (this is one way to write the user cost)

- Profits, in real terms $= Y - \left(\frac{W}{P}\right)L - uc \cdot K$

The gap between revenues and costs is equal to profits



When this gap is maximized, profits are maximized (initially hold A and K fixed)



Profit maximizing condition

- Write the marginal product of labor as MPL
  - The MPL indicates how much more additional output a little more labor is able to generate
  - The MPL is the slope of the production function
- From the graph, the profit maximization condition is:

$$W/P=MPL$$

  - This says that the Real Wage is equal to the Marginal Product of Labor
- Recall the production function has diminishing MPL
  - This along with the previous profit maximizing condition implies there is an inverse relationship between W/P and the amount of L a firm demands – a very intuitive result

- Scientists generally use calculus to maximize or minimize a function.
  - This more precise quantitative relationship can be very useful

- Optimization is done using the following steps:

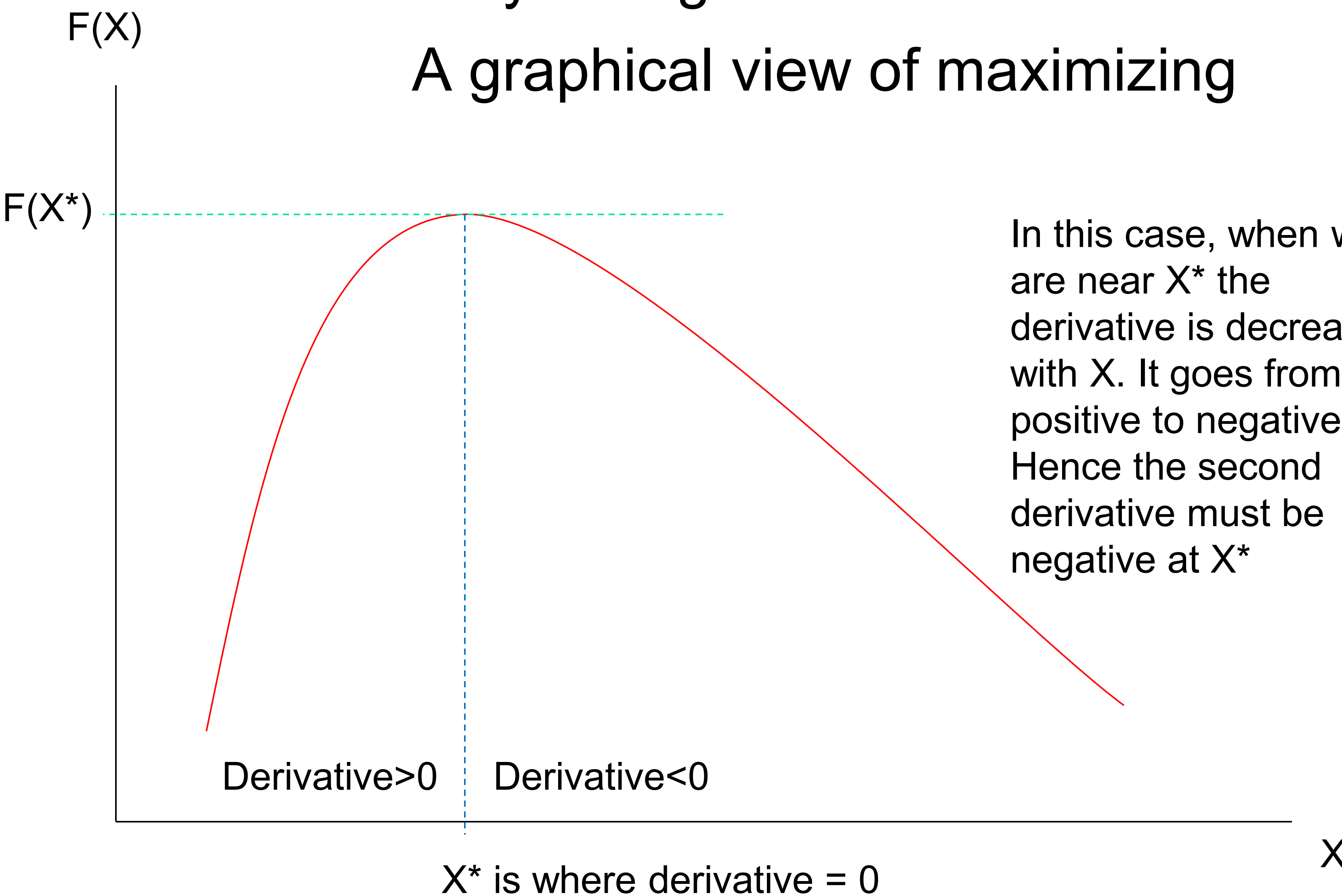
- To find the point or points that maximize or minimize a function:
  1. Start with the function: $F(X)$
  2. Take the derivative of the function: $\frac{d}{dX}F(X)$
  3. Set the derivative equal to zero: $\frac{d}{dX}F(X) = 0$
     - This last equation is sometimes called a first order condition
  4. Determine all particular values for X that solve this last equation. Call these values X^*. For each X^*, the function is either at a maxima or a minima.
  5. To determine whether a point is a maxima or a minima use a second order condition. Take the second derivative of the function:

$$\frac{d^2}{dX^2}F(X) \qquad \text{and}$$

  - IF this second derivative is positive, the point is a minimum
  - IF this second derivative is negative, the point is a maximum

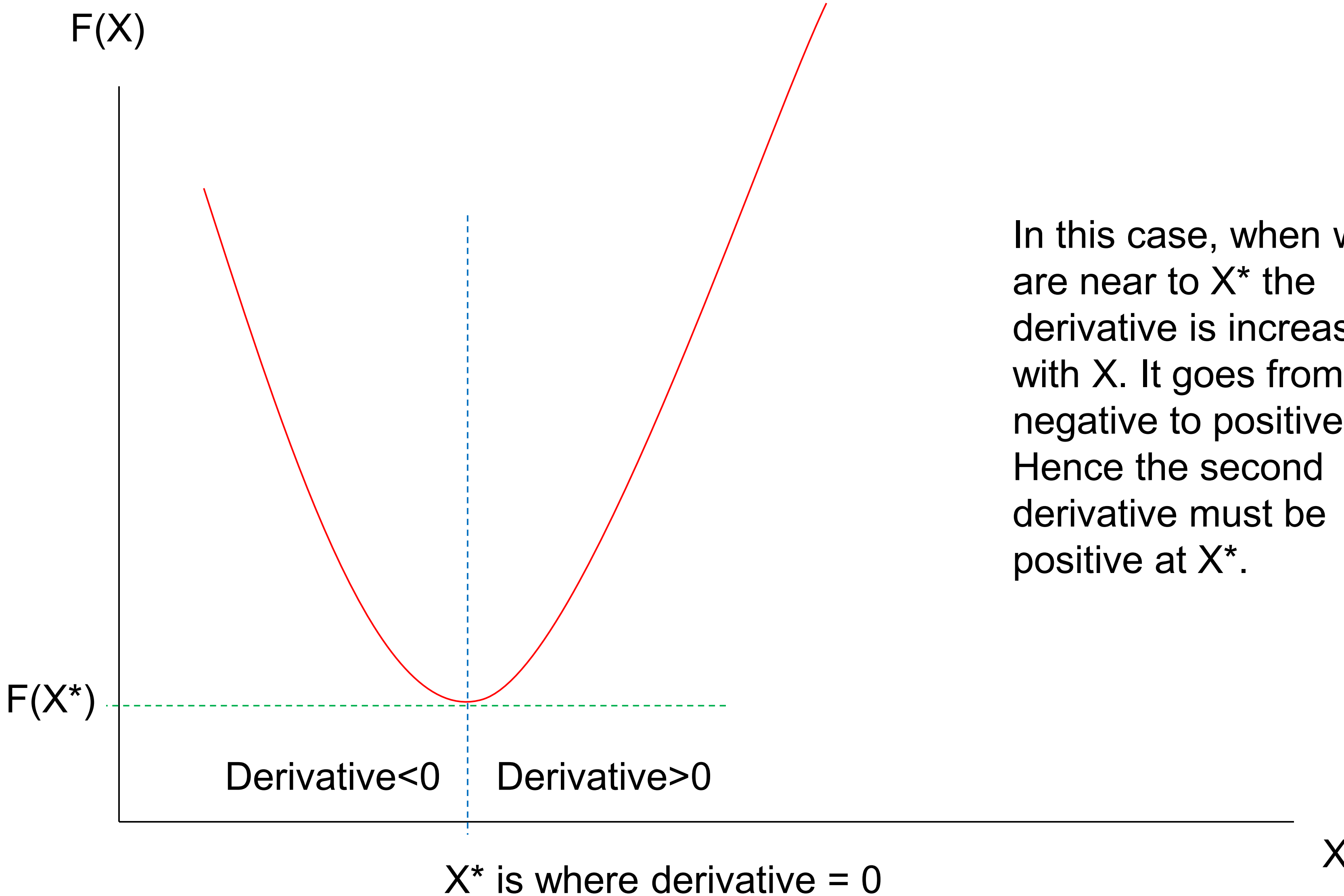
Why taking derivatives works:

A graphical view of maximizing



In this case, when we are near X* the derivative is decreasing with X. It goes from positive to negative. Hence the second derivative must be negative at X*

A graphical view of minimizing



In this case, when we are near to X* the derivative is increasing with X. It goes from negative to positive. Hence the second derivative must be positive at X*.

Profit maximization using derivatives

- Profits $= Y - \left(\dfrac{W}{P}\right)L - uc \cdot K$
- Using the production function, $Y=AK^{\alpha}L^{1-\alpha}$:
- Profits $= AK^{\alpha}L^{1-\alpha} - \left(\dfrac{W}{P}\right)L - uc \cdot K$
- Determine the amount of labor and capital that will maximize profits

- Take the first derivative of profits with respect to labor:

$$\frac{d}{dL}\text{Profits} = (1-\alpha)AK^{\alpha}L^{1-\alpha-1} - \left(\frac{W}{P}\right)$$

- Setting this derivative equal to zero we obtain:

$$\frac{W}{P} = (1-\alpha)AK^{\alpha}L^{-\alpha}$$

This proves what was claimed previously - profits are maximized by choosing L such that:

Real Wage = Marginal Product of Labor

– We can solve for this L, will do so soon, and we will see there is only one solution

To determine whether a solution to the first order condition is a maxima or a minima, take the second derivative of the profit function. In other words, take the derivative of the first derivative of profits:

$$\frac{d}{dL}\left[(1-\alpha)AK^{\alpha}L^{-\alpha}-\left(\frac{W}{P}\right)\right]=$$

$$\frac{d}{dL}\left[(1-\alpha)AK^{\alpha}L^{-\alpha}\right]-\frac{d}{dL}\left[\frac{W}{P}\right]=-\alpha(1-\alpha)AK^{\alpha}L^{-\alpha-1}$$

- Note that A, K, L, (1-α) and α are all positive numbers
  - Hence, this second derivative is negative because everything in the last equation is positive except for the first negative sign
- If there is only one solution to the first order condition, then the maximum is a global maximum – the maximum over the entire function

- Now solve the first order condition for any L that maximize profits (there is only one)
- Multiply both sides by L^{α} and divide both sides by W/P:

$$L^{\alpha} = \frac{(1-\alpha)AK^{\alpha}}{\left(\frac{W}{P}\right)}$$

- Raise both sides by the 1/α power:

$$L = \frac{(1-\alpha)^{1/\alpha}A^{1/\alpha}K}{\left(\frac{W}{P}\right)^{1/\alpha}}$$

This equation tells us that

- L is positive (if K, W/P and A are positive)
- Anything that raises the marginal amount of labor will cause firms to hire more workers. For example:
  - An increase in productivity (A)
  - An increase in capital (K)
- Anything that raises the cost of labor will lower the demand for labor. For example:
  - An increase in the real wage (W/P)
- NOW YOU ANSWER FOR K …

Homework: The firm chooses K to maximize profits just as defined in class using a Cobb-Douglas production function.

- Determine the first order condition.
- Show that the second order condition for a maximum is satisfied.
- Solve for the profit maximizing level of capital as a function of economic factors
- Explain how each factor affects the demand for capital. Explain why these results make sense or why they do not make sense

Homework:

Using our previous results show that if every unit of capital is paid the marginal product of capital and every unit of labor is paid the marginal product of labor, then the labor share of income and the capital share of income must sum to 1.

Hint: Use the first order conditions for choosing K and L.

The Basic Solow Model

- Solow won the Noble Prize primarily for his contributions to Growth Theory
- His model is the foundation of all modern growth theories

- Solow model can include the demand for labor that we already derived and as well as the demand for capital that you will be deriving in the homework question
  - These results have no bearing on growth rates of output, capital and labor
  - Previous results can, however, be used to investigate what influences the growth rate of the real wage

- The simplified Solow model
- Accumulation of physical capital, K, is an important feature in this model
  - Capital is built by investing in capital goods.
  - Each dollar of investment, I, builds an additional dollar of capital. This means the capital stock will increase. This suggests

$$\Delta K = I$$

    Where ΔK is the change in the capital stock
    - Capital increases if we invest
  - But something is missing from this simple equation

- We know that something must be missing from this simple equation because it implies that the capital stock never falls.
  – Why? Because I can never be negative!
  – What is missing is the fact that capital depreciates and that a lot of investment is done to replenish depreciated capital.
  – If we let: D=depreciated capital, and the equation becomes

$$\Delta K = I - D$$

- Capital depreciates by
  - wearing out from use
  - becoming technologically out of date and needing replacement
- Since we model variables in per capita terms to compare across countries, divide all variables in the equation by L

$$\frac{\Delta K}{L} = \frac{I}{L} - \frac{D}{L}$$

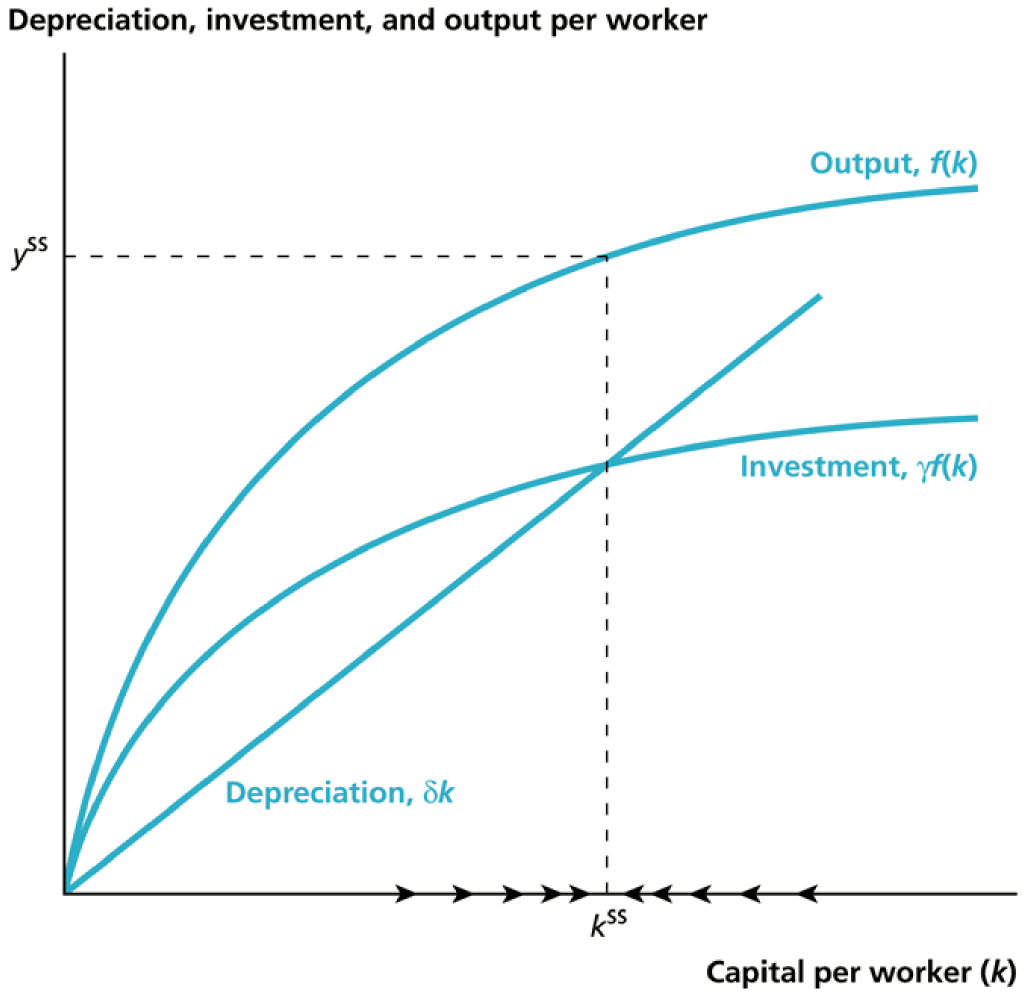
- Redefine variables so that lower case letters denote per capita values:
- $\Delta k = i - d$
- For now assume that L is fixed – not growing

- Assume that investment is a fixed share of income: $\gamma = i/y$ which also means $I/Y = i/y$ and that $0 < \gamma < 1$
- Assume that capital depreciates at a constant rate: $d = \delta k$
- (from $D = \delta K$ and then dividing by L)
- Assume a general form for a production function with the standard properties of CRS along with positive and diminishing marginal products: $y = A \cdot f(k)$

- Putting all of these assumptions into the equation for capital accumulation ($\Delta k = i - d$)
- We obtain: $\Delta k = \gamma \cdot A \cdot f(k) - \delta \cdot k$
- This equation tells us how the capital stock k is determined given specific values of γ, A, δ and parameters in the production function (e.g. α in Cobb-Douglas production function.
- It is convenient to analyze this model graphically (To make my equation line up with Weil's graph let A in the previous equation be 1, temporarily)

- The graph plots three equations
  - Investment per capita: $\gamma \cdot A \cdot f(k)$
  - Depreciation per capita: $\delta \cdot k$
  - Output per capita: $A \cdot f(k)$
  - The gap between the investment per capita line and depreciation per capita tells us how much the capital per capita will change

Figure 3.4 The Steady State of the Solow Model



- If the levels of γ, A, δ and the parameters in the production function (α if its a Cobb-Douglas production function) are constant, these 3 curves will be fixed – they will never move

  An important implication of these assumptions is that the economy eventually settles down to a steady state level of k - and consequently to a steady state level of y as well.

  Why?

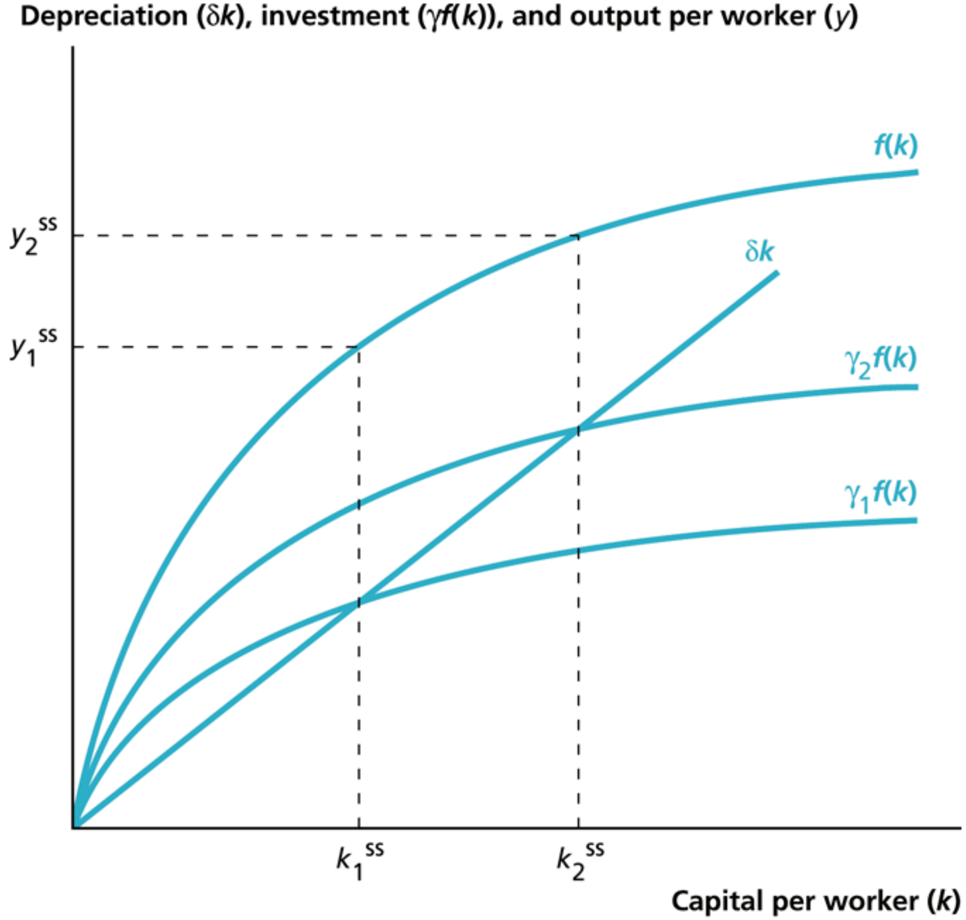
  – If we start out with $k>k_{ss}$ depreciation exceeds investment and the capital stock falls
  – If we start out with $k<k_{ss}$ investment exceeds depreciation and the capital stock rises
  – When $k=k_{ss}$, depreciation equals investment and the capital stock does not change
    - The tendency for the economy to stay at this point, k_{ss}, k reaches that level, is why the point is called a steady state

- Output is determined by the production function and the level of capital
  - Output follows movements in the capital stock
    - At this point, nothing else is changing in the production function
  - When capital settles down to its steady state, output reaches its steady state, y_{ss}, which is determined using the production function:

$$y_{ss} = Af(k_{ss})$$

- The parameters that we have assumed are constant need not always be constant.
  - For example, γ may change because:
    - Policymakers implement a policy to stimulate more investment
    - More savings becomes available to a country, which induces more investment in that country
      - Why? Investment is financed by savings γ
  - A or δ may also be change for various reasons (we will consider this later)
- What happens when the investment rate (investment share of income) increases in our model?
  - That is to say, when γ rises from γ_1 to γ_2 which curve(s) move and what happens as a result?

Figure 3.6 Effect of Increasing the Investment Rate on the Steady State



Note: $\gamma_2 > \gamma_1$

- When considering how the economy responds to some change in a parameter or an exogenous variable, it is useful to assume the economy starts off in an equilibrium position
  - Then we can analyze
    - If a change in some parameter (or exogenous variable) pushes the economy away from equilibrium
      - And if so, how this works in the economy and in what way are variables affected
    - If the economy eventually returns to equilibrium
      - And if so, how it does this and how is the equilibrium position of the economy affected
    - In the picture the initial position of the economy is

$$k = k_{ss1} \quad \text{and} \quad y = y_{ss1}$$

- An increase in the investment rate causes the steady state value of k to increase
  - In the graph the new steady state k is k_{ss2}
  - k_{ss2} is greater than k_{ss1}
  - So k must rise from k_{ss1} and eventually reaches k_{ss2}
  - Once k reaches k_{ss2} it will stop rising and stay there

    (until/unless something else happens)

- Similar behavior is found for y
  - The initial steady state is y_{ss1}.
  - As k rises so does y
    - This comes from the production function and the fact that k has a positive marginal product
  - k stops rising when it reaches its steady state
    - at that point y also reaches its new steady state labeled y_{ss2} in the graph

- The previous analysis explained what happens if the investment rate rises for a country
  - But it can just as well describe what happens if two countries have different investment rates
- Suppose Country 1 has an investment rate of γ_1
  Country 2 has an investment rate of γ_2 and

$$\gamma_2 > \gamma_1$$

- Our graphical model predicts that a higher investment share yields a higher steady state level of output per capita
- What does the cross-country evidence tell us?

- At this point in the course, we don't know how to measure steady state output per capita
  - But we do know how to measure output per capita in a given year
- Also, we can measure the average investment share over a period of time
- When we plot actual y in a given year against the average investment rate (investment share of GDP) we find there is a positive relationship

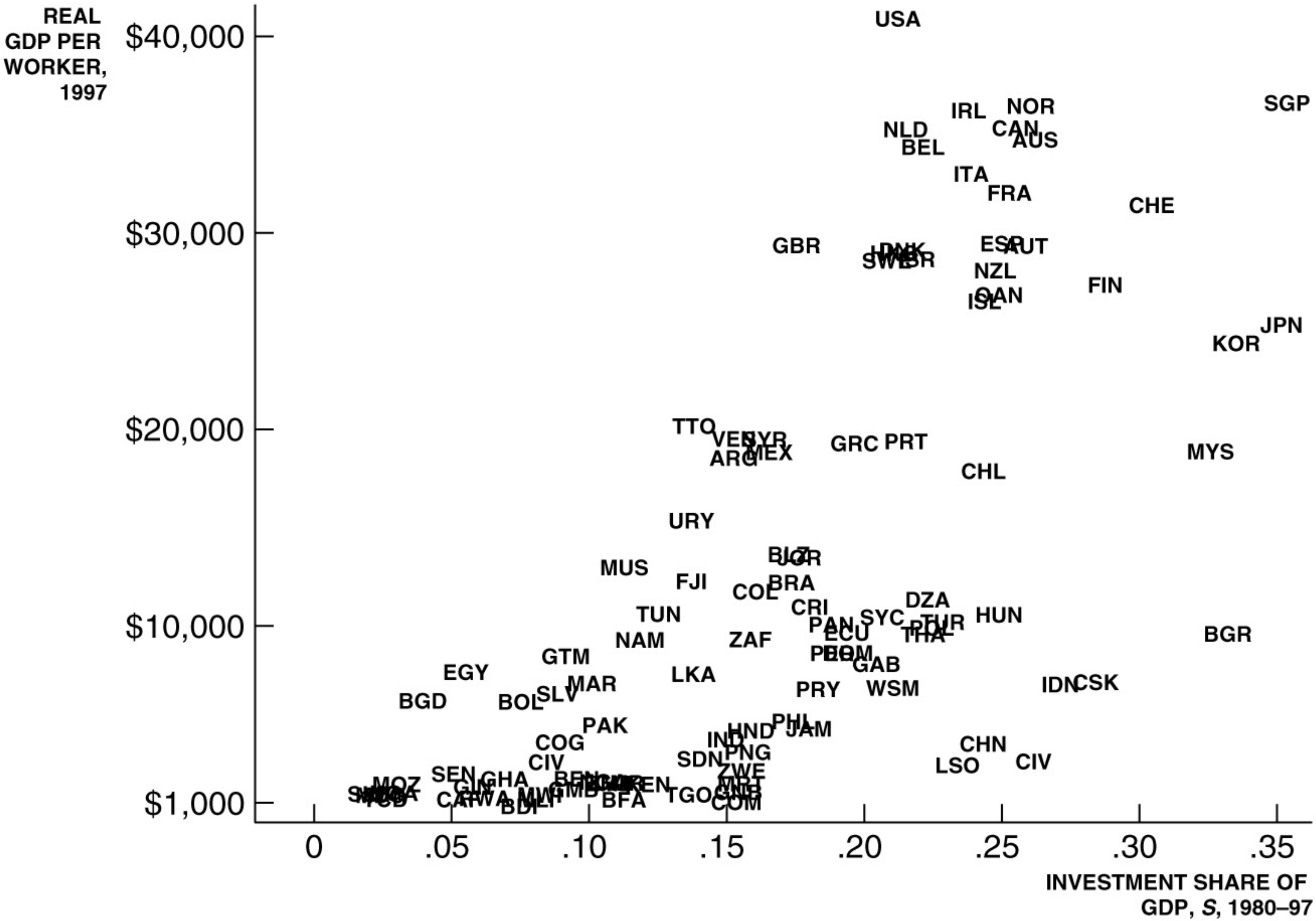
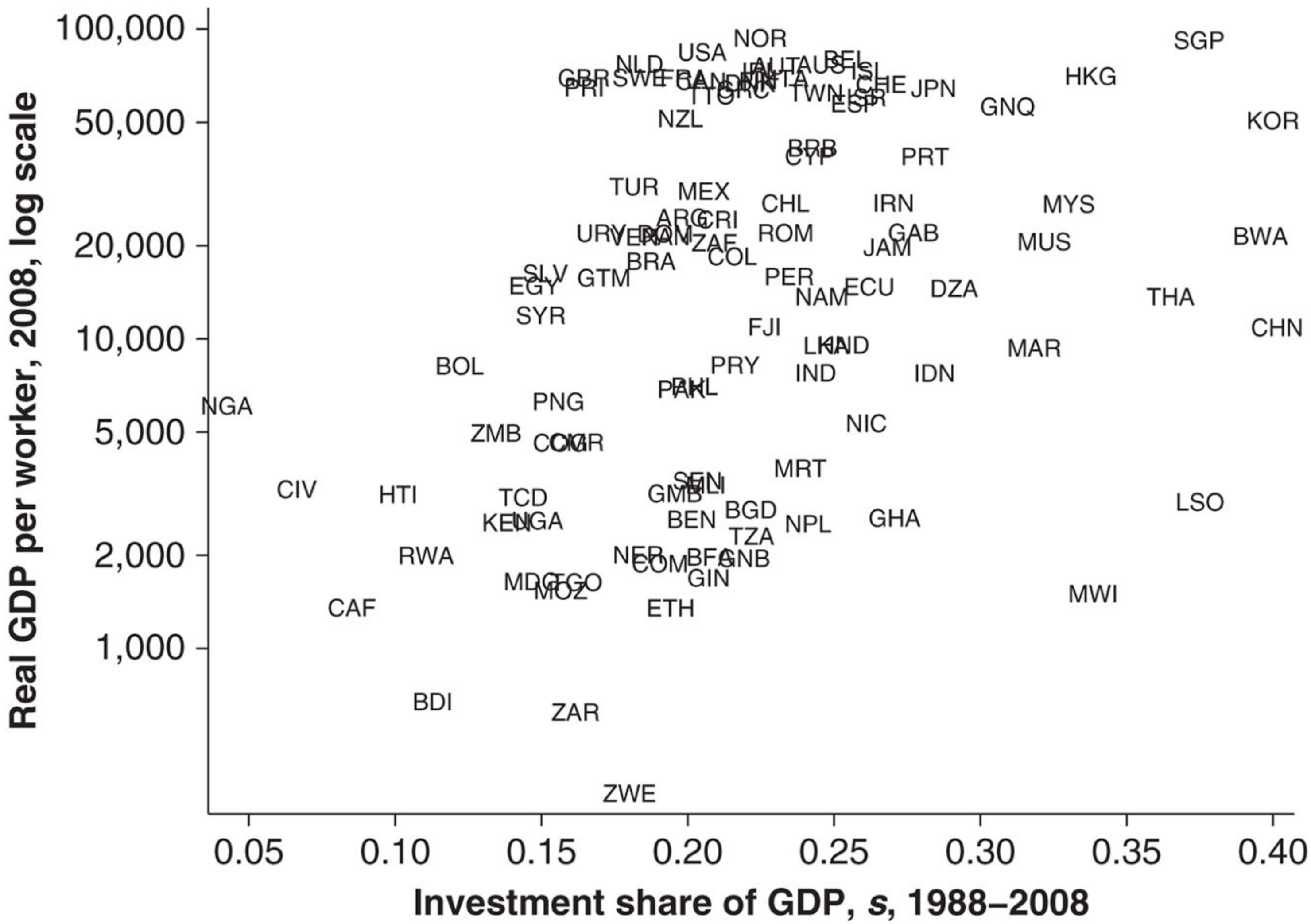


FIGURE 2.6 **GDP PER WORKER VERSUS THE INVESTMENT RATE**

Economic Growth, 2nd Edition

- Although this positive relationship is not as strong as the simple theory might suggest, particularly when we look at more recent data

FIGURE 2.6 GDP PER WORKER VERSUS THE INVESTMENT RATE



- In any case, a positive empirical relationship is observed between output-per-capita and the investment share across countries. And this is predicted by the Solow model.

- But we also saw that a permanent increase in the investment share will not lead to persistent growth in y or k
  – Eventually k and y settle down to a steady state and growth discontinues

- The model still needs to have something in it to make y and k both grow over a long period of time (Spoiler alert: It will be for productivity to have a positive growth rate.)

- You might think y and k could grow forever if the investment share were to continually increase over time
  - While this may at first sound like a reasonable proposition, it is not.
  - Why? Two good reasons.

1. Many of the world's economies have had output per capita grow for long periods of time even while their investment shares have not grown over time

2. The investment share, I/Y, can not grow forever

- If it kept growing eventually all a country's income would go toward investment leaving nothing for consumption,
  - Zero consumption means death if maintained for an extended period.

- Homework: Suppose that δ falls from δ_1 to δ_2 in our model ($\delta_1 > \delta_2$). Hold all other parameters constant. Explain what happens to y and k over time. Do y and k grow forever or will they eventually arrive at a steady state? How does the new steady state compare to the initial steady state? How would δ have to change in order for y to grow forever? Is it reasonable to think that the depreciation rate can continue to change like this over time?

- Homework: Suppose that A rises from A_1 to A_2 in our model ($A_1 < A_2$). Explain what happens to y and k over time. Do y and k grow forever or will they eventually arrive at a steady state? How does the new steady state compare to the initial steady state? How would A have to change in order for y to grow forever? Is it reasonable to think that productivity will continue to change like this over time?

- The conclusion from class and the two most recent homework problems is:
  - Rising investment share can not cause continuing growth of y and k for reasons cited a few pages back
  - The only way that changes in δ may cause y and k to grow indefinitely is if the depreciation rate continues to fall. But the problem with this hypothesis is that
    - Depreciation rates do not exhibit any tendency to fall over time
    - The depreciation rate can not fall below zero. This means that eventually there would come a time when depreciation would stop falling - thus k and y would eventually stop rising
  - The only plausible way for y and k to grow indefinitely is if A continues to rise

- The only thing that causes growth in Solow’s model is productivity growth
  - Unfortunately, Solow assumed productivity grew at some exogenous rate
    - Exogenous means outside the model so Solow’s growth model doesn’t explain what influences the source of growth, but simply assumes it is exogenous
- While Solow’s model does not explain why productivity grows it has been used by economists try to explain cross-country differences in income per capita

- An advantage of the Cobb-Douglas production function is that it allows us to get an exact analytical solution to all variables of interest in the model
- Putting Cobb-Douglas in to our capital accumulation equation yields

$$\Delta k = \gamma \cdot A \cdot k^{\alpha} - \delta \cdot k$$

- If there is no growth in A, then k settles down to a steady state: $\Delta k=0$

- When $\Delta k=0$:

$$\gamma \cdot A \cdot k_{ss}^{\alpha} - \delta \cdot k_{ss} = 0$$

- Solve for the k_{ss}:

$$\gamma \cdot A \cdot k_{ss}^{\alpha} = \delta \cdot k_{ss}$$

$$\frac{k_{ss}}{k_{ss}^{\alpha}} = \frac{\gamma \cdot A}{\delta}$$

$$k_{ss}^{1-\alpha} = \frac{\gamma \cdot A}{\delta}$$

$$k_{ss} = \left(\frac{\gamma \cdot A}{\delta}\right)^{1/(1-\alpha)}$$

- Then we can solve for $y_{ss:}$: $y_{ss} = A \cdot k_{ss}^{\alpha}$

$$y_{ss} = A \cdot \left[\left(\frac{\gamma \cdot A}{\delta} \right)^{1/(1-\alpha)} \right]^{\alpha}$$

$$y_{ss} = A \cdot \left(\frac{\gamma \cdot A}{\delta} \right)^{\alpha/(1-\alpha)}$$

$$y_{ss} = A^{(1-\alpha)/(1-\alpha)} \cdot A^{\alpha/(1-\alpha)} \cdot \left(\frac{\gamma}{\delta} \right)^{\alpha/(1-\alpha)} = A^{1/(1-\alpha)} \cdot \left(\frac{\gamma}{\delta} \right)^{\alpha/(1-\alpha)}$$

- Our final result is:

$$y_{ss} = A^{1/(1-\alpha)} \cdot \left(\frac{\gamma}{\delta}\right)^{\alpha/(1-\alpha)}$$

- Suppose we have two countries, Country i and Country j. Each will have its own steady state, y_i and y_j and the ratio of the steady states is:

$$\frac{y_i}{y_j} = \frac{A_i^{1/(1-\alpha_i)} \cdot \left(\frac{\gamma_i}{\delta_i}\right)^{\alpha_i/(1-\alpha_i)}}{A_j^{1/(1-\alpha_j)} \cdot \left(\frac{\gamma_j}{\delta_j}\right)^{\alpha_j/(1-\alpha_j)}}$$

- The previous equation allow each country to potentially have a unique value α, δ, A or γ
- For the moment, suppose the investment share is the only thing that differs across countries.
  - Then $A_i=A_j$, $\alpha_i=\alpha_j$ and $\delta_i=\delta_j$,
    - And our general result simplifies as follows:

$$\frac{y_i}{y_j} = \frac{A_i^{1/(1-\alpha_i)} \cdot \left(\frac{\gamma_i}{\delta_i}\right)^{\alpha_i/(1-\alpha_i)}}{A_j^{1/(1-\alpha_j)} \cdot \left(\frac{\gamma_j}{\delta_j}\right)^{\alpha_j/(1-\alpha_j)}} = \left(\frac{\gamma_i}{\gamma_j}\right)^{\alpha/(1-\alpha)}$$

- Measures are available for
  - The investment share for every country, and
  - The parameter α
    - Economic theory tells us that α is equal to the share of income that goes to capital, which we estimate as roughly equal to 1/3
    - So if α=1/3, $$\frac{\alpha}{1-\alpha}=\frac{1/3}{2/3}=\frac{1}{2}$$
  - Thus the model predicts the ratio of incomes per capita will equal:

$$\frac{y_i}{y_j}=\left(\frac{\gamma_i}{\gamma_j}\right)^{1/2}$$

- Numerical examples: Plausible ranges for investment rates suggest the model does not yield variation in y_i/y_j that matches the data

  - If $\gamma_i = .2\ (20\%)$ and $\gamma_j = .05\ (5\%)$

    then $$\frac{y_i}{y_j} = (4)^{1/2} = 2$$

  - If $\gamma_i = .32\ (32\%)$ and $\gamma_j = .02\ (2\%)$

    then $$\frac{y_i}{y_j} = (16)^{1/2} = 4$$

- Lets look at a broad selection of countries to see how well or poorly the model performs
- We use a graph and a large cross section of countries that plots

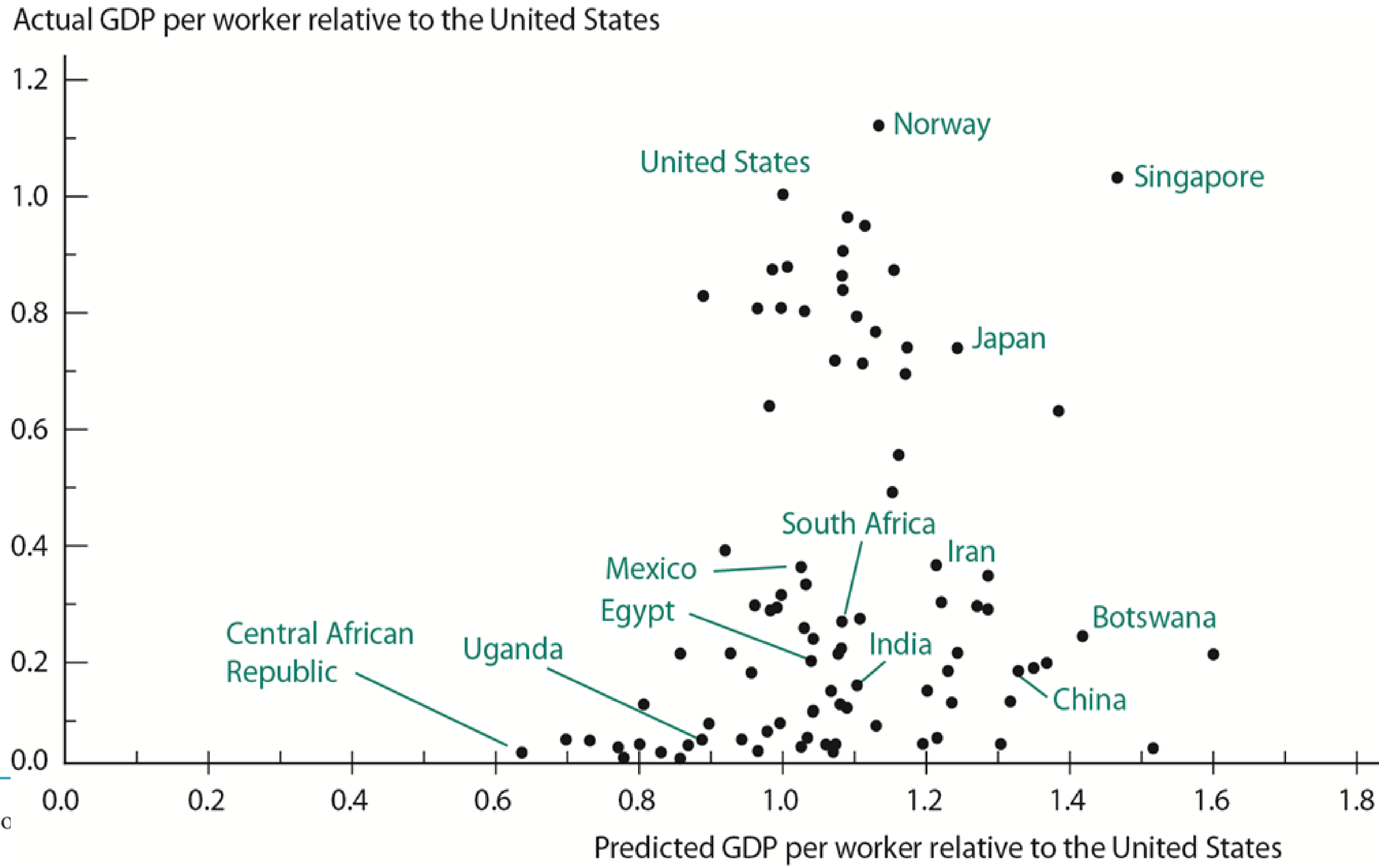
  – actual data y_i/y_j along with

  – predicted y_i/y_j which equals: $\left(\frac{\gamma_i}{\gamma_j}\right)^{1/2}$

  (remember: the prediction is based on the assumption that countries only differ in terms of the investment share and that $\alpha=1/3$)

FIGURE 3.7

Predicted Versus Actual GDP per Worker

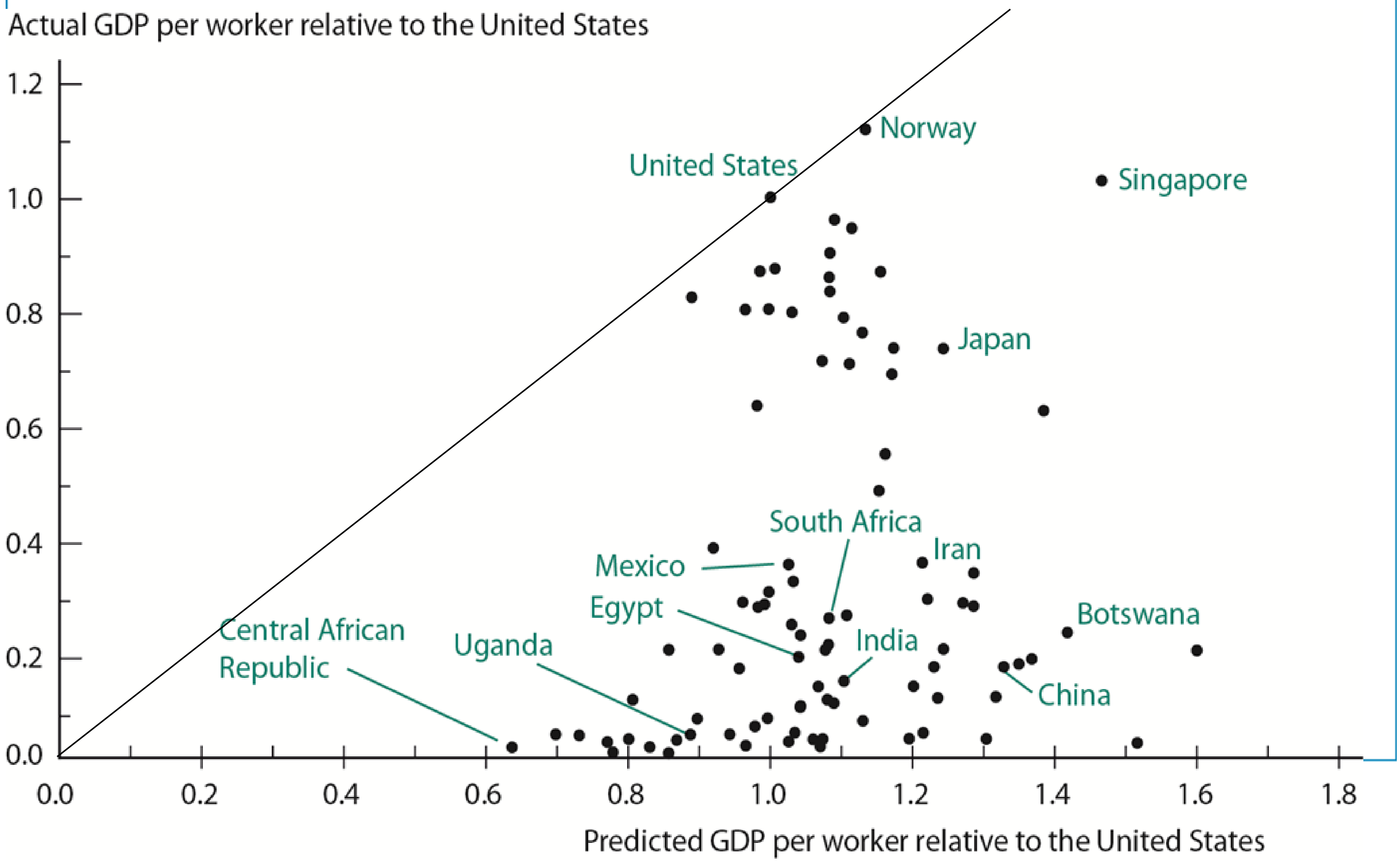


Sc

- The good news:
- Actual output and predicted output are positively related
- Thus, countries with a higher investment share tend to have higher output per-capita, as the model predicts

- However, if the is simple version of Solow’s model is perfectly correct, all the data points will be on a straight line with a slope of 1 that goes through the origin
  - That is if the investment share is the only thing that matters for explaining cross-country differences in GDP per capita, the data will show up on this particular line
    - We don’t expect any macroeconomic theory to be perfectly correct because macroeconomies are rather complicated social systems
    - How far the data points are from this line yields some indication of how well or how badly the simple version of Solow’s model actually works
- So putting that line on the previous graph …

FIGURE 3.7
Predicted Versus Actual GDP per Worker



- The US is, by construction, on the line
    - Output per capital in US relative to output per capital in the US is always equal to 1
        - Nothing is learned here, but this helps us draw the line

- What do we learn from this picture?
    - Except for Norway which is on the line, all other countries are below the line, and most of them are well below the line
        - A higher investment rate for Norway may explain all the difference in output-per-capita between Norway and the US
        - But for nearly all of the countries, the model predicts that output-per-capita should be much higher in countries than is actually seen
    - Implication: The Solow model with only the investment rate differing across countries does a poor job of explaining differences in output-per-capita for nearly all economies of the world
        - This simple version of the model does not do very well

- How should we interpret this finding?????

- So the model in its current form does not look very promising
    - It doesn’t explain why countries grow for an extended period of time
    - It doesn’t explain the wide variation in income per capita that we observed across countries
- But don’t give up on Solow
  - We will reexamine the model under alternative assumptions that are more reasonable
- The key conclusion from this is: Cross-country variation in the investment rate, by itself, is unable to explain key features in the data

- Our current simplistic version of Solow’s model does have an interesting property
  - The farther a country operates below its steady state, the faster capital-per-worker and output-per-worker will grow
- that property turns out to be a general property of the Solow model under all kinds of conditions
  - It is also a feature of many other growth theories

- To see this point, return to the capital accumulation equation

$$\Delta k = \gamma \cdot A \cdot k^{\alpha} - \delta \cdot k$$

- Divide both side of the equation by k

$$\frac{\Delta k}{k} = \gamma \cdot A \cdot k^{\alpha - 1} - \delta$$

- Define the growth rate of k as: $\hat{k} = \frac{\Delta k}{k}$

- Then $\hat{k} = \gamma \cdot A \cdot k^{\alpha - 1} - \delta$

- We can plot the function that determines growth in k. It is constructed from two terms

1. A function of k: $\gamma \cdot A \cdot k^{\alpha-1}$

   Which is

   - A declining function of k

     (negative first derivative with respect to k)

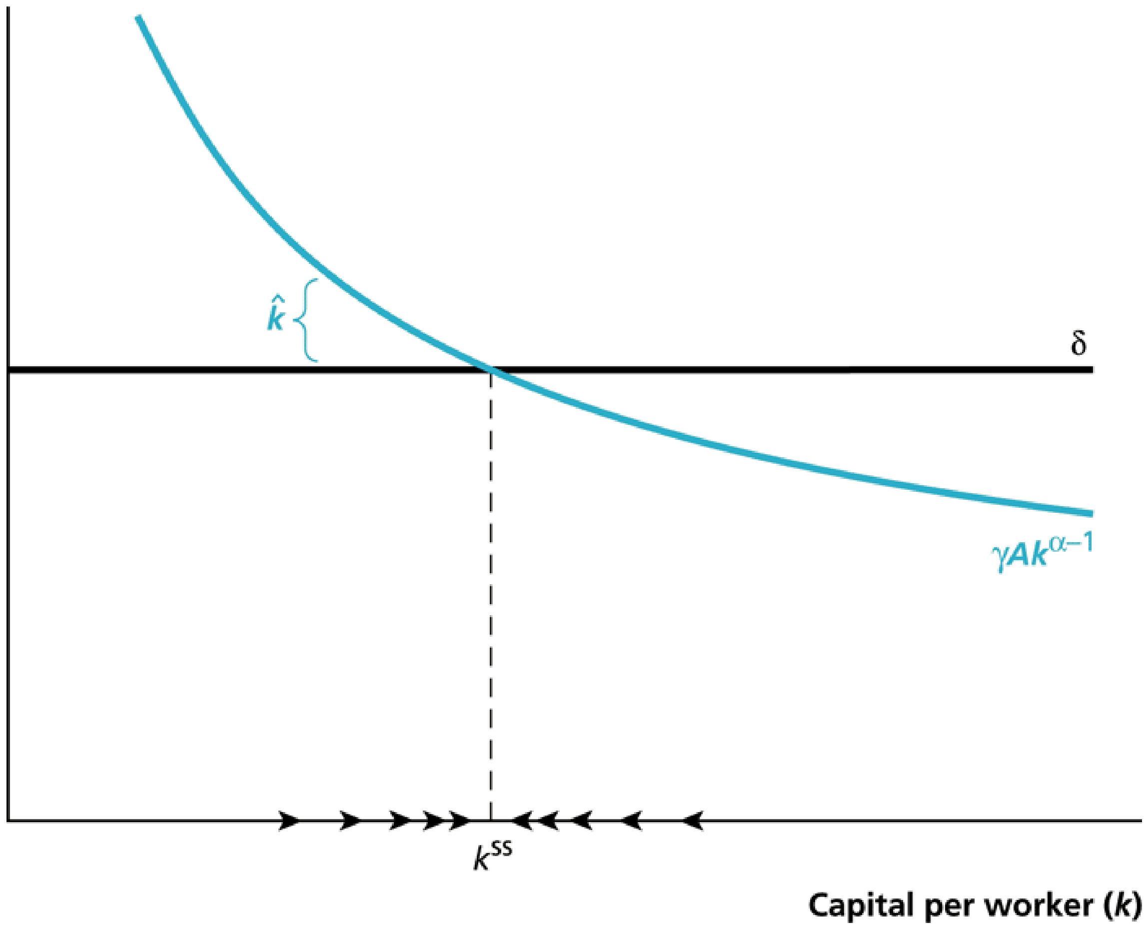
   - A convex function of k

     (positive second derivative with respect to k)

2. the depreciation rate (which is not a function of k)

- The difference between the two terms gives us the growth rate of k

Figure 3.10 Speed of Convergence to the Steady State



- First notice that the graph provides another way of seeing why k_{ss} is a steady state
  - k rises when $k<k_{ss}$ and k falls when $k>k_{ss}$
- This graph also shows that the farther k is below k_{ss}, the larger is the growth rate of k
- And similarly, the farther k is above k_{ss} the slower is the growth rate of k
  - in this case, growth of k is negative when k is above k_{ss}

- Output per capita is determined by the production function, and so it behaves like capital per capita
  - Recall the Cobb Douglas production function
-

$$y = Ak^{\alpha}$$

  - It turns out that if y is determined by this production function, one can show that the growth rate of y is equal to the growth rate of A plus α time the growth rate of k:

$$\hat{y} = \hat{A} + \alpha\hat{k}$$

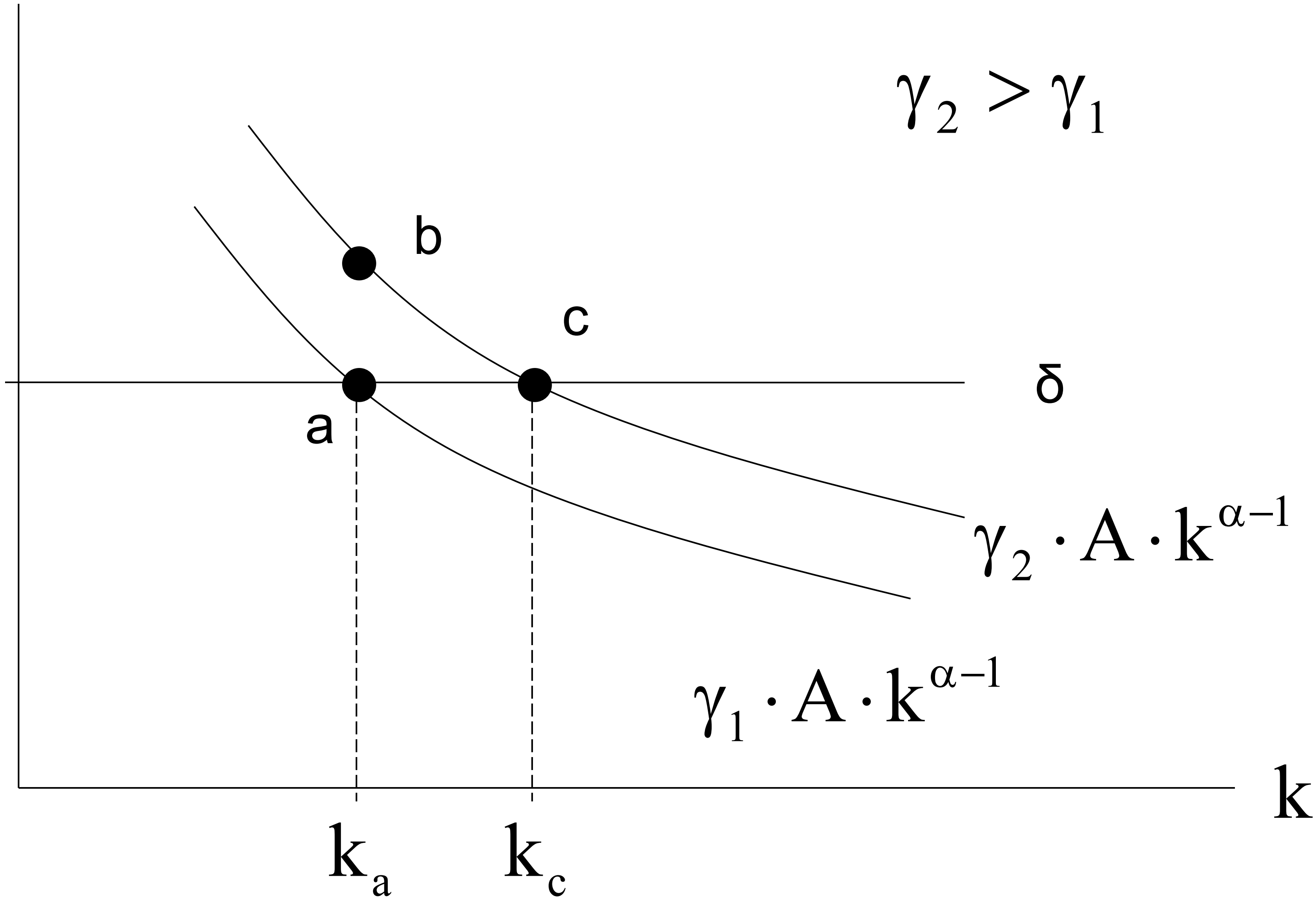
  - This equation allows for growth in A, and that is something we did not allow initially, but will be needed for the model to fit data
  - Therefore, the behavior of y is similar to the behavior of k:
    - The farther y is below y_{ss}, the larger is the growth rate of y
    - The farther y is above y_{ss} the slower is the growth rate of y
      - in this case growth of y is negative when y is above y_{ss}

We can derive 3 important conclusions from this analysis (these will also be found in a Solow model that allows more than just investment share to vary)

1. If two countries have the same levels of productivity, depreciation rate and investment rate and they both use the same production function, but one country starts out at a lower level of k and y, that country will grow at a faster rate (until both countries get to the steady state)
   – This result is a direct implication of Fig 3.10

2. If two countries start at the same level of y, but one of the countries has a higher investment rate, and that is the only difference, then that country will for a while grow at a faster rate

- The country with higher γ has higher steady state levels for k and y.
  - If both countries start at the same levels of k and y, the one that has farther to go (higher steady state levels of k and y) must grow at a faster rate to make it to these higher levels of k and y (until both countries get to their steady states)
- In the following variation on Fig 3.10, country 2 has a higher investment rate than country 1: $\gamma_2 > \gamma_1$



$\gamma_2 > \gamma_1$
b
c
δ
a
$\gamma_2 \cdot A \cdot k^{\alpha-1}$
$\gamma_1 \cdot A \cdot k^{\alpha-1}$
k
k_a
k_c

3. When a country raises γ it will begin to grow at a faster rate
   - The higher investment rate causes k to grow faster which of course causes y to also grow at a faster rate
   - This is seen in the previous graph, by assuming it refers to a particular country for which the investment rate rises from γ_1 to γ_2

Savings and Investment

- Savings and investment are intimately connected by an important national income accounting identity

$$I = S - CA$$

$$(I/Y) = (S/Y) - (CA/Y)$$

- If CA (the current account) is equal to zero (it must be zero for a closed economy) then savings is equal to investment. Furthermore,

$$(I/Y) = (S/Y)$$

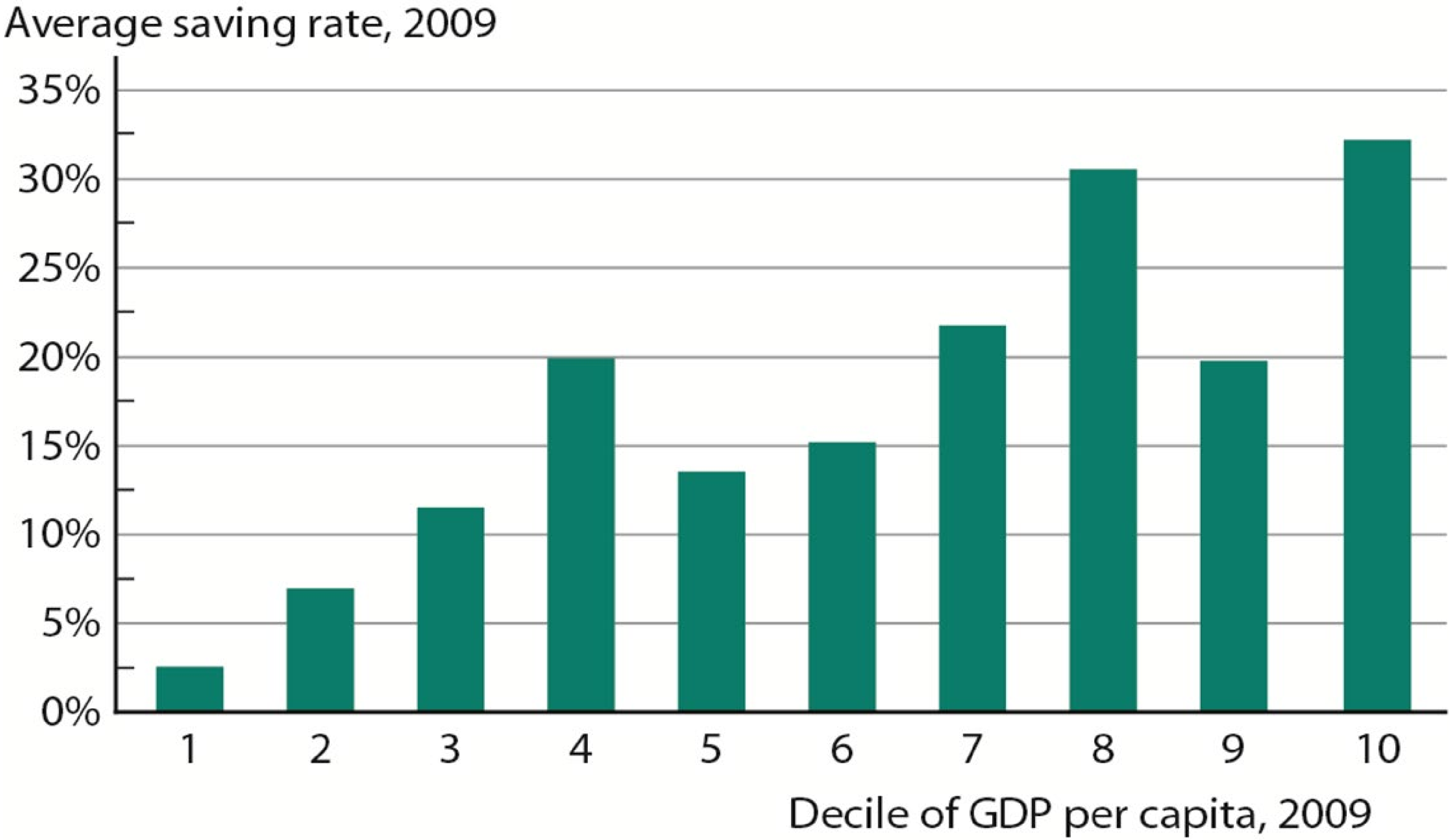
investment rate = savings rate

- But in general CA is not small and so we need the more general result:

$$(I/Y) = (S/Y) - (CA/Y)$$

- Feldstein and Horioka (1980) showed a very close cross-country relationship between the investment rate (I/Y) and the savings rate (S/Y)
  - This is called the Feldstein and Horioka puzzle because:
    - International capital markets should funnel savings toward the highest rate of return, adjusted for risk
      - The fact that people tend to invest a lot more in their own country, on average, than in foreign countries is called a home country bias
        - Sometimes we observe overseas assets yielding incredibly high returns which implies a level of risk aversion that is unbelievably high
- Hence, the positive relationship between investment shares and savings rate implies a positive relationship between savings rates and income-per-capita, which is very evident in aggregate data

Figure 3.8 Saving Rate by Decile of Income per Capita



- A higher national savings rate causes the investment share to rise which ultimately causes output-per-capita to rise to a new steady state level in the Solow model

- What causes the savings rate to rise, and How may government policy be used to increase it?

$$S=S_{pvt}+S_{govt}$$

  - Combining this with a prior equation we obtain:

$$I=S_{pvt}+S_{govt}-CA$$

  - For domestic investment to increase, at least one of the following must occur:
    - private savings increases;
      - Governments often propose policies to raise private savings because it may promote investment
    - government savings increases;
      - Reducing the budget deficit will do this; this is why many people argue that an increased deficit will hurt the economy by reduce investment
    - the CA decreases
      - CA can get smaller when Investment increases relative to domestic savings (S), in this case capital is flowing in to finance investment

- The empirical evidence relating savings rates to income per capita provides some support for Solow’s model – But other interpretations are possible
- Frequently, alternative structural explanations for a set of empirical evidence exist, and many times an alternative works in the opposite way to the first theory

- E.g. Perhaps savings rates rise with income-per-capita, which is the reverse to what is happening in Solow’s model (recall Solow’s model predicts that a higher savings rate causes income-per-capita to increase)
  - Why might this be?
    - Extremely poor nations may be unable to save because saving requires the sacrifice of some current consumption
    - Perhaps as income rises beyond a certain point, a poor nation may be able to afford some savings

- We present a model in which the savings rate depends on the level of output per capita
- Assume we have a closed economy. That means the savings rate, s, will equal the investment rate, γ .
- Assume the savings rate depends on the level of y as follows:

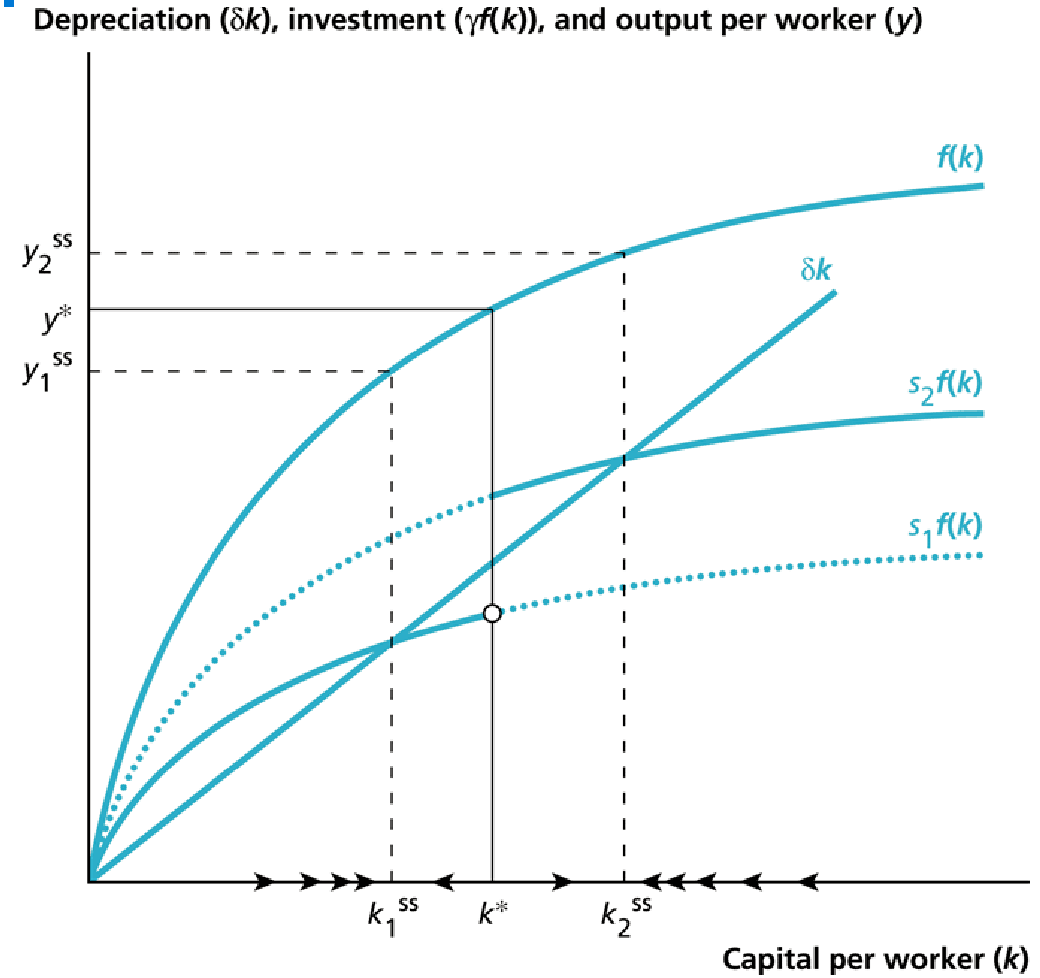
$$s = s_1 \quad \text{if} \quad y < y^*$$

$$s = s_2 \quad \text{if} \quad y > y^*$$

$$\text{with} \quad s_2 > s_1$$

That yields two investment curves depending on how y relates to y*

Figure 3.9 Solow Model with Saving Dependent on Income Level



- The previous slide shows that the alternative explanation, high GDP per capita induces higher savings rates, is possible
  – This theory suggests that a country could be pushed to a permanently higher steady state for y (and k) by some temporary capital flows from abroad (i.e. a temporary increase in foreign savings flowing into the poor country)
  – This is an interesting implication for policy

- In fact, the IMF (International Monetary Fund) and World bank have sent capital into poor countries attempting to make those countries permanently better off
- Problem: there are many examples where such policy has not been successful
- Does this mean the model/theory is wrong?
  - Maybe not. Many of the recipient countries have used the capital injection from international agencies (or countries like the US) in ways that benefit the leaders and politically strong instead of the economy

How has wealth evolved over time

- A long, long time before the Industrial Revolution, there was very little capital in the world
  - Wealth was largely determined by the value of land, not capital
  - The importance of land was stressed by early Classical economists
- But over time the fraction of total wealth accounted for by land has fallen steadily and significantly
- Today the share of wealth accounted for by agricultural land is quite small
  - Interestingly, this share is about the same as the share of agricultural output in GDP
- Capital (tangible, intangible & housing capital) has replaced land as the primary means of holding wealth

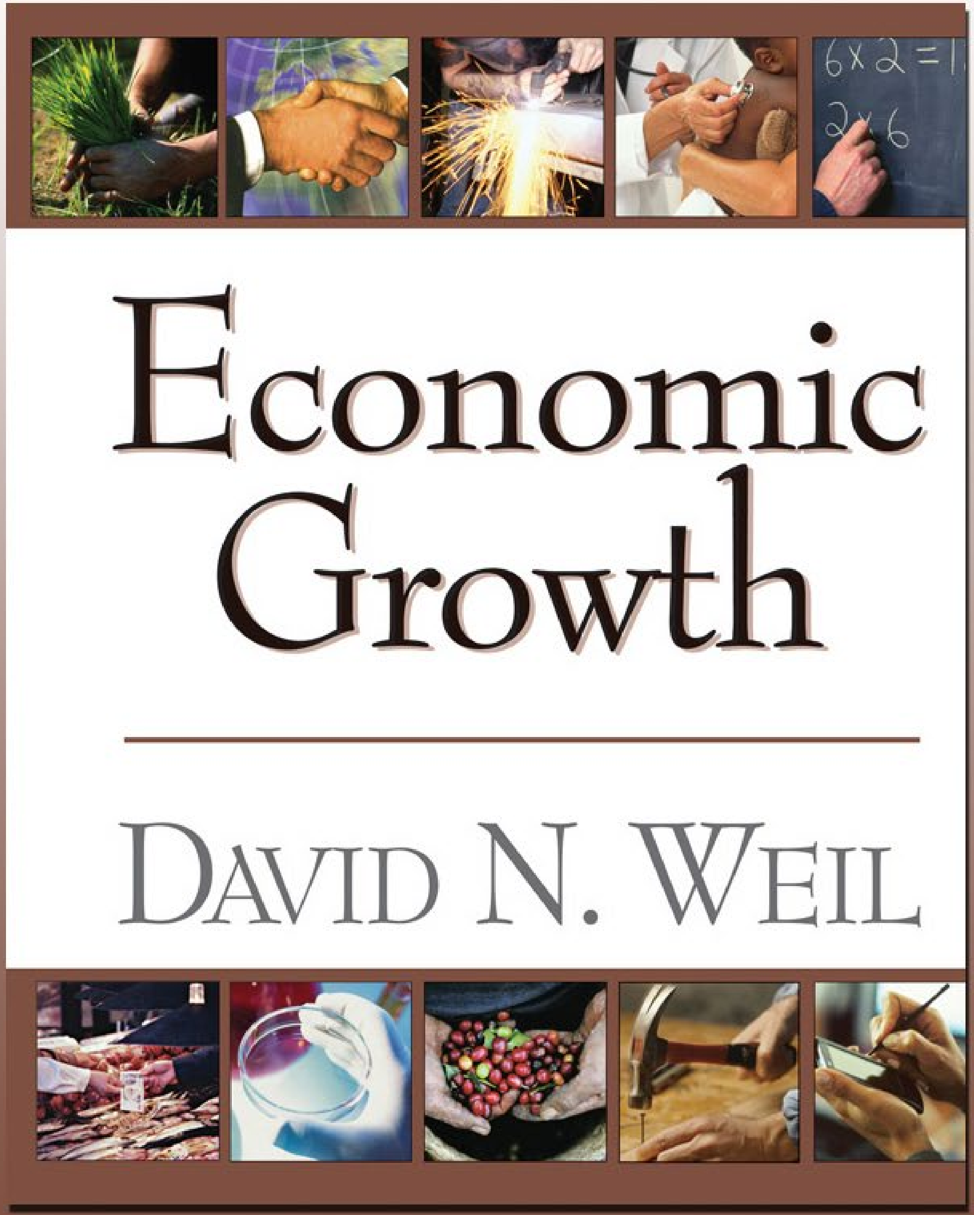
Table 3.1

Agricultural Land as a Fraction of Total Wealth in the United Kingdom

1688	64%
1798	55%
1885	18%
1927	4%
1958	3%

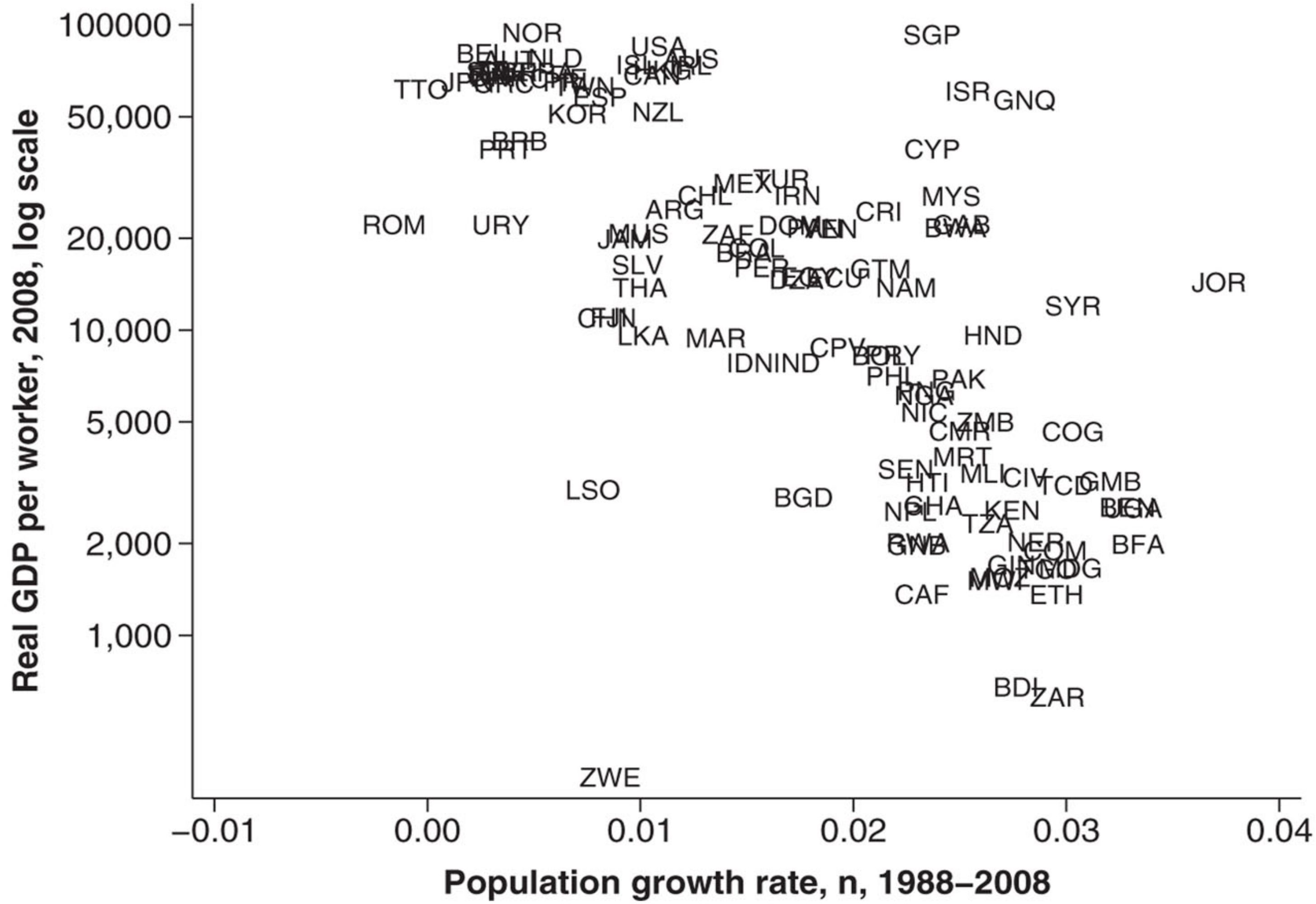
Chapter 4

Population and Economic Growth



- A useful starting point is some of the data about population growth and economic performance
  - In, fact we will examine two important findings that may seem contradictory – though later we will develop a model that can explain them both
- First finding: A negative cross-country relationship between population growth rates and output per-capita
  - Countries with higher population growth have lower real GDP per-capita, on average, or GDP per-worker

FIGURE 2.7 GDP PER WORKER VERSUS POPULATION GROWTH RATES



Introduction to Economic Growth, 3rd Edition

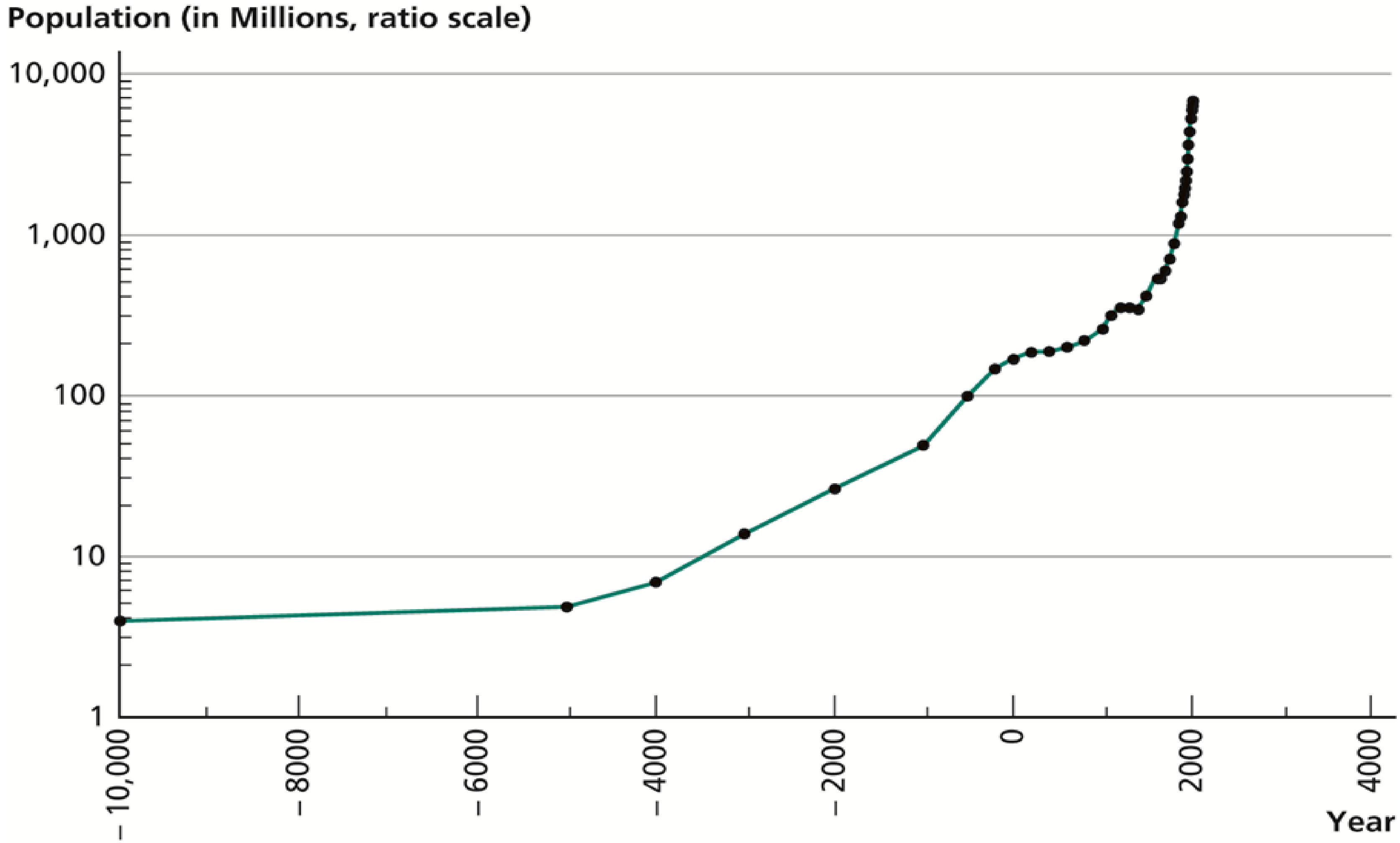
- Why might there be a negative relationship?
  - In trying to answer this question, we face a common dilemma in economics: The data did NOT come from a scientific experiment

  Hence, there are at least 3 possible explanations for the empirical finding:

    - More population growth has a negative effect on GDP per-capita
    - Higher income per-capita causes population growth to fall,
      - Perhaps, for some reason, higher income per-capita causes people to have smaller families
    - Some omitted 3rd factor affects population growth and income per-capita, driving them in opposite directions
- We will provide explanations for this fact

- Next we examine population growth which has been trending upward over most of time
  - Population growth rates have varied somewhat over time
    - Recall that by using a ratio scale, the growth rate is equal to the slope of the line
      - Not true when we use a levels scale
    - We can determine from the following graph that for most of the time population growth has been rather slow

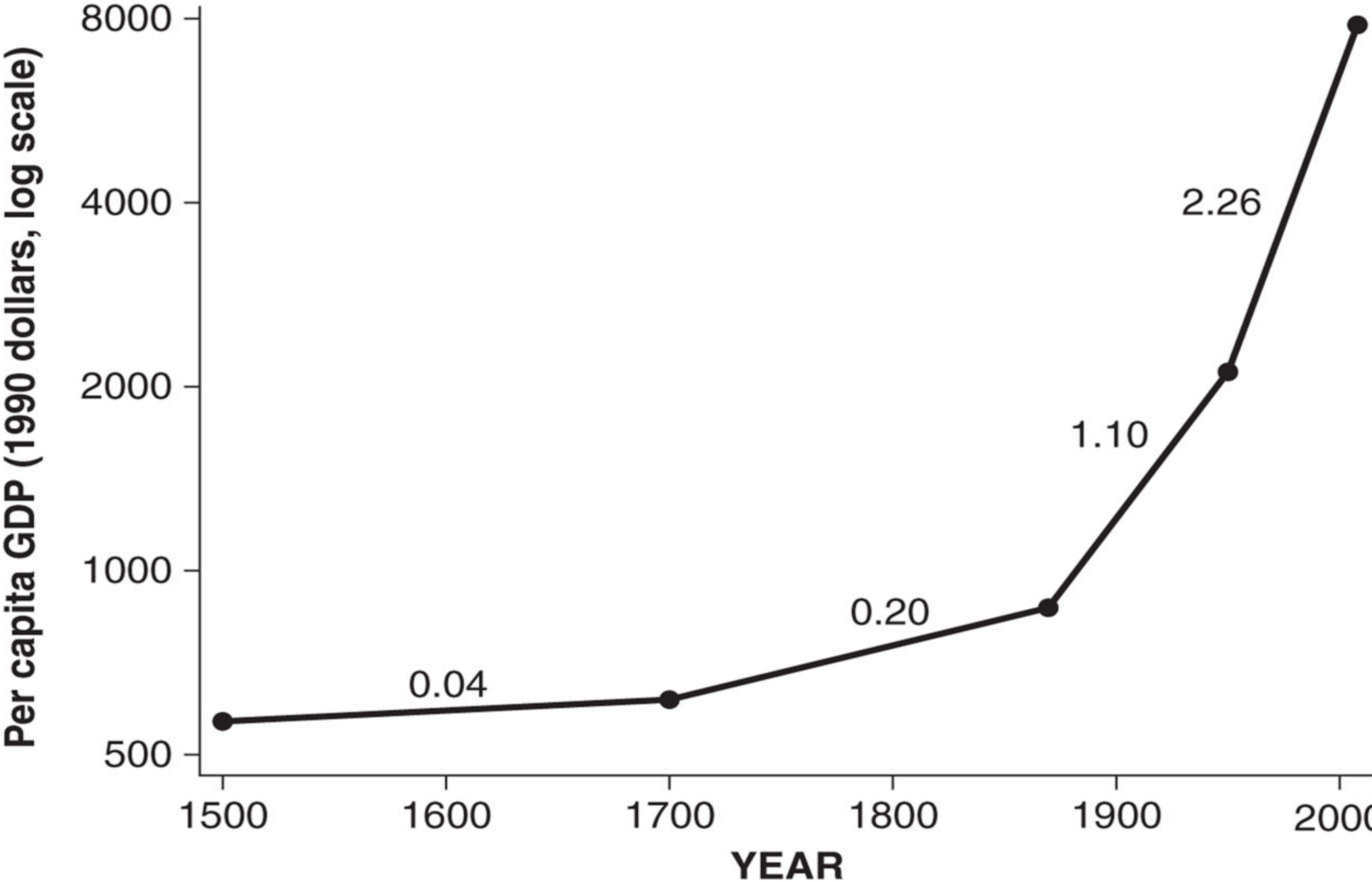
Figure 4.2 World Population, 10,000 B.C. to A.D. 2010



- 12000 years back the number of people in the world was less than 4 million
  - There are more people living in the metropolitan areas of Kansas City and St. Louis combined than were alive on the planet 12000 years ago
  - From 10000 BCE to 5000 BCE the population growth rate was nearly zero
- 6000-8000 years ago the population growth rate started to rise a bit faster. It doubled 3 times (grew by a factor of 8) from 4000 BCE to 1000 BCE
- Even 1000 years ago, the population of the whole world was roughly equal to the current US population
- The slow rate of population growth continued until the 18th century (i.e. 1700s), at which point in time the world population growth rate started to rise and in fact this growth rate continued to rise (as we will see later)
- World population growth seems to have been faster in the last half of the 20th century than at any other time period, averaging about 1.8% per year (although you can’t really tell that from this graph)

- It is interesting to examine changes in the world’s per capita GDP growth rate
  - And in doing this compare changes in world GDP growth to changes in world population growth

FIGURE 1.3 WORLD PER CAPITA GDP AND GROWTH RATES, 1500–2000



- When we compare changes in world GDP growth to changes in world population growth we obtain two interesting findings
  - World output per-capita began growing at a faster rate at roughly the same time that the world population growth rate increased
    - This happened some time around 1800
      - This period in time is known as The Industrial Revolution (or the First Industrial Revolution)
  - Output per-capita in the world began growing at its fastest rate ever in the second half of the 20^{th} century, and this change coincides with world population growing at its fastest rate ever

- The fact that world population growth rate has a positive relationship to world GDP growth rate may seem puzzling when combined with the previous empirical fact:

  Across countries there is an inverse relationship between population growth rate and the level of output per capita

- How does population growth affect variables in the Solow model?
  - For a fixed level of capital (K), a higher population (L) reduces capital per person (k) and so output per person (y) would also be smaller
    - This effect of population on capital is known as capital dilution (As L gets larger a given stock of capital must be shared by more workers)
  - for output per capita to reach a steady state, capital per person must also reach a steady state
    - Thus if population grows, capital must grow at the same rate as population growth to maintain a steady state capital per person

- We need to modify the capital accumulation equation to allow for population growth since we derived the earlier version assuming there was no population growth
- First, we will show that the earlier capital accumulation equation doesn’t work properly and then we will repair it

- Recall our capital per person accumulation equation (assuming fixed population)

$$\Delta k = \gamma \cdot A \cdot f(k) - \delta \cdot k$$

- We know that by dividing both sides of this equation by k we get an expression for the growth rate of k

$$\frac{\Delta k}{k} = \hat{k} = \gamma \cdot A \cdot f(k)/k - \delta$$

- Suppose that the investment rate and the depreciation rate are equal to zero. In that case the last equation says that k grows at the rate zero. If k growth is zero then k is at some constant value.
- Recall an even earlier equation: $\Delta K = I - D$
  - If the investment rate = 0, investment = 0
  - If the depreciation rate = 0, depreciation = 0
  - Thus $\Delta K = 0$, which means K grows at a rate of zero (divide both side of the equation by K, to get $\Delta K/K$
- Here's the problem: $k = K/L$
  - If K is NOT growing while L is growing then k must be shrinking ---- it can NOT reach a positive steady state level
- We need to fix our $\Delta k/k$ equation

- Mathematical notes about growth rates:
  - Growth of (A•B) = Growth of (A) + Growth of (B)
  - Growth of (A/B) = Growth of (A) - Growth of (B)
  - Growth of (A^c) = c•Growth of (A) (for a constant c)
  - First for any variable A: $$\frac{d \ln A}{dt} = \frac{1}{A}\frac{dA}{dt}$$
  - Also note that $$\frac{1}{A}\frac{\Delta A}{\Delta t} \rightarrow \frac{1}{A}\frac{dA}{dt} \text{ as } \Delta t \rightarrow 0$$
    - This says that the growth rate over finite length of time converges to the growth rate in continuous time as Δt gets smaller and smaller

- We can now prove the previous results:
- Proof that
  - Growth of (A•B) = Growth of (A) + Growth of (B)

$$\ln(AB) = \ln A + \ln B$$

$$\frac{d\ln(AB)}{dt} = \frac{d(\ln A + \ln B)}{dt} = \frac{d\ln A}{dt} + \frac{d\ln B}{dt} = \frac{1}{A}\frac{dA}{dt} + \frac{1}{B}\frac{dB}{dt}$$

- HOMEWORK:

A. Prove that:

Growth of (A/B) = Growth of (A) - Growth of (B)

B. Prove that:

Growth of (A^c) = c•Growth of (A)   (for a constant c)

- We now know that: k=K/L implies $g_k = g_K - g_L$
  - For some reason economists like to define: $g_L = n$
  - So if $g_K = 0$, the first growth equation yields: $g_k = -n$
    - If K doesn't change and L grows at a rate n, k must shrink at the rate n (another way of saying "grow at the rate –n")
- This means we can adjust our Δk/k equation to account for population growth by subtracting n:

$$\frac{\Delta k}{k} = \hat{k} = \gamma \cdot A \cdot f(k)/k - \delta - n$$

- Then we can multiply both sides by k to adjust our Δk equation for population growth

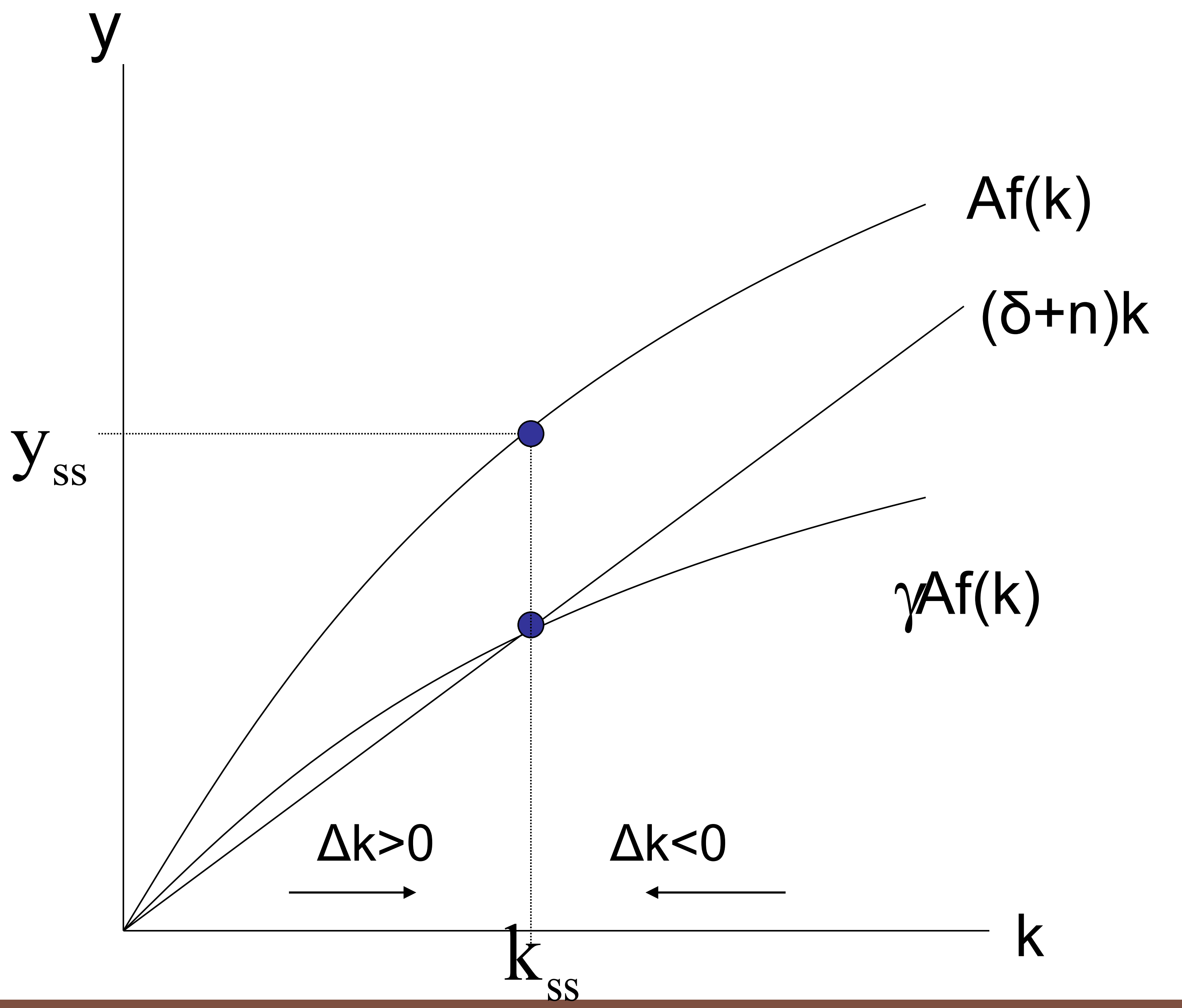
$$\Delta k = \gamma \cdot A \cdot f(k) - \delta \cdot k - n \cdot k$$

- The last equation holds for any values of the investment rate and the depreciation rate, not merely when the two are equal to zero
- Note that population growth shows up in the equation in much the same way as the depreciation rate
  - But instead of depreciating capital stock, population growth dilutes the capital stock
- Interesting questions: How does the addition of population growth in the Solow model affect the behavior in the model? Does this change improve the performance of the model?

- Graph

$$\Delta k = \gamma \cdot A \cdot f(k) - \delta \cdot k - n \cdot k = \gamma \cdot A \cdot f(k) - (\delta + n) \cdot k$$

for constant values of the investment rate, the depreciation rate, productivity, the parameters in the production function and population growth rate


y
Af(k)
(δ+n)k
y_{ss}
γAf(k)
Δk>0
Δk<0
k_{ss}
k

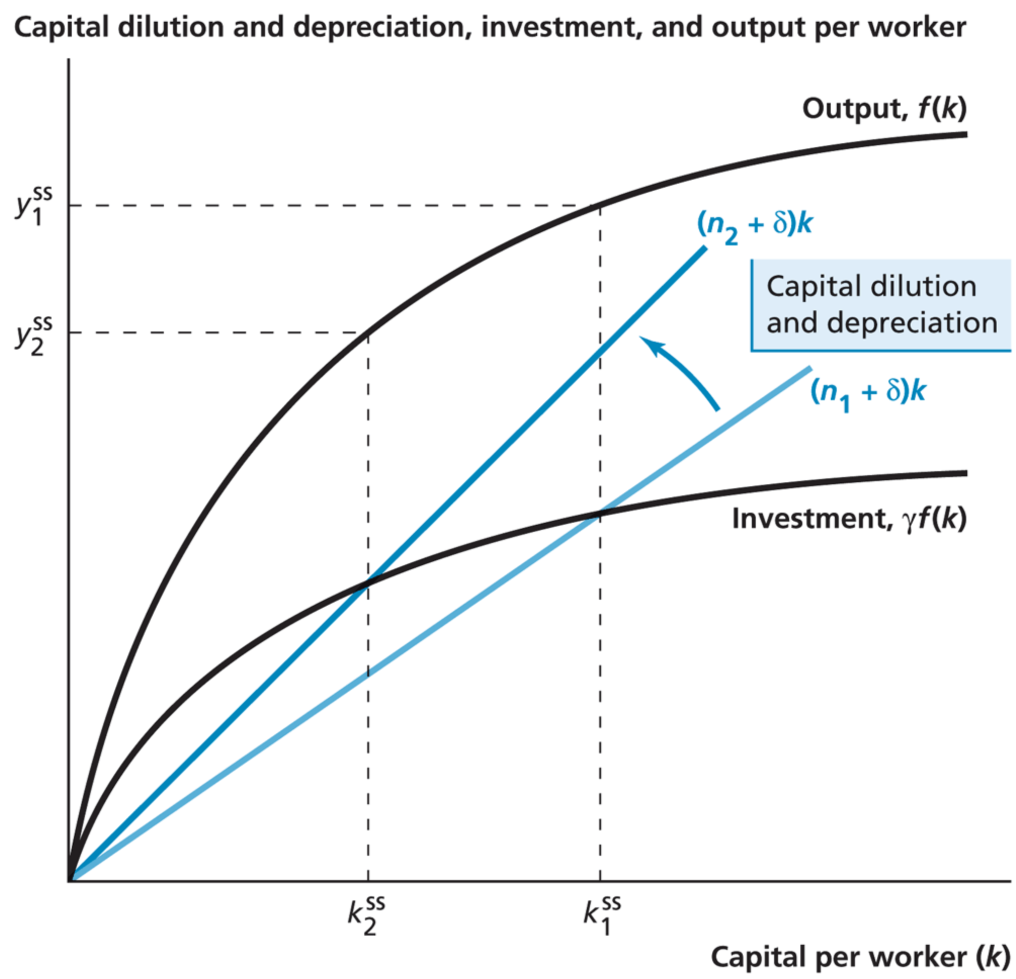
- Given constant values of all these parameters
  - We see that the model once again must have a steady state for k and y
    - Again this occurs when $\Delta k=0$
    - population growth does not eliminate the steady state outcome for k and y in Solow's model
- If the economy stays in a steady state, population growth will NOT cause k to grow indefinitely

- The next question is can a change in the population growth rate affect y and k in the steady state, and if so how?
- Assume the population growth rises

  from n_1 to n_2 with $n_1 < n_2$.

  – A rise in n rotates counter-clockwise the line associated with capital depreciation and capital dilution
  – If n falls it rotates that line clockwise

FIGURE 4.7
The Solow Model Incorporating Population Growth



The figure shows how raising the population growth rate from n_1 to n_2 affects the steady-state level of capital per worker (k) and the steady-state level of output per worker (y).

- An increase in n, the population growth rate, reduces k and y in the steady-state
- An increase in n has a quantitatively similar effect on k and y as an increase in δ
  - However, the mechanism by which it works is somewhat different
    - increased n causes capital dilution, forcing more workers to use the same amount of capital, thus shrinking capital per worker which leads to less output being produced by a worker
      - In contrast, an increase in δ causes capital to wear out faster, but that yields a quantitatively similar effect on y and k

- So a reduction in n causes y to rise in the steady state
  - Once again, someone might think that n could keep falling over time and that would cause y to keep rising.
    - We don’t observe countries with faster growth having a continuous decline in n
    - Over the long run, if declining n were the source of rising y, n would eventually have to become negative, and then. It would have to become becomes increasingly negative to get y to rise even more.
      - Problem: If n is negative, the population will keep shrinking and eventually shrink to zero

- We can do quantitative analysis with this modification to the Solow model
  – Assuming a Cobb Douglas production function, in our new Δk equation, we obtain

$$\Delta k = \gamma \cdot A \cdot k^{\alpha} - \delta \cdot k - n \cdot k$$

- And the steady state occurs when $\Delta k=0$
- The following calculation are exactly the same as before except that we have $\delta+n$ in place of δ

- When $\Delta k=0$:

$$\gamma \cdot A \cdot k_{ss}^{\alpha} - (\delta + n) \cdot k_{ss} = 0$$

- Solve for the k_{ss}:

$$\gamma \cdot A \cdot k_{ss}^{\alpha} = (\delta + n) \cdot k_{ss}$$

$$\frac{k_{ss}}{k_{ss}^{\alpha}} = \frac{\gamma \cdot A}{\delta + n}$$

$$k_{ss}^{1-\alpha} = \frac{\gamma \cdot A}{\delta + n}$$

$$k_{ss} = \left(\frac{\gamma \cdot A}{\delta + n} \right)^{1/(1-\alpha)}$$

- Then we can solve for $y_{ss:}$: $y_{ss} = A \cdot k_{ss}^{\alpha}$

$$y_{ss} = A \cdot \left[\left(\frac{\gamma \cdot A}{\delta + n} \right)^{1/(1-\alpha)} \right]^{\alpha}$$

$$y_{ss} = A \cdot \left(\frac{\gamma \cdot A}{\delta + n} \right)^{\alpha/(1-\alpha)}$$

$$y_{ss} = A^{(1-\alpha)/(1-\alpha)} \cdot A^{\alpha/(1-\alpha)} \cdot \left(\frac{\gamma}{\delta + n} \right)^{\alpha/(1-\alpha)} = A^{1/(1-\alpha)} \cdot \left(\frac{\gamma}{\delta + n} \right)^{\alpha/(1-\alpha)}$$

- Our final result is:

$$y_{ss} = A^{1/(1-\alpha)} \cdot \left(\frac{\gamma}{\delta + n} \right)^{\alpha/(1-\alpha)}$$

- Suppose we have two countries, Country i and Country j. Each may have its own steady state, y_i and y_j, and the ratio of the steady states is:

$$\frac{y_i}{y_j} = \frac{A_i^{1/(1-\alpha_i)} \cdot \left(\frac{\gamma_i}{\delta_i + n_i} \right)^{\alpha_i/(1-\alpha_i)}}{A_j^{1/(1-\alpha_j)} \cdot \left(\frac{\gamma_j}{\delta_j + n_j} \right)^{\alpha_j/(1-\alpha_j)}}$$

- The previous equation allow each country to potentially have a unique value n, α, δ, A or γ
- Suppose the population growth is the only thing that differs across countries.
  - Then $A_i=A_j$, $\alpha_i=\alpha_j$, $\delta_i=\delta_j$, and $\gamma_i = \gamma_j$
    - And our general result simplifies as follows:

$$\frac{y_i}{y_j} = \frac{A_i^{1/(1-\alpha_i)} \cdot \left(\frac{\gamma_i}{\delta_i + n_i}\right)^{\alpha_i/(1-\alpha_i)}}{A_j^{1/(1-\alpha_j)} \cdot \left(\frac{\gamma_j}{\delta_j + n_j}\right)^{\alpha_j/(1-\alpha_j)}} = \left(\frac{\delta + n_j}{\delta + n_i}\right)^{\alpha/(1-\alpha)}$$

- We set α=1/3 for the same reasons as before and obtain:

$$\frac{y_i}{y_j}=\left(\frac{\delta+n_j}{\delta+n_i}\right)^{1/2}$$

- Let the depreciation rate = .05 (5%)
- Now take the widest range of plausible n:

$n_i = 0 \qquad n_j = .04\ (4\%)$

- observed today

$$\frac{y_i}{y_j}=\left(\frac{.05+.04}{.05}\right)^{1/2}=(9/5)^{1/2}=1.34$$

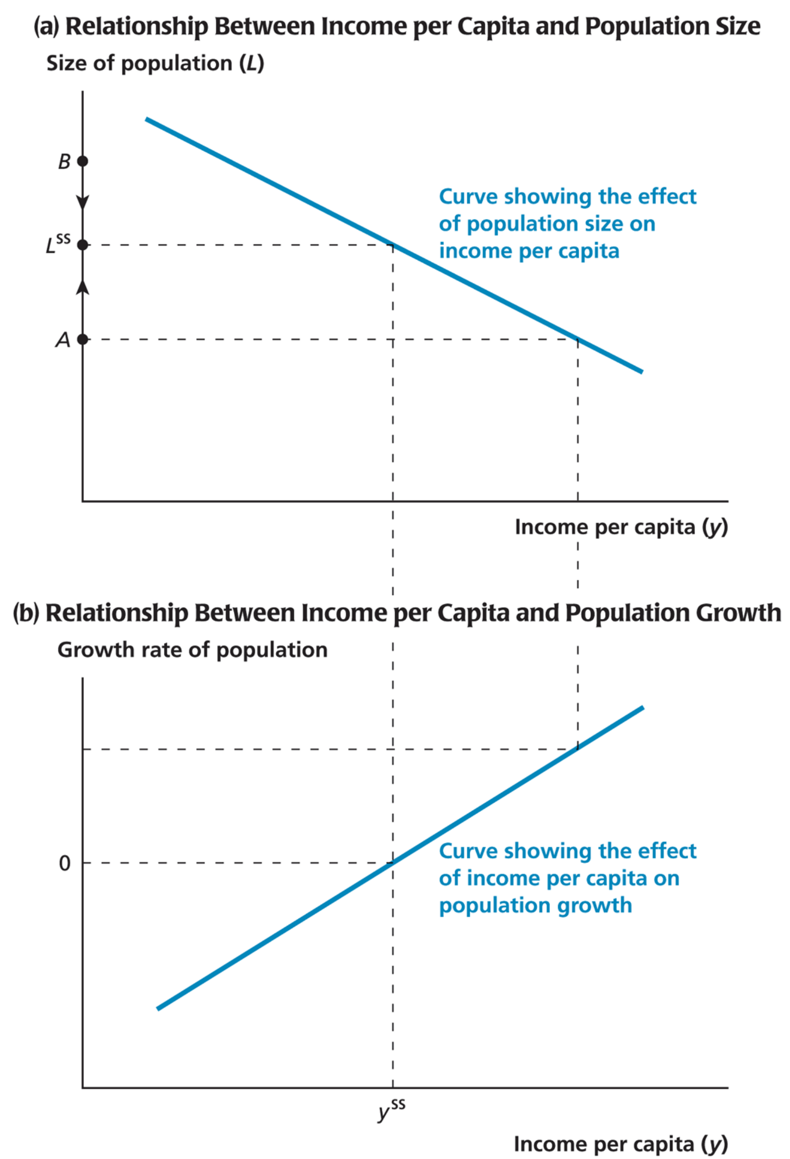
- The conclusion from the previous quantitative exercise: In the Solow growth model, a country with zero population growth will have only about 34% higher GDP per capita than countries with a population growth rate of 4%.
  - The range of between 0% and 4% is about the widest range for n seen in countries of the world over long periods of time
- This result means that in the Solow model, population growth rates can not explain the wide range of outcomes for output per capita that we see today
  - Ratios of over 50, rather than 1.34!

Exam 1 will cover material up to here

- The Malthusian Model

- The Malthusian Model
  - Depends on two relationships
    - Income per capita falls when population increases (and income percapita rises when population falls)
      - Reason: Resources, land in particular, is shared amongst more people. As resources-per-capita fall people produce less output-per-capita
    - Population growth changes with income per capita
      - Reason: When there is a decline in income-per-capita, people have fewer children. Population falls or population growth declines.
- The following graph illustrates these two relationships

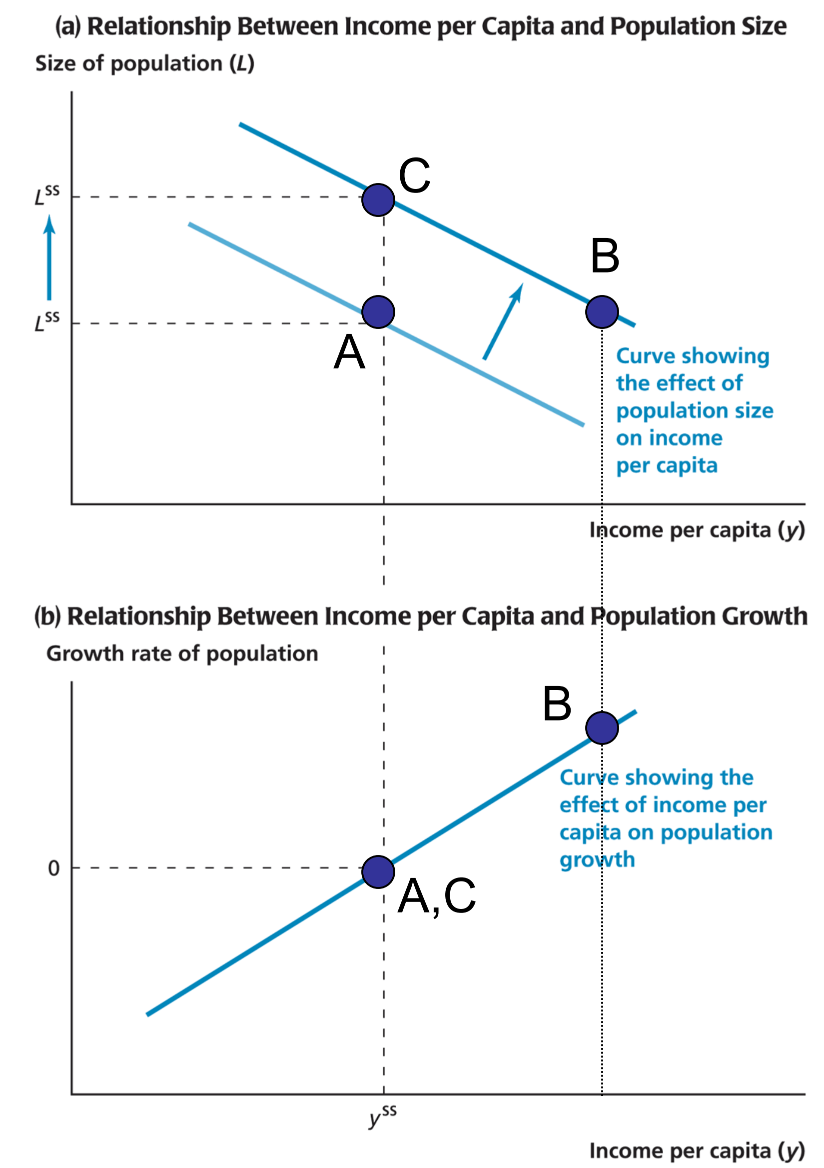
FIGURE 4.3
The Malthusian Model



- The Malthusian Model will reach a steady state when population growth rate is zero
- If the economy is not at its steady state, changes in the economy will tend to push the economy toward its steady state
- We can use this model to analyze different circumstances

- Suppose there is some change to the economy causing workers to be more productive
  - An example: If a technological innovation causes us to be able to produce more food per acre of land
    - This affects the relationship that output per capita has with labor
      - the amount that each worker can produce increases
      - Hence improved productivity shifts this curve to the right

FIGURE 4.4
Effect of Productivity Improvement in the Malthusian Model

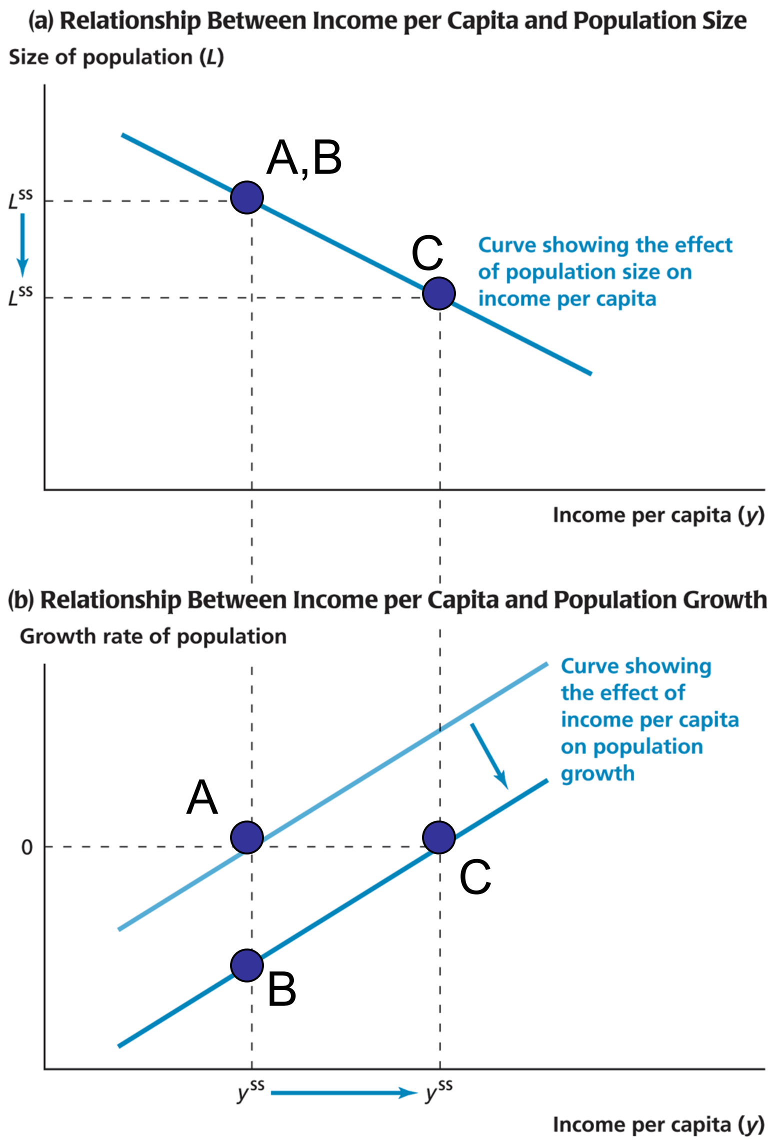


- The initial effect of incased productivity would be for output per capita to rise
  - Labor does not adjust immediately to this new circumstance
- However higher output-per-capita causes population growth to increase
  - Over time, rising L reduces y
  - L continues to rise and y continues to fall, until the adjustment is complete and the economy is back to the steady-state where L and y are no longer changing
- In the steady state, output per capita returns to its initial level and population is higher
  - Along the path to steady state, y would be higher than its steady state value
  - The ultimate effect of higher productivity would be higher population and not a higher level of output per capita

- The previous analysis assumed a one-time increase in productivity.
- Later we will allow productivity rises continually over time

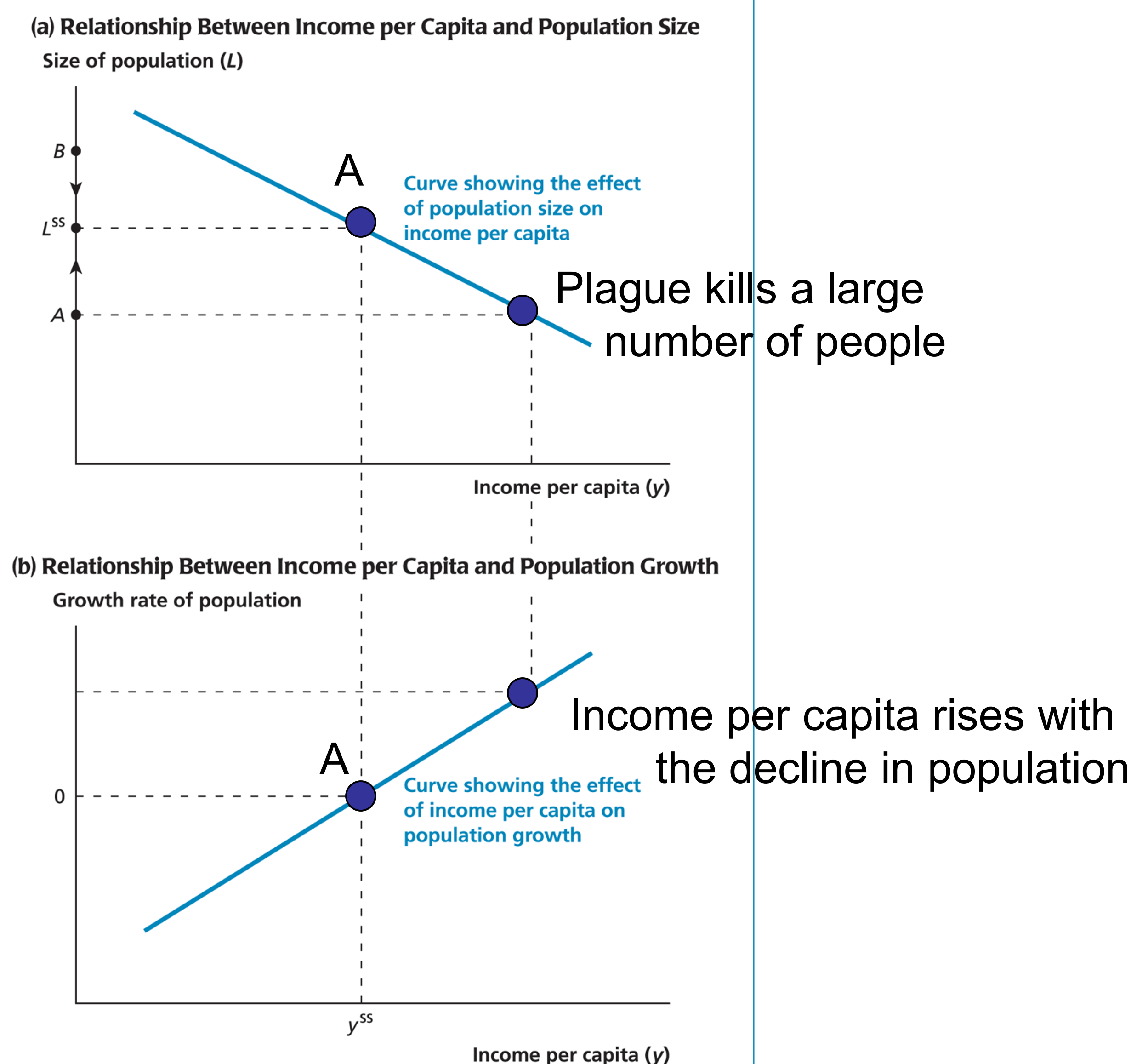
- In the Malthusian model, a permanent increase in productivity does not make people better off in the long run. What can?
  - Reducing the number of births i.e. lower fertility
    - This is illustrated in the following graph

Figure 4.5
Effect of "Moral Restraint" in the Malthusian Model



- How well does the Malthusian model work, in practice?
  - Countries with higher productivity will be larger without having a much higher standard of living
    - Ancient China (and also during the first half of the Medieval period) was a technological world leader. Its population grew enormously while its standard of living was a little bit better than the technologically-inferior Europe of that time period
  - The relatively meager improvement in standard of living from ancient times until about 200 years ago is explained by this model
  - The model explains another historical experience
    - The effects of a Plague
      - L is reduced but No Shift in either curve

FIGURE 4.3
The Malthusian Model



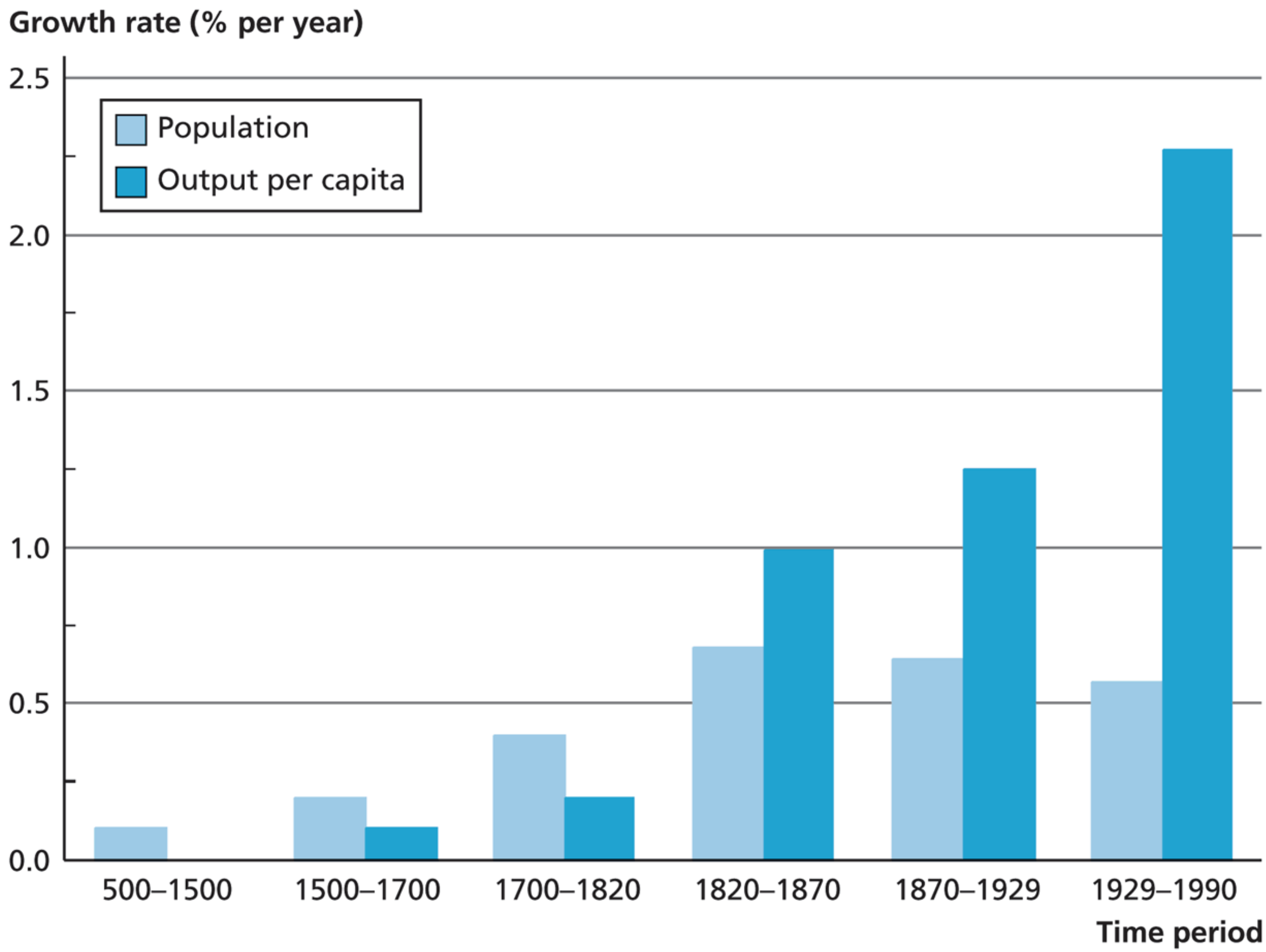
- The decline in population from a plague raises income per capita
  - With fewer people there are more resources per person
- A plague also raises the real wage that labor earns.
  - Profit maximization yields that the real wage equals the marginal product of labor:

$$\frac{W}{P} = (1-\alpha)AK^{\alpha}L^{-\alpha}$$

  - We see that a decline in L raises the real wage by raising the marginal product of labor
    - Intuitively, when labor is more scarce it becomes more valuable
- Both income per capita and real wages appear to have risen during the various plagues for which we have data

- The Malthusian Model can explain some of the historical experiences of Western Europe, but it also fails in some very important ways.

FIGURE 4.6
Breakdown of the Malthusian Model in Western Europe



Source: Galor and Weil (2000).

- The model is a particular good description of the period between 500 and 1500
  - During that period, population grew at a small rate while there was no growth in output-per-person
- From 1500 to 1700 population and income per capita both begin to grow a little faster
- And from 1700 to 1820, the growth rate for each of these two variables increases a little more
  - These two periods can be explained by the Malthusian model if these periods experienced persistent technological improvement. In that case, population grows at a faster rate and there is a small amount of growth in output-per-capita

- However, after 1800 the growth rate of output per capita and population growth rate were much larger than they were prior to 1800
  - And the rise in the growth rate of output per capita is much greater than the rise in the population growth rate
    - The Malthusian model can not explain this fast rise in output per capita because in that model the only way output per capita can grow at a high rate is if population is shrinking at a fast rate (negative population growth)

The Malthusian Model: The case of continual productivity growth

- If g_A increases in the Solow model, the output per capita growth rate will increase
- This is not the case for the Malthusian Model, as we will now determine

- Start with the production function that has a fixed supply of land (no capital)

$$y = A\left(\frac{\text{LAND}}{L}\right)^{\alpha}$$

- From this equation and our previous analytical results for growth rates:

$$g_y = g_A - \alpha g_L$$

- Where g_i for i = y, A or L, refers to the growth rate of y (output per capita) or A (productivity) or L (labor)

- Now recall the key equation from the Malthus model - population growth is positively related to the level of output per capita:

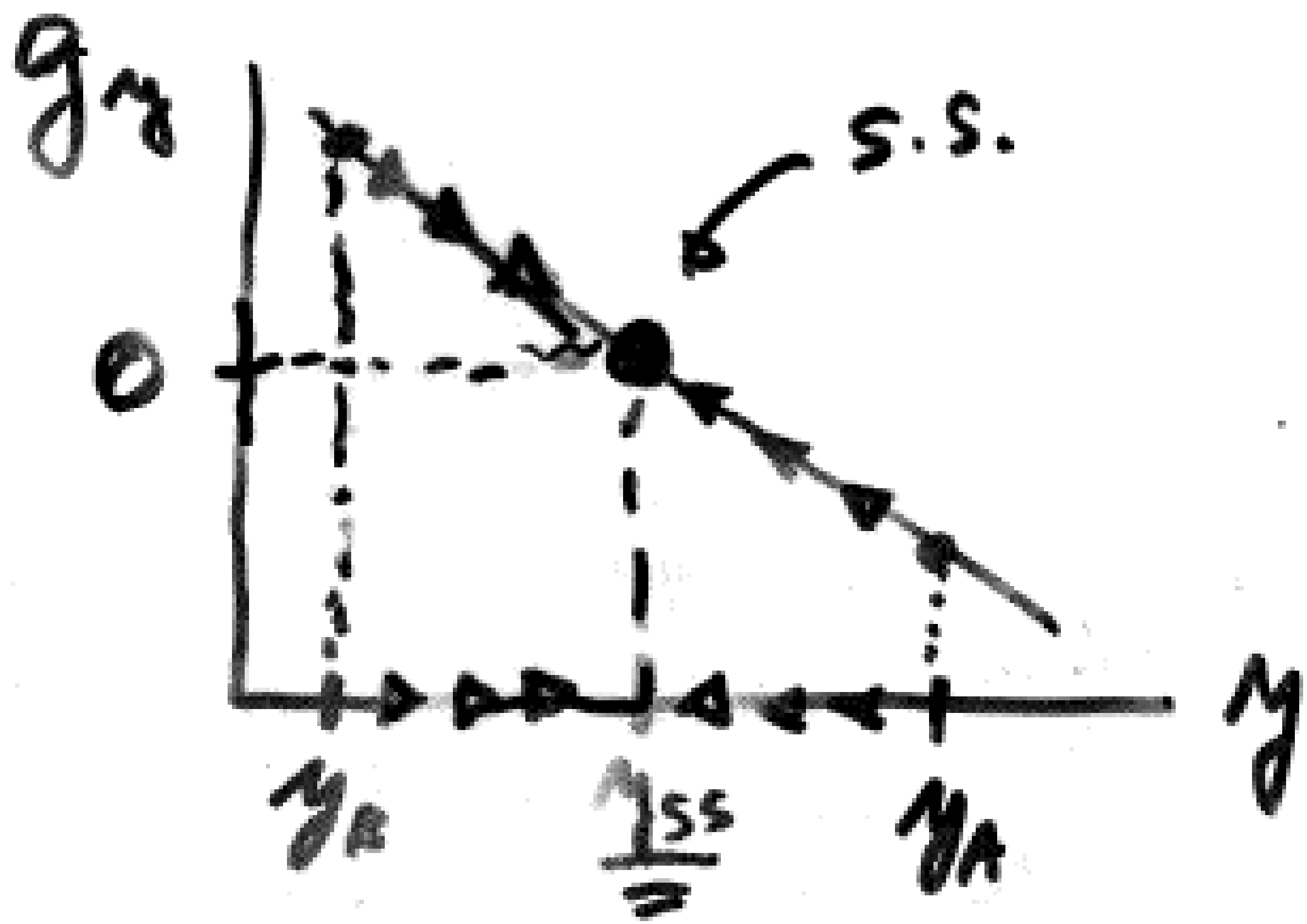
$$g_L = \beta y$$

  – β indicates how much the family size rises with y.

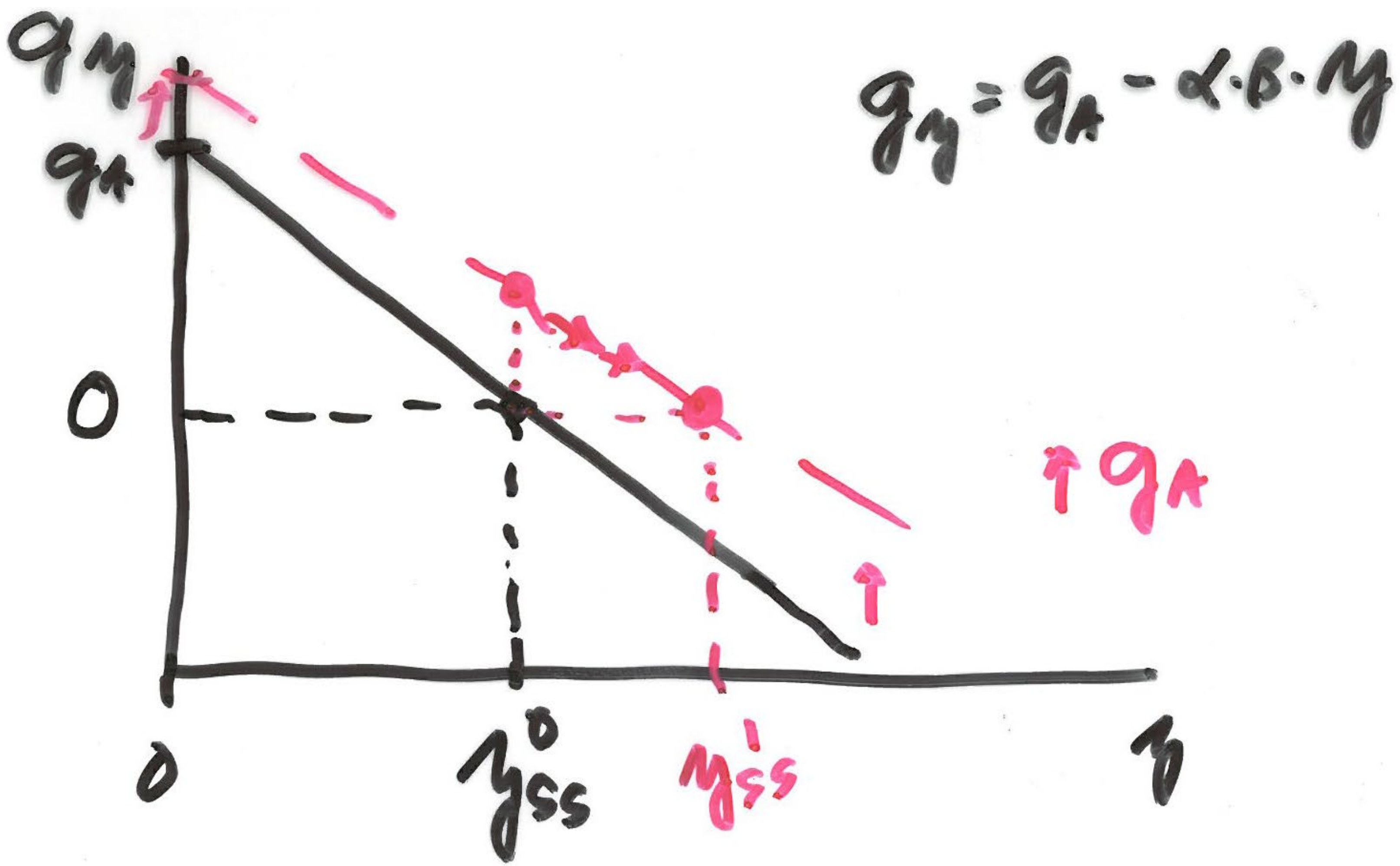
- Inserting this equation into the previous equation for output growth yields:

$$g_y = g_A - \alpha\beta y$$

- From this equation we can see why a steady state level in y must occur.
  - If g_y is positive y is rising, but that pushes g_y downward. This back and forth continues until g_y hits zero. Then it will stay at this steady state level
  - If g_y is negative y is falling and that will push g_y up until it finally hits zero. Then it will stay at this steady state level
- The following graph indicates what is happening:


g_y
0
S.S.
y
y_B
$\underline{y_{SS}}$
y_A

- Now we examine what happens when g_A increases.
- Start from the case of zero output growth (i.e. the time 0 or initial steady state y_{ss}^{0}).
- An increase in g_A shifts the entire curve upward (to red line) and output growth becomes positive. (See next slide)



$g_y = g_A - \alpha \cdot \beta \cdot y$
g_y
g_A
0
0
y_{ss}^0
y_{ss}^1
y
$\uparrow g_A$

- Positive growth in y means that y is rising. As that happens we move down the curve to a lower but still positive growth rate of y.
- y rises until eventually the growth in y is zero, and at that point a new steady state level of y is achieved: y_{ss}^{1}
- Thus, in the Malthusian Model a permanent increase in productivity growth has a permanent positive effect on the level of y, but …..
- Growth in y eventually becomes zero.

What explains population and population growth?

- In the Malthusian model population is determined by productivity
  - Hence, population growth can result from productivity growth
    - Population and its growth rate are endogenous in the Malthusian model
      - Recall: Endogenous means determined by the model
- But the Malthus Model can not explain the outcomes for labor and output-per-person over the last 200 years
- Solow’s model takes population growth as exogenous
  - Recall: Exogenous means NOT determined by the model

The population rises when we are adding people to the economy faster than they are leaving

- People are added to an economy by
  - Being born into the country, OR
  - People immigrating to the country
- People are removed from an economy by
  - Death of people in the country, OR
  - People emigrating from the country

- The Population Growth Rate equals:

Birth Rate

+ Net Immigration Rate

- Death Rate

Birth Rate = Births/Pop

Death Rate = Deaths/Pop

Net Immigration Rate = Net Immigration/Pop

where Pop = Population

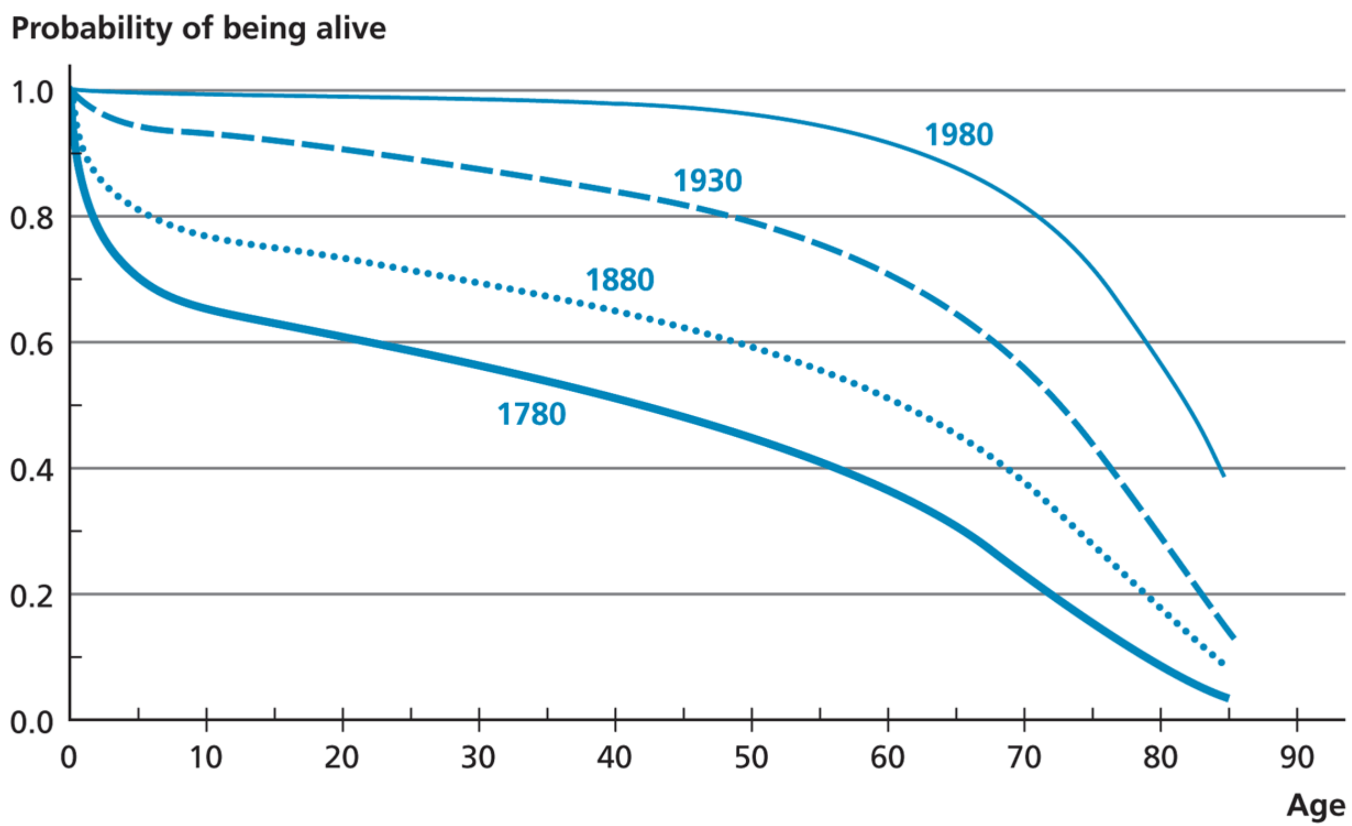
- Net Immigration Rate is small for most countries, most of the time
- For now, we concentrate on the BirthRate and the DeathRate as the key factors explaining population growth
  - Rarely is the Net Immigration Rate important, although, the rate for the US today is positive and a fairly high value

- DeathRate is sometimes called Mortality – it is the opposite of Life Expectancy
  - Life Expectancy is the number of years someone born in a particular year is expected to live
    - Life expectancy can vary a great deal across countries and across time within a particular country
    - An equation:

$$\text{Life expectancy at birth} = \sum_{i=0}^{T} \pi(i)$$

where π(i)=probability of being alive in year i and T is the maximum number of years anyone has ever lived

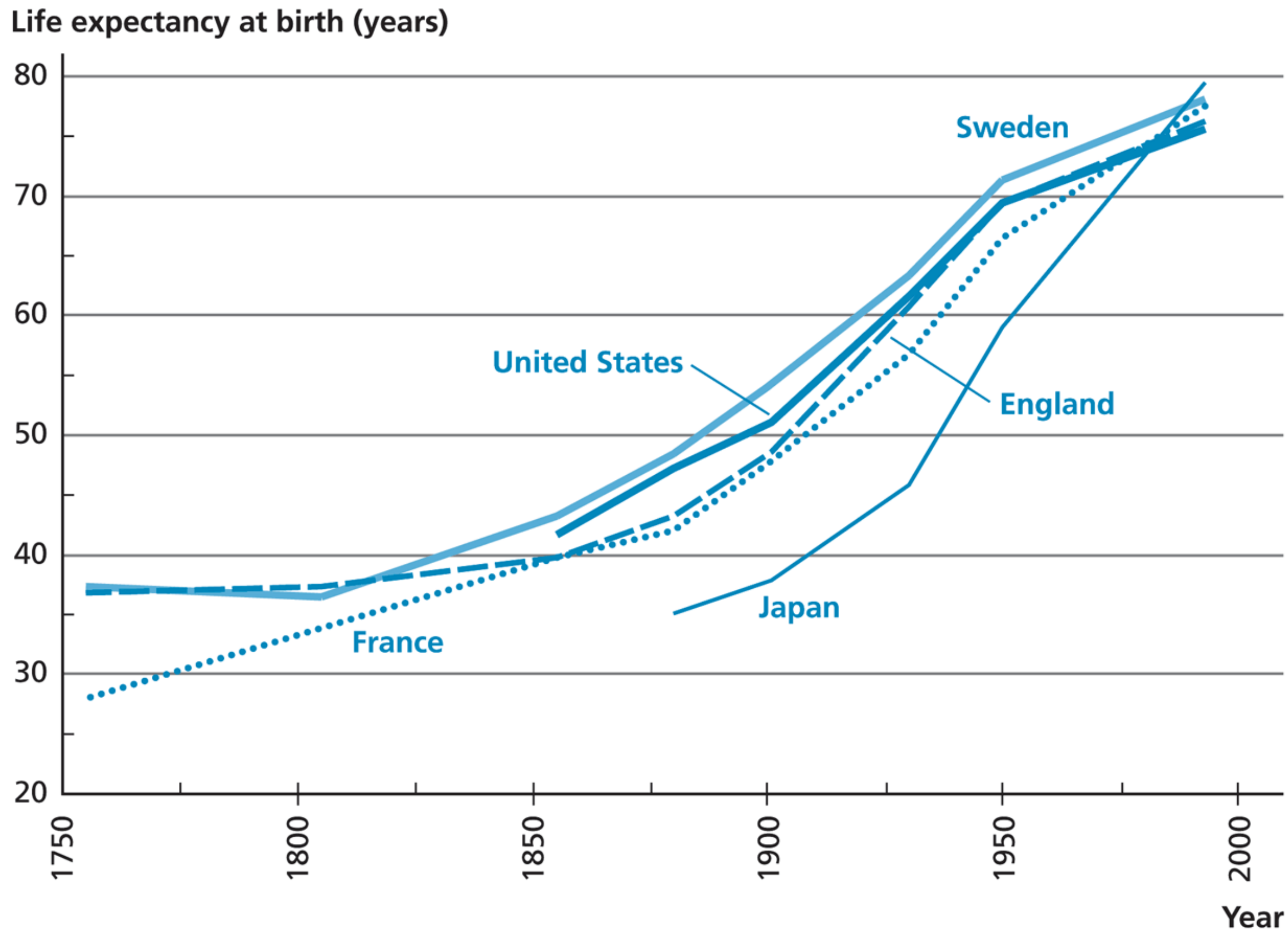
FIGURE 4.13
The Survivorship Function for Women in Sweden



Source: Keyfitz and Flieger (1968, 1990).

- We examine a selection of Developed and Developing Countries for some perspective on differences in Life Expectancy

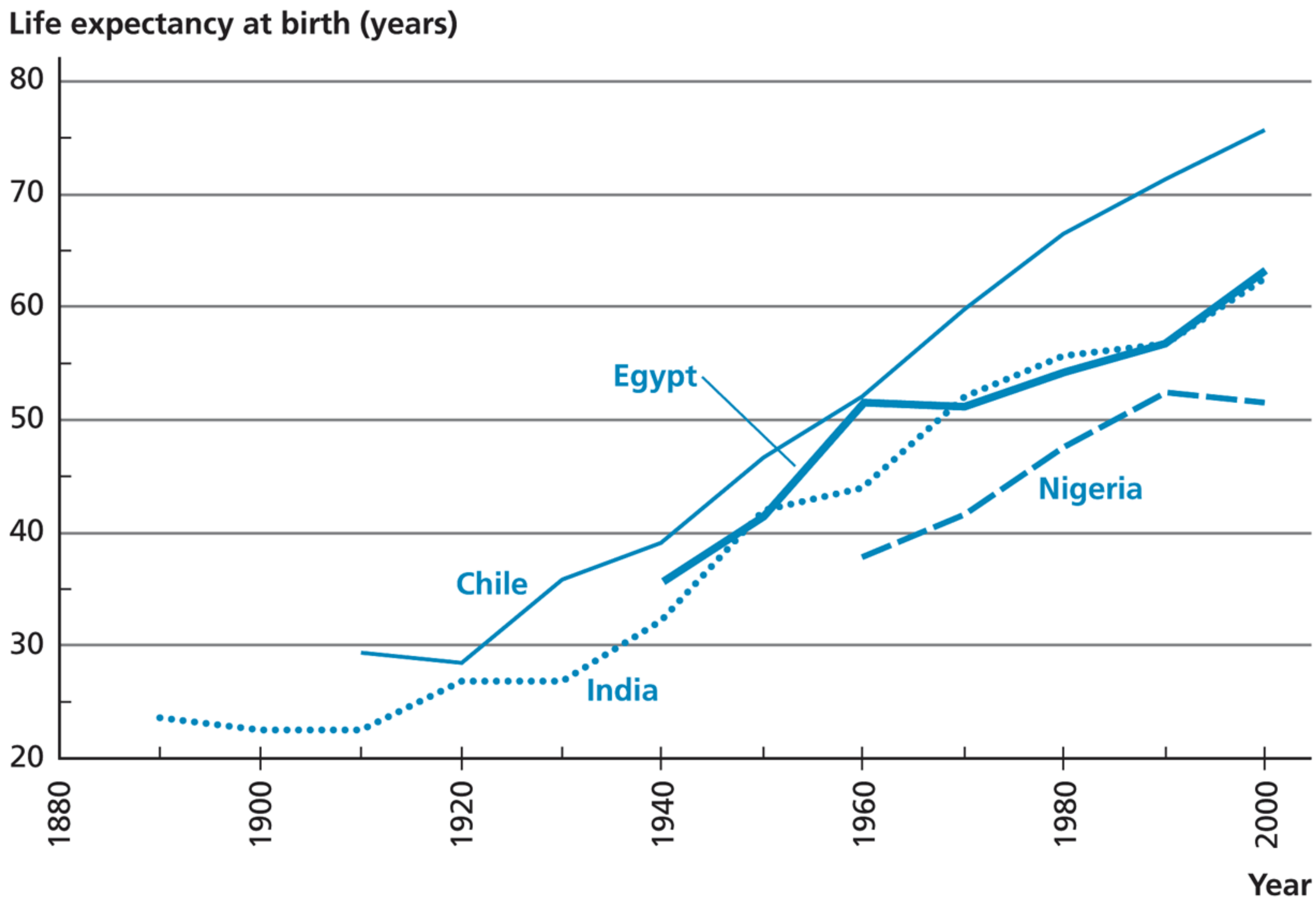
FIGURE 4.8
Life Expectancy in Developed Countries



Source: Livi-Bacci (1997).

- Life Expectancy tends to behave in a similar fashion to the trends in output-per-person for a country
  – There was little improvement in Life Expectancy before 1800 in the countries we now describe as Developed Economies
  – There has been an upward trend in Life Expectancy since 1800 for most of the developed countries
    - Note that Japan’s Life Expectancy started well below that of other Developed Countries, but now Japan’s life expectancy exceeds that of almost every other country
  – The next graph shows Life Expectancy for a number of developing countries

FIGURE 4.9
Life Expectancy in Developing Countries



Source: Kalemli-Ozcan (2002).

- Things to note about developing countries
  - In the early and mid 1900s, Life Expectancies were well below the measure for the developed countries
  - Life expectancies for many developing countries have risen at a much faster rate in recent years than in the developed world
  - For most developing countries, Life Expectancy is still less than that of most developed countries
  - Most poorer countries have reached higher Life Expectancies at levels of GDP per capita well below the level most developed countries had when they achieved a given Life Expectancy

- This evolution of Life Expectancies is sometimes called “The Mortality Transition”

- Why have Mortality rates been falling OR Why have Life Expectancies been rising?

There are 3 major factors in this declining mortality (a.k.a. rise in life expectancy)

1. Living standards have improved
   - Increases in food quantity and quality
2. Public health standards improved
   - Water quality improved and public sewage treatment systems were put in place
3. Medical treatments improved
   - New medicines and innovative procedures have been developed.

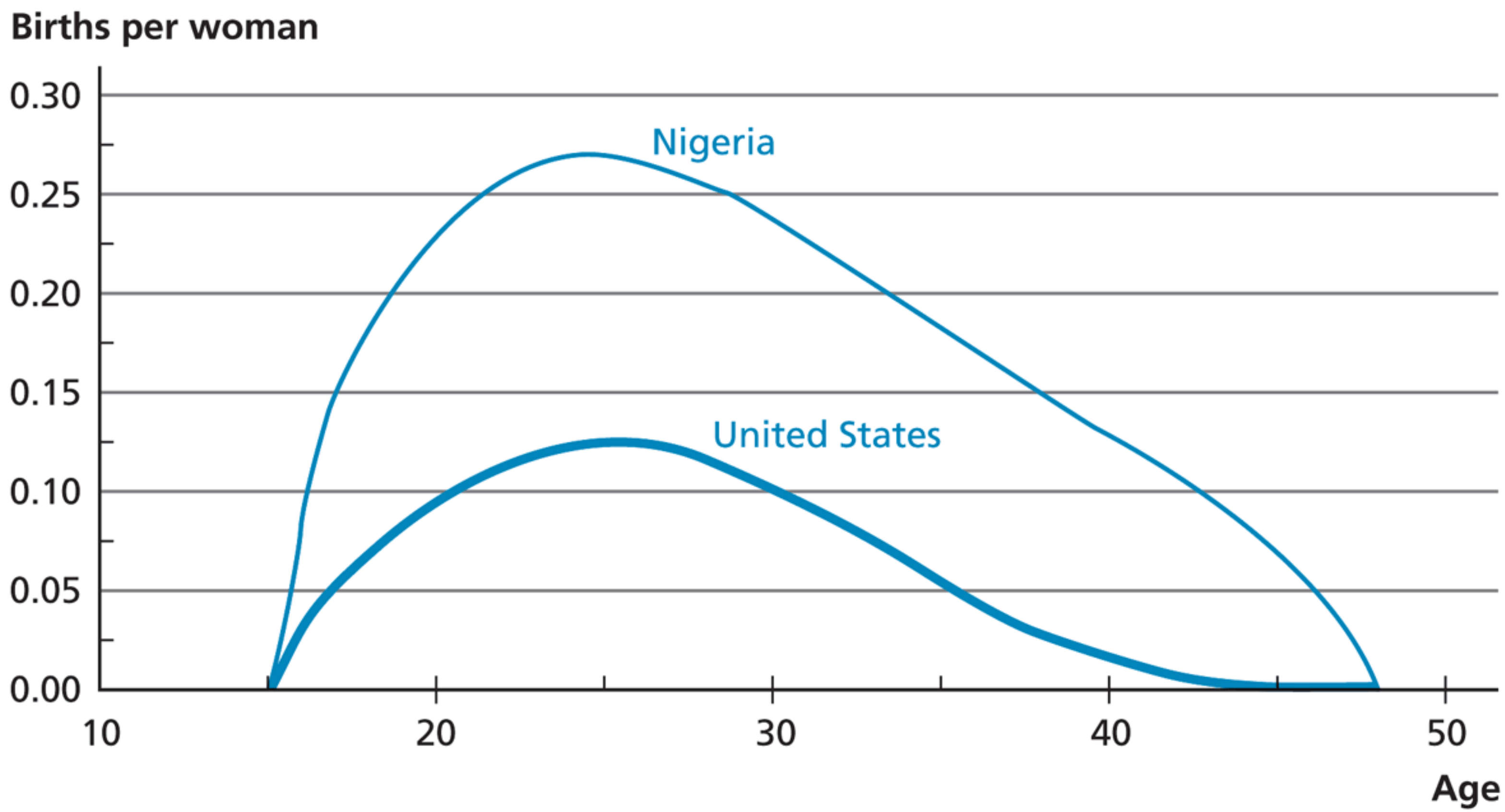
- These factors arose and developed gradually in the Developed world.
  - The 3 factors arrived over time in developed countries in the sequence listed above
- However, these factors were all available when developing countries were ready to adopt them
  - The developed world had already made these discoveries
  - Thus Mortality Rates declined a lot faster in the developing countries than they did in Developed countries

- The developed world’s relatively higher income per capita was essential for these developed countries to increase the quantity and quality of food, improve public health standards and develop new medicines and innovative procedures
  - In contrast, developing countries needed relatively less income per capita to adopt these 3 factors
    - Why? Because it is more costly, in general, to invent something new than it is to adopt something that has already been invented by someone else

- The BirthRate was the other key variable in the rate of population growth
- BirthRate is related to what demographers call the Fertility Rate
  - A Fertility Rate can measure the average number of children a woman will have during a certain period of time
    - It can vary over time and across age, personal income and other factors

- The Total Fertility Rate (TFR) is defined as the number of children a woman will have, on average, if she lives throughout all the childbearing years
- TFR = $\sum_{i=0}^{T} F(i)$ where F(i) = the age specific fertility rate

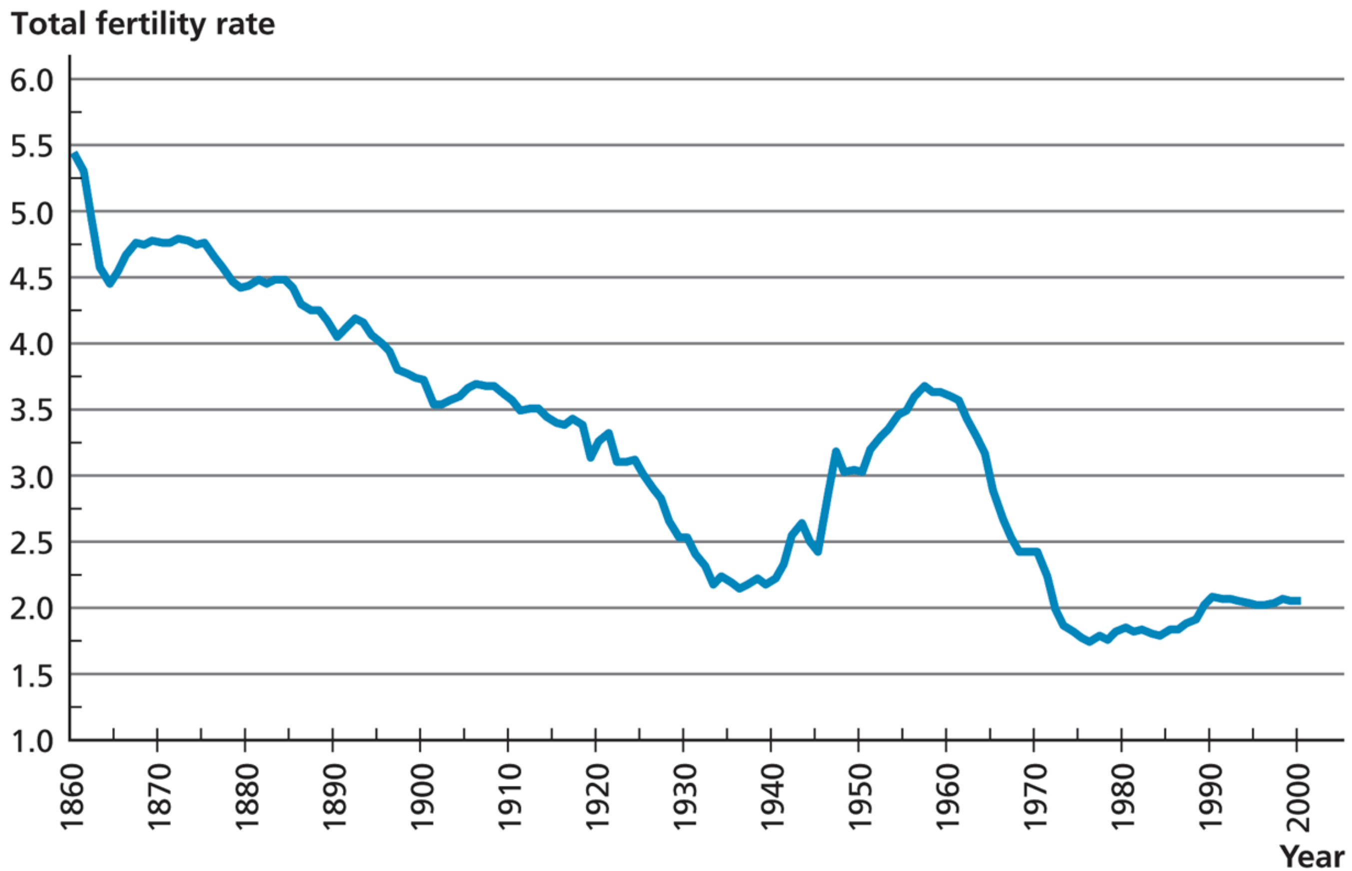
Figure 4.14
Age-Specific Fertility Rates



- An aggregate measure of total fertility uses the number of people in each age group and the fertility of each group to calculate the Total Fertility Rate.
- If there is no immigration, then TFR=2.1 is roughly the number of births each woman must provide to keep the population constant
- Looking at the Total Fertility Rate for the US over time …

FIGURE 4.10

Total Fertility Rate in the United States, 1860–2000



Source: Coale and Zelnik (1963), Wade (1989).

- Overall, there has been a trend downward from 1860 until WWII
  - There was a very large decline during the Civil War a notable pick up after that war, but then the trend was downward for more than half a century
  - There was a large drop in fertility during the Great Depression that lasted until the end of World War II
  - A very substantial rise in fertility occurred following the end of WWII
    - From 1946 to 1964 is called The Baby Boom

- Other developed countries experienced similar movements over time in their Total Fertility Rates

- Fertility rates in developing economies have fallen, but in a shorter span of time
  - The Total Fertility Rate for all the developing countries today is about half of what it was 30 years ago

Table 5.1 Fertility in the Developing World

	2004 Population (millions)	Total Fertility Rate, 1970–1975	Total Fertility Rate, 2000–2005
All developing countries	5093.60	5.50	2.90
Sub-Saharan Africa	689.6	6.80	5.50
Arab States	310.50	6.70	3.70
East Asia & Pacific excluding China	636.10	5.45	3.19
China	1307.99	4.90	1.70
South Asia excluding India	441.00	6.21	3.94
India	1087.12	5.40	3.10
Latin America and the Caribbean	548.30	5.10	2.60

Source: United Nations Development Program (2007).

- China stands out amongst the Developing regions with the largest decline in Fertility Rate since the 1970s
  - The reason: China implemented a “one child policy” rule
    - Obviously, with TFR a little less than 2 the policy is not perfectly enforced, but it did lead to a dramatic reduction in birth rates and population growth rate

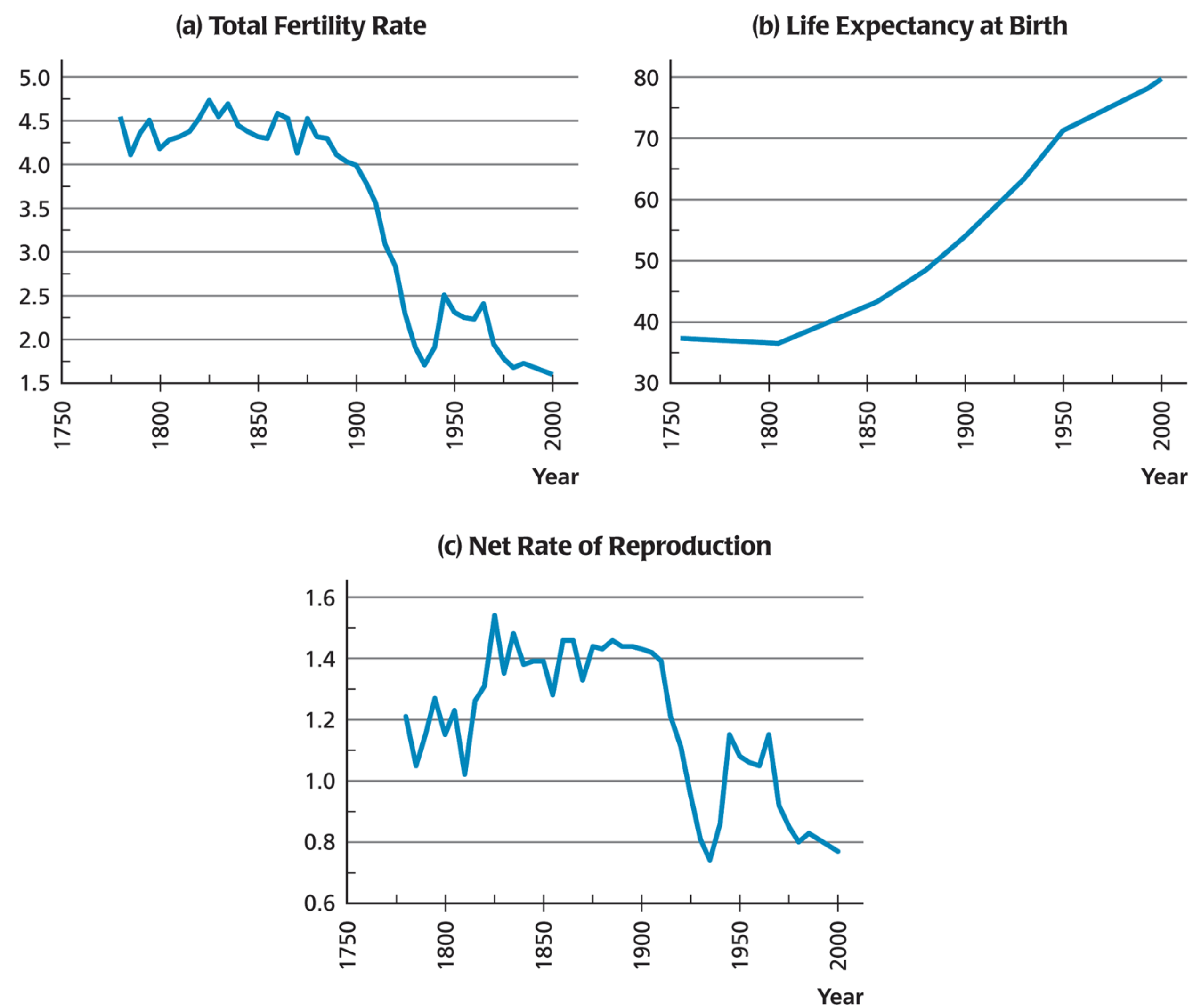
- The Net Rate of Reproduction (NRR) is closely related to the population growth rate.
  - It measures the average number of females that a female will produce in a lifetime
  - It is calculated using Fertility rates, Mortality rates and the percentage of live births that are female (represented by β)

$$\text{NRR} = \beta \bullet \sum_{i=0}^{T} \pi(i) \bullet F(i)$$

(When it comes to total population guys don't matter as much as we might have thought)

- If the NRR equals 1, population will remain constant, there is zero population growth
- NRR > 1 means the population growth is positive
- NRR < 1 means the population growth is negative – population is declining
- NRR = 2, population will double every generation

FIGURE 4.11
Fertility, Mortality, and the Net Rate of Reproduction in Sweden



Sources: Keyfitz and Flieger (1968, 1990), Livi-Bacci (1997).

Table 4.1 Demographic Data for India

Period	Total Fertility Rate	Life Expectancy at Birth	Net Rate of Reproduction
1955–1960	5.92	42.6	1.75
1965–1970	5.69	48.0	1.87
1975–1980	4.83	52.9	1.73
1985–1990	4.15	57.4	1.61
1995–2000	3.45	62.1	1.43
2000-2005	2.73	64.2	1.17

Source: United Nations Population Division (2010).

Table 4.2 Demographic Data for Nigeria

Period	Total Fertility Rate	Life Expectancy at Birth	Net Rate of Reproduction
1955–1960	6.90	38.2	1.97
1965–1970	6.90	42.0	2.12
1975–1980	6.90	46.1	2.28
1985–1990	6.70	50.2	2.38
1995–2000	5.92	52.5	2.20
2000-2005	5.61	50.3	2.00

Source: United Nations Population Division (2010).

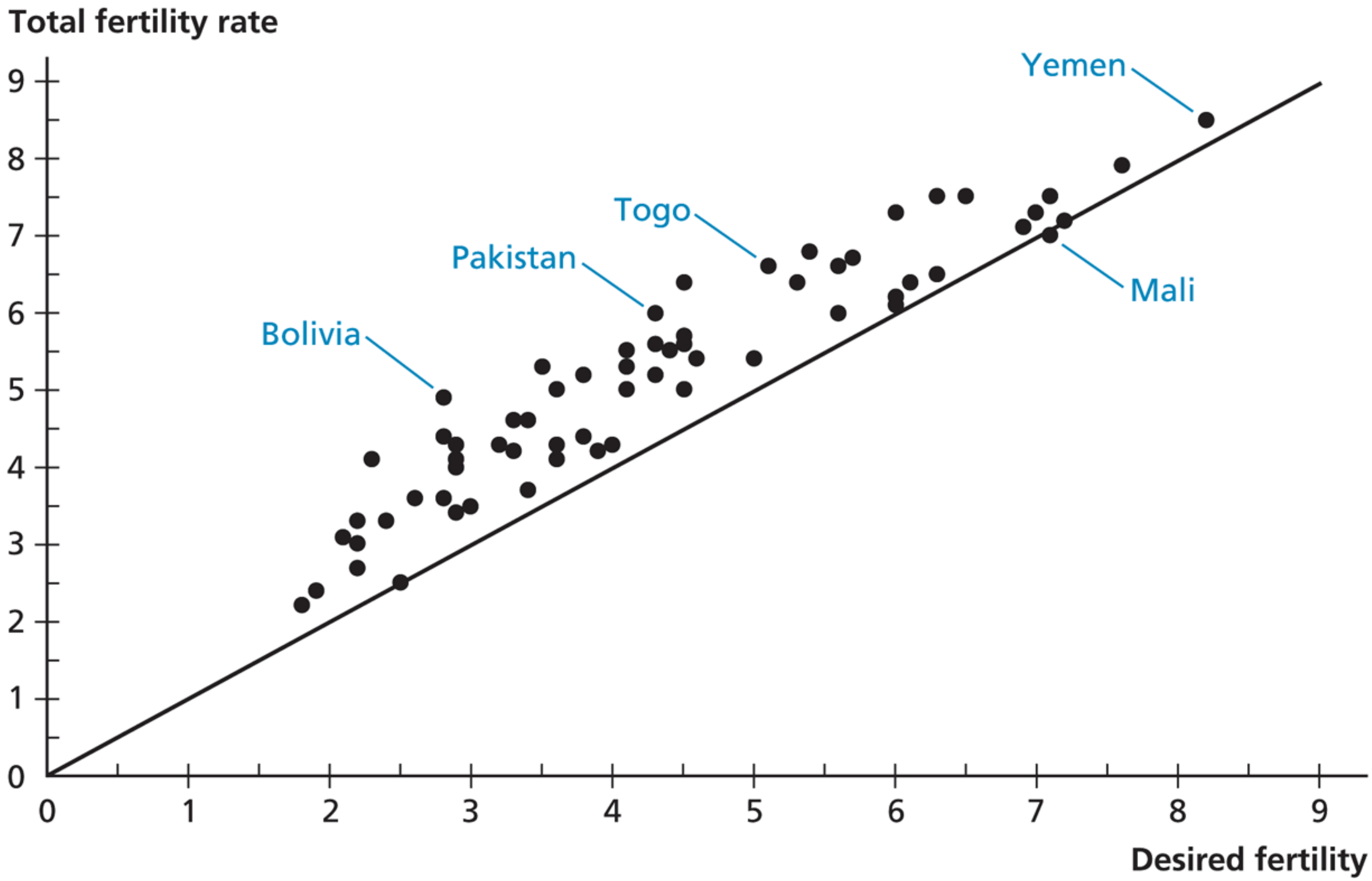
- A decline in the fertility rate has sometimes been accompanied by a rising net rate of reproduction and therefore faster population growth rate
  - This outcome seems puzzling at first
  - However, it is explained by mortality rates that are falling at the same time, particularly for women of child-bearing ages

What explains the movements in Fertility Rates?

- The methods of controlling fertility have evolved over time
  - Technological developments
  - Changing laws
  - Variation in customs

- Desired and actual fertility can be measured …

FIGURE 4.12
Desired Fertility Versus Total Fertility Rate in Developing Countries



Source: Pritchett (1994).

- Desired fertility has been measured by surveys of women
- We see from the previous data plot that desired and actual fertility are very closely related
- The fact that they move together is not surprising since desired outcomes will influence actual outcomes
  - environmental factors affect the desired family size

Motives to reduce fertility

- The UN has often claimed that “development is the best contraceptive”
- But why does the stage of development affect fertility?
- Four explanations have been offered:

1. The decline in mortality, that typically comes with greater economic development, may cause fertility to decline
   - Greater life expectancy for offspring means you need to give birth to fewer children in order to achieve a desired family size

2. Income and Substitution Effects

- Income effect: People want more goods when they have higher incomes. People value children. If people think of children in similar fashion to goods, as income rises people should have more children (This is the Malthusian model assumption)
- Substitution effect: The costs of children increase with the number of children. In particular, the time involved with raising and taking care of children rises with the number of children.
  - The opportunity cost of time NOT spent working is the real wage
    - The real wage rises with economic development, and that means the cost of having a child is also increasing and so people would have fewer children
  - Women's wages rise as an economy becomes more developed.
    - Women's wages have tended to be lower than men's, on average. However, women's wages tend to rise relative to men's wages as an economy becomes more developed
- If the substitution effect dominates the income effect, economic development will causes a decrease in the number of children

3. Resource flows from children to parents fall as the economy becomes more developed, so the benefit of an additional child declines

- In a more developed country, children cost more and produce a smaller share of family income than in a less developed country
- Children become somewhat productive at a fairly young age, particularly for certain manual tasks that don't require a great amount of strength
  - In less developed countries, a larger share of the jobs are manual labor
- This work yields income to parents and so having more children can yield more family income
- In more developed economies, jobs tend to require more years of education than young children possess
  - Education costs are paid by parents to some extent

- Parents in developing countries tend to depend more on their children for support when they reach old age
  - In contrast to most underdeveloped nations, people in developed countries tend to have:
    - government sponsored retirement programs, and
    - higher rates of savings

4. The Quality-Quantity Trade-off

- Countries with higher income per capita tend to require workers to have higher skills
- With reduced fertility parents can devote more resources - e.g. time, wealth, etc. - to each child's development
- Better education and an improved general welfare of children leads to a better expected outcome for a child, economically and in other ways.

- Other reasons parents may choose quality over quantity?
  - Parents may derive greater income flows from higher quality children who make better income.
    - Unlikely the prime reason since most parents in developed countries spend substantially more on a kid than they the income received from a child’s labor
  - Parents value a child’s happiness and believe that children who possess higher quality - more varied experiences and abilities, in desirable activities, of course - will be happier

Another look at cross country income differences in the Solow model

- The value of the parameter α has a significant effect on relative income differences
  - The larger is α the more y can vary across countries as important factors differ across countries
    - We show this by examples of different values for:
      - The population growth and
      - The investment rate

- Recall that we can calculate:

$$y_{ss} = A^{1/(1-\alpha)} \cdot \left(\frac{\gamma}{\delta + n} \right)^{\alpha/(1-\alpha)}$$

- And two different countries may each have their own steady state, y_i and y_j, and so the ratio of the steady states is:

$$\frac{y_i}{y_j} = \frac{A_i^{1/(1-\alpha_i)} \cdot \left(\frac{\gamma_i}{\delta_i + n_i} \right)^{\alpha_i/(1-\alpha_i)}}{A_j^{1/(1-\alpha_j)} \cdot \left(\frac{\gamma_j}{\delta_j + n_j} \right)^{\alpha_j/(1-\alpha_j)}}$$

- What if countries have different population growth rates, and different investment rates, but have the same productivity, production function and depreciation rate.
  - Then $A_i = A_j$, $\alpha_i = \alpha_j = 1/3$ and $\delta_i = \delta_j$
    - And our general result simplifies as follows:

$$\frac{y_i}{y_j} = \frac{A_i^{1/(1-\alpha_i)} \cdot \left(\dfrac{\gamma_i}{\delta_i + n_i}\right)^{\alpha_i/(1-\alpha_i)}}{A_j^{1/(1-\alpha_j)} \cdot \left(\dfrac{\gamma_j}{\delta_j + n_j}\right)^{\alpha_j/(1-\alpha_j)}} = \left(\frac{\delta + n_j}{\delta + n_i}\right)^{1/2} \left(\frac{\gamma_i}{\gamma_j}\right)^{1/2}$$

- Now perform calculations with a reasonably ranges of plausible γ and n between the wealthiest and poorest nations

$$\gamma_i = .2 \ (20\%) \text{ and } \gamma_j = .05 \ (5\%)$$

– then $\left(\dfrac{\gamma_i}{\gamma_j}\right)^{1/2} = (4)^{1/2} = 2$

– Again let depreciation rate = .05 (5%)

– And take a plausible range for n:

$$n_i = 0 \qquad n_j = .04 \ (4\%)$$

$$\left(\frac{\delta + n_j}{\delta + n_i}\right)^{1/2} = \left(\frac{.05 + .04}{.05}\right)^{1/2} = (9/5)^{1/2} \approx 1.34$$

- So combining changes in investment rate and population growth rate, we obtain

$$\frac{y_i}{y_j} = \left(\frac{\delta + n_j}{\delta + n_i}\right)^{1/2} \left(\frac{\gamma_i}{\gamma_j}\right)^{1/2} = \left(\frac{.09}{.05}\right)^{1/2} \left(\frac{.2}{.05}\right)^{1/2} \approx (1.34)2 \approx 2.68$$

- Which means that under these assumptions the Solow model can explain a steady state variation in y of roughly a factor of about 2.68 which is quite far from the numbers we see today of 50 or more

- Another possibility is that Solow model is correct, but the poorest countries are operating way below their steady state.
  - That means the poorest countries should grow much faster than the wealthy ones,
    - This prediction holds fairly well if we examine the data on countries that are fairly similar in structure, development and variables that arise in the Solow model
    - But this is not always true

- Another possibility: What if the parameter α takes on a number that is different than 1/3?
- Suppose we double it to 2/3
  - Why would α be this much greater than capital's income share?
    - Human capital is another form of capital (we've omitted human capital so far)
    - Some of labor income is compensation for human capital
    - If we use a broader and better measure of capital, one that includes human and physical capital, the share of income going to capital becomes larger, maybe even as large as 2/3.
      - For example if labor earns a 2/3 share of income and half of labor's income is compensation for human capital, the share of income going to human capital is (1/2)(2/3) = 1/3
      - Hence, income share for capital is equal to
        - The income share for physical capital
        - Plus income share for human capital

          = (1/3)+(1/3) = 2/3

– Varying investment rates as before:

$$\gamma_i = .2\ (20\%) \text{ and } \gamma_j = .05\ (5\%)$$

– letting depreciation rate = .05 (5%)
– And again taking the range for n as:

$$n_i = 0 \qquad n_j = .04\ (4\%)$$

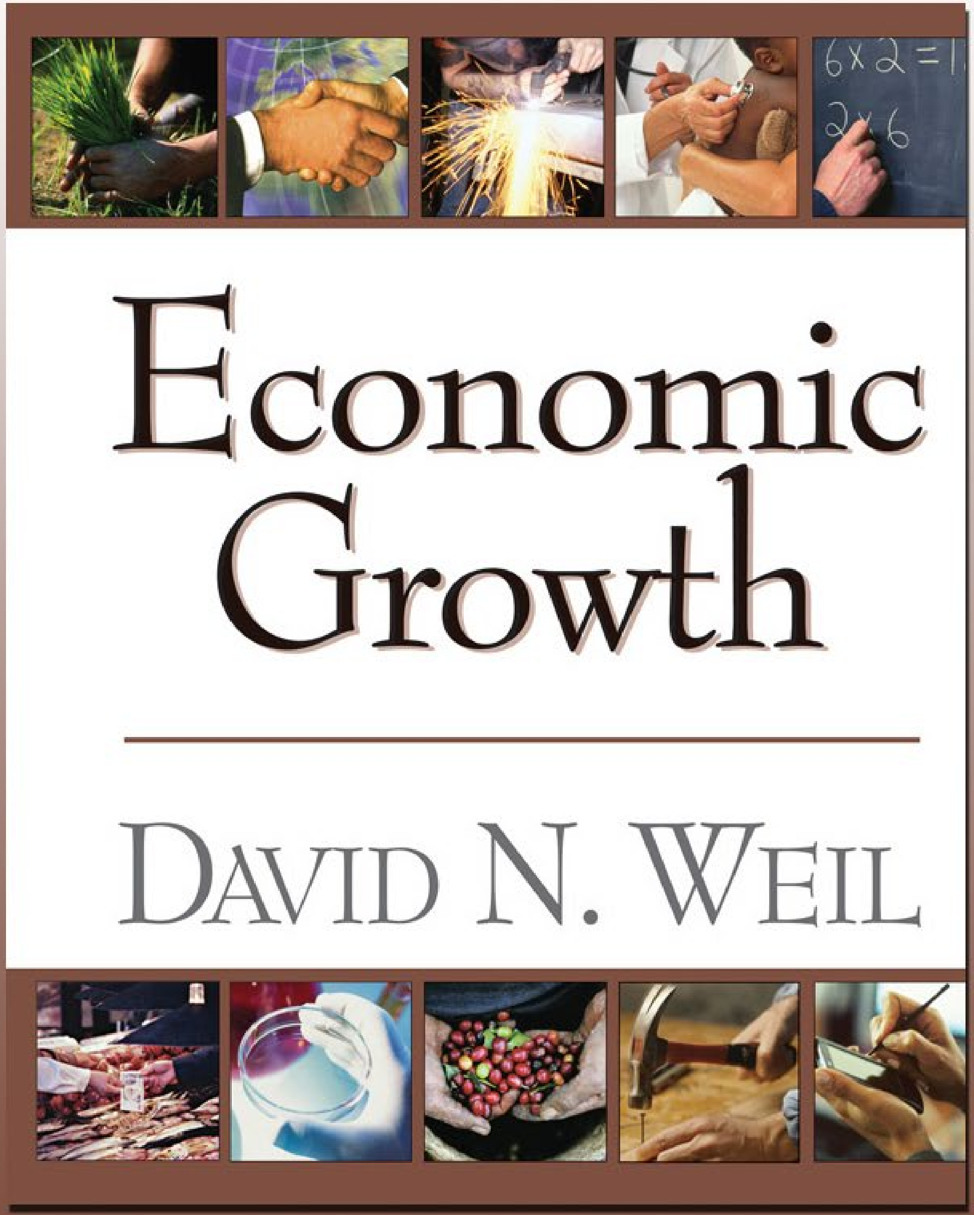
- Calculate the steady state ratio of GDP per capita for the rich and poor countries:

$$\frac{y_i}{y_j} = \left(\frac{\delta + n_j}{\delta + n_i}\right)^2 \left(\frac{\gamma_i}{\gamma_j}\right)^2 = \left(\frac{.09}{.05}\right)^2 \left(\frac{.2}{.05}\right)^2 \approx (3.24)16 \approx 52$$

- So the Solow model with α=2/3 is able to explain variation in output per capita of about a factor of 52, which is the ratio of some of the richest to some of the poorest countries in the world
  - Does this mean the steady state in the Solow model describes the way economies are today? Not necessarily.
    - But if countries are at their steady states, we see they are growing at vary different rates and so that means productivity growth rates must differ across countries
  - A better explanation may be that some, most or maybe even all the countries are NOT operating at a steady state

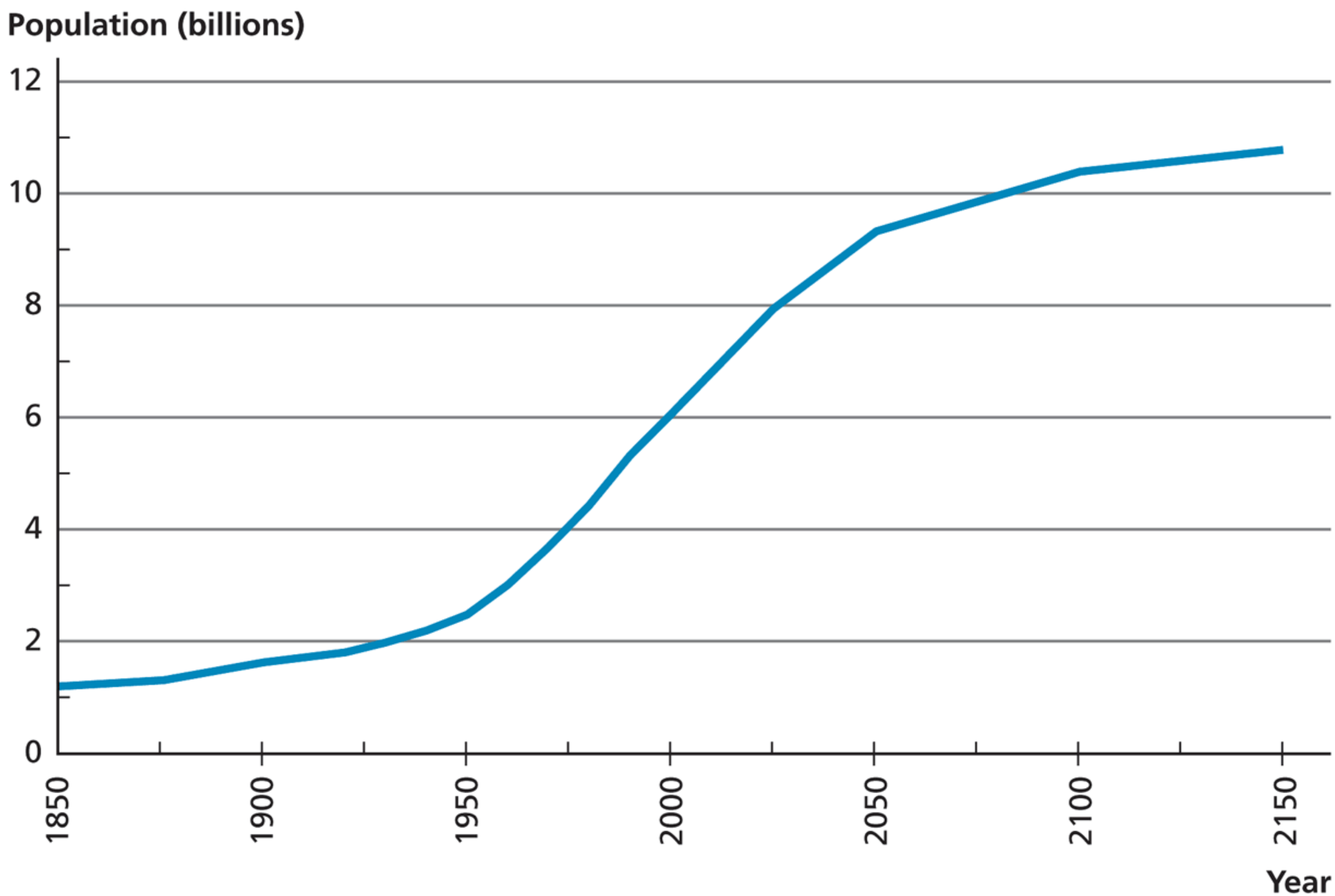
Chapter 5

Future Population Trends



- Population has grown rapidly in recent decades but the forecast is for world population growth rate to shrink in the next few decades.
  - Longer run forecasts are for the population growth rate to eventually fall to about zero percent.

FIGURE 5.1
World Population, 1850–2150

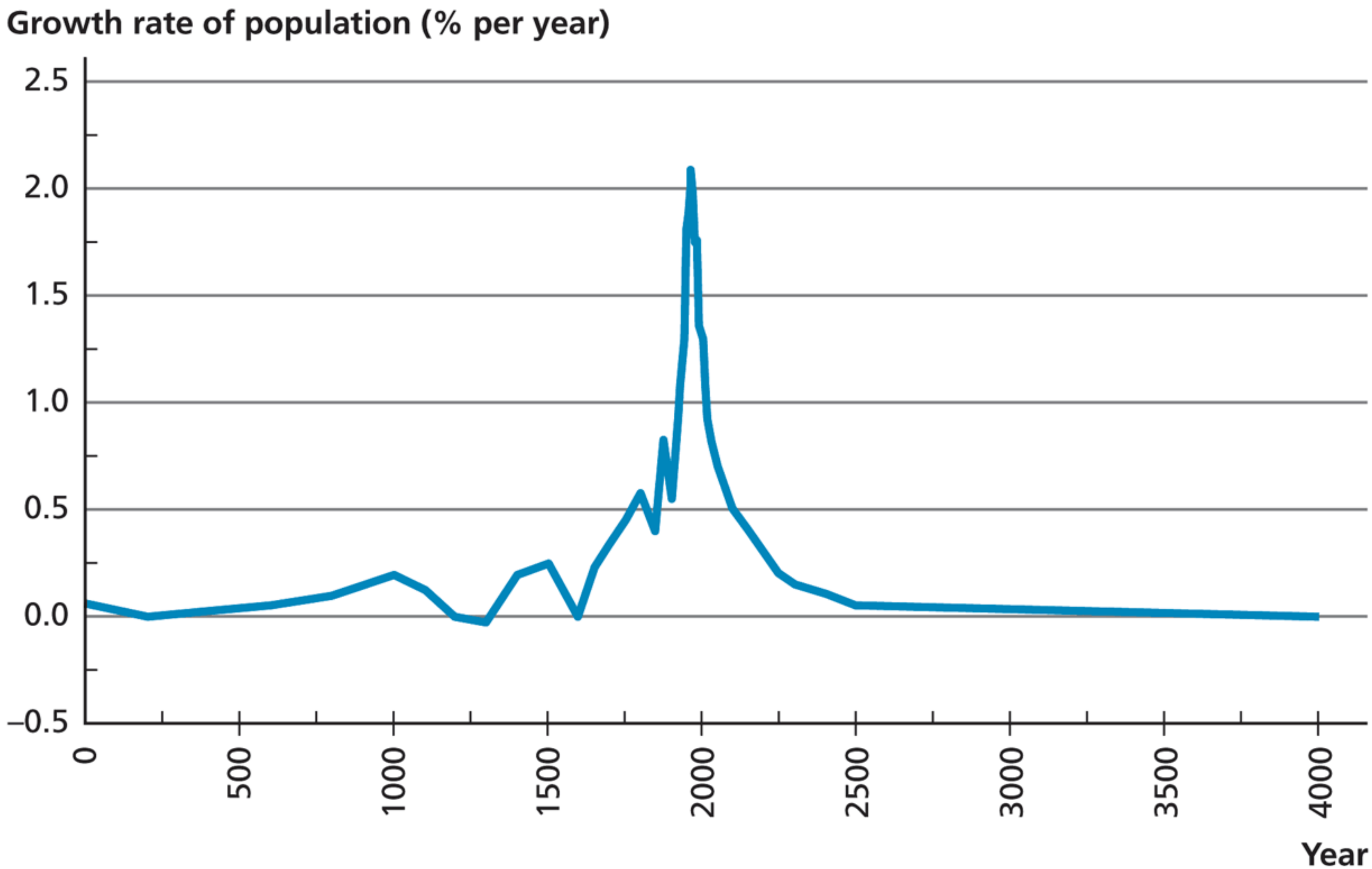


Source: United Nations Population Division (2000).

- An alternative look at the data from the previous graph, and covering a longer span of data

Figure 5.5

The Great Spike in World Population Growth



- What accounts for predicted world wide slow down in population growth?
  – Birth rates are declining across most of the world, (except for some of the least developed parts of the world)
  – this is starting to bring population growth rates down

Table 5.2
Average Annual Growth Rates of Population by Country Group

	1950–2000	2000–2050
More Developed	0.8%	0.0%
Less Developed	2.1%	0.8%
Least Developed	2.4%	2.1%

- Of course, many developing nations are rapidly catching up to the low mortality rates found in developed countries and so for a while they exhibit rising population growth rates with the decline in fertility rates
  - But some day when (if?) virtually all women of the world survive through all the child bearing year, then the only factor that could explain a lower population growth rate is a lower rate of life-time fertility for women
    - It will take some time before the developing world is fully caught up in terms of life expectancy

- Other reason why population growth is expected to decline toward zero
    - Large parts of the world have faster growing y and we know that wealthier countries tend to have lower birth rates and lower population growth rates
        - But this requires that higher y causes lower n, in contrast to Malthus and the opposite direction of causality in Solow’s model (where lower n causes higher y
    - The must have some finite limits to the number of people it can support and so as we approach those limits, people will presumably have fewer children to benefit the standard of living of their offspring
    - This last point raises an interesting question: How many people can the world support?

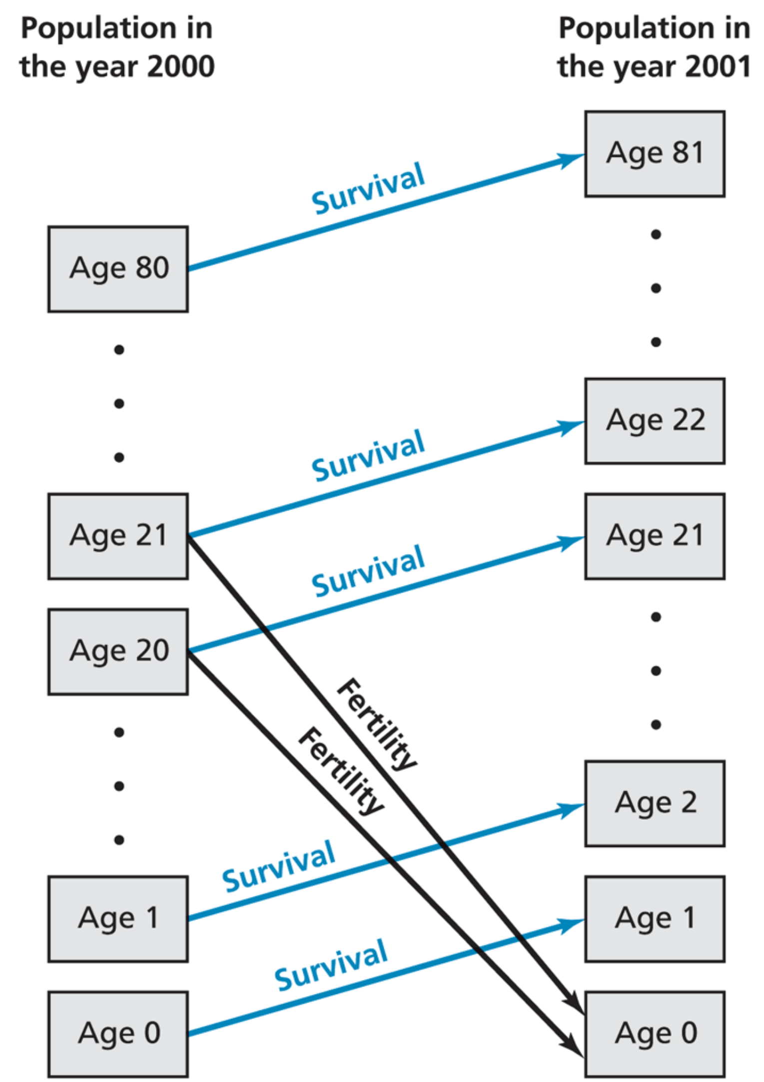
- The answer is not so simple because it depends on a number of factors:
  - What level of standard of living is considered appropriate?
    - The lower that level is, the more people the world can support
  - Are we talking about a level of standard of living that could be sustainable for an indefinitely long period of time OR a level that would use up world resources at such a rapid rate that standards of living could not be maintained at that level
  - How will future technological developments improve (or maybe even hinder) our ability to support a given level of the population

- Many people, including Malthus, have concluded that a rising population would eventually outstrip food production and eventually that would cause panic, starvation and possibly a collapse of societies.
  - So far these gloomy predictions have always been wrong
    - they will be wrong as long as new technologies continue to keep food production ahead of population
  - On the other hand, perhaps these practitioners of “the dismal science” may some day be right

- Population forecasts have been surprisingly accurate even when we have looked back at forecasts many years before
  - E.g. in 1960 the forecast for world population in 2000 was only off by a few percentage points

- The way population is forecast is nicely illustrated by Fig 5.2

Figure 5.2
Population Forecasting

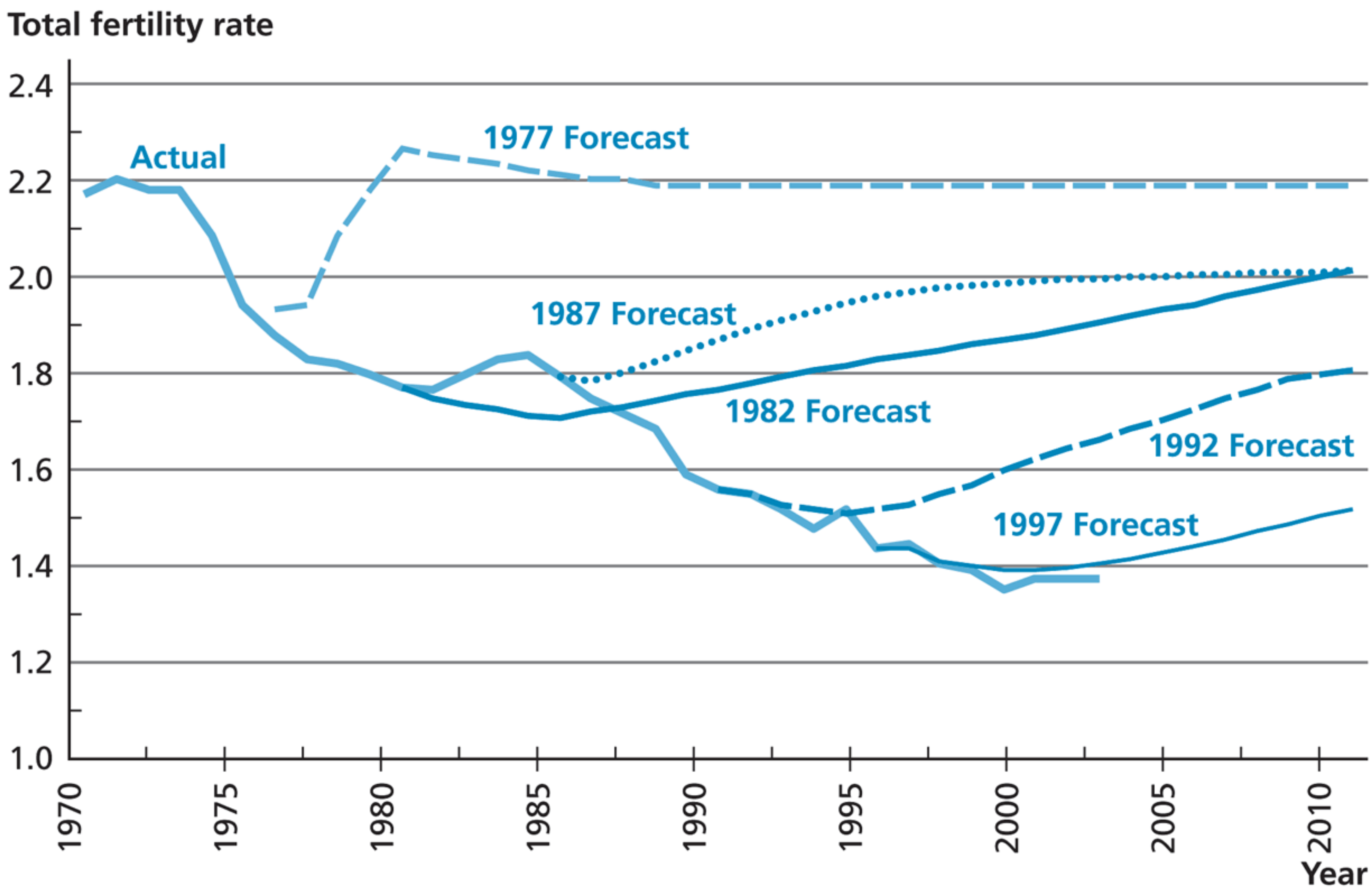


- This figure indicates how population is forecast
  - The survival rate is used to predict how many of a particular age will be around in the following year given the number alive in the current year
  - The number of children predicted to be born in the next year is obtained from the fertility rate for each group of women in the current year
- This calculation is done for each year in the future based on the actual or forecast data from the previous year
- Since the survival rates and the fertility rates usually change very slowly, if at all, over time, population forecasts have usually been pretty good out for a number of decades
  - Of course, “past performance does not guarantee a similar future performance”.
    - perhaps future changes in mortality and fertility rates will make population forecasts less reliable than we’ve seen in the past.

- Mortality rates are fairly low in the developed countries today
- Mortality rates are falling rather rapidly in the developing world
- When survivorship rates are high (i.e. low mortality rates) further changes are smaller and have a smaller effect on the NRR. Hence, the NRR will be less affected by mortality changes and more affected by changes in the fertility rate
  - Over time fertility rates will become more of a dominant factor in explaining differences in population growth rates

- Some evidence on the recent Japanese experience with population is shown with total fertility rates and fertility rate forecasts of Fig 5.3.
  - It has been difficult recently to forecast the population of Japan. In particular, forecasts have been much higher than the outcomes observed
    - The reason: Forecasters have been predicting fertility rates were only temporarily low because women were waiting longer to have children
    - They forecast a bounce back to the higher levels consistent with a rate that will not allow the population to fall
      - But people have not only been waiting till they were older to have children, they have also been not having as many children as before
        - So NRR is less than 1 due to relatively low fertility rates
    - Same thing is happening in many developed countries

Figure 5.3
Total Fertility Rate in Japan: Actual Versus Forecast



Source: Yashiro (1998).

- Table 5.1 shows the fertility rates in some of the primary regions of the world were developing countries are
  - In 2000 the fertility rates are smaller than they were in 1970 for all the regions
    - Significantly smaller in all regions except for Sub-Saharan Africa where fertility rates are still quite high
  - Since population is growing in all of these countries, that means the decline in fertility rates has lately been dominated by the decline in mortality rates
  - The developing world's population growth is the dominant factor in world population growth because there are many more people in developing countries
  - If fertility rates continue to change by large percentages, this could make population forecasting even more difficult

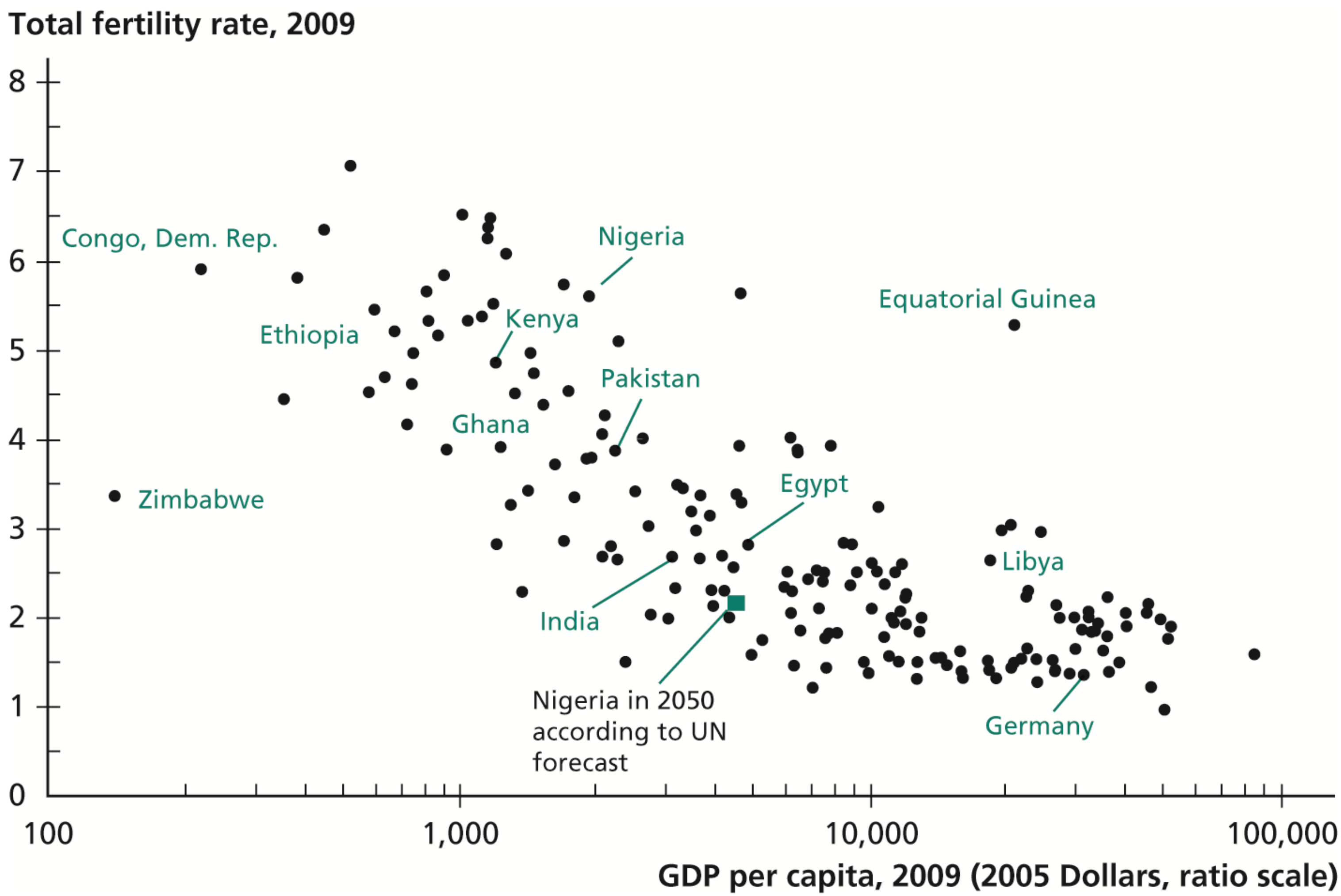
Table 5.1 Fertility in the Developing World

	2004 Population (millions)	Total Fertility Rate, 1970–1975	Total Fertility Rate, 2000–2005
All developing countries	5093.60	5.50	2.90
Sub-Saharan Africa	689.6	6.80	5.50
Arab States	310.50	6.70	3.70
East Asia & Pacific excluding China	636.10	5.45	3.19
China	1307.99	4.90	1.70
South Asia excluding India	441.00	6.21	3.94
India	1087.12	5.40	3.10
Latin America and the Caribbean	548.30	5.10	2.60

Source: United Nations Development Program (2007).

- Fig 5.4 shows that there is an inverse cross-country relationship between fertility rates and income per capita
  - This resembles the inverse relationship between population growth rates and income per capita

Figure 5.4 Income per Capita versus Total Fertility Rate



- Population growth rates are falling in most countries of the world, and they are predicted to fall even more in countries, except for the very least developed countries

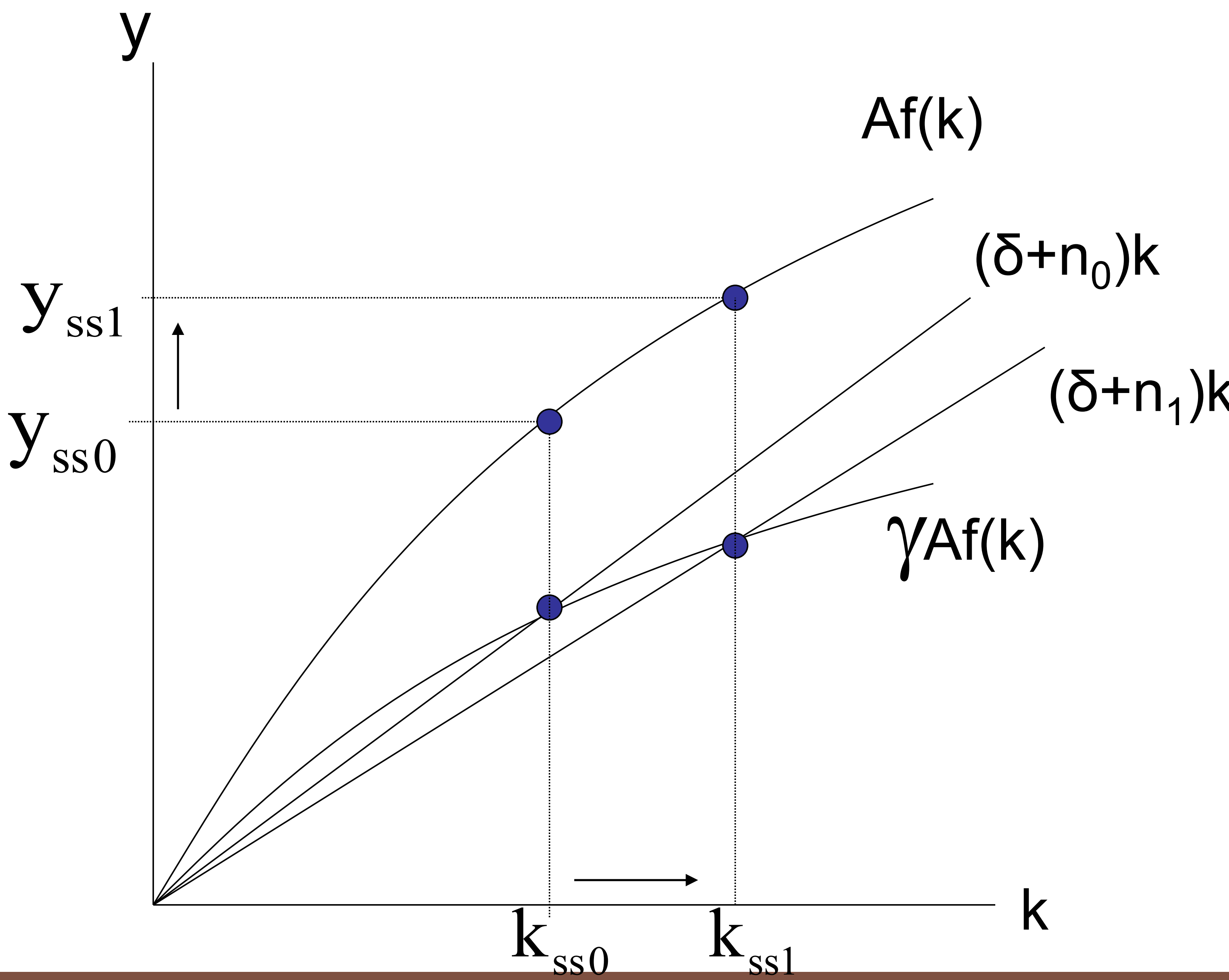
TABLE 5.2

Average Annual Growth Rates of Population by Country Group

	1950–2000	2000–2050
More Developed	0.8%	0.0%
Less Developed	2.1%	0.8%
Least Developed	2.4%	2.1%

- What should we expect will happen to output per capita when world population grows at a slower rate?
  - One way to answer this question is by using the Solow model
  - What does Solow's model predict will happen to y when n falls?

- Solow's model predicts that a decline in population growth rate will raise output per capita
  – Remember, as population grows at a slower rate, the capital dilution effect shrinks.
  – In the graph, the depreciation-dilution line gets flatter and that causes k and y to both increase as n falls from n_0 to n_1 ($n_0 > n_1$)


y
Af(k)
(δ+n0)k
(δ+n1)k
γAf(k)
yss1
yss0
kss0
kss1
k

- Will this decline in population growth rate cause output growth to rise forever?
  - No, not in Solow's model
    - y will rise by some percentage until it reaches its new higher steady state and then it will grow no more
- How much will y increase?
  - In Solow's model that depends on
    - how much n falls
    - how large is α
  - Suppose that y_i is world output per-capita after population growth shrinks to zero while y_j is output per capita before population falls from its 4% level. Assume nothing else changes and that the depreciation rate is .05

- We can calculate the steady effect on output using our equations from before, again assuming that y is output per capita for the entire world. Note our assumptions greatly simplify the ratio of world incomes after (i) and before (j) population growth fell

$$\frac{y_i}{y_j} = \left(\frac{\delta + n_j}{\delta + n_i} \right)^{\alpha/(1-\alpha)}$$

- Use our numbers for n and the depreciation rate
  - If α=1/3 we obtained a y-ratio of 1.34
    - a 34% increase in y
  - If α=2/3 we obtained a y-ratio of 3.24
    - a 224% increase in y
  - Small effects on y from large increases in n

- Dynamic costs of changing population growth adjustment effects could be more substantial than the steady state effects

1. With a significant decline in population growth, at some point share of retired older people will be high and share of workers low
   - Fewer workers relative to the number of retired people means each worker may have to pay more in taxes to finance all the retirees
     - Almost always, a National Retirement plan, e.g. Social Security, is a Pay As You Go system

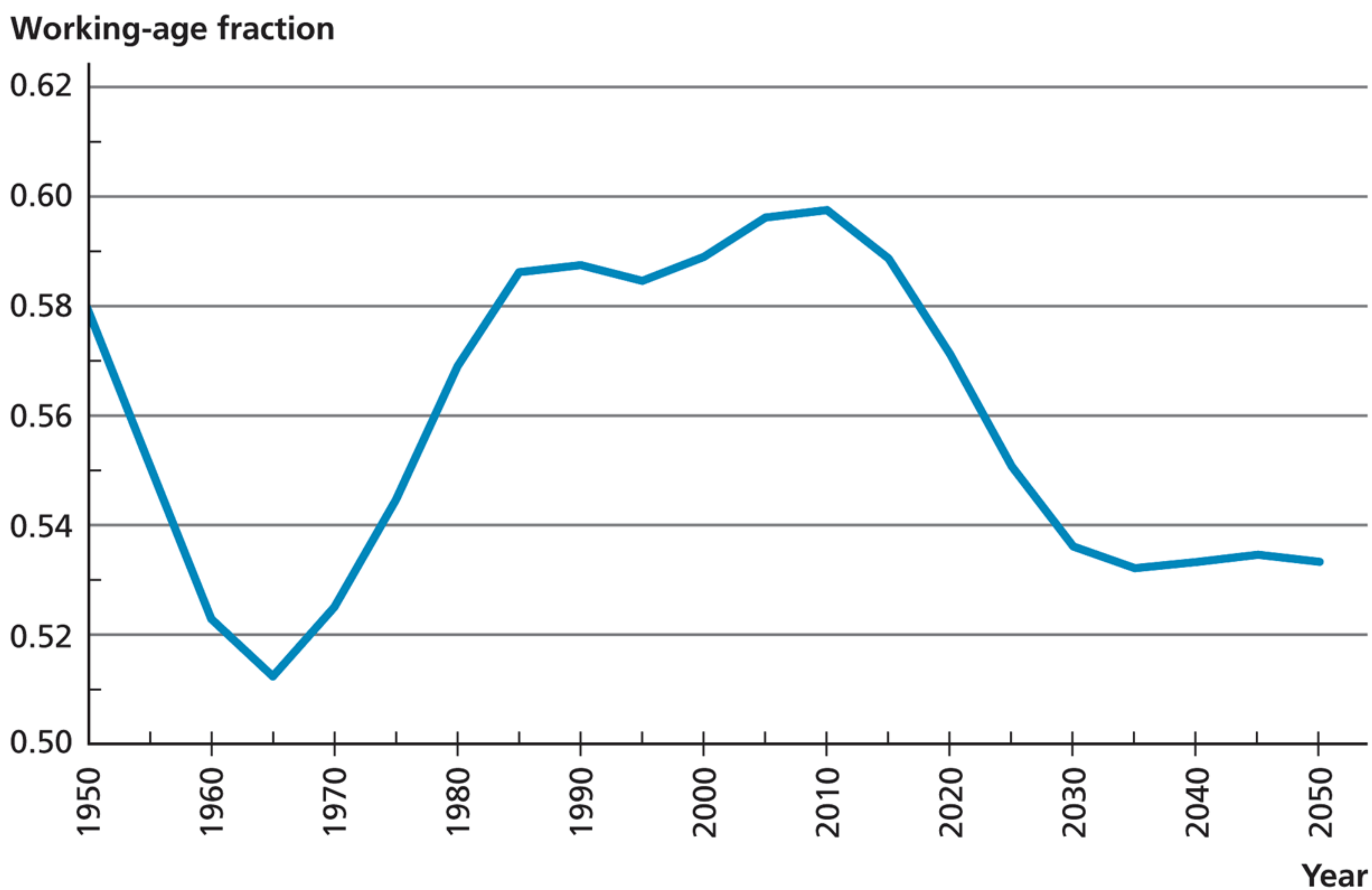
2. If there is a significant rise in the population growth rate, the costs for caring for children could cause hardships
   - Again its too many total people relative to the number of people of productive working age
     - E.g. higher cost per worker in paying for public schools

- The age structure of the world has experienced large changes over time and is expected to continue undergoing significant change in the future

- The US working age share of population has evolved over time largely as result of the Baby Boom generation.
  - The working age share of the population fell throughout the 50s as the generation of Baby Boomers started to be born in 1946
  - As Baby Boomers started to enter the labor force, the working age share fell at a slower and slower rate, eventually starting to rise in the mid-60s
  - Those born in 1946 turned 65 in 2011 which is about the time the US working age share of the population is predicted to start to fall

FIGURE 5.7

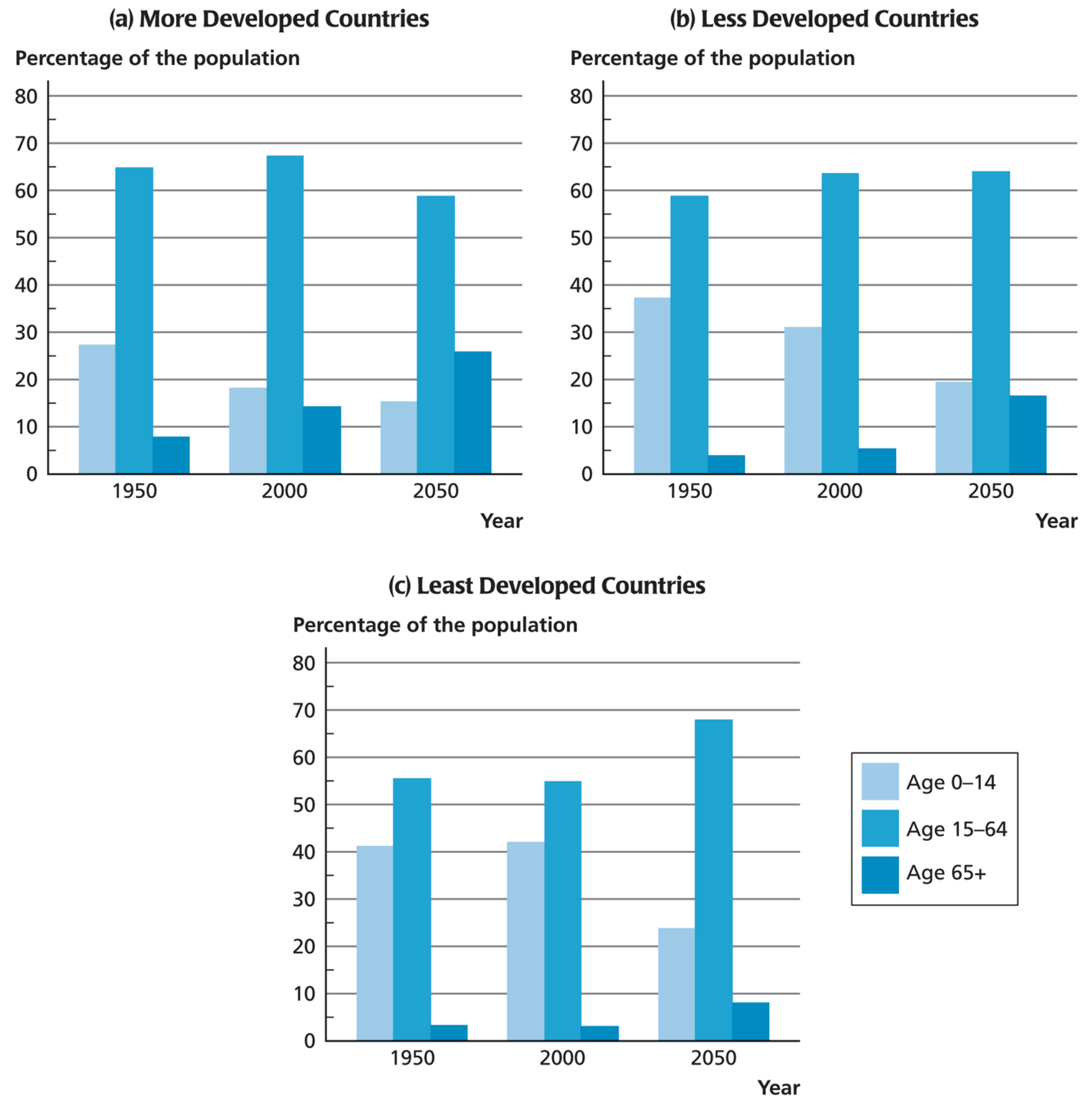
Working-Age Fraction of the U.S. Population, 1950–2050



Source: U.S. Census International Database.

- World wide we are seeing a decline in children and an increase in senior citizens as shares of the population

Figure 5.6
Changes in the Age Structure of the Population, 1950–2050



Source: United Nations (1998).

Compositional Effects on Standard of Living

- Changing demographics in a country can affect the average standard of living
- More specifically, when the ratio of workers in the population changes, this can affect the growth rate of GDP per capita in an economy
  - Below we calculate this effect:

- First, divide GDP per capita by GDP per worker. GDP cancels from numerator and denominator and the worker share of population remains:

$$\frac{\text{GDP}-\text{per}-\text{capita}}{\text{GDP}-\text{per}-\text{worker}} = \frac{\left(\dfrac{\text{GDP}}{\text{Population}}\right)}{\left(\dfrac{\text{GDP}}{\text{Workers}}\right)} = \left(\frac{\text{Workers}}{\text{Population}}\right)$$

- Then we can multiply by GDP per worker and obtain:

$$\text{GDP}-\text{per}-\text{capita} = \left(\frac{\text{Workers}}{\text{Population}}\right)\left(\text{GDP}-\text{per}-\text{worker}\right)$$

- Finally we can use our rule for the growth rate of a product of two variables:

Growth of GDP per person	=	Growth of worker share	+	Growth of GDP per worker

- Implications of the previous equation
  - Since Worker share is bounded between 0 and 1, it can not grow over a long period of time. Hence, over a long period of time, GDP per capita and GDP per worker will grow at the same rate
  - However, over shorter periods of time, positive or negative growth in worker share can take place, and this may have a significant effect on output per capita
    - The last equation tells us that a 1% change in worker share will yield a 1% change in the GDP per capita in the same direction, holding the growth rate of output per worker constant

- We can see just how important this effect is quantitatively

Table 5.3

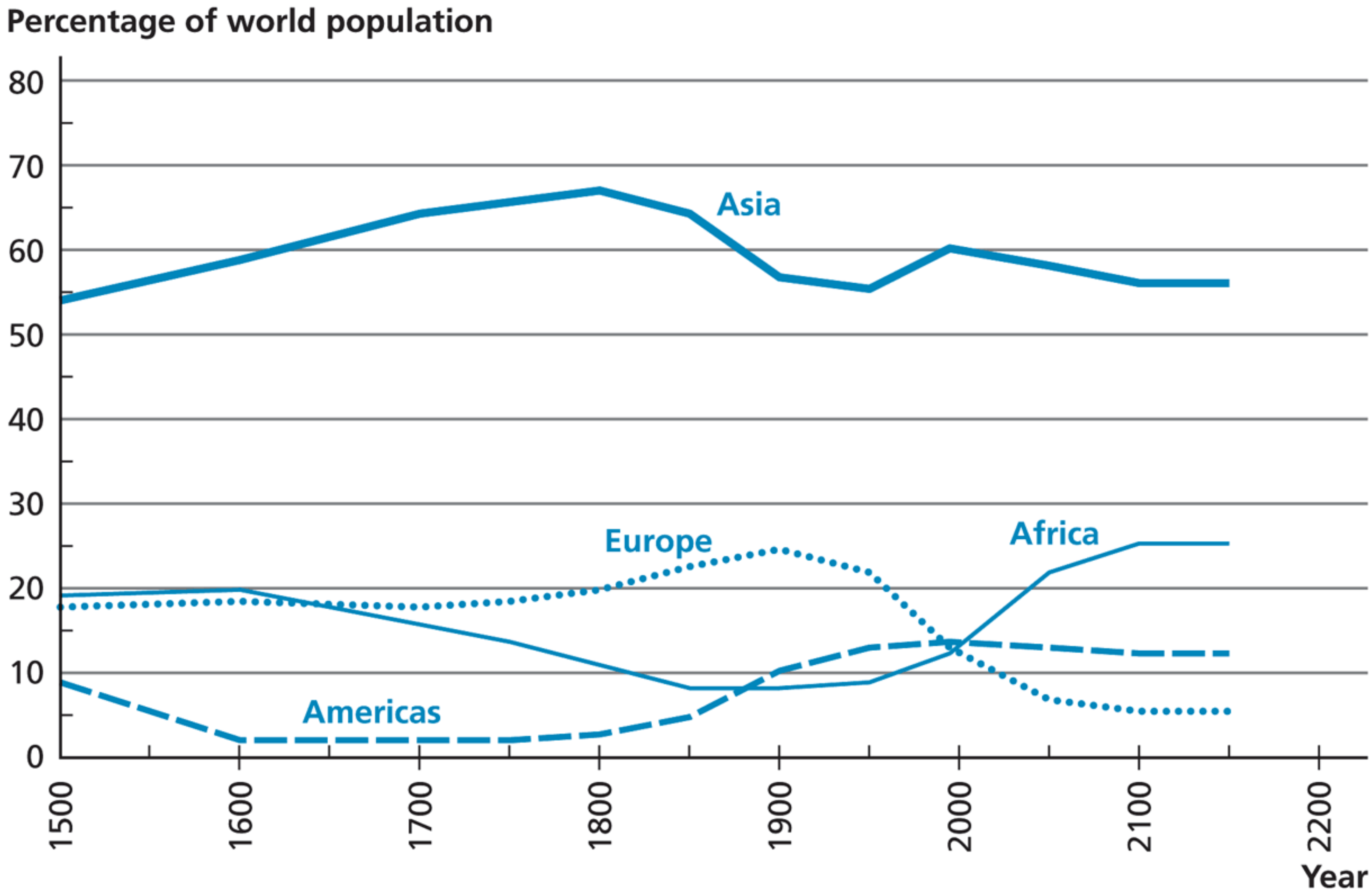
Some Cases of Population Aging

Country	Time Period	Percentage of Population Aged 20–64 in the First Year	Percentage of the Population Aged 20–64 in the Last Year	Effect of Aging on Growth of Income per Capita (% per Year)
Japan	2000–2020	62.3	54.9	−0.6
Malaysia	1980–2010	45.9	54.1	0.6
Mexico	1985–2015	42.7	57.7	1.0
Thailand	1990–2010	55.2	62.3	0.6
Turkey	1990–2010	49.2	63.2	0.8
Bangladesh	2000–2020	47.1	59.8	1.2

Source: U.S. Bureau of Census International Database.

- The world population distribution will see a shift towards relatively more people in Africa and relatively fewer in Europe
  - This is due to wide differences in population growth rates
    - Most countries in Europe have population growth that gives a NRR of less than 1 and so these countries will see a decline in population --- that is unless they receive more immigrants or have population growth rates increase substantially

FIGURE 5.8
Distribution of the World's Population



Sources: Livi-Bacci (1997), United Nations Population Division (2000).

- Fig 5.4 provides a fictitious but rather useful quantitative example of something called the composition effect
- This can actually important sometimes when trying to interpret real data

Table 5.4

The Composition Effect

	2000			2050			Growth Rate of GDP per Capita, 2000–2050
	Population (Millions)	Total GDP ($ Billions)	GDP per Capita ($)	Population (Millions)	Total GDP ($ Billions)	GDP per Capita ($)	
More Developed	1,191	23,921	20,084	1,181	63,845	54,060	2.00%
Less Developed	4,207	17,601	4,184	6,312	71,077	11,261	2.00%
Least Developed	658	800	1,216	1,830	5,990	3,273	2.00%
World	**6,056**	**42,322**	**6,988**	**9,323**	**140,912**	**15,114**	**1.55%**

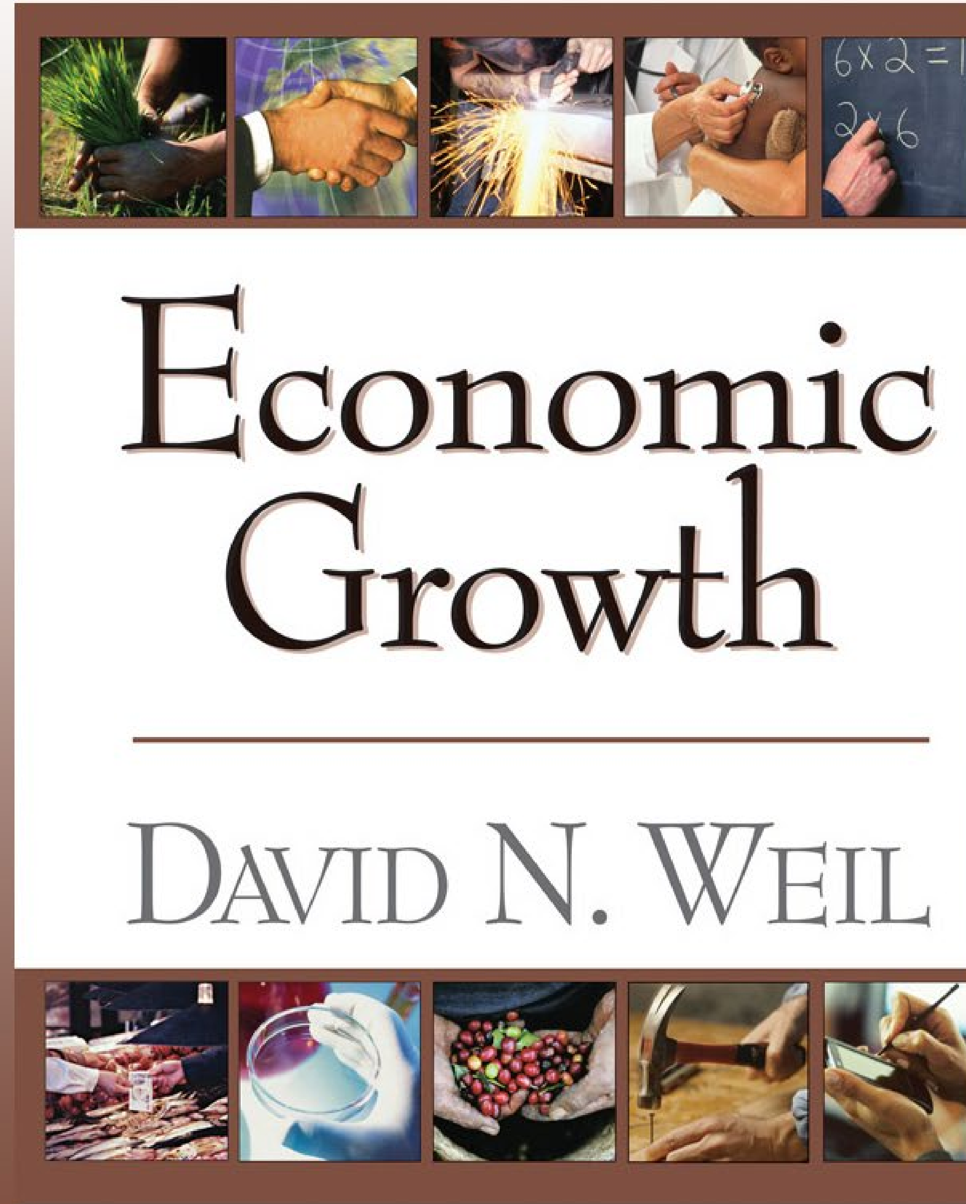
Sources: United Nations Population Division (2000), United Nations Development Program (2002).

- The basic idea is:
  - Suppose that the rich and poor countries all have y growing at the same rate, a constant rate of 2%
  - Suppose that population is growing at a faster rate in the poorer countries than in the richer countries
    - This is an assumption that fits well the experience in the world today
    - Naturally, poorer countries have lower levels of y relative to the level in richer countries
  - Under these assumptions, growth of the world GDP per capita will be positive BUT less than 2%. But why?

- Positive growth is not a surprise since y is growing for everyone
- But the less than 2% growth rate may have been unexpected by you
  - This obtains intuitively because the world has a larger and larger proportion of its population making the lower level of GDP per capita
    - If richer and poorer countries all had the same population growth rates, then there would be no composition effect and the world growth rate of GDP per capita would then be 2%
    - But the relatively lower output-per-capita countries are making up a larger share of the world population if poorer countries are growing aster than richer countries

Chapter 6

Human Capital



- Human Capital
  - Labor input is often measured as the amount of time spent working. But time is not the only factor. Additional factors that are important include:
    - The amount of effort put into the job
    - The abilities/skills workers bring to the workplace
  - Human capital is a term used to describe these worker skills and abilities
  - Human capital shares similar features to physical capital
    - Human capital is produced
      - Human capital is costly to produce
      - Human capital is produced using a production function
    - Human capital has a rate of return
    - Human capital also depreciates
      - However, physical capital wears out faster the more we use it, and instead human capital wears out from the lack of use.
        - When it comes to human capital, use it or lose it

- Adding human capital to the production function

$$Y = AK^{\alpha}(hL)^{1-\alpha}$$

  - Since h augments labor hours we model it as a factor that is multiplied times L to calculate total labor input
  - Divide by L to convert to per-capita quantities

$$Y / L = AK^{\alpha}(hL)^{1-\alpha} / L$$

$$y = Ak^{\alpha}h^{1-\alpha}$$

    - So an increase in h will increase the amount of output per capita (y) that can be produced
  - Human capital is sometimes thought of as a function of health
    - Improved health makes labor hours more productive because healthy workers
      - Are able to work harder
      - Can perform better tasks that require cognitive functioning

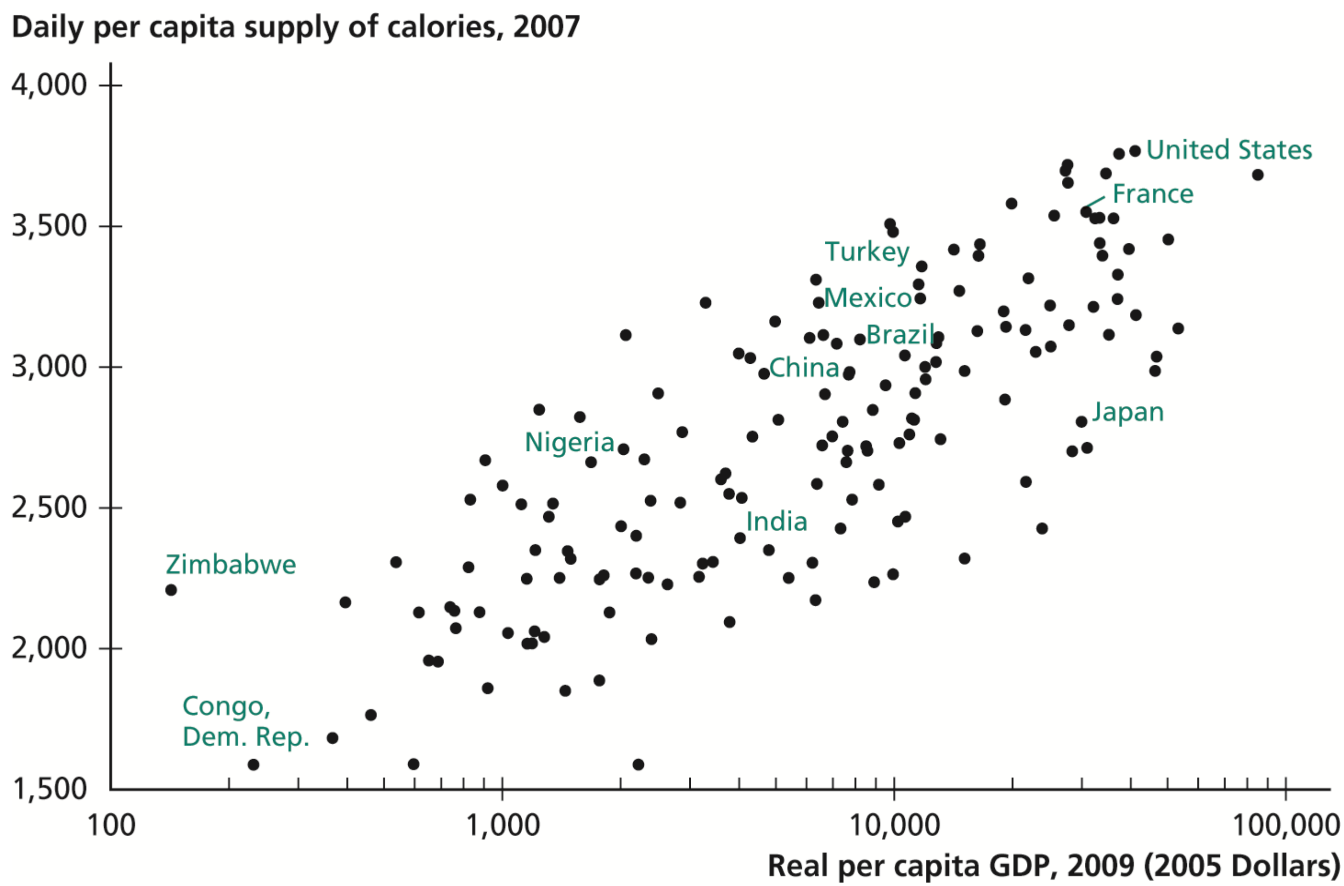
    compared to sick or malnourished workers

The production function can be modified to include human capital

- Human capital augments labor input
  - For a given amount of L (whether L is hours or number of workers), human capital raises the amount of labor input

- Nutrition is a major factor for health
- When an economy is able to feed workers enough food and food of sufficiently high quality they will be stronger and healthier and thus able to produce more output per capita
- Consequently, it is not surprising that health, as measured by nutrition, is positively related to GDP per capita

Figure 6.1 Nutrition versus GDP per Capita

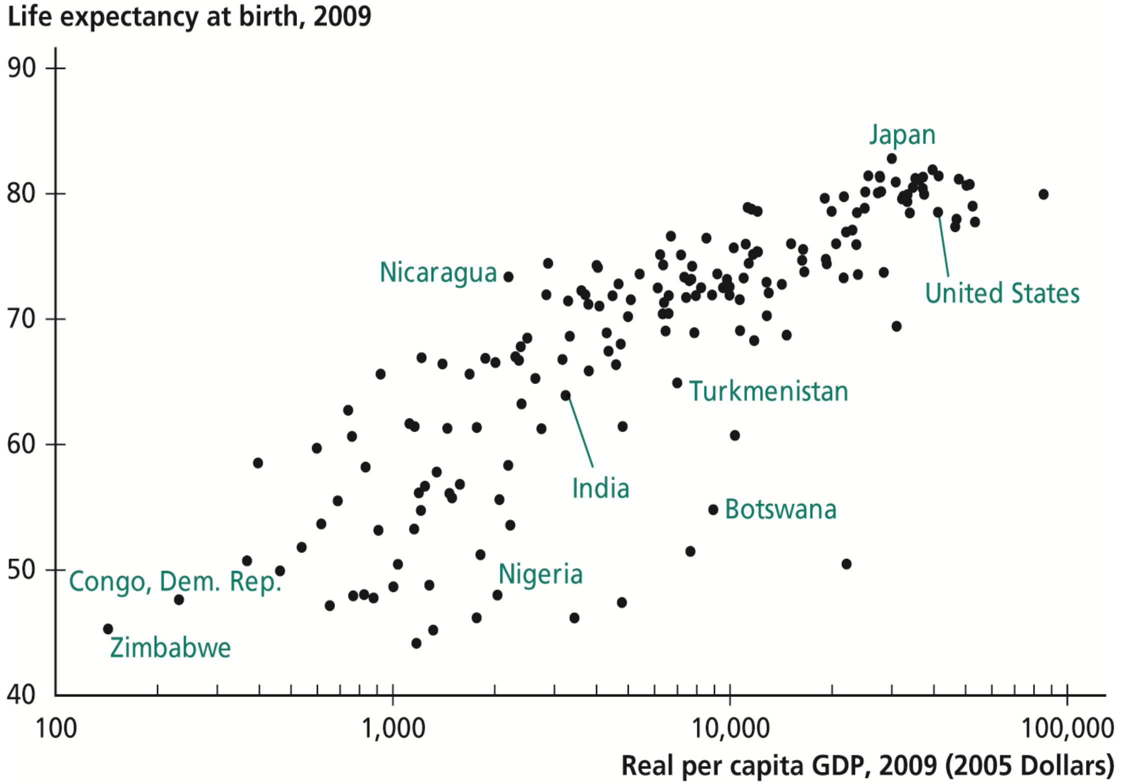


Sources: FAOSTAT database, Heston, Summers, and Aten (2011).

- But, causation may work in the opposite direction: In other words, people in a more developed economy can afford to spend more on food consumption – in contrast to better nutrition making people more productive

- We also see that life expectancy, another variable related closely to health, is positively associated with y

Figure 6.2 Life Expectancy versus GDP per Capita



Sources: Heston, Summers, and Aten (2011), *World Development Indicators* database.

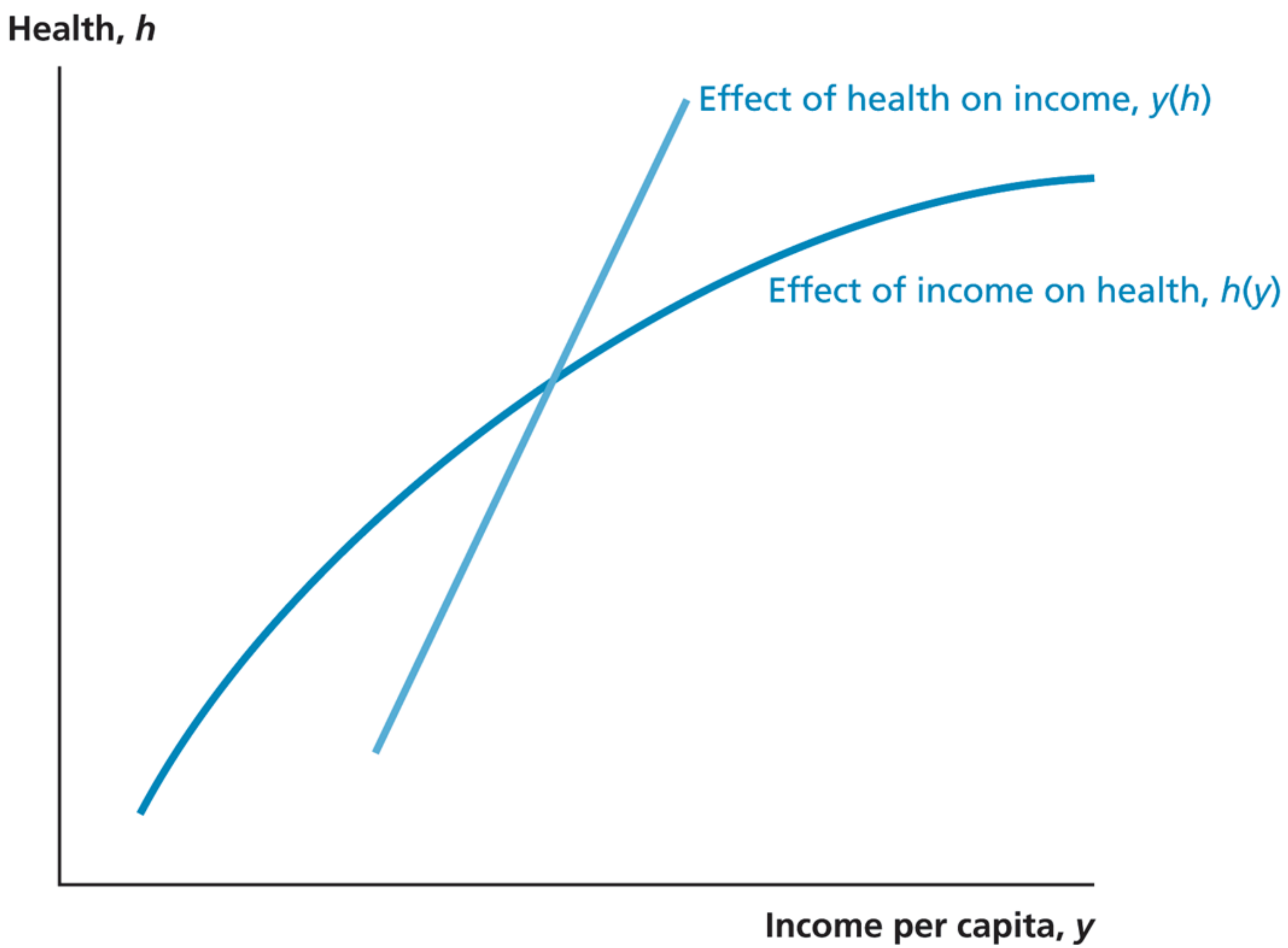
- But the same reverse causation story may be at work
  - Richer people can afford to pay more for health care and so they live longer

- A Model of health and an income per capita being simultaneously determined
  - This is another example of the classic simultaneity problem that plagues much of economic analysis (or any other science that does not have experimental means to test all theories)

- There are two structural relationships
  - h(y) specifies the way that h (health) responds to y (income per capita)
    - h(y) rises with y
      - but as y rises, h rises as at a diminishing rate
      - As the standard of living rises, health improves but not by the same proportion. Doubling income leads to a less than doubling of health
  - y(h) specifies the way that y responds to h
    - y(h) rises with h
      - And when h rises, y rises proportionally
      - As health improves, the amount of output per worker rises by the same percentage. Doubling health will double income per capita

- The text graphs this simultaneous relationship:

FIGURE 6.3
How Health Interacts with Income



- The idea that y(h) rises proportionally to a rise in h comes from the Solow model.
- We can solve that model for y as a function of the parameters and factors to see this
- Recall the key equation in the Solow growth model, the capital accumulation equation, is:

$$\Delta k = \gamma \cdot A \cdot k^{\alpha} h^{1-\alpha} - \delta \cdot k - n \cdot k$$

  – but note that here we write investment per capita using our new production function (in terms of income per capita) which includes human capital

HOMEWORK

- Show using our new production function that the solution for k_{ss} is:

$$k_{ss} = h\left(\frac{\gamma \cdot A}{\delta + n}\right)^{1/(1-\alpha)}$$

(Hint: recall the steady state occurs when $\Delta k=0$)

- Then, using the production function

$$y = A \cdot k^{\alpha} h^{1-\alpha}$$

show that:

$$y_{ss} = h \cdot A^{1/(1-\alpha)} \cdot \left(\frac{\gamma}{\delta + n}\right)^{\alpha/(1-\alpha)}$$

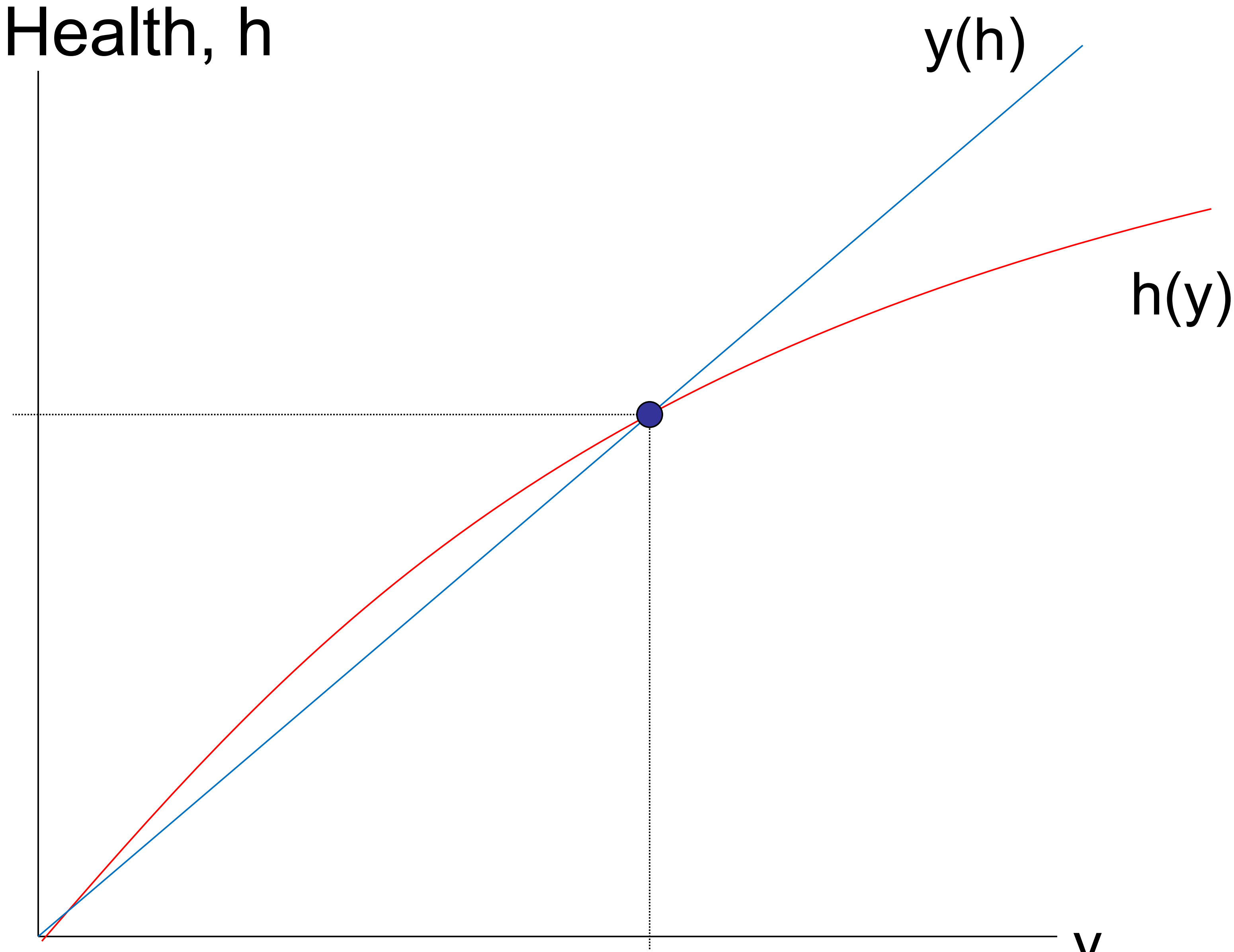
- The significance of this result for y_{ss}:
  - It shows why steady state y changes proportionally when h changes
    - y is linear in h, and the slope of the h(y) line is the inverse of :

$$A^{1/(1-\alpha)} \cdot \left(\frac{\gamma}{\delta + n} \right)^{\alpha/(1-\alpha)}$$

$$A^{1/(1-\alpha)} \cdot \left(\frac{\gamma}{\delta + n} \right)^{\alpha/(1-\alpha)}$$

- If there is no health there is no output
  - When h=0, then y=0
  - This means the y(h) graph should always go through the origin
- Hence, all factors in the Solow model that affect y(h) rotate the curve about the origin
  - In the text, the curve is shifted, not rotated
    - While technically not correct, the text does get the right qualitative answers, if not the right quantitative answers, to an economic question

- Here is the way the graph should look in the text



Health, h
y(h)
h(y)
y

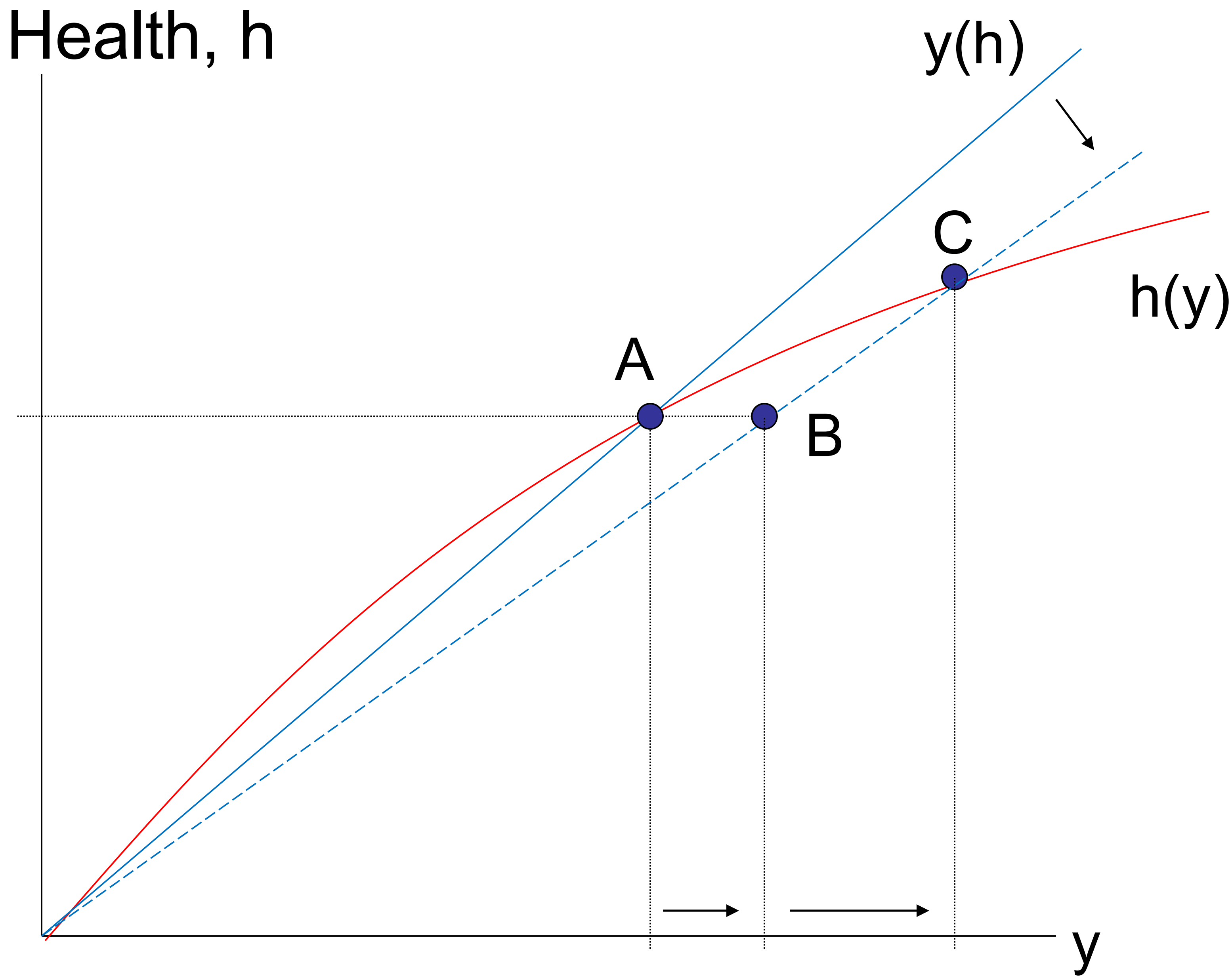
- The plot of y(h) is linear in h
  - this comes directly from our of the equation for y_{ss}.
- We continue to plot h(y) as concave
  - We also have it running through the origin: If income is zero, people will have no health

- This picture looks a lot like the Solow model graph and the mechanics of working with the model are similar to Solow's model, but the curves here are not the same as in Solow

- We can examine how some factor that shifts either curve will affect health and income per capita in an economy.

- First we will suppose something raises y_{ss} in the Solow. We know from before examples are:
  - Increased productivity
  - a higher investment rate
  - lower depreciation rate or
  - lower population growth rate

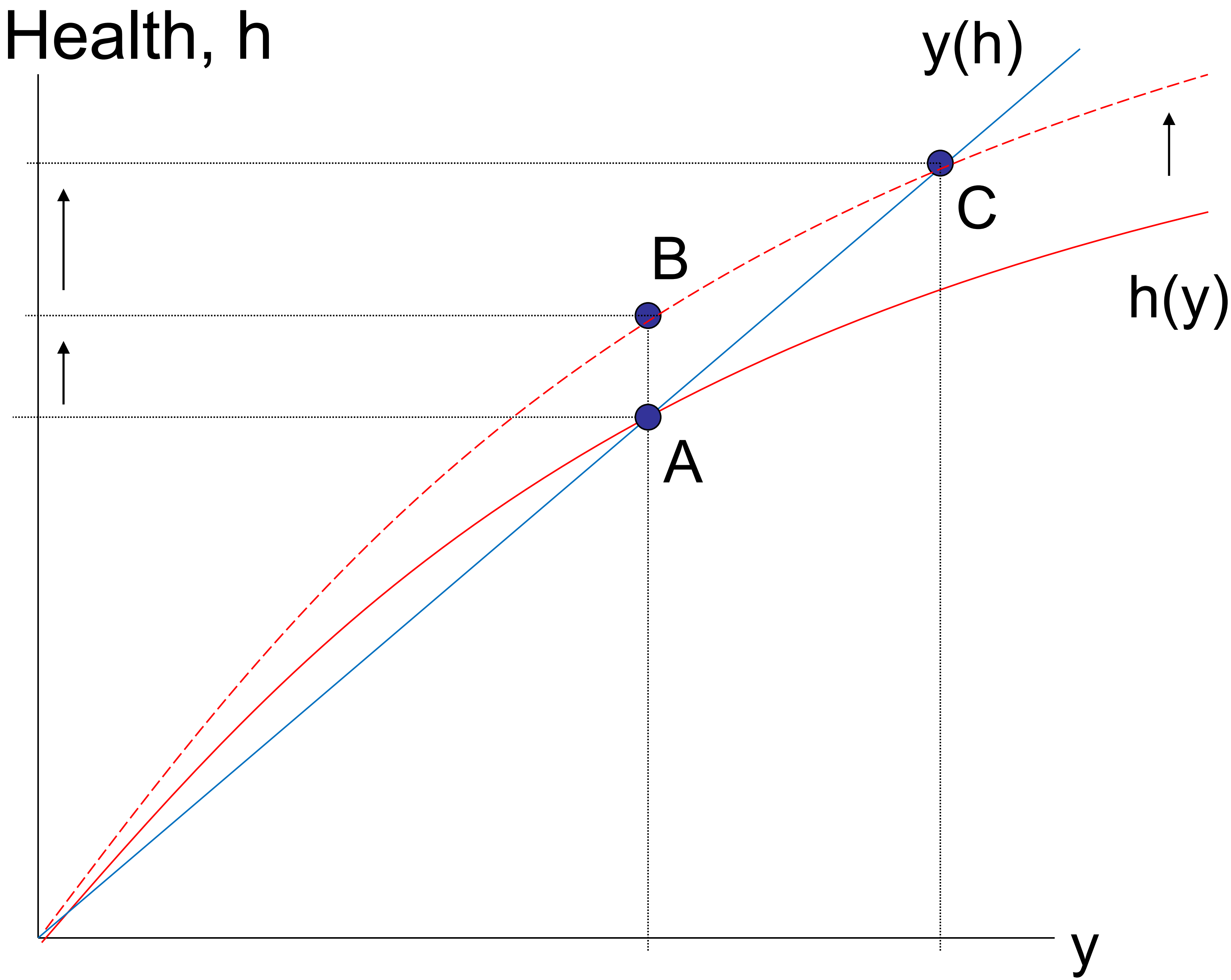
  Any one of these 4 changes raises income for an arbitrary positive level of health and so rotates the straight line clockwise


Health, h
y(h)
C
h(y)
A
B
y

- So when income rises due to these Solow model factors, the rotation of the line causes output to rise (from point A to point B)
- But higher income causes improved health, and better health causes higher income. These two work together to push output and health higher until we reach point C
  - This is called a multiplier effect: The effect on output is multiplied because of heath improvement

- Poorer countries have worse health conditions.
- So the graph suggest one way to improve health is to improve output per capita by rotating clockwise the y(h) lines
  - Increasing the investment rate or raising productivity or reducing the population growth rate, if policymakers can affect these variables

- A policy of directly making improvements to health might also work
  - Increasing number and/or the quality of medical professional, improved medical facilities, increased supply of antibiotics, vaccines, and other medicine, etc.


Health, h
y(h)
C
B
h(y)
A
y

- This has a direct effect on h, but then y increases and we have a multiplier effect on health

- Which policy is best, an incomes policy or direct spending on health, is an open question.
  – We’d need to compare the costs and benefits of these two policies to determine whether the health or the incomes policy is preferable
    - Cost a government incurs and the possible costs to society of a policy are weighed against the benefits derived from improved y and h

- Education is another important component of human capital
  - In a developed economy skills play a more important role in production than the physical attributes of a worker
    - Health still matters, but most workers have adequate health and differ more in terms of skills
  - Education is often measured by years of education
    - Number of years on the job may also affect the level of skills, but we don’t always have that information, particularly for cross-country comparisons
  - Based on years of schooling, we see that education and development are related for countries

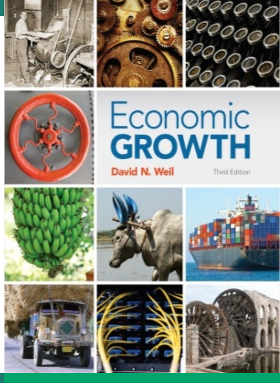
TABLE 6.1

Changes in the Level of Education, 1960–2000

			Percentage of the Adult Population with			
		Average Years of Schooling	No Schooling	Complete Primary Education	Complete Secondary Education	Complete Higher Education
Developing Countries	1960	2.05	64.1	17.1	2.5	0.4
	2000	5.13	34.4	43.0	14.8	3.0
Advanced Countries	1960	7.06	6.1	72.9	20.2	3.0
	2000	9.76	3.7	84.6	44.7	13.0
United States	1960	8.49	2.0	78.4	31.0	7.0
	2000	12.05	0.8	94.9	68.1	24.5

Source: Barro and Lee (2000). Data are for population aged 15 and over.

Table 6.1 Changes in the Level of Education, 1975-2010



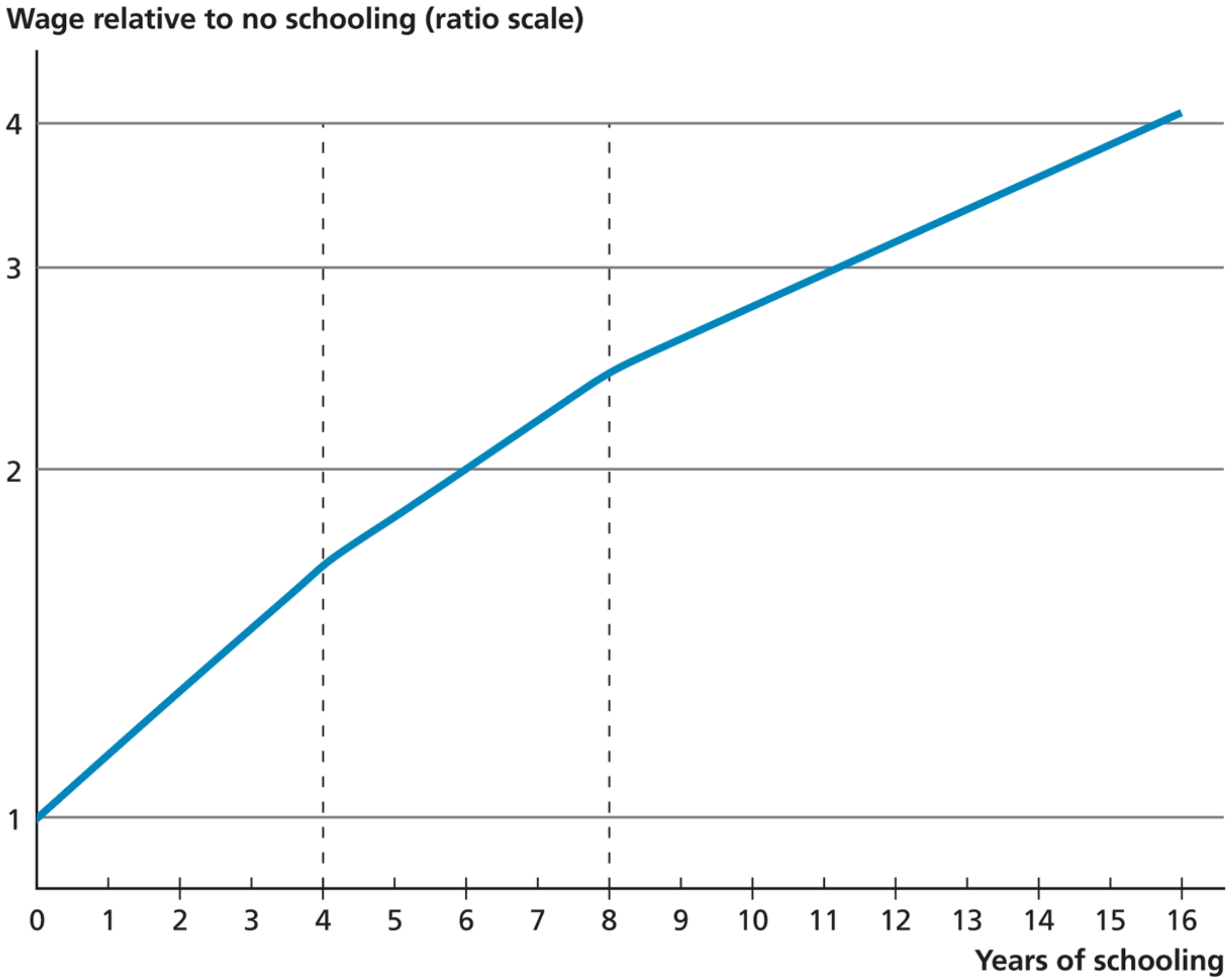
			Percentage of the Adult Population with			
		Average Years of Schooling	**No Schooling**	**Complete Primary Education**	**Complete Secondary Education**	**Complete Higher Education**
Developing Countries	1975	3.2	47.4	32.9	8.1	1.6
	2010	6.7	20.8	68.8	31.5	5.3
Advanced Countries	1975	8.0	6.2	78.8	34.9	8.0
	2010	11.0	2.5	94.0	63.9	16.6
United States	1975	11.4	1.3	94.1	71.1	16.1
	2010	12.4	0.4	98.8	85.4	20.0

Source: Barro and Lee (2010). Data for population 25+.

- Compared with Developing Countries, the Advanced Countries have:
  - People averaging more years of schooling
  - Fewer people with no schooling
  - More people who have completed Primary, Secondary and Higher (College) levels of education
- From 1975 to 2010, all types of countries have made improvements in every education category

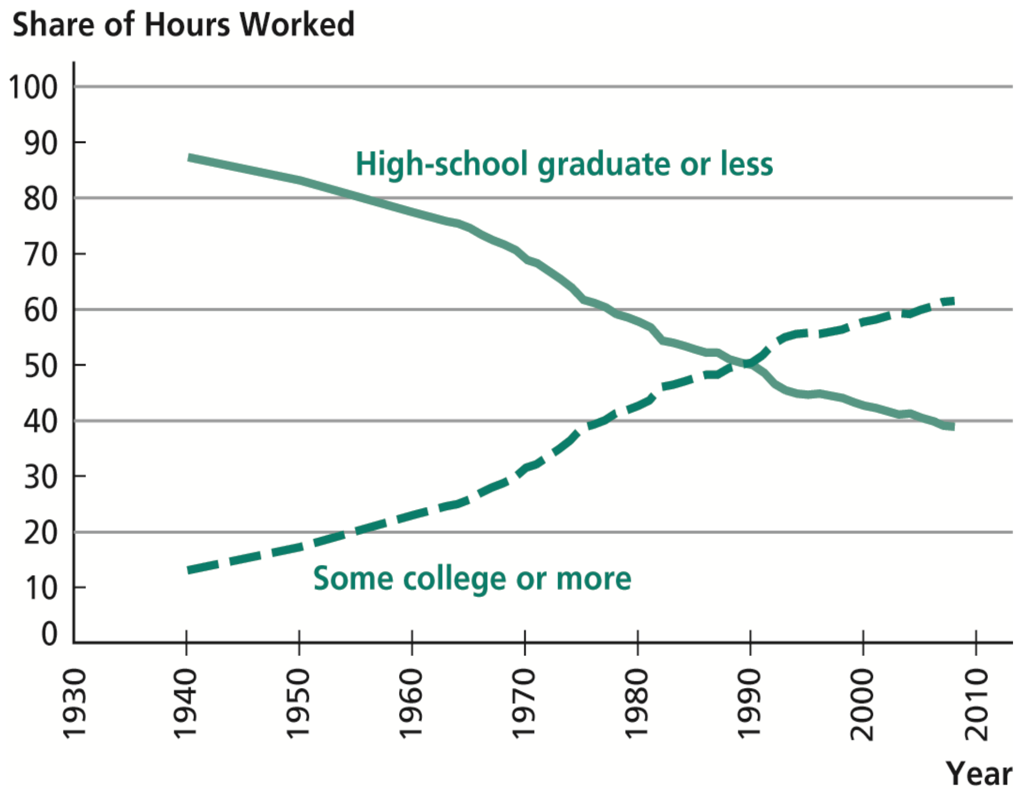
- The value of an additional year of education is called the Return to Education
  - For each year this return can be measured relative to the Return to Education from no schooling
    - Thus the relative return to no years of schooling is 1 by definition
- The Return to Education is plotted in the following graph.
  - Each of the first 4 years earns a return of 13.4%
  - Years 5 through 8 each earn a return of 10.1%
  - And years 9 through 12 each earn a return of 6.8%

FIGURE 6.6
Effect of Education on Wages



- The number of people with at least some college education has been rising since before 1940 in the US.

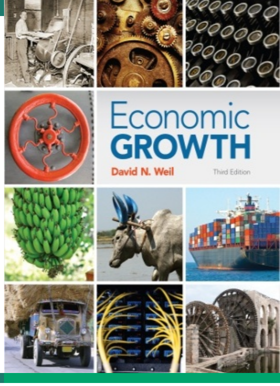
Figure 6.7 Share of Hours Worked by Education Level, 1940–2008



Sources: Autor, Katz, and Krueger (1998), Autor, Katz, and Kearney (2008), Acemoglu and Autor (forthcoming).

- The wage paid to college graduates has fluctuated during this same period of time that more and more people have been going to college

Figure 6.8 Ratio of College Wages to High-School Wages



Sources: Autor, Katz, and Krueger (1998), Autor, Katz, and Kearney (2008), Acemoglu and Autor (2010).

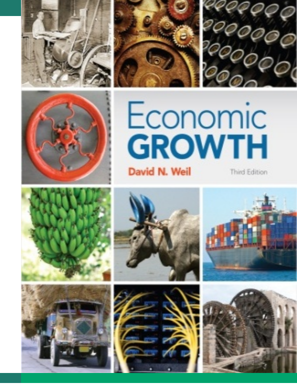
– Fluctuations in the wage paid to college grads relative to high school grads - called the college wage premium - reflect changes in the supply and demand for college educated workers relative to workers with only a high school education

- An increase in the relative supply of college educated workers would reduce their wage relative to the wage paid high school grads
  - By the 1970s the relatively young Baby Boomers with a relatively high propensity for college degrees began to flood the labor market. This drove the relative wage for college grads down
  - Prior to 1950 the rise in supply of college educated workers, due to the GI bill which gave returning soldiers from World War II a free college education, dominated the increase in demand for more highly educated workers driving the wage downward

- An increase in the demand for college educated workers relative to high school educated workers will raise the relative wage of college people
  - Except for the 1970s, the trend in college wage premium has been upward since about 1950. This implies that the demand for college educated workers has been rising faster than the demand for workers with less education since about 1950.

- Table 6.2 defines 7 categories of education, provides the wage relative to no schooling for each category and then provides share of the population in each category for Developing and Advanced Countries
  - Developing countries have a much larger share of population with No Schooling or Incomplete Primary Education
  - All other categories consist of higher levels of education, and the Advanced countries have a larger share of population in each of these

Table 6.2 Breakdown of the Population by Schooling and Wages



Highest Level of Education	Years of schooling	Wage Relative to No Schooling	Percentage of the Population: Developing Countries	Percentage of the Population: Advanced Countries
No Schooling	0	1.00	20.8	2.5
Incomplete Primary	4	1.65	10.4	3.4
Complete Primary	8	2.43	18.0	12.3
Incomplete Secondary	10	2.77	19.3	17.8
Complete Secondary	12	3.16	23.2	37.4
Incomplete Higher	14	3.61	2.9	9.9
Complete Higher	16	4.11	5.3	16.6

Source: Barro and Lee (2010).

- The data in the previous table can be used to estimate the payment to human capital as a share of total wages paid to workers
  - Any wages attributed to education are associated with human capital

- Plotting the data for developing countries allows us to see that 49% of the wages paid to workers in developing countries was attributed to human capital in the 2nd edition of the book
- And in the 3rd edition with more recent data human capital now accounts for a larger amount of income, about 58%

FIGURE 6.9

Share of Human Capital in Wages in Developing Countries

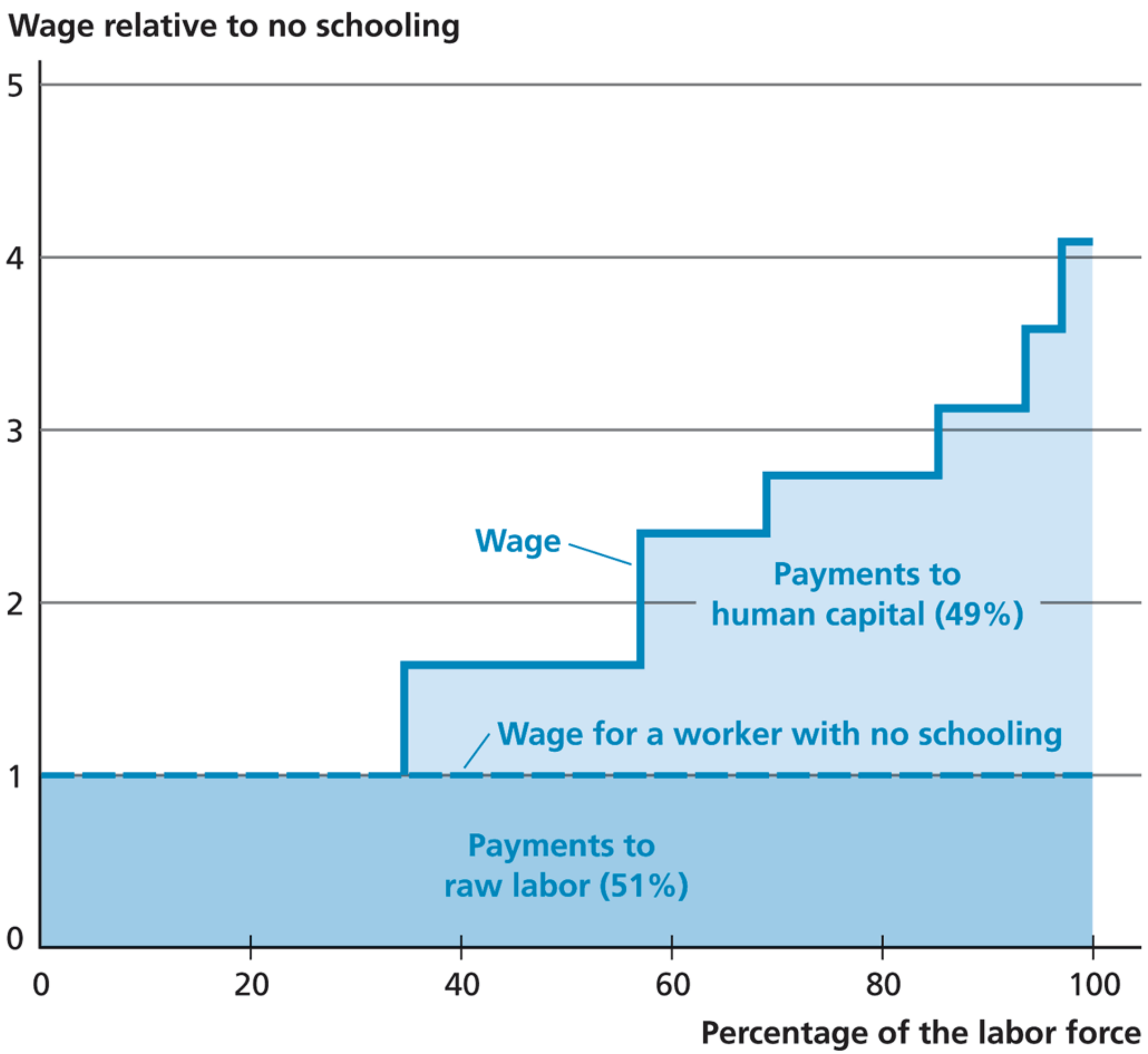
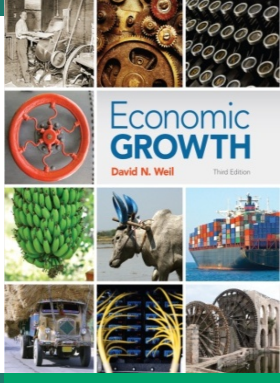
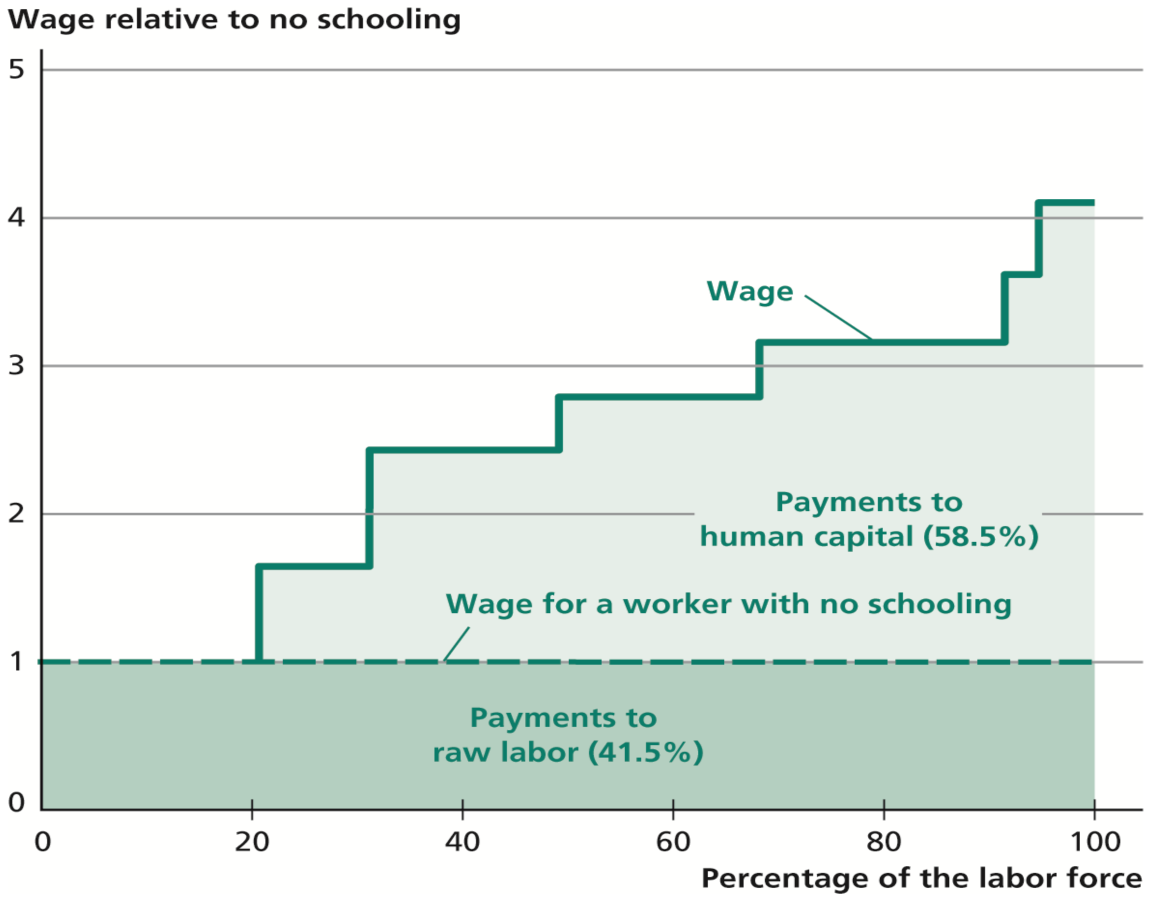


Figure 6.9 Share of Human Capital in Wages in Developing Countries





- The same number can be calculated for Advanced countries
  - We can see that about 2/3 of the wage paid to workers in Advanced Countries goes toward compensating workers for their human capital.
  - That number has not changed much in the last decade

Figure 6.10
Share of Human Capital in Wages in Advanced Countries

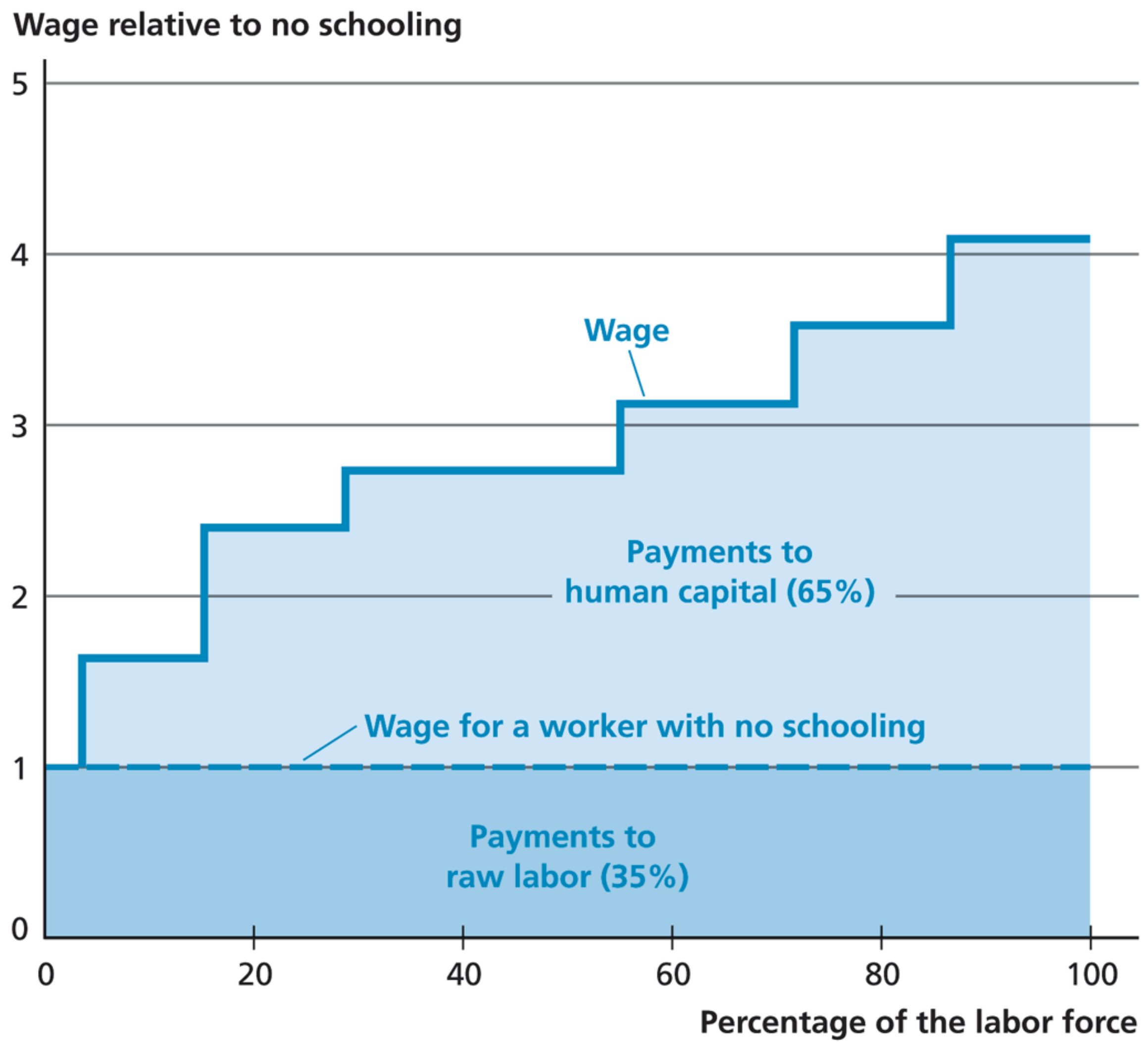
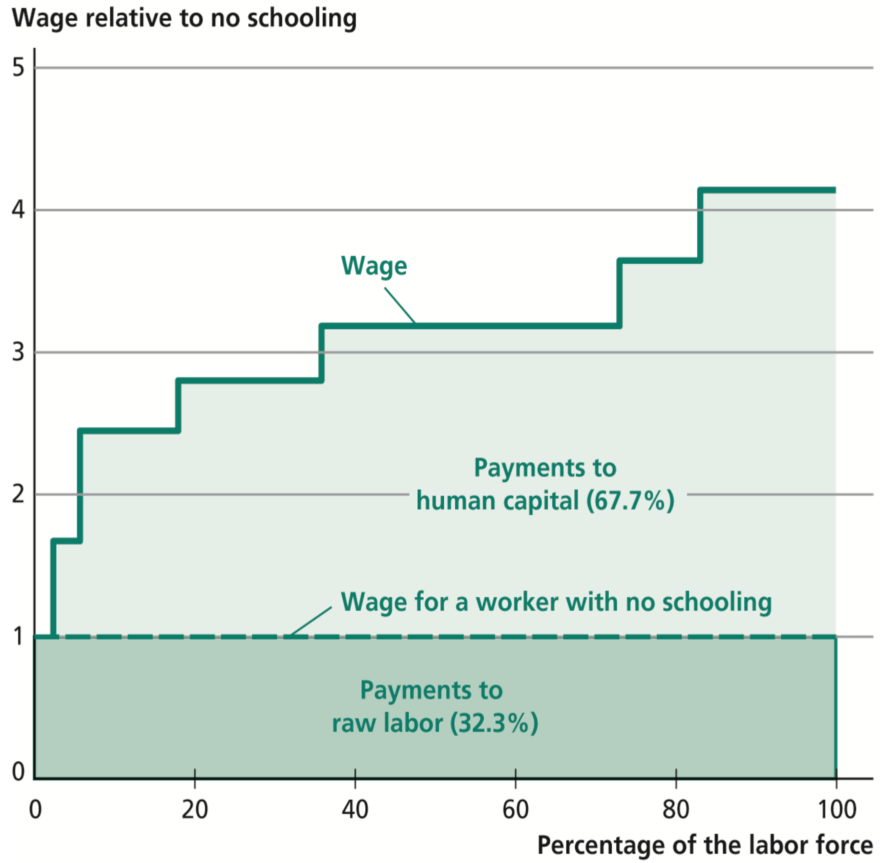


Figure 6.10 Share of Human Capital in Wages in Advanced Countries



- Human capital accounts for a higher share of wages in Advanced Countries than in Developing Countries.
  - This higher share of income suggests that the demand for human capital is higher in Advanced compared to Developing countries

- There is evidence for a cross country relationship between education and output per capita.

  Why?

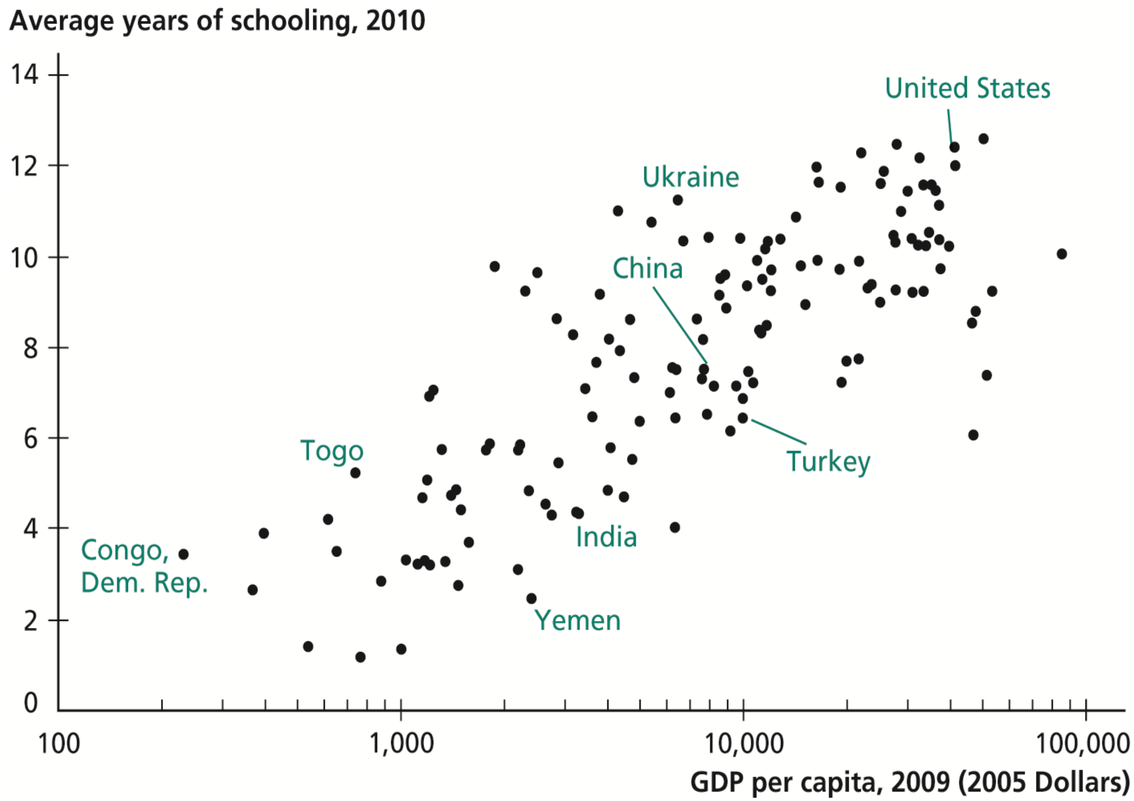
  - People get more human capital and that makes economies able to produce more output

    OR

  - In advanced countries, people have more income and wealth and therefore are able to spend more time and money to increase their human capital

  (its simultaneity once again)

Figure 6.11 Average Years of Schooling versus GDP per Capita



Sources: Barro and Lee (2010), Heston, Summers, and Aten (2011).

- The effect of schooling differences
  A quantitative analysis

  - We can show that if the following are the same across countries:
    - Productivity (A)
    - Investment rate (γ)
    - Population growth rate (n)
    - Depreciation rate (δ)
    - The parameters in the production function (α)
  - Then the ratio of output per capita in two countries is equal to the ratio of human capital

- Recall the steady state result for y:

$$y_{ss} = h \cdot A^{1/(1-\alpha)} \cdot \left(\frac{\gamma}{\delta + n} \right)^{\alpha/(1-\alpha)}$$

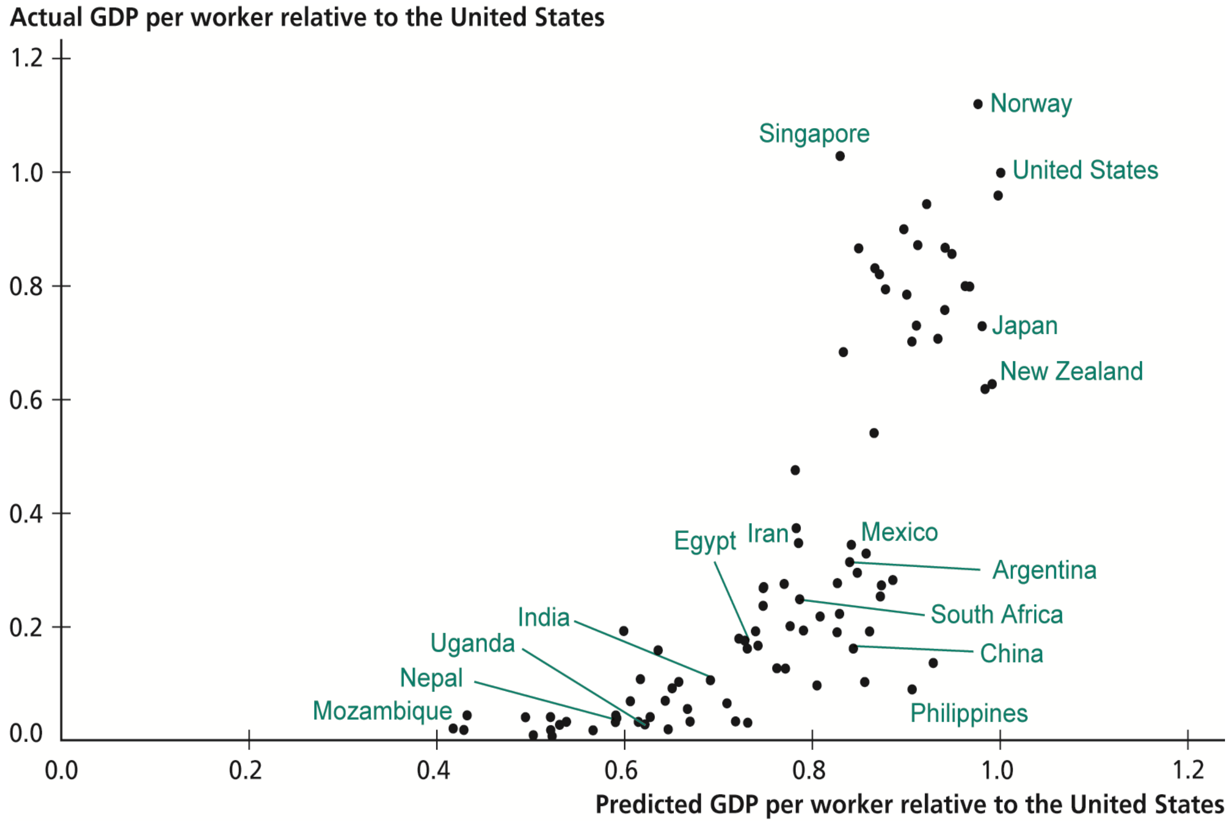
- In general, the ratio of steady state GDP per capita for two countries, named 1 and 2, is:

$$\frac{y_1}{y_2} = \frac{h_1 \cdot A_1^{1/(1-\alpha_1)} \cdot \left(\frac{\gamma_1}{\delta_1 + n_1} \right)^{\alpha_1/(1-\alpha_1)}}{h_2 \cdot A_2^{1/(1-\alpha_2)} \cdot \left(\frac{\gamma_2}{\delta_2 + n_2} \right)^{\alpha_2/(1-\alpha_2)}}$$

- But if h is the only thing that is different: $\frac{y_1}{y_2} = \frac{h_1}{h_2}$

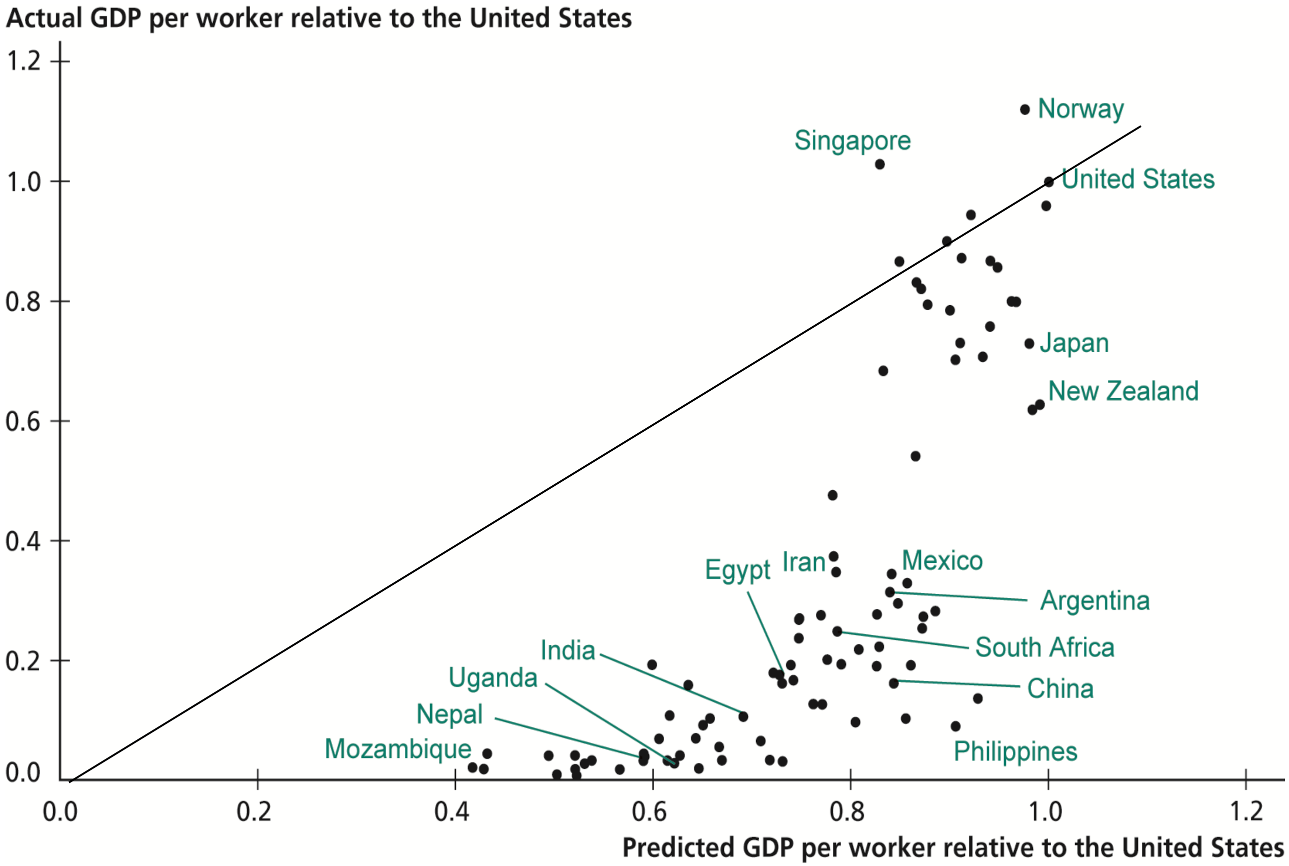
- Can differences in human capital explain all the cross country evidence on differences in GDP per capita?

Figure 6.12 Predicted versus Actual GDP per Worker



– If variation in h explained all of the cross country differences in y, the data would all line up on a line through the axis with a slope of one.

Figure 6.12 Predicted versus Actual GDP per Worker

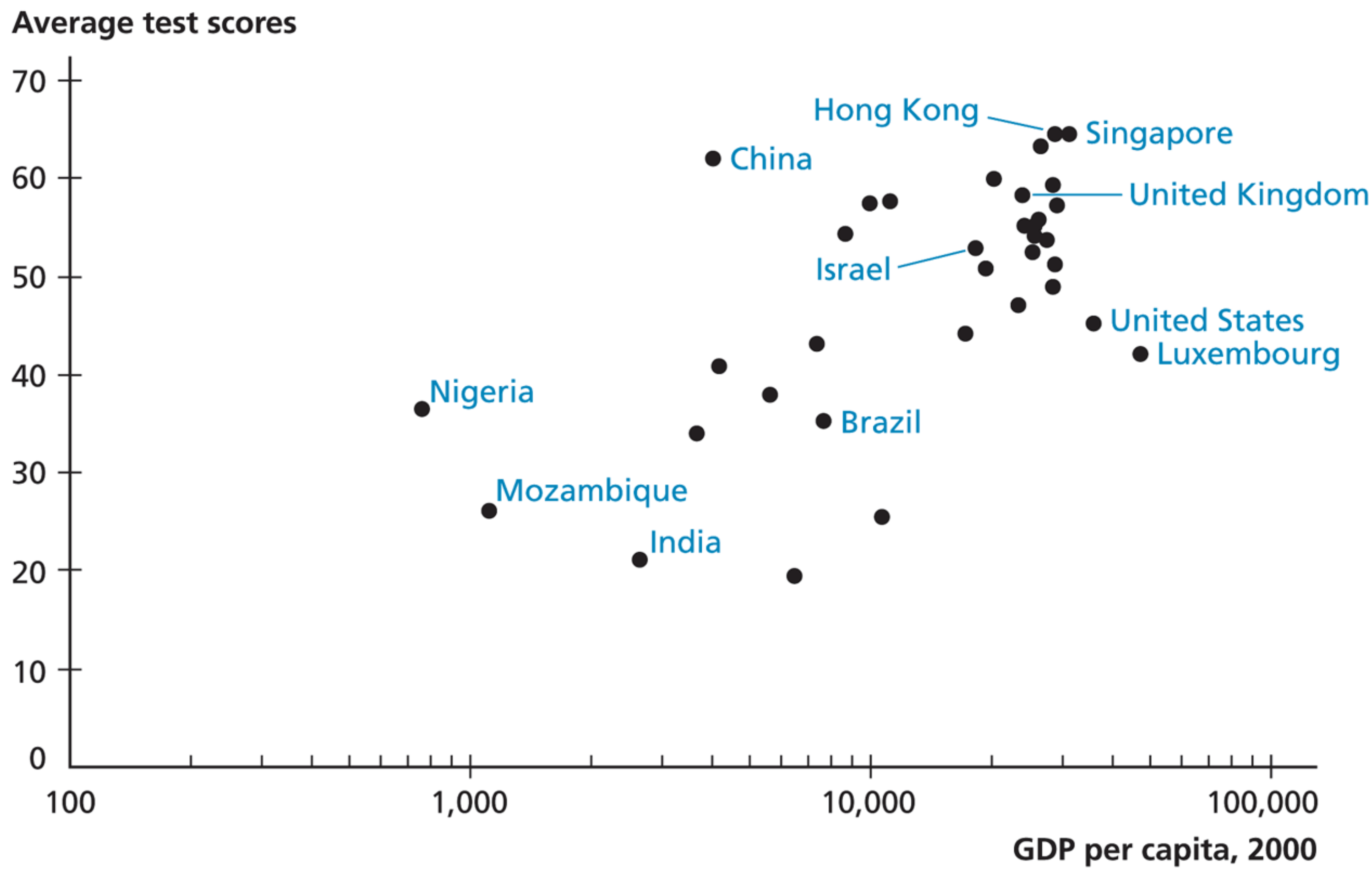


- There is a positive relationship between human capital and output per capita in comparison to the US levels.
- But the graph clearly indicates that human capital does not explain all the variation in output per capita across countries

- What could be missing from the human capital story?

- Is education quality the same across countries?
  - Not according to Figure 6.13
    - Rich countries tend to have better test scores
      - Raises another simultaneity problem all over again
        - Does better schooling create more human capital and therefore more output per capita
        - Or does more output per capita allow students more time to study and also provide better health conditions so that students can perform better
  - Education quality may play a role in the failure of education to explain all the cross country differences in output per capita
    - Education quality is affected by:
      - How good teachers are at conveying their subject matter to students
      - How much effort students are able and willing to contribute to the learning process

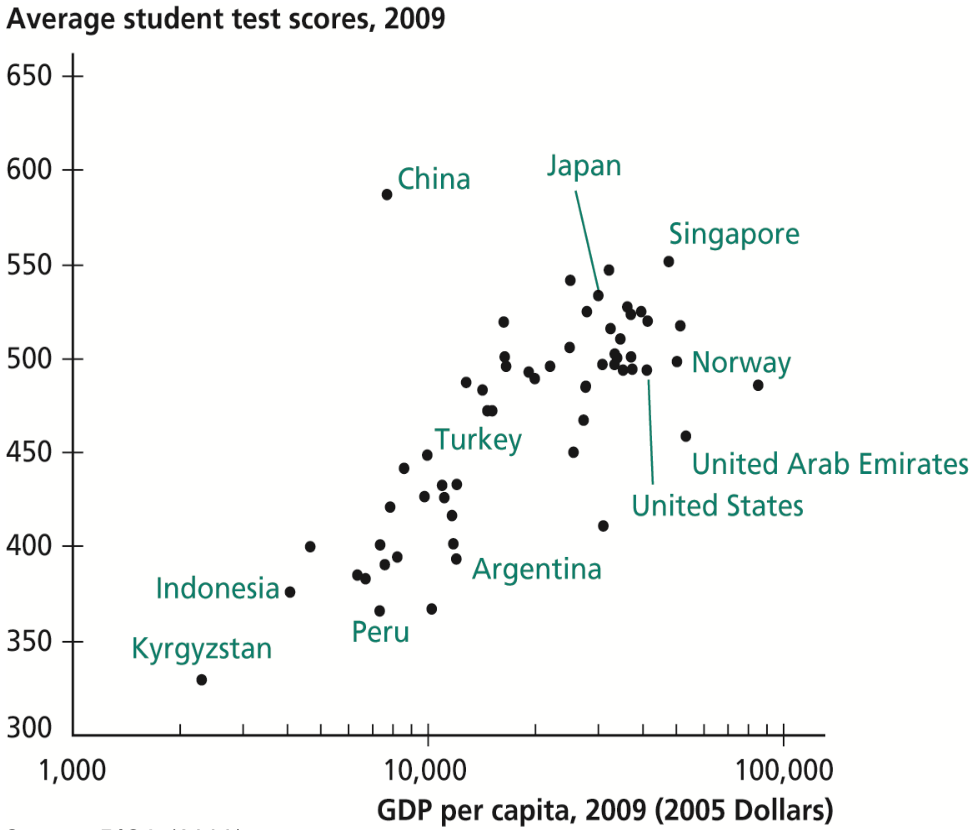
FIGURE 6.13
Student Test Scores Versus GDP per Capita



Source: Hanushek and Kimko (2000).

- And if we update the data from the old to the new version of the text note how China has risen considerably relatively to the rest

Figure 6.13 Student Test Scores versus GDP per Capita

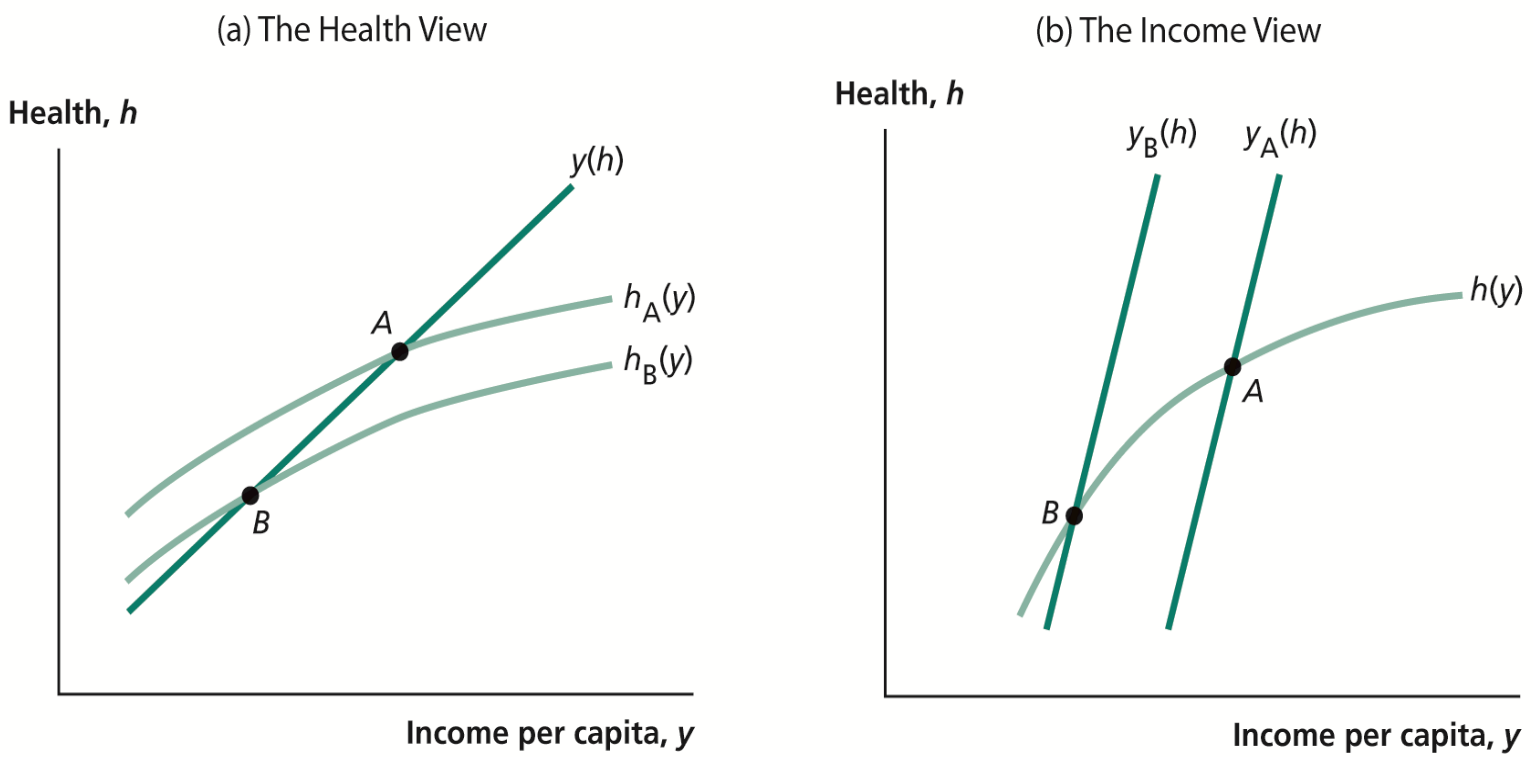


Source: PISA (2009).

- Why has China improved test scores so much?
  - China has invested considerably in educating its better students to perform well on these standardized tests

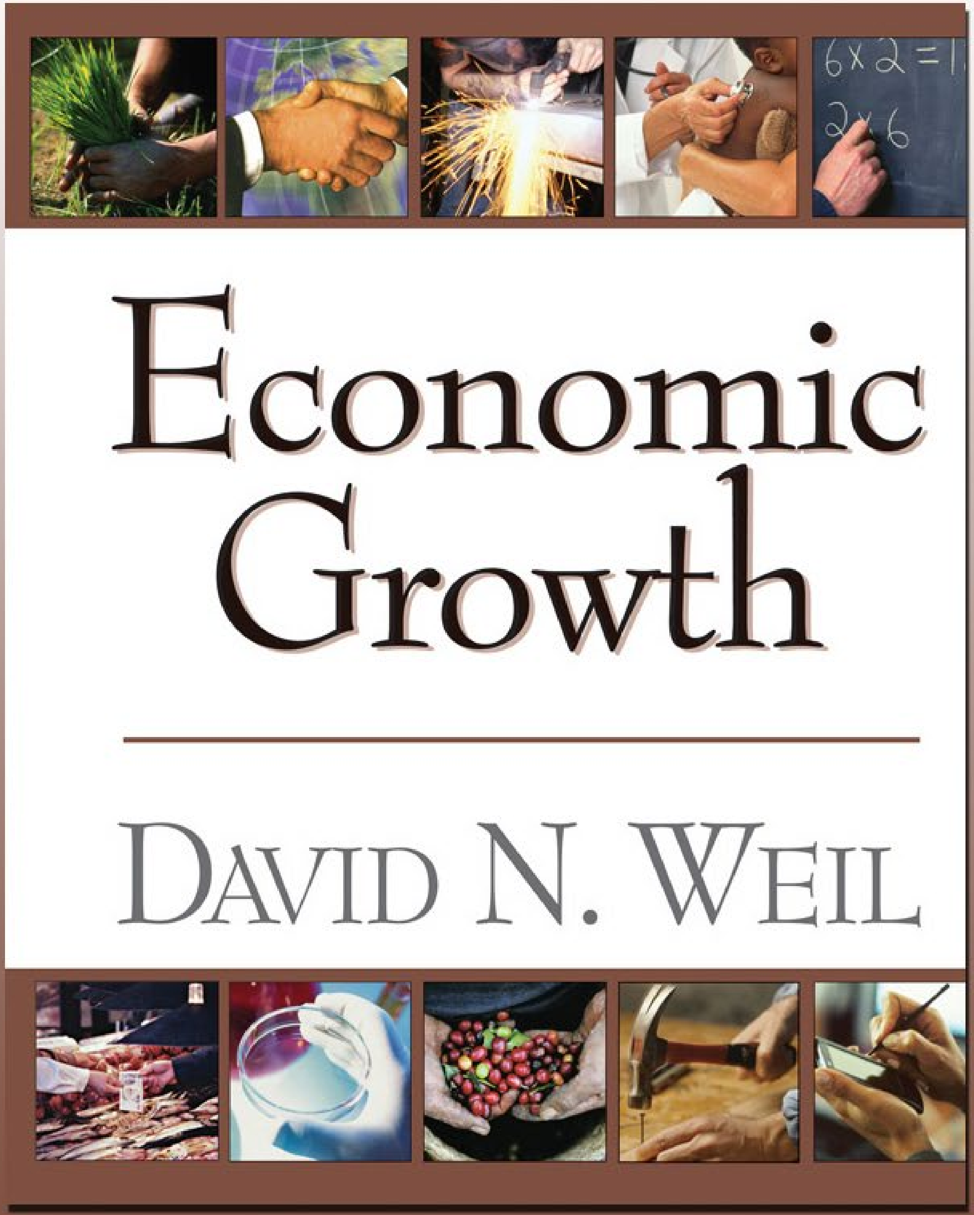
- Another factor in human capital is the externality effect
  - A more educated person can positively affect the performance of employees, co-workers, friends or competitors

Figure 6.4 Health and Income per Capita: Two Views



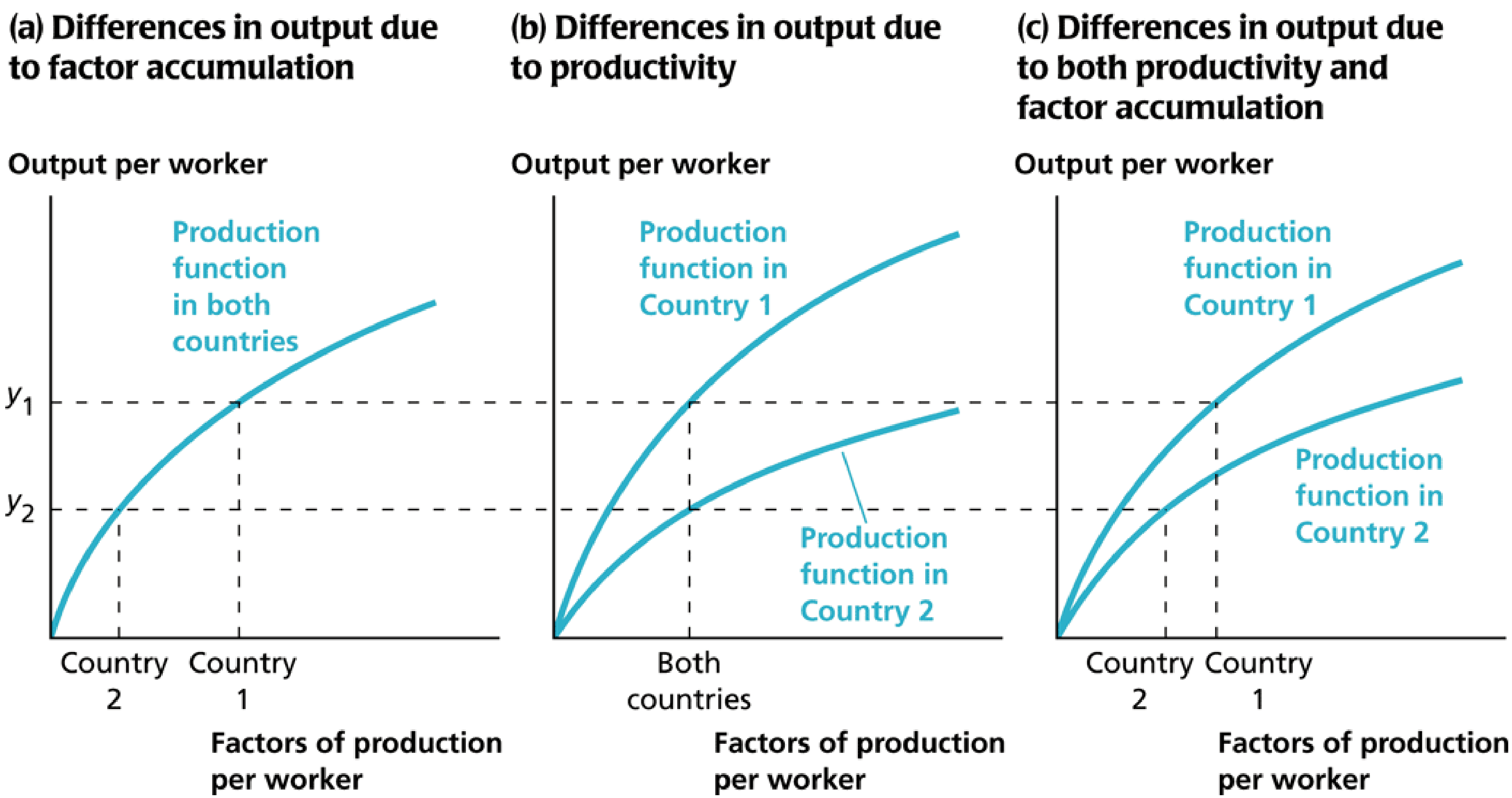
Chapter 7

Measuring Productivity



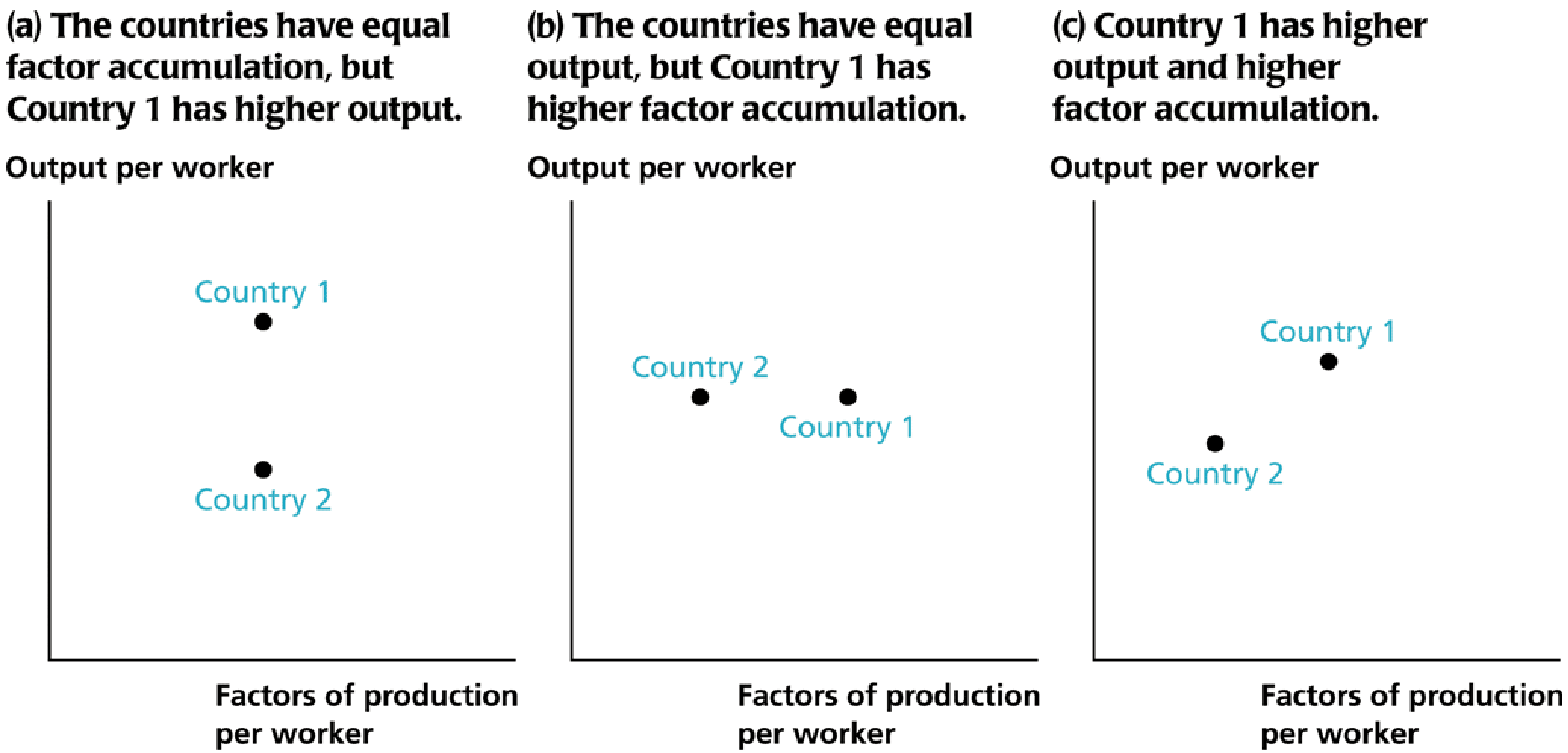
- What can explain why two countries have different levels of income per capita?

Figure 7.1 Possible Sources of Differences in Output per Worker



- Can we use cross-country evidence on Income per Capita and Factors per Worker to infer which country has higher productivity?

Figure 7.2 Inferring Productivity from Data on Output and Factor Accumulation



- Measuring Productivity and the Ratio of Productivity for two different economies

- Start with Production Function

$$Y=AK^{\alpha}(hL)^{1-\alpha}$$

OR in per-capita terms:

$$y=Ak^{\alpha}h^{1-\alpha}$$

- If we define $k^{\alpha}h^{1-\alpha}$ as the factor contribution to output then, the last equation says:

(Output per capita) = productivity • (factor contribution)

- Thus for Economy 1:

$$y_1=A_1k_1^{\alpha}h_1^{1-\alpha}$$

- And for Economy 2:

$$y_2=A_2k_2^{\alpha}h_2^{1-\alpha}$$

- Then we can calculate the ratio of income per capita for these two economies:

$$\frac{y_1}{y_2} = \frac{A_1 k_1^{\alpha} h_1^{1-\alpha}}{A_2 k_2^{\alpha} h_2^{1-\alpha}} = \left(\frac{A_1}{A_2}\right)\left(\frac{k_1^{\alpha} h_1^{1-\alpha}}{k_2^{\alpha} h_2^{1-\alpha}}\right)$$

- This equation says the ratio of income per capita equals the ratio of productivity times the ratio of factor contributions. Use that equation to solve for the ratio of productivity

$$\left(\frac{A_1}{A_2}\right) = \frac{\left(\frac{y_1}{y_2}\right)}{\left(\frac{k_1^{\alpha} h_1^{1-\alpha}}{k_2^{\alpha} h_2^{1-\alpha}}\right)}$$

– The last equation shows how to calculate the ratio of productivity. Using rules for exponents, we can further refine the ratio of factors:

$$\left(\frac{k_1^{\alpha} h_1^{1\text{-}\alpha}}{k_2^{\alpha} h_2^{1\text{-}\alpha}}\right) = \left(\frac{k_1}{k_2}\right)^{\alpha} \left(\frac{h_1}{h_2}\right)^{1-\alpha}$$

– Note that this turns the ratio of factor contributions into a function of the ratios of physical capital and human capital. Now insert this last result into the equation for the ratio of productivity:

$$\left(\frac{A_1}{A_2}\right) = \frac{\left(\frac{y_1}{y_2}\right)}{\left(\frac{k_1}{k_2}\right)^{\alpha} \left(\frac{h_1}{h_2}\right)^{1-\alpha}}$$

- An example of how to use the equation to calculate relative levels of productivity

TABLE 7.1
Data Used to Analyze Productivity in Country 1 and Country 2

	Output per Worker, *y*	Physical Capital per Worker, *k*	Human Capital per Worker, *h*
Country 1	24	27	8
Country 2	1	1	1

- So the ratio of productivity can be calculated by the equation given, assuming a value of α=1/3

$$\left(\frac{A_1}{A_2}\right) = \frac{(24)}{(27)^{1/3}(8)^{2/3}} = \frac{24}{(3)(4)} = 2$$

- Next we examine real data for a number of different economies.
  - For comparison purposes, a set of countries are ranked according to income per capita
  - Also the US is the country that each country's data is compared to (that is why all US data are equal to 1)

Table 7.2 Development Accounting

Country	Output per Worker, y	Physical Capital per Worker, k	Human Capital per Worker, h	Factors of Production, $k^{1/3}h^{2/3}$	Productivity, A
United States	1.00	1.00	1.00	1.00	1.00
Norway	1.12	1.32	0.98	1.08	1.04
United Kingdom	0.82	0.68	0.87	0.80	1.03
Canada	0.80	0.81	0.96	0.91	0.88
Japan	0.73	1.16	0.98	1.04	0.70
South Korea	0.62	0.92	0.98	0.96	0.64
Turkey	0.37	0.28	0.78	0.55	0.68
Mexico	0.35	0.33	0.84	0.61	0.56
Brazil	0.20	0.19	0.78	0.48	0.42
India	0.10	0.089	0.66	0.34	0.31
Kenya	0.032	0.022	0.73	0.23	0.14
Malawi	0.018	0.029	0.57	0.21	0.087

Sources: Output per worker: Heston, Summers, and Aten (2011); physical capital: author's calculations; human capital: Barro and Lee (2010). The data set used here and in Section 7.3 is composed of data for 90 countries for which consistent data are available for 1975 and 2009.

- US and Canada have roughly the same amount of factors per capita
  - the big difference in income per capita comes from the US having higher productivity
- Compared with the US, Japan has much higher capital per person and much lower human capital per person
  - Taken together these factors contribute about the same as factors for the US
  - Again US productivity is much higher to account for the difference in output per capita
- The UK has less of both factors than Japan and Canada, but has higher productivity and so has income per capital only a little less than those two countries
- The big income difference between the UK and South Korea comes from productivity differences
- South Korea has substantially more income per capita than Mexico primarily because South Korea's factors contribute so much more.
  - Productivity is about the same in these two countries
- India, Kenya and Tanzania have very low levels of income per capita.

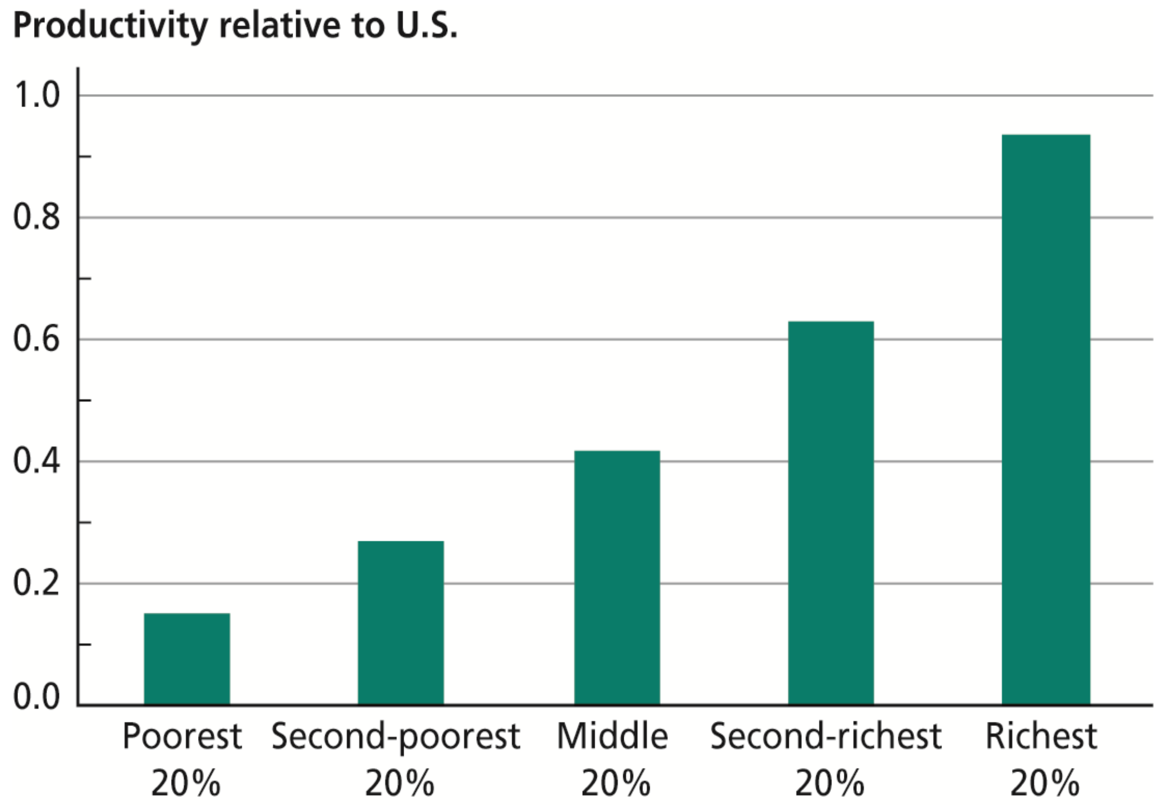
- Looking at data from all countries we see that factor differences play an important role in explaining differences in income per worker across countries

Figure 7.3 Role of Factors of Production in Determining Output per Worker, 2009

For sources, see Table 7.2.

- Productivity differences also play an important role in explaining differences in income per worker across countries

Figure 7.4 Role of Productivity in Determining Output per Worker, 2009



For sources, see Table 7.2.

- In general, the reason why richer countries are doing better than the poorer ones is that they have higher productivity and larger amounts of both physical and human capital

- What explains different growth rates in productivity?
  - We derive the measure of the growth rate of productivity based on the production function

- The Production Function in per-capita terms is:

$$y=Ak^{\alpha}h^{1-\alpha}$$

Define: $X=k^{\alpha}h^{1-\alpha}$:

Then: $y=A\bullet X$

- We know from earlier mathematical results (by taking the natural log of the last equation and then taking the derivative with respect to time of that expression) to obtain:

$$\hat{y}=\hat{A}+\hat{X}$$

- In other words, the growth of income per capita equals productivity growth plus the growth contribution from the factors:

- Given the definition for growth factors: $X=k^{\alpha}h^{1-\alpha}$,

  we can calculate the growth rate relationship for factors:

$$\hat{X} = \alpha\hat{k} + (1-\alpha)\hat{h}$$

- In other words, growth in factors is equal to α times the growth rate of physical capital plus (1-α) times the growth rate in human capital
- Combine this result with the growth rate in output per capita equation from the last slide:

$$\hat{y}=\hat{A}+\alpha\hat{k} + (1-\alpha)\hat{h}$$

- And then we can calculate productivity growth:

$$\hat{A}=\hat{y} - \alpha\hat{k} - (1-\alpha)\hat{h}$$

- Thus we can use measures of growth in y, k and h along with an estimate of the α parameter are what we need to calculate productivity growth for a country
- The following Table provides a simple example of calculating the growth rate of productivity

Table 7.3
Data for Calculating Productivity Growth in Erewhon

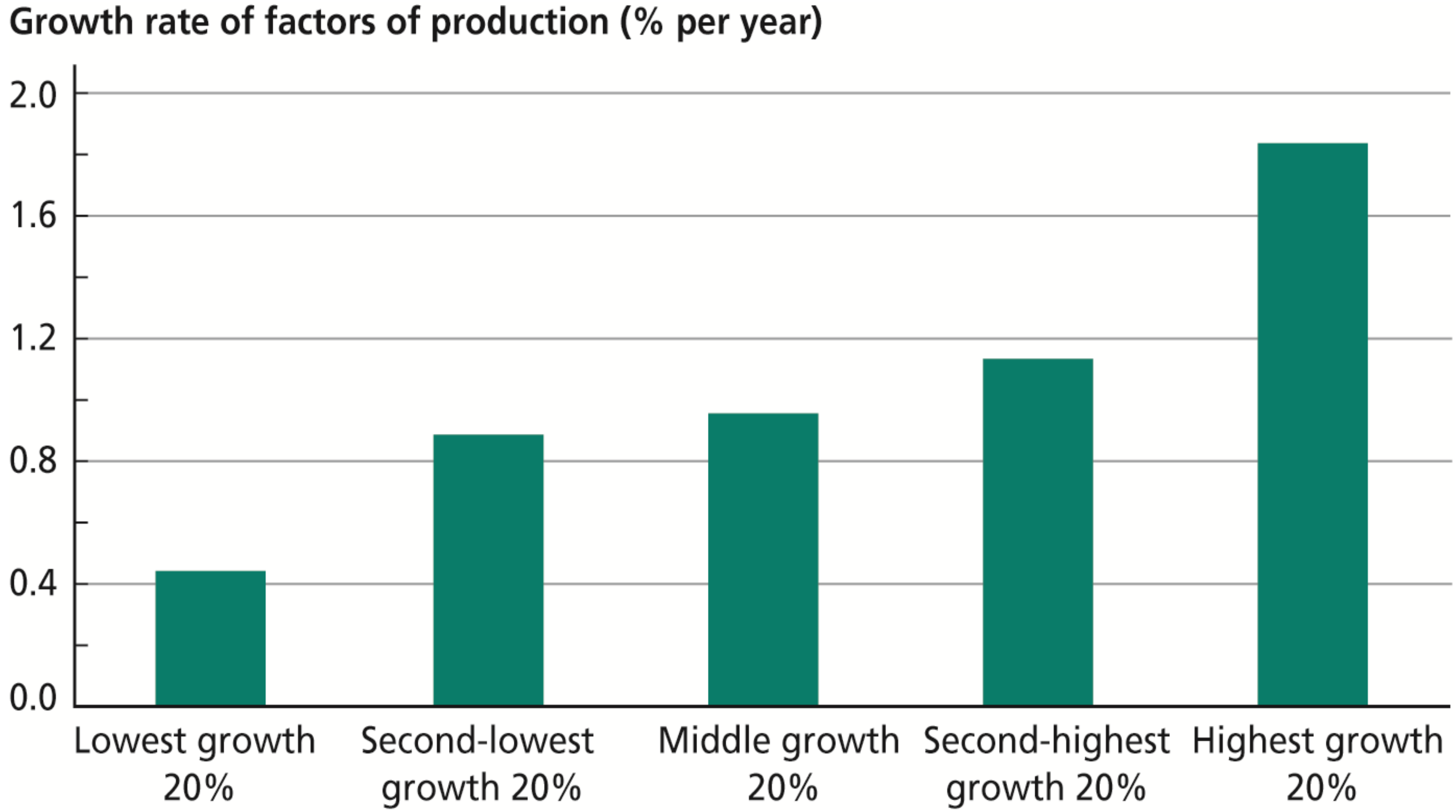
	Output per Worker, *y*	Physical Capital per Worker, *k*	Human Capital per Worker, *h*
Erewhon in 1965	1	20	5
Erewhon in 2000	4	40	10
Annual Growth Rate	4%	2%	2%

- Given these growth rates, calculated on the basis of the rule of 70, and using the standard value of 1/3 for the α parameter, we can calculate the growth rate of productivity is 2 percent:

$$\hat{A} = .04 - (1/3)(.02) - (2/3)(.02) = .02$$

- How important is the growth of factors in explaining growth of countries?

Figure 7.5 Role of Factors of Production in Determining Growth, 1975–2009

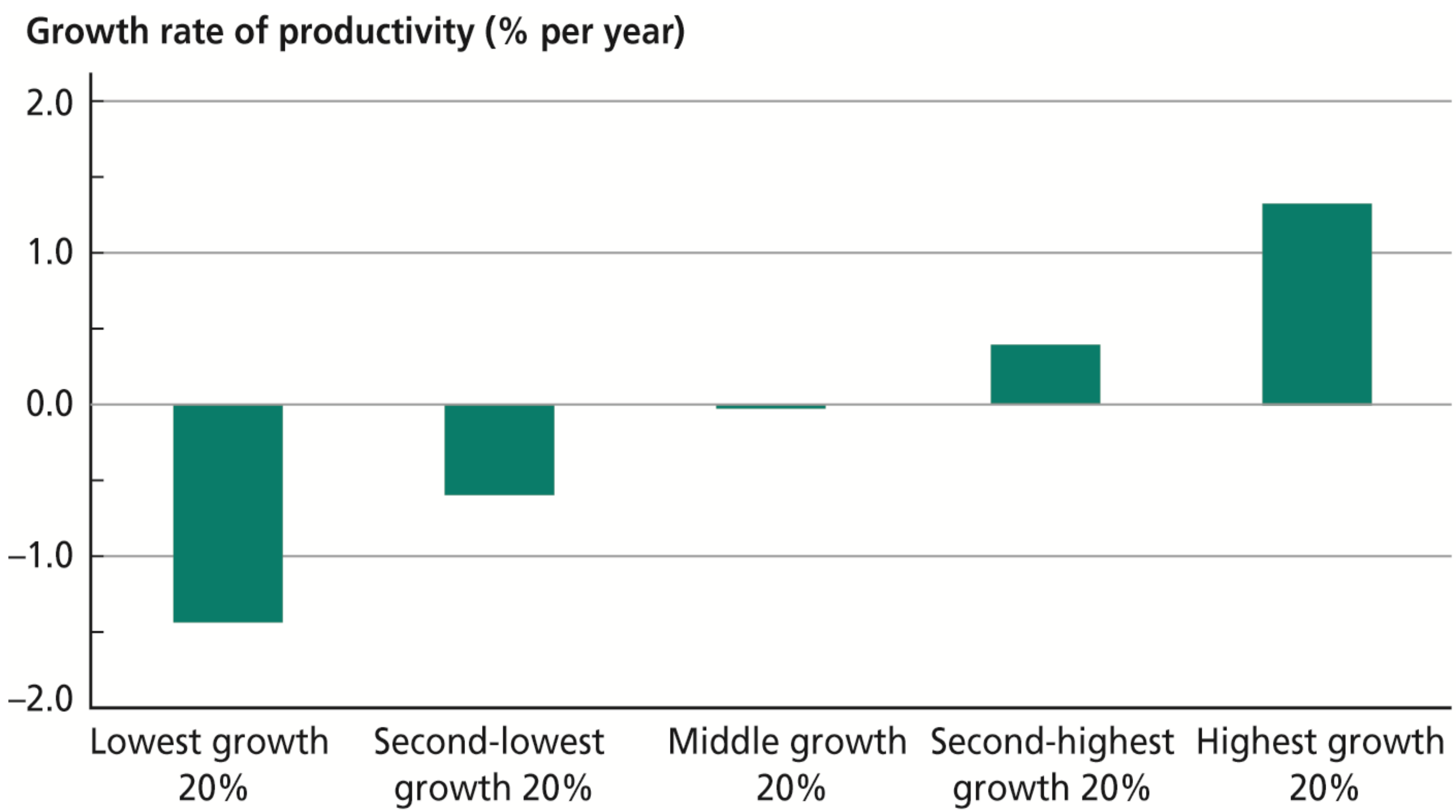


For sources, see Table 7.2.

- Countries tend to grow faster when their factors grow at a higher rate
- But growth in factors is particularly important for the fastest growing nations

- How important is productivity growth in explaining the growth rate of countries

Figure 7.6 Role of Productivity in Determining Growth, 1975–2009



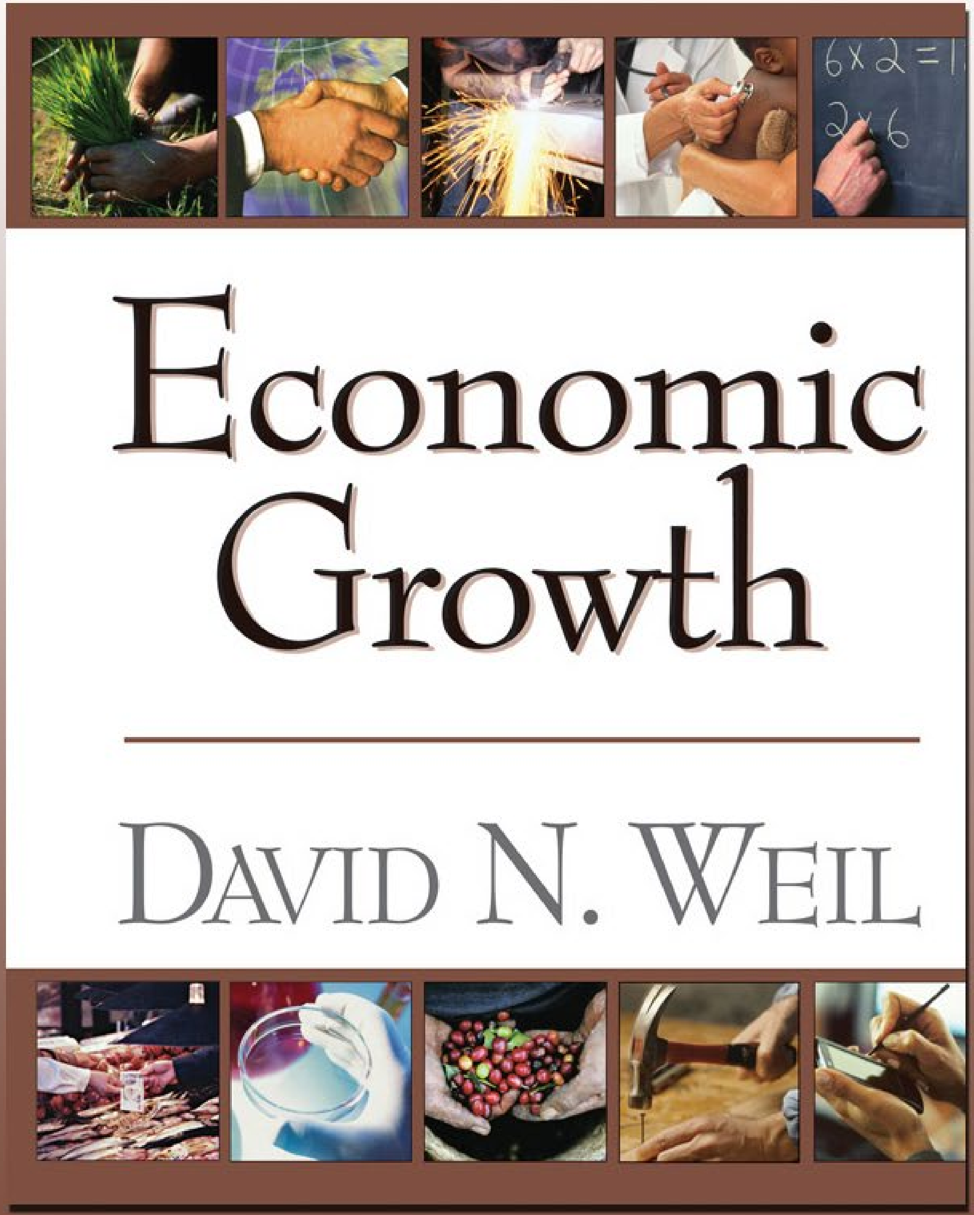
For sources, see Table 7.2.

- Productivity growth rates are higher in faster growing countries
  - The slowest growing countries actually have negative productivity growth
  - The second slowest growth group of countries also has a negative growth rate of productivity, though not as negative as the bottom quintile
  - The middle group has a positive growth rate of productivity, a little less than the second quintile

Second test material Stops here

Chapter 8

The Role of Technology in Growth



PEARSON Addison Wesley

- Our first model of how technology is endogenously created and how that affects economic growth
  - Assume labor does one or two things:
    1. Produces output: L_Y
    2. Research and Development (R&D) : L_A

    If total labor is equal to L, $L=L_Y+L_A$
  - Assume γ_A is the share of labor involved with R&D
  - Using the definition of total labor:

$$L = L_Y + \gamma_A L$$

  - And solving for L_Y:

$$L_Y = (1-\gamma_A)L$$

  - Finally assume the production function has constant returns to scale for factors and labor is the only factor

$$Y = AL_Y$$

- Insert the definition of output producing labor into the production function:

$$Y = A(1-\gamma_A)L$$

- Dividing by L, obtain the output per capita production function:

$$y = \left(\frac{Y}{L}\right) = A(1-\gamma_A)$$

- Now we need to determine how technology is determined. Let μ be the price of creating new technology.
- Assume the following technology production function is:

$$\hat{A} = \frac{L_A}{\mu}$$

- Substituting the definition of L_A into this production function: $\hat{A} = \frac{\gamma_A L}{\mu}$
- On the basis of this equation we can determine what factors can change the growth rate of technology. From the last equation we see that technology grows faster when:
  1. Increased γ_A (share of labor force doing R&D)
  2. Increased L (total labor force)
  3. Decreased μ (price of innovation)

- How well does the prediction that a higher population causes an increase in the productivity growth rate fit the data?
  - It does NOT fit well with cross country data – we DON'T find that countries with larger populations tend to have faster growth in productivity
  - It seems to do a bit better with world-wide performance – world wide GDP per capita and the world's population have been rising over time
    - However, when we took more carefully at the data, we see that the population growth rate, not the level, is more closely associated with growth in productivity and output per capita.
      - When the population growth rate increases growth rates for productivity and output per capita have increased

- Given the equation for output per capita:

$$y = A(1-\gamma_A)$$

- We can use our rules for calculating growth rates to show that:

$$\hat{y} = \hat{A} + \text{growth of } (1-\gamma_A)$$

- And since γ_A bounded between zero and one it can not grow over time. The same is true for $(1-\gamma_A)$ and so that means that in the long run, the previous growth equation yields:

$$\hat{y} = \hat{A}$$

- This simple model omits:
  - Spending that firms must do to create R&D (it only emphasizes number or workers)
  - It is reasonable to think that R&D requires that firms have certain types of capital and so perhaps k should be a factor in the production of knowledge
  - Most likely the production of knowledge depends on the human capital of the researchers
- This model, like all models in economics, is a simplification of the real world

- R&D can be financed at the private level or by the government
  - Private R&D funding is driven by the profit-making motive
  - Government funding for a certain type of R&D may be required if the private sector does not fund it and if it is thought to be have some chance of being very useful in the future
    - The private sector rarely spends money to develop highly speculative technologies, especially when it is unclear that marketable products will arise from this technology

R&D Spending for some of the developed countries

Table 8.1 Researchers and Research Spending, 2005

Country	Number of Researchers	Researchers as a Percentage of the Labor Force	Research Spending ($ billions)	Research Spending as a Percentage of GDP
United States	1,334,628	0.89%	312.5	2.5
Japan	677,206	1.02%	118.0	3.0
Germany	268,100	0.61%	61.7	2.4
France	200,064	0.72%	40.4	2.1
Korea	179,812	0.76%	31.6	2.9
OECD Total	3,707,255	0.66%	740.5	2.1

Source: OECD Main Science and Technology Indicators database.

Table 8.1 Researchers and Research Spending, 2009

Country	Number of Researchers	Researchers as a Percentage of the Labor Force	Research Spending ($ billions)	Research Spending as a Percentage of GDP
United States	1,412,639	0.89%	398.2	2.8%
Japan	655,530	1.00%	137.9	3.4%
Germany	311,519	0.74%	82.7	2.8%
France	229,130	0.80%	48	2.2%
Korea	236,137	0.96%	43.9	3.3%
OECD Total	4,199,512	0.70%	965.6	2.4%

Source: OECD Main Science and Technology Indicators database.

- From the table we can see
  - Japan has a larger share of its workers in R&D than the US
  - Japan also devotes a larger share of its R&D spending to income
  - Given these two pieces of data, in combination with the model, it seems surprising that Japan's productivity is so much lower than that for the US (as we saw before)

TECHNOLOGY IS FUNDAMENTALLY DIFFERENT THAN FACTORS

(1) PHYSICAL CAPITAL, LABOR + HUMAN CAPITAL ARE RIVAL FACTORS

(2) IDEAS ARE TECHNOLOGY + IDEAS ARE NON-RIVAL

EXCLUDABILITY: ABILITY TO KEEP OTHERS FROM USING SOMETHING. IDEAS MAY NOT BE EXCLUDABLE. IN FACT, GENERALLY THEY ARE NOT WITHOUT SOME TYPE OF REGULATION.

IMPLICATION: IF WE CAN'T CREATE EXCLUDABILITY FOR IDEAS, THE RETURN ON IDEAS IS LOWER. PRODUCTION OF NEW IDEAS WILL BE VERY LOW.

- How do firms protect their ideas?
  - Patents
    - Anyone using the idea must appropriately compensate the holder of the patent
  - Trade secrets
    - If a secret can be kept this will be even more secure than a patent

The 3 key equations in this simple growth model.

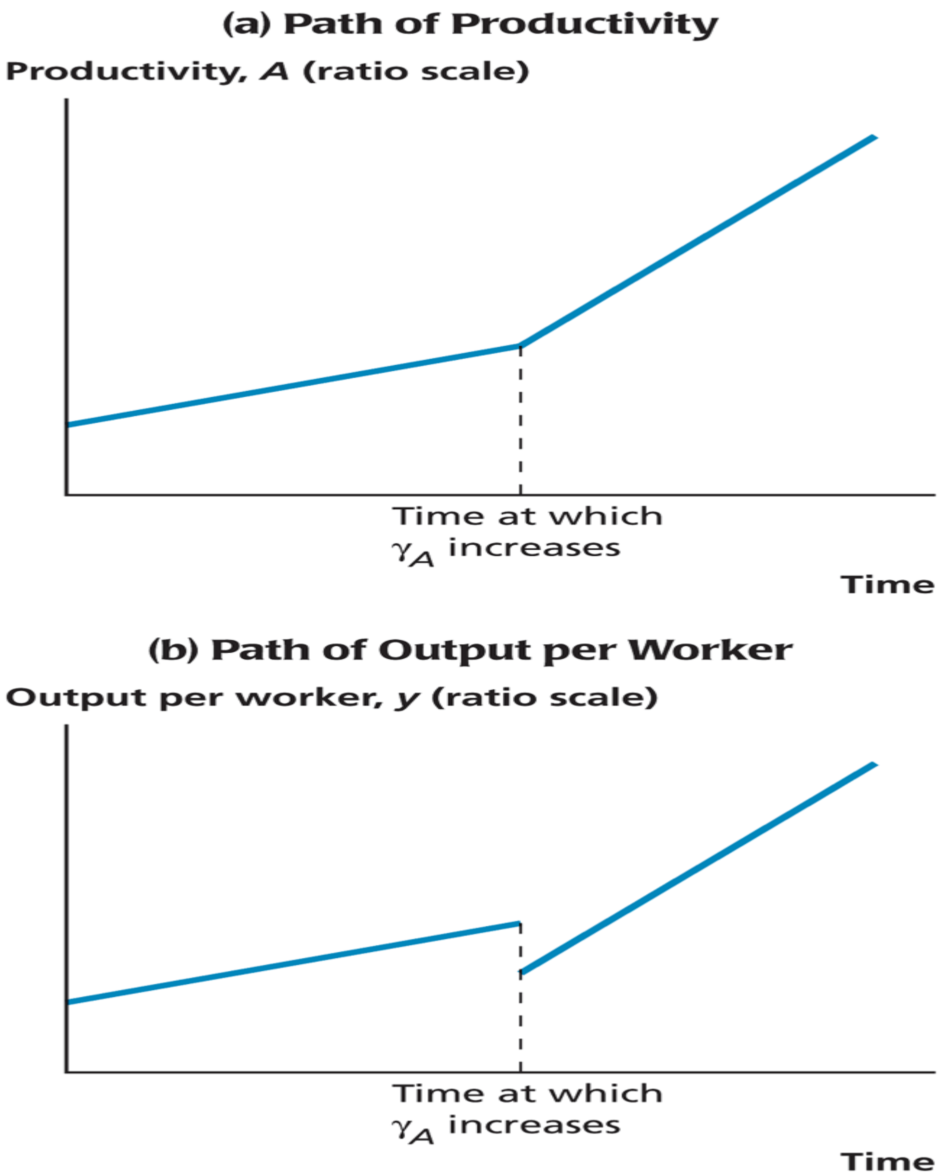
$$\hat{y} = \hat{A}$$

$$y = A(1 - \gamma_A)$$

$$\hat{A} = \frac{\gamma_A \cdot L}{\mu}$$

- A graphical version of the effects in this model

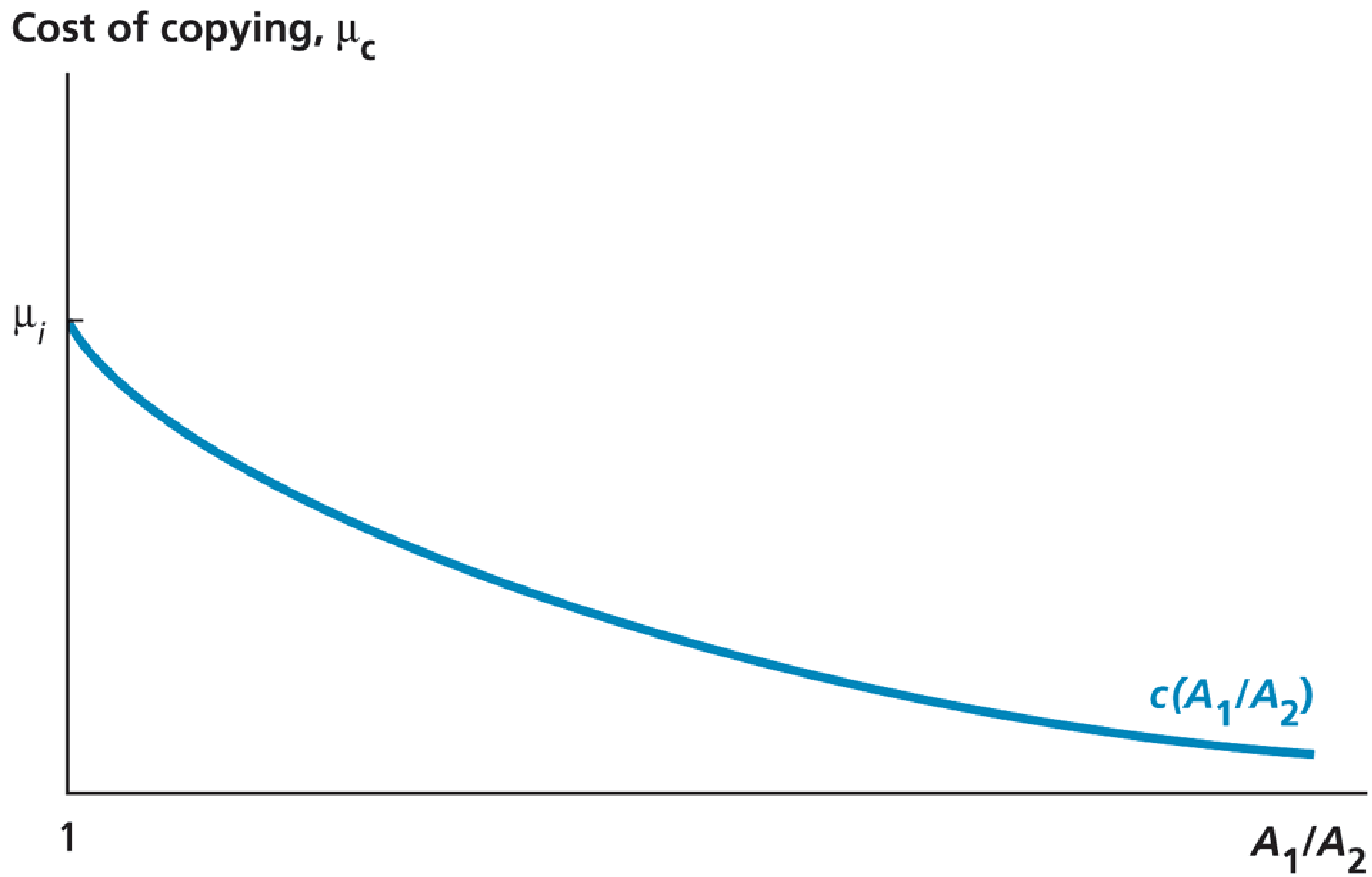
FIGURE 8.1
Effect of Shifting Labor into R and D



- an increase in the share of people developing new technologies leads to:
  - Productivity growing at a faster rate
  - Output per person falling initially
  - But, after this initial decline in y, output per person grows at a faster rate than before the share parameter increased

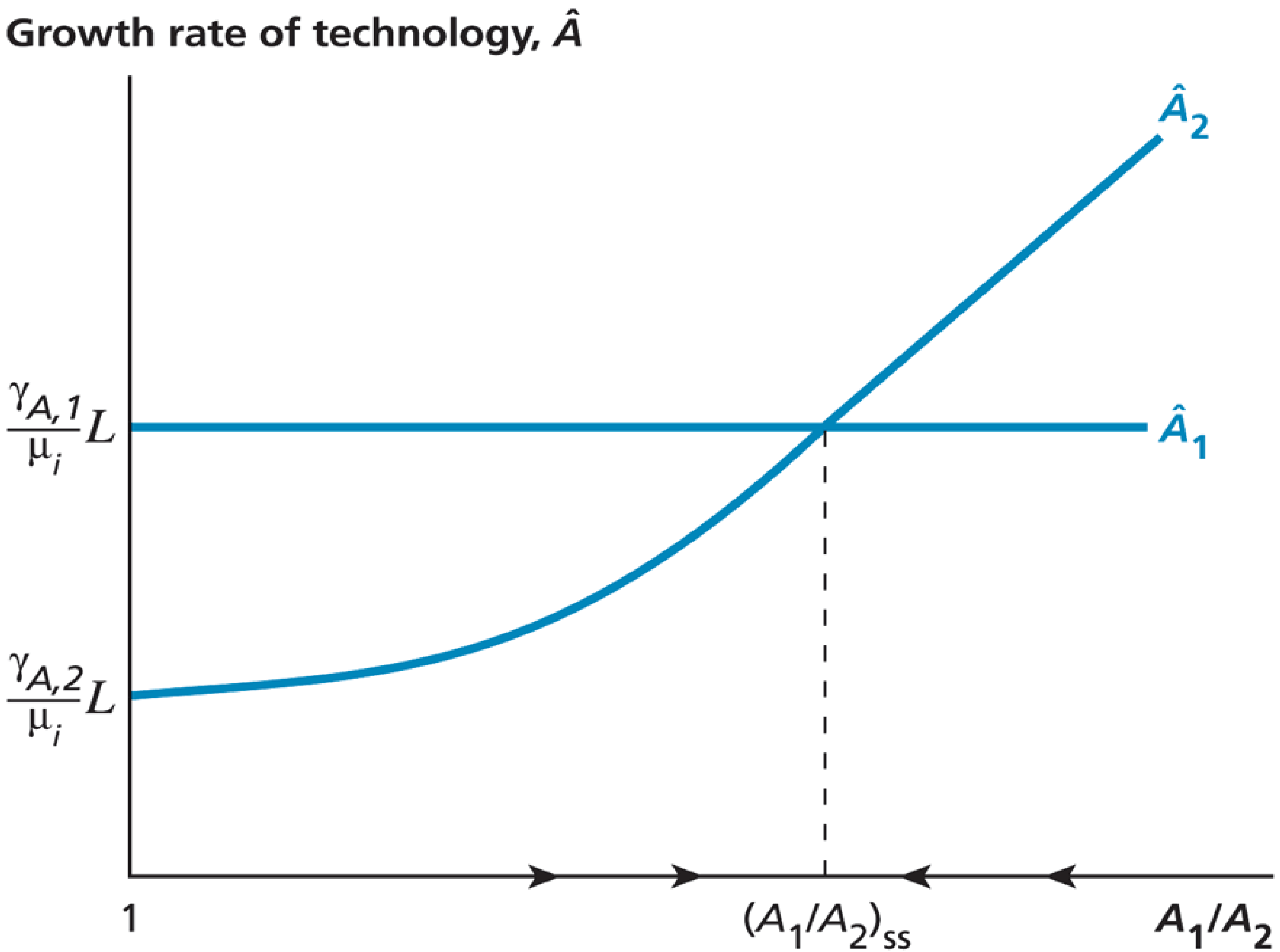
- A two country version of this growth model:
  - Technology leader (Country 1)
    - Must innovate to raise its productivity, A_1
    - Output and productivity growth for the leader country are modeled using our previous model of technological growth
    - The cost of innovation is μ_i
  - Technology follower (Country 2)
    - Is able to innovate
    - But instead, finds it easier and cheaper to imitate than innovate to achieve its level of productivity, A_2
    - Imitation has a cost, μ_c

Figure 8.2
Cost of Copying for the Follower Country



- This function describes the cost of copying technology
  - The farther the technology in Country 2 is from the leader, Country 1, the less expensive it is for Country 2 to copy the technology of Country 1
  - For smaller (A_1/A_2), the closer Country 2 is to Country 1 in terms of its technology
    - Country 2 is assumed to never have better technology than Country 1
    - Also, the leader country is assumed to employ a larger share of labor in R&D (research and development)
  - The lower the cost of copying, the faster Country 2 (the follower country) will grow

Figure 8.3
Steady State in the Two-Country Model

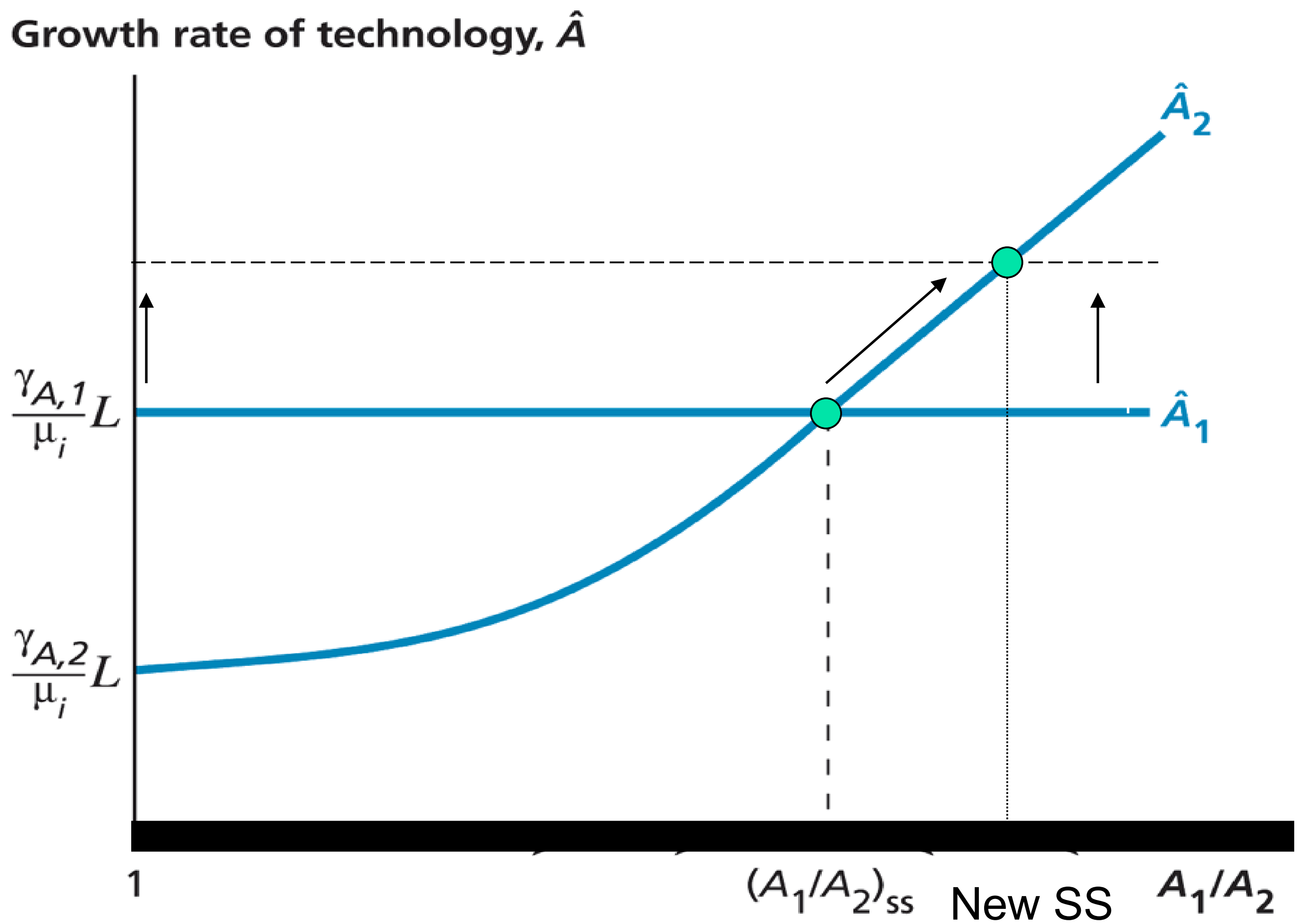


- In the steady state, the growth rates of productivity for the two countries will be equal. Why?
  - If A_1/A_2 is less than its steady state value, then A_1 is growing faster than A_2
  - If A_1/A_2 is greater than the steady state value, then A_1 is growing slower than A_2
  - These forces push the economy toward the steady state ratio of A_1/A_2
    - At the steady state value, A_1 and A_2 will be growing at the same rate
    - However, this steady state growth rate is determined solely by the leader

- An important implication of this model: An increase in the number of people working on R&D in the leader country causes every country's productivity to grow at a permanently faster rate
  - In equilibrium
    - both countries grow at the rate determined by the leader
    - A_1/A_2 rises in the steady state. In the steady state, productivity of the leader country rises relative to the follower
      - Hence, productivity temporarily (i.e. until the steady state is reached) grows at a faster rate in the leader country
  - Initially the leader grows faster, but eventually the followers growth rate catches up to the leader's

Increased share of workers in R&D for Leader Country

Steady State in the Two-Country Model

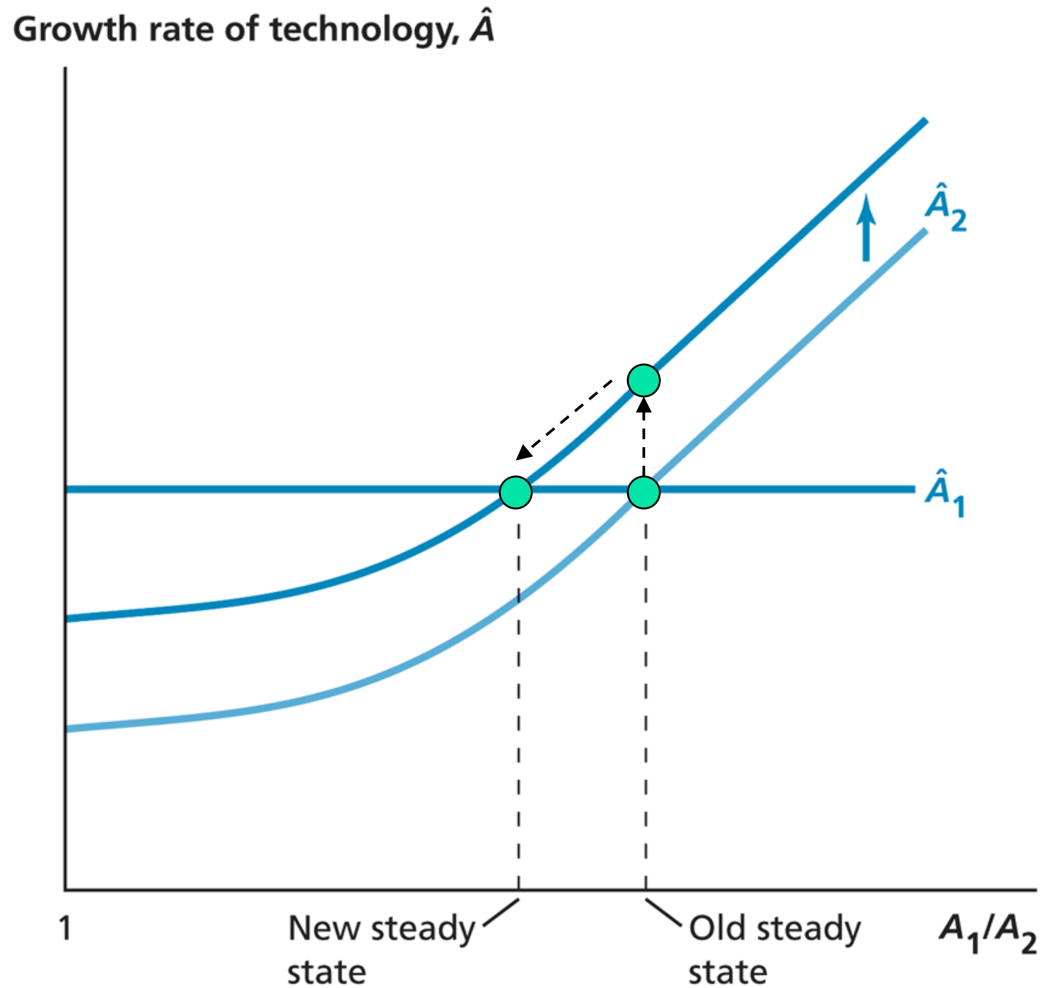


A second important implication is that an increase in the number of people working on R&D in the follower country will:

- Raise the steady state level of A_2 relative to A_1
- Will not affect growth rate of productivity in the steady state for any country
  - Combined, these two implications mean that productivity growth in the follower country will be temporarily faster. until that country reaches the steady state
- To see these implications more clearly, lets look at the following diagram

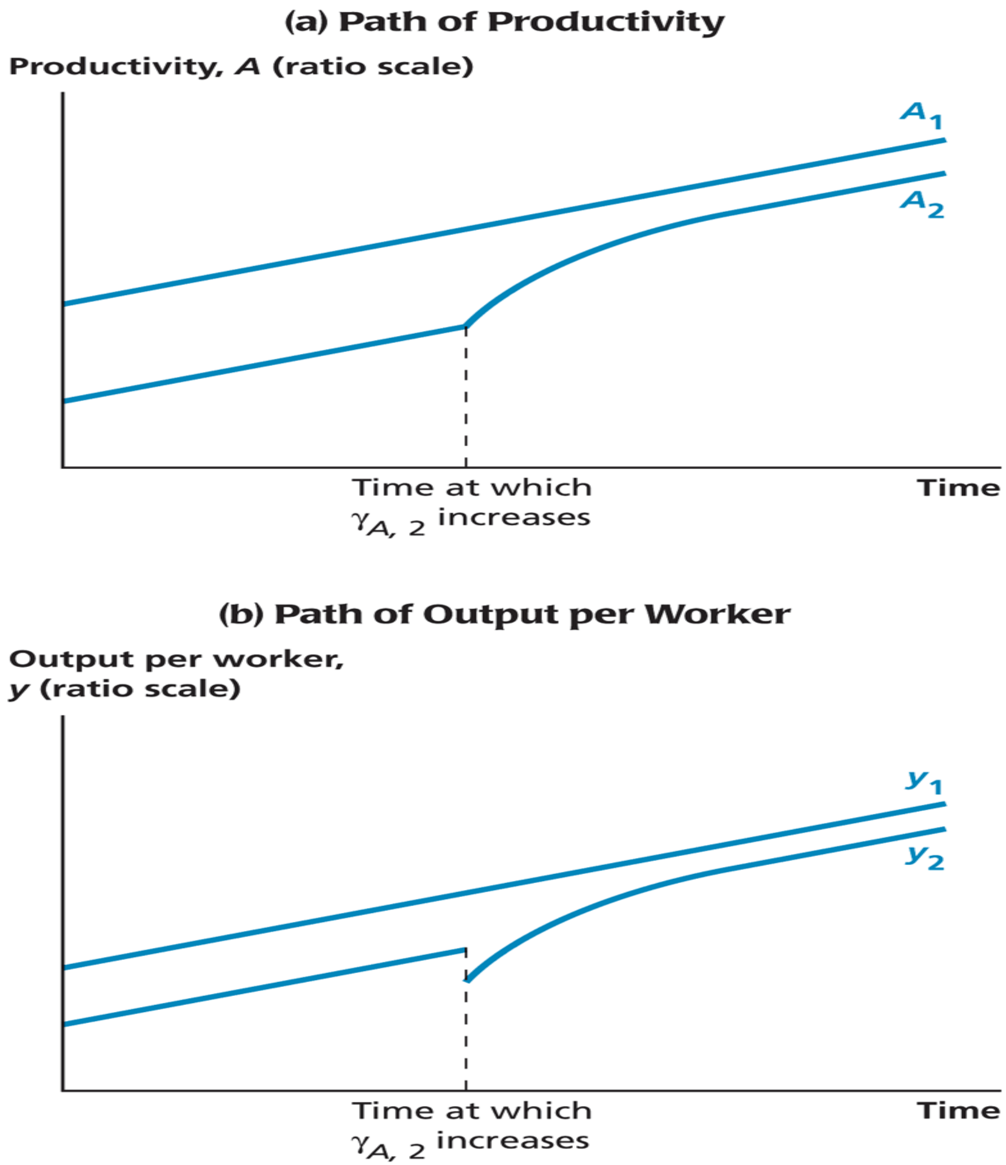
FIGURE 8.4

Effect of an Increase in R and D in the Follower Country on the Steady State



- Using ratio plots of A and y we can show how these variables change over time for the two countries when R&D increases in the follower country

Figure 8.5
Effect of an Increase in $\gamma_{A,2}$ on Productivity and Output



- In practice, technology doesn't transfer as easily as the simple model would suggest. Why?
    1. Leaders are protected by legal rights (patents) or they protect themselves using trade secrets
    2. Less developed countries may not be able to fully utilize leader technologies
        1. Some advanced technologies may require hands on experience in order to make them run properly. People in less developed countries may have no experience to draw on
        2. Some advanced technologies may be capital biased. Less developed countries may not have the necessary amount of capital to take advantage of a new technology

The following two graphs illustrate two different changes in technology: The first is neutral with respect to capital, the second is capital biased

Figure 8.6 Neutral Technological Change

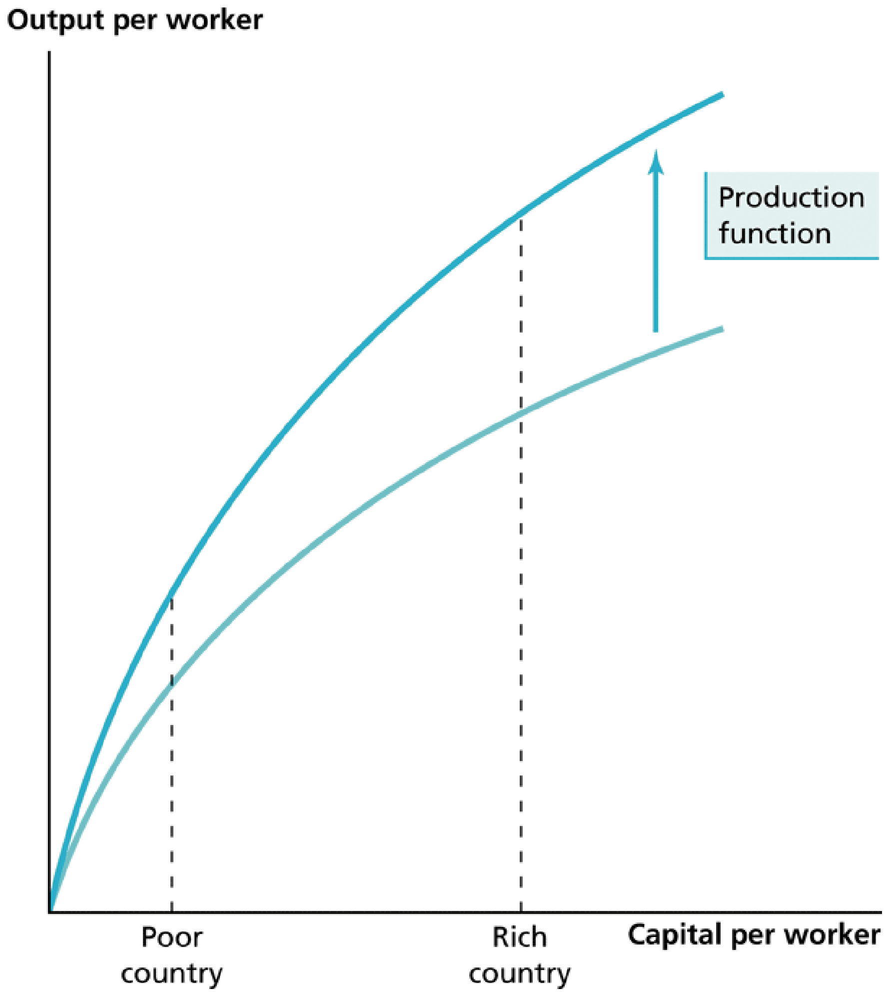
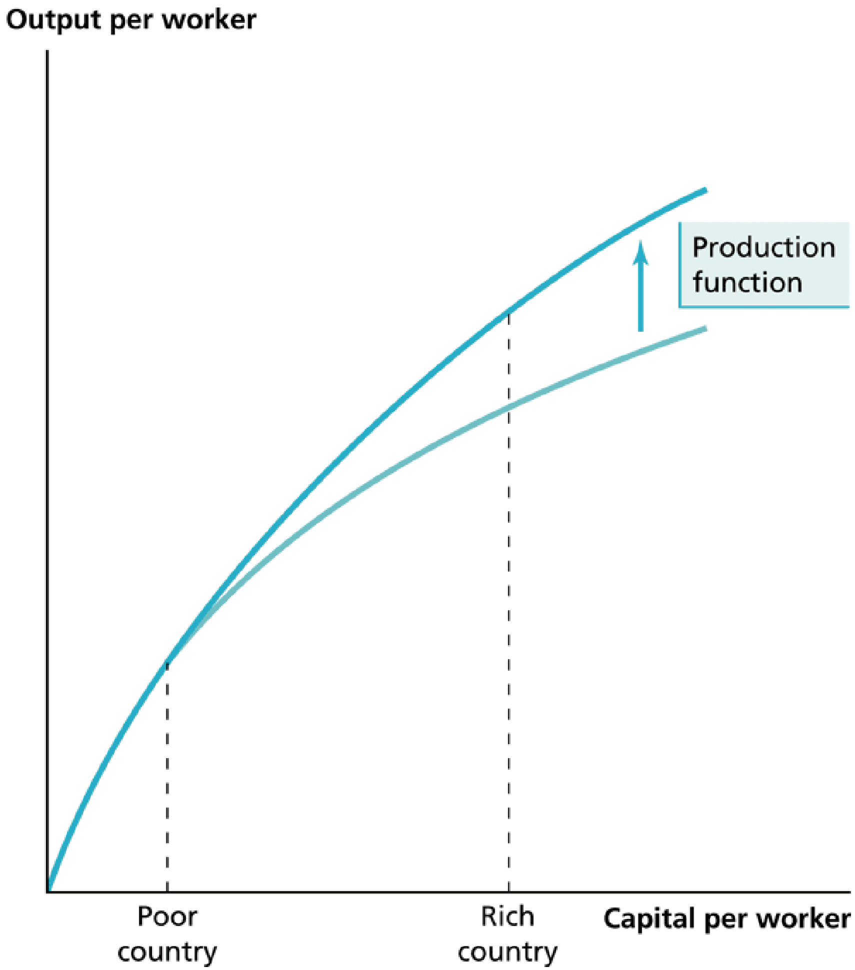
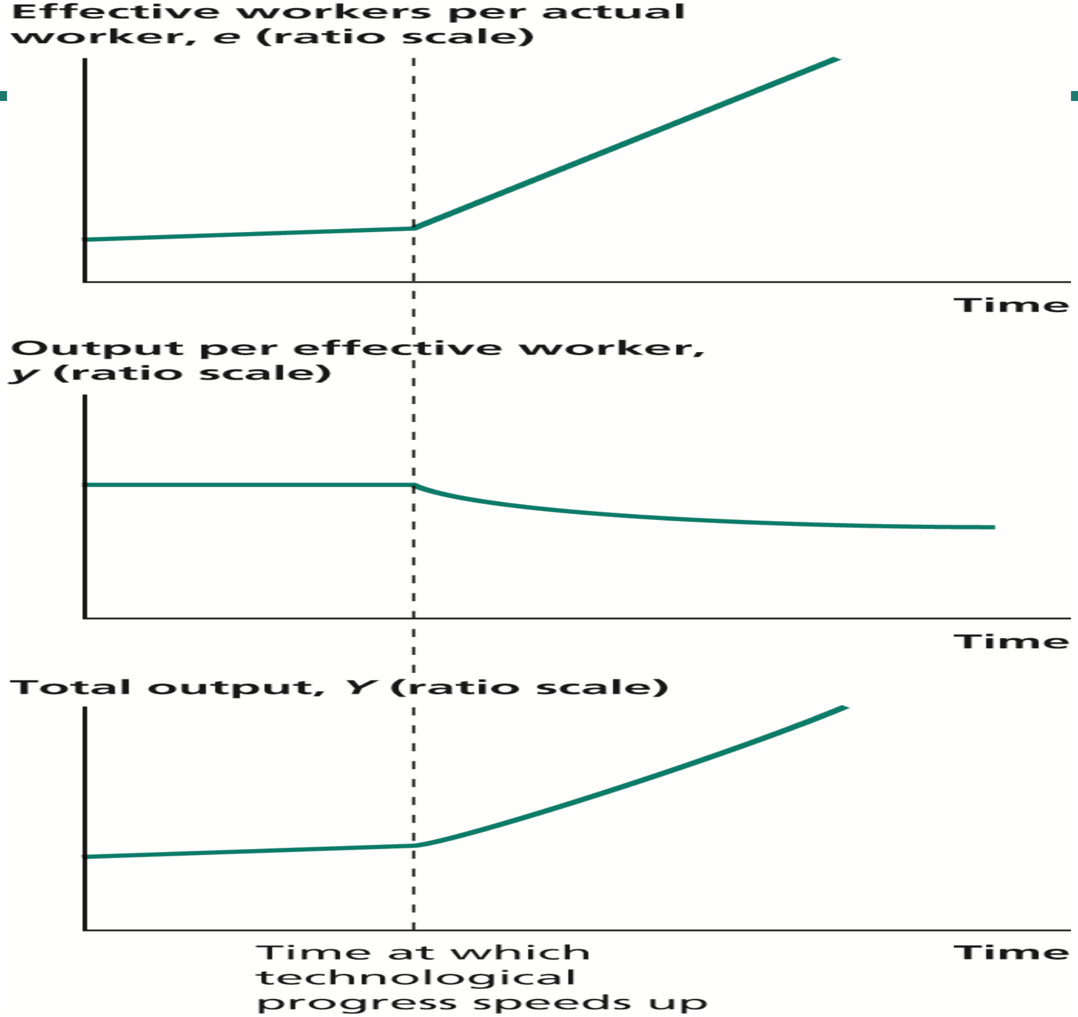


Figure 8.7 Capital-Biased Technological Change



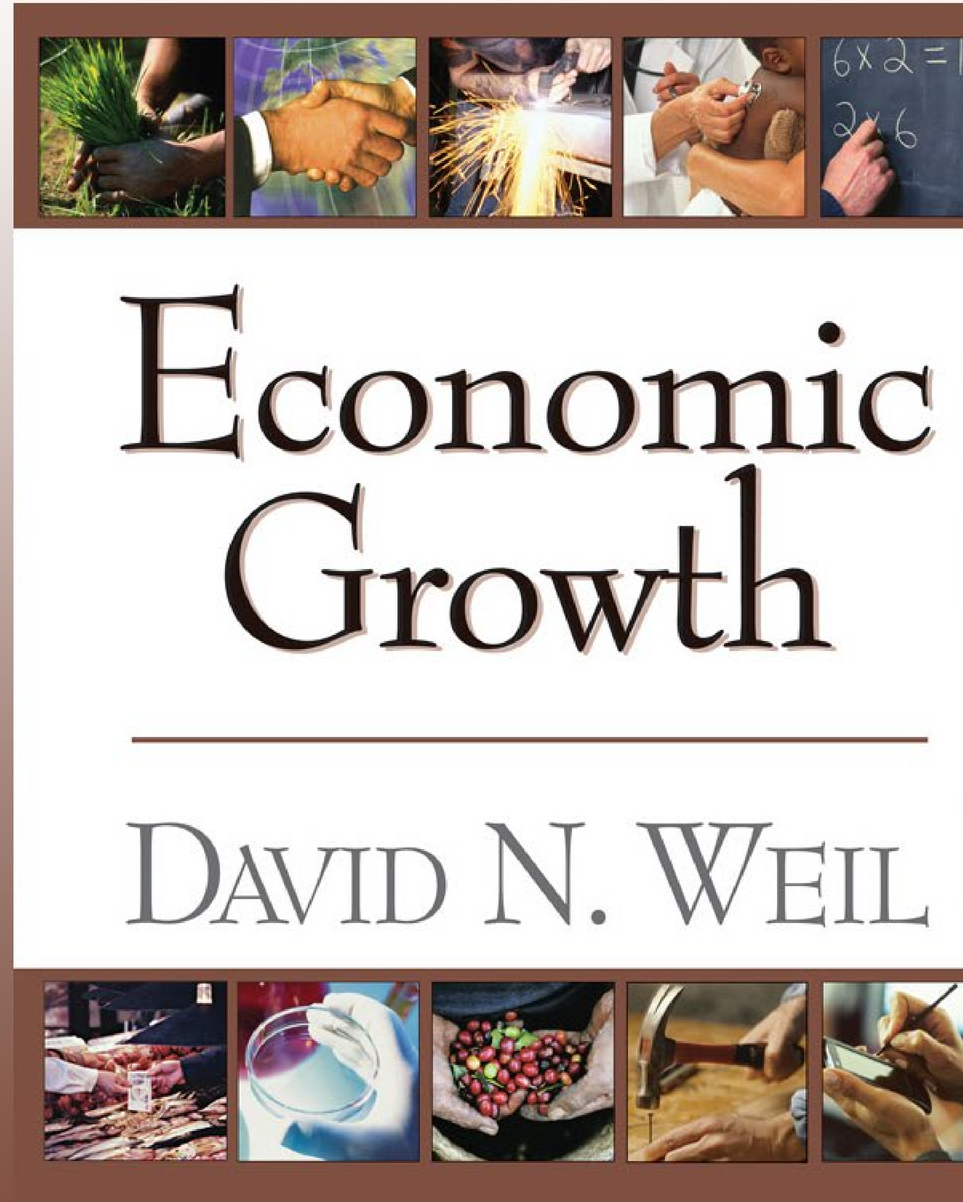
- The difference:
  - The neutral technological change raises the amount of output per capita proportionally for all countries
  - In this graph, the capital biased technological change does not improve the Poor Country’s output per capita at all
    - More generally, a capital biased technological change improves output per capita by a greater amount proportionally as the level of capital per capita increases

Figure 8.8 Effect of an Increase in Technological Progress



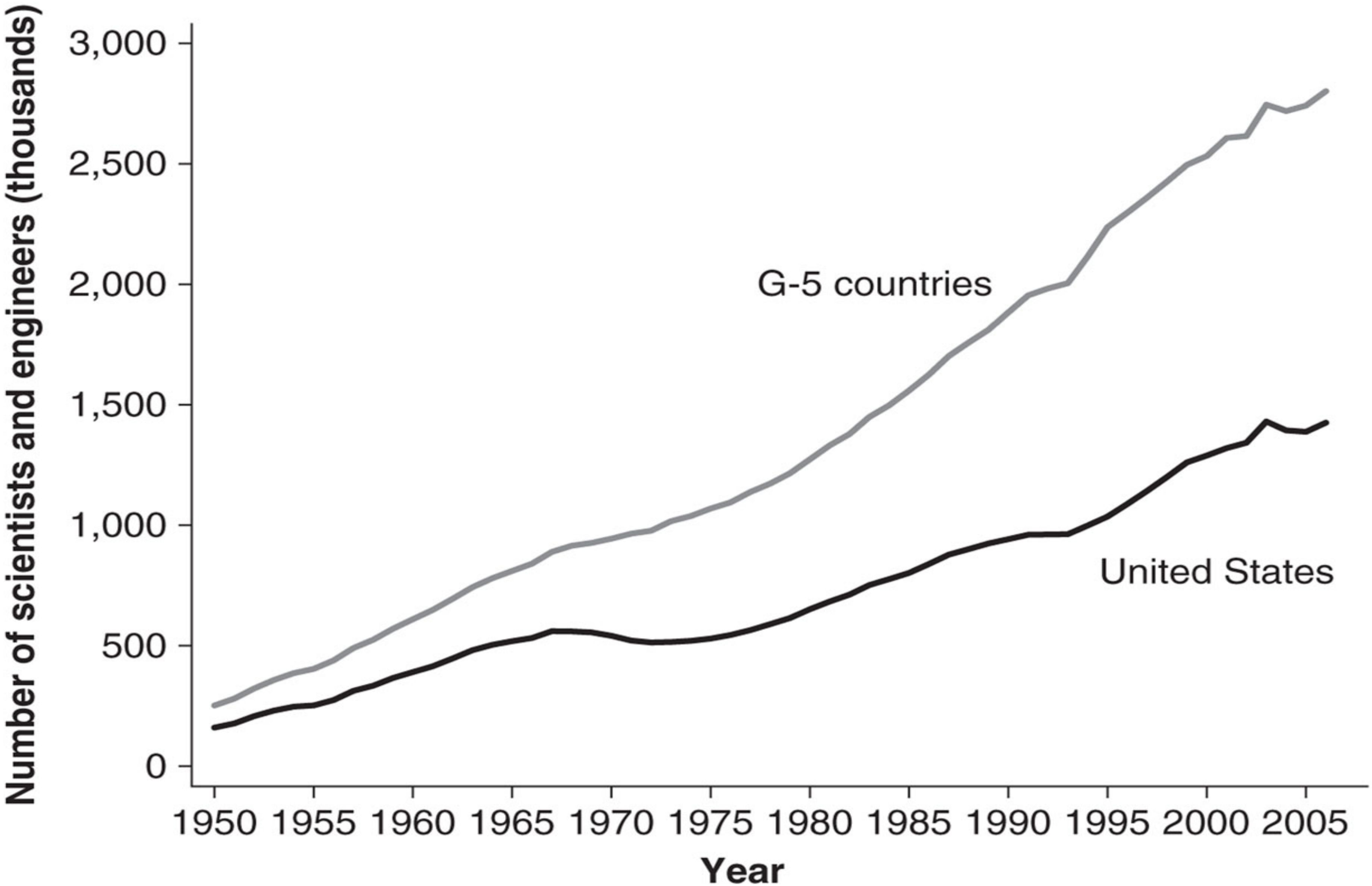
Chapter 9

The Cutting Edge of Technology



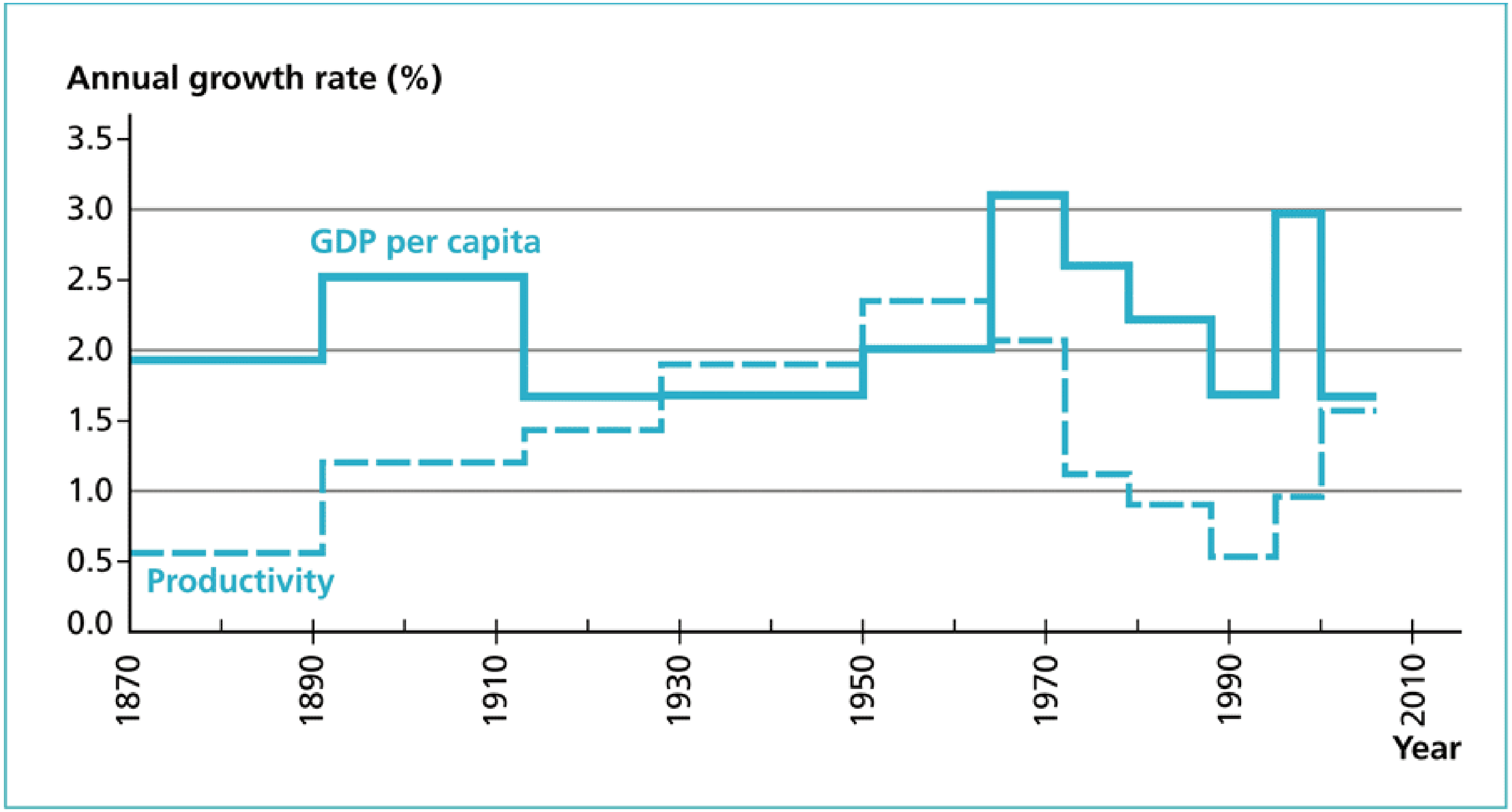
- An implications of the model from Chapter 8: The more workers in R&D the higher growth rate of productivity
  - In particular, the model says when you double the number of workers in R&D you double the growth rate of productivity
    - Does this prediction fit the evidence?

FIGURE 4.6 **SCIENTISTS AND ENGINEERS ENGAGED IN R&D, 1950–2006**



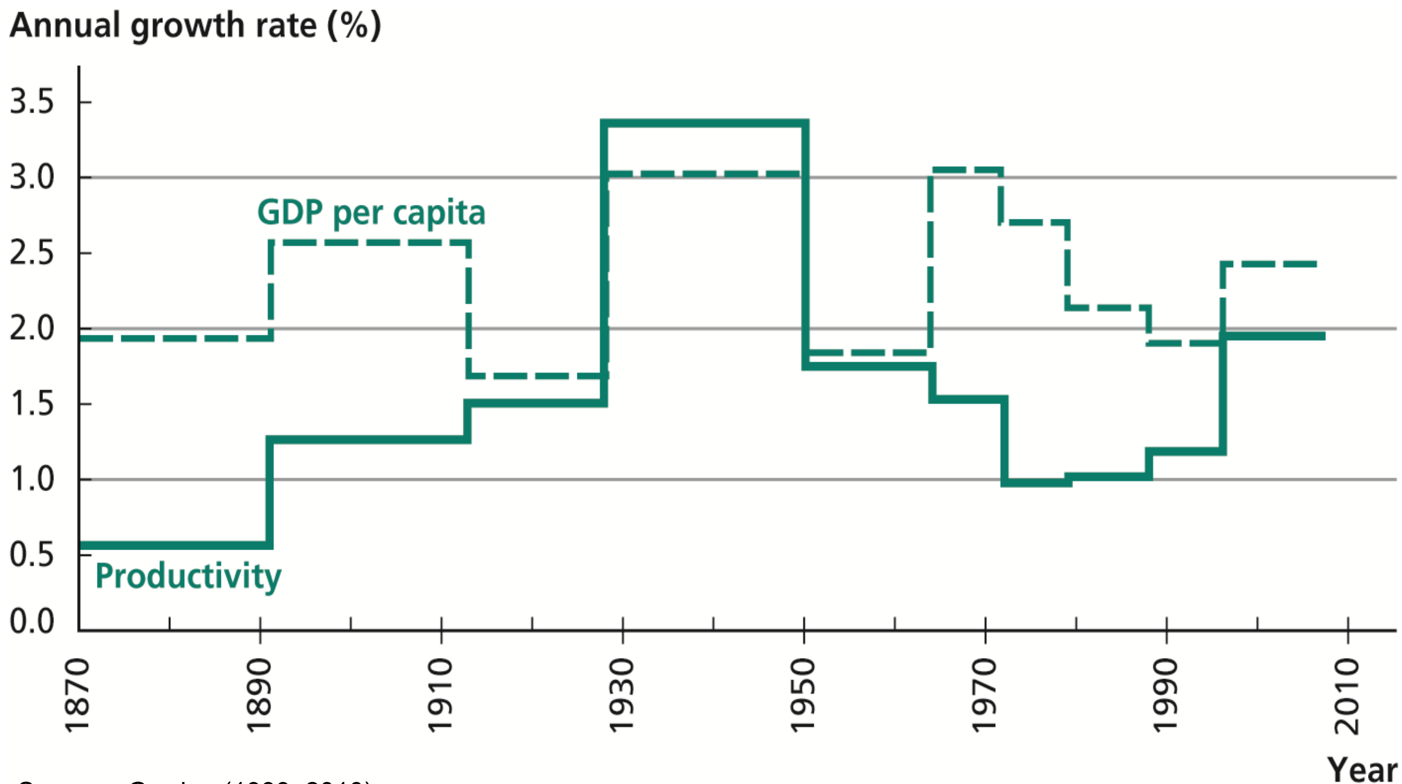
- The number of workers in R&D for the Advanced countries has been growing rapidly
  - In fact, this number has doubled twice from 1955 to 1993
- In recent years, has the productivity growth been doubled roughly every 24 years?
  - Unfortunately for this theory, the answer is NO
  - In fact, long-run productivity has hardly changed

Figure 9.3 U.S. Output and Productivity Growth, 1870–2006



Sources: Gordon (1999, 2000).

Figure 9.3 U.S. Output and Productivity Growth, 1870–2007



Sources: Gordon (1999, 2010).

- During the period of time in which the number of workers was growing rapidly there is no evidence of an upward trend in the productivity growth rate.
  - In fact, there was a tendency for the growth rate of productivity to fall (NOT the level, but its growth rate) during most of the post-1955 period, at least until the 1990s

- An improved model of endogenous productivity growth

IMPROVED MODEL OF THE TECHNOLOGY PRODUCTION FUNCTION

FIRST ONE: $\hat{A} = \frac{L_A}{M}$

WHY MIGHT ~~AN~~ TECHNOLOGY GROWTH MAY DEPEND ON THE CURRENT LEVEL OF TECHNOLOGY?

(1) $\hat{A}$ MAY RISE WITH THE BASE OF TECHNOLOGY ("STANDING ON THE SHOULDERS OF GIANTS")

(2) $\hat{A}$ MAY FALL WITH THE BASE OF TECHNOLOGY ("FISHING OUT EFFECT")

IF #2 DOMINATES #1:

THEN TECH. PROD. FUNCT. LOOKS LIKE: $\hat{A} = \left(\frac{L_A}{M}\right) A^{-\theta}$

$0 < \theta < 1$

A SECOND CHANGE TO TECH. PROD. FUNCT. ASSUME DECREASING RETURNS TO SCALE — DOUBLING FACTORS → LESS THAN A DOUBLING OF GROWTH RATE OF PRODUCTIVITY

$$\hat{A} = \frac{L_A^{\lambda} A^{-\theta}}{M} \qquad 0 < \lambda \leq 1$$

ASSUME $\hat{A}$ = A CONSTANT IN STEADY-STATE GROWTH

$$\hat{A} = \hat{A}_{ss} = \frac{L_A^{\lambda} A^{-\theta}}{M}$$

THIS IMPLIES:

$$0 = \lambda \cdot \hat{L}_A - \theta \hat{A}_{ss} - \hat{M}$$

$$\boxed{\hat{A} = \frac{\lambda \cdot \hat{L}_A - \hat{M}}{\theta}}$$

IMPLICATIONS OF THIS MODEL:

(1) HIGHER $\hat{L}_A \rightarrow$ HIGHER $\hat{A}$

(2) " $L_A \rightarrow$ NO CHANGE IN $\hat{A}$

(1)+(2) FIT EVIDENCE A LOT BETTER THAN OUR ORIGINAL MODEL (ie $\hat{A} = \frac{L_A}{\mu}$)

(3) WE NEED $\hat{L}_A$ TO BE POSITIVE INDEFINITELY FOR $\hat{A}$ TO REMAIN POSITIVE.

HOW DO WE GET $\hat{L}_A$ TO REMAIN POSITIVE?

IF $L_A = \gamma_A \cdot L$ HOLDS, THEN

$$\hat{L}_A = \hat{\gamma}_A + \hat{L}$$

(1) IF $\hat{L}$ IS POSITIVE, $\hat{L}_A$ WILL BE POSITIVE

(2) ~~GROD~~ IF $\hat{\gamma}_A$ IS POSITIVE $\hat{L}_A$ WILL BE POSITIVE.

THE PREDICTION FROM THIS MODEL IS BLEAK FOR VERY LONG RUN PRODUCTIVITY GROWTH :

- $\hat{L}$ IS EXPECTED TO APPROACH 0 % IN 50 TO 100 YEARS, IF NOT SOONER, FOR COUNTRIES
- $\hat{\gamma}_A$ CAN'T GROW FOREVER, $0 < \hat{\gamma}_A < 1$
- AS MORE COUNTRIES BECOME CUTTING EDGE TECHNOLOGY PRODUCERS, THE WORLDS $\hat{L}_A$ WILL CONTINUE TO RISE, BUT THIS HAS ITS LIMITS.

– $\hat{\mu}$ NEGATIVE, WILL ALSO HELP KEEP $\hat{A} > 0$, BUT THIS ALSO HAS LIMITS ($\mu > 0$)

μ can't fall forever since it has to be a positive number

The model does fit the broad evidence on world output growth and world population growth found previously

– Long periods in which world population growth is fastest correspond with periods in which world output growth is fastest

- Lets examine some key features related to the Industrial Revolution

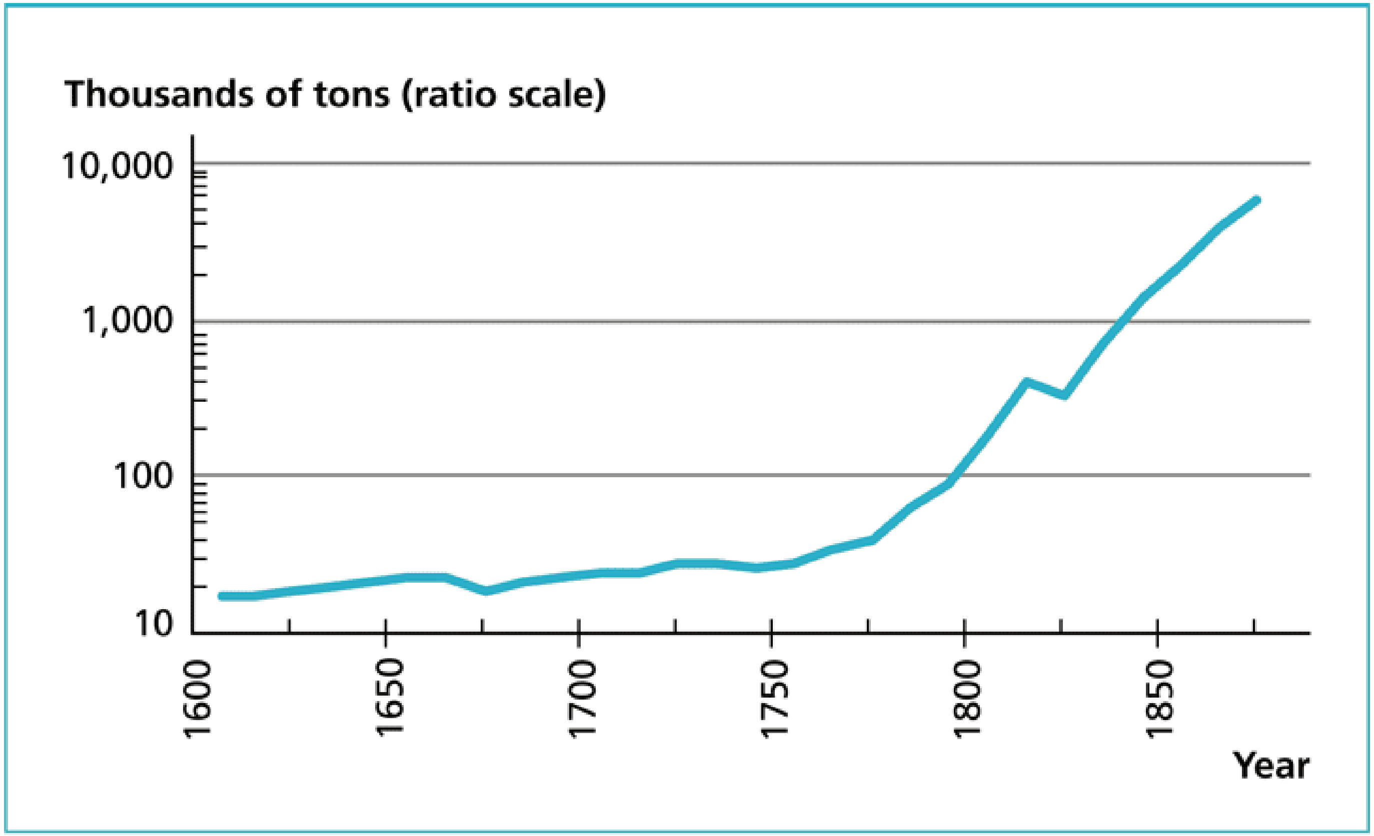
– Growth Accounting: Europe before the Industrial Revolution

Table 9.1 Growth Accounting for Europe, A.D. 500–1700

Period	Annual Growth Rate of Income per Capita, $\hat{y}$	Annual Growth Rate of Population, $\hat{L}$	Annual Growth Rate of Productivity, $\hat{A}$
500–1500	0.0%	0.1%	0.033%
1500–1700	0.1%	0.2%	0.166%

- Just as the Malthusian model claims, labor supply grows at the rate such that productivity improvements lead to no increase in output per capita before 1500 and almost no improvement in output per capita between 1500 and 1700
- But by the mid 1700s Britain was entering the Industrial Revolution

Figure 9.1 British Iron Production, 1600–1870



Source: Riden (1977).

- Economists often use iron to proxy for aggregate output when they don’t have enough data to get a measure of GDP
- Production of pig iron began to accelerate in the mid-1770s about the same time as the start of the industrial revolution

- Since the Industrial Revolution is such a crucial period in the history of economic growth, a brief look at the history is useful.

- First Phase: (mid 18th century) the 1st true steam engine, advances in textile, iron, and coal industries;
- Second Phase: (mid 19th C.) the rapid growth of the railroad industry, mass production of steel, replacement of sail ships with steamships, and the use of new technology in agriculture;
- Third Phase: (turn of the century – end of 19th and early 20th C.) the rapid growth of the automobile, electrical, telephone, and petroleum industries;
- Fourth Phase: (WW II and afterwards) developments in aviation, aluminum, electronics, plastics, nuclear power, computers, and automation
- Fifth Phase: (Recently, and expected for the near future) BIOLOGY: genetic research (e.g. growing new organs), novel medications (e.g. AIDS cocktails, new antibiotics), new procedures (e.g. artificial joints)

The 1st IR occurred 1770-1840, continued impact through 1900

- Steam engine, railroad, steamships;
- Cotton spinning and weaving;
- Transition from wood to steel

The 2nd IR occurred 1870-1920, continued impact through 1970

- Electricity, light, elevators, machines, air conditioning
- Internal combustion engine, vehicles, air transport
- Telephone, phonograph, movies, radio, TV
- Running water, sewer pipes, and the conquest of infant mortality
- Chemicals, plastics, antibiotics, modern medicine
- Massive changes in working conditions, job characteristic & features of the home

The 3rd IR

- Since 1960 the “EICT” Revolution
  - Entertainment: the evolution of TV from color to time-shifting and streaming
  - Information Tech – the evolution from mainframes to PCs, the web, and e-commerce
  - Communications: mobile phones, smart phones
  - Productivity enhancers: ATM, bar-code scanning, fast credit card authorization, debit cards

Are we now in a 4th IR?

- 3D Printing
- Robotics
- Driverless Vehicles
- AI (Artificial Intelligence)

- One important fact regarding the Industrial Revolution: revolution suggests dramatic change, however, at the start of the IR the growth rate of England and soon after that the rest of Western Europe was small compared to the more rapid rates we have seen in the late 19th C. the 20th C. and so far in the 21st C.

- David Landes' book "The Unbound Prometheus" provides a nice overview of economic history with special emphasis on the Industrial Revolution

- Landes describes a number of important technical changes that began to occur in England and other Western European economies during the Industrial Revolution:
- Machines and tools became more useful and more wide spread
- Replacement of human and animal strength with inanimate power
  - Development of the steam engine during the First Industrial Revolution is a prime example
- Improved methods of extracting and working with raw materials
  - There became particularly important for the development of metallurgy and chemical industries
- It is these 3 basic types of technical change that were really revolutionary in the early years of the IR

- Landes also discusses how new forms of industrial organization resulted from the Industrial Revolution.
- The new devices and the improved power sources that emerged during the Industrial Revolution made it more profitable to increase in the scale of production
  - Before the Industrial Revolution, production was done in shops or in work rooms at homes
  - After the Industrial Revolution, mills and factories became more attractive

- The increased scale of production led to gains from specialization of workers
  - With more people involved in production, tasks can be divided among workers. This allows each worker to become more specialized at what they are doing
  - Specialization leads to more efficient production
    - Now, more output can be produced for a given set of inputs OR the same amount of output can be produced at lower cost

Why did the Industrial Revolution start in Western Europe and not somewhere else?

Landes argues the key reasons are:

Compared to the rest of the world, Western Europe:

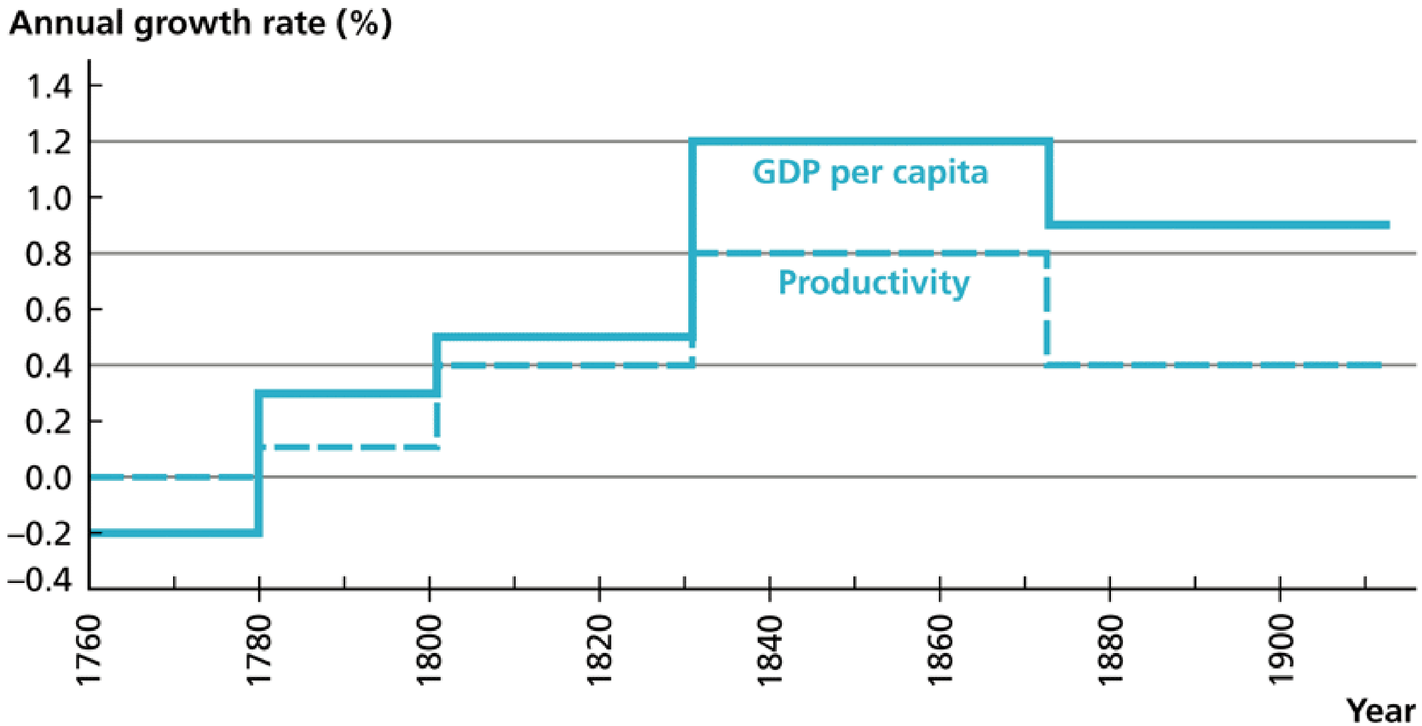
- Was already richer;
- Placed greater emphasis on private enterprise;
- Provided better protection of property (i.e. had established superior property rights);
- Allowed greater personal freedoms which stimulated more creativity;
- Possessed wider application of and experience with scientific methods.

- Landes also argues that a number of significant, though gradual, social changes were a direct consequence of the Industrial Revolution:
  - Industrialization: The transformation from agriculture to economies that were increasingly based on factories and non-agricultural industries
  - Urbanization: Cities grew up as businesses benefitted from being closer to their suppliers, closer to buyers of their goods and closer to a larger source of laborers
  - Demographic change: Death rates and birth rates begin to fall.
    - Death rates fell from a better understanding of the causes of death and illness and the things people could do to reduce these bad outcomes. Birth rates fell for a number of reasons we've already discussed in class.
  - Governments become more effective: This was achieved by governments becoming relatively more centralized and more bureaucratic (we might call this gains from specialization in government)
  - Improved educational systems: With the Industrial Revolution comes a need for a more educated workforce

- As we near the end of the 19th Century, some of the key industries in what is often called the First Industrial Revolution begin to lose their luster.
  - Growth rates slow in the textiles, railroads and steam engines industries
- But there are changes at this time starting a period that is called The Second Industrial Revolution
  - Spectacular advances were occurring in chemistry, mechanical sciences, steel and internal combustion engines

– In the following graph we return to British data on growth rates of GDP and productivity

Figure 9.2 British Output and Productivity Growth, 1760–1913



Source: Crafts (1996).

- Nearing the end of the 19th Century, British GDP per capita and productivity began to grow at slower rates
  - The industries that were fast growers during the Industrial Revolution began to experience slower growth
  - Since Britain was world leader in most of the industries, British productivity also began to grow at a slower rate.
- As the 19th Century comes to a close the US is growing faster than Britain in output per capita and productivity
  - The so called Second Industrial Revolution began in the second half of the 19th century
  - the US was particularly good at some of the industries that were productive in that period including: steel, electrical and chemical industries, and the internal combustion engine

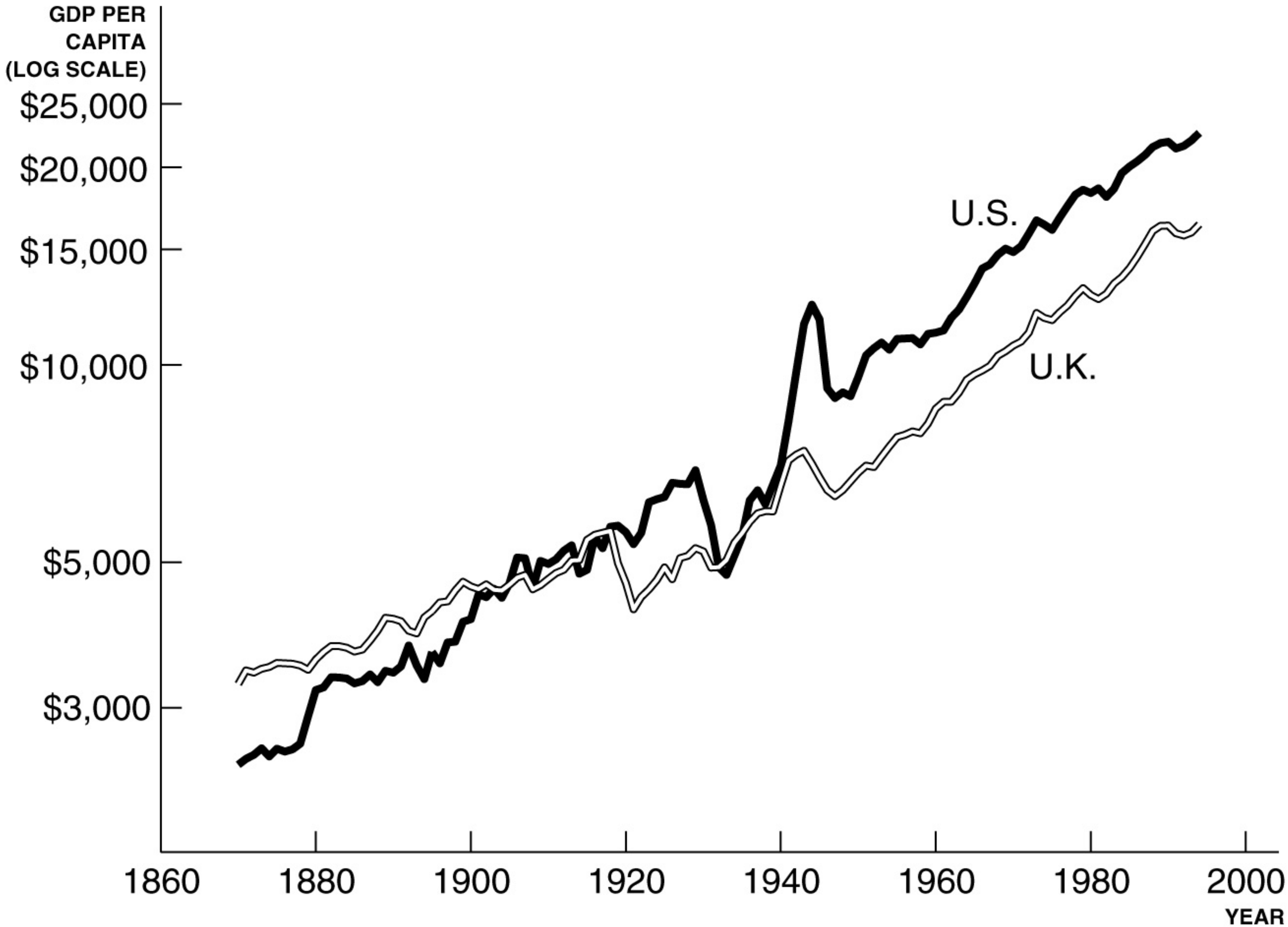
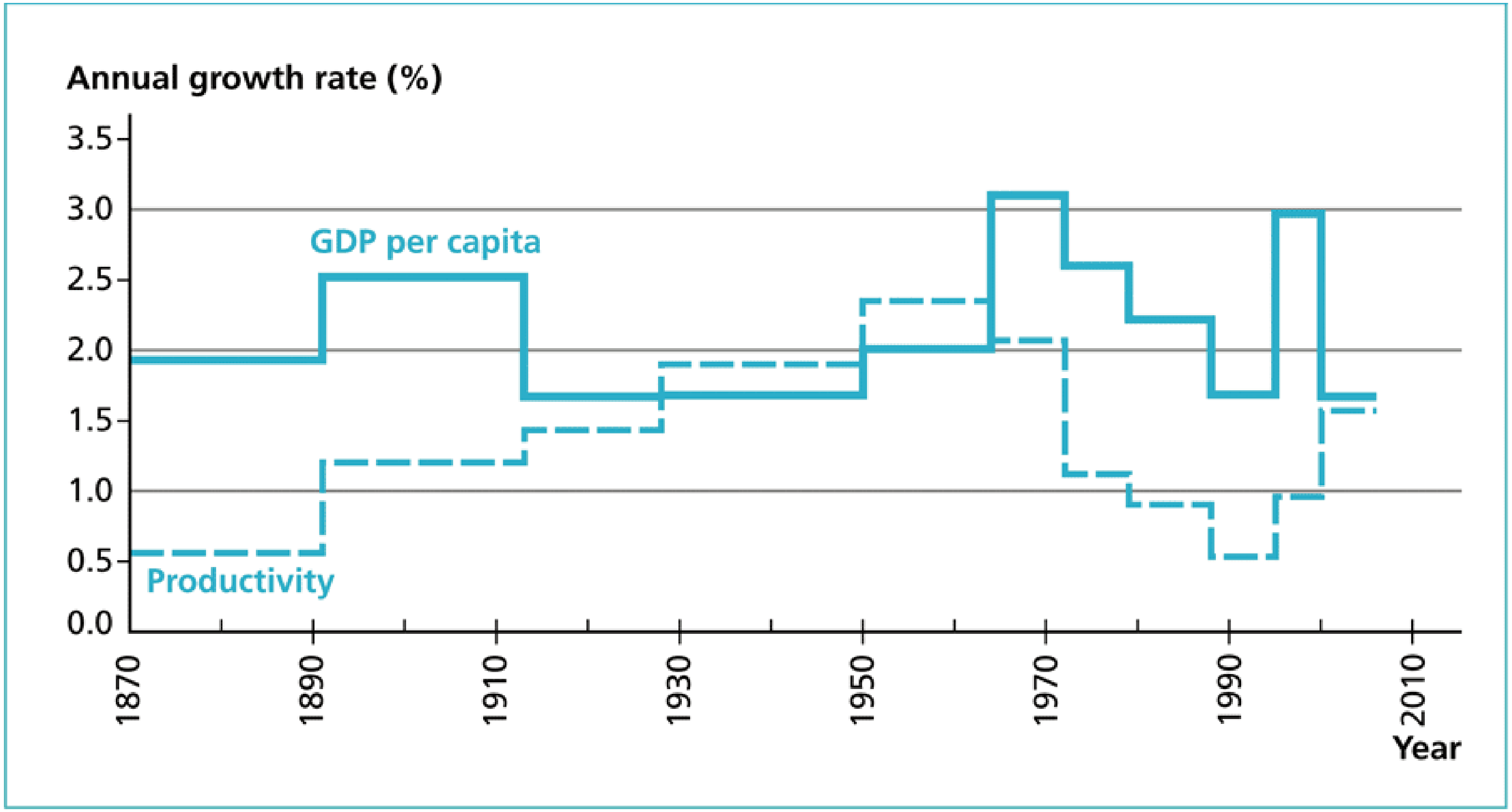


FIGURE 6.1 **INCOME IN THE U.S. AND THE U.K., 1870–1994**

- Returning to the US data we see 3 different periods
  - The rise of productivity growth in the US from the later part of the 1800s until the 1960s
    - The US become a dominant world leader in technology and output per capita over that period of time
  - A slowdown in productivity growth starting (perhaps) in the early 1970s
  - A resurgence of productivity growth in the mid-1990s

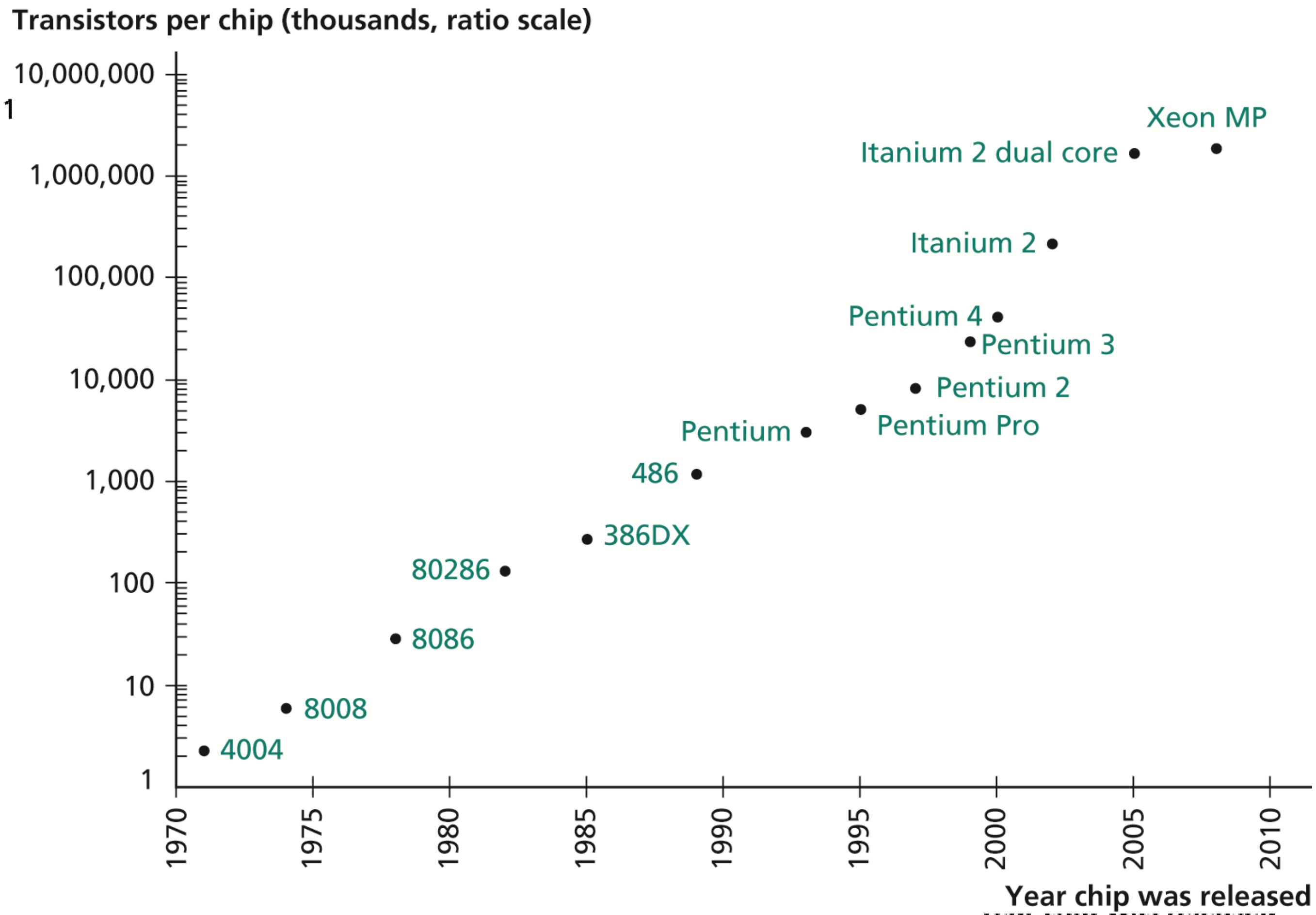
Figure 9.3 U.S. Output and Productivity Growth, 1870–2006



Sources: Gordon (1999, 2000).

– Why did productivity growth start to slow down in the 1970s for the US and many other countries?
  - Was it because technology was growing at a slower pace?
    – This hypothesis does not appear plausible when we look at various measures of technological improvement

Figure 9.4 Moore's Law as Seen in Intel Microprocessors



Source: Intel Corporation.

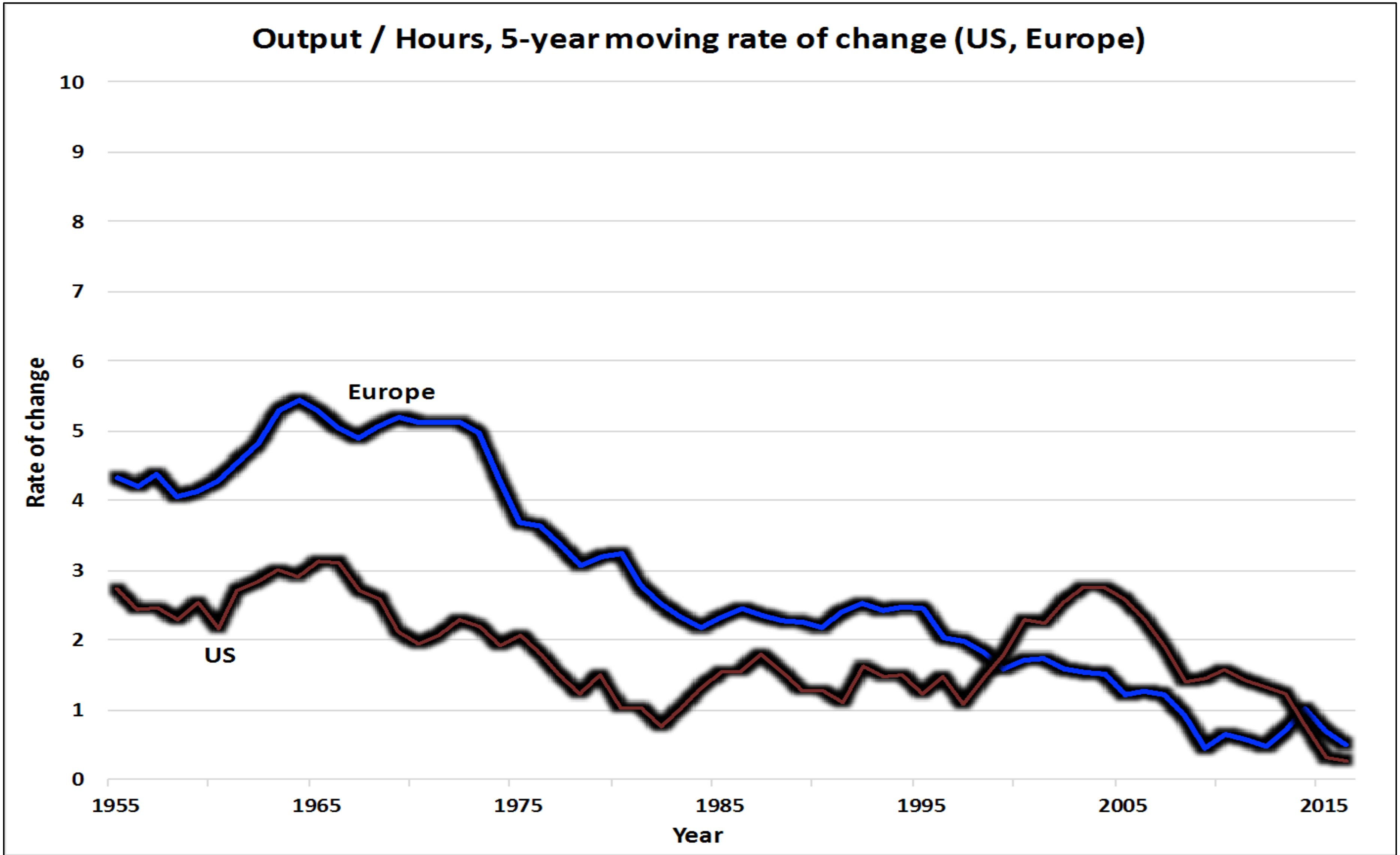
- There is ample evidence of technology rapidly improving, not slowing down
- A better explanation for the slow down in productivity growth in the 1970s: Reduced Efficiency
  - Efficiency refers to the way that Inputs and technology are combined
  - Reduced efficiency means that inputs and technology are combined in less productive ways
- In the 1970s, there were large increases in oil prices
  - This forced changes upon firms and it took some time for them to learn how to do things efficiently under new operating conditions
    - Firms had to develop ways to economize on the use of energy in the production of goods
    - Products that used a lot of energy --- cars in particular --- needed to be reengineered to use less energy

- Another interesting fact: Productivity grew notably faster from the mid-1990s to about 2004
- Some people also claim that the reason for this is because our economy is evolving into a type of New Economy
  - Some go so far as to claim that this recent period of faster growth is actually a Third Industrial Revolution
    - This new revolution involves pervasive usage of computers and telecommunications
  - Some also assert that the long period of slow growth in productivity, roughly 1970 to 1995, was actually a part of this Third Industrial Revolution
    - They argue that it takes time for people to learn how best to make use of new technology
      - During this learning period, people will be less efficient than they were with the old technology
      - But eventually people develop the level of skills needed to take advantage of the new technology
    - This story can explain the pattern of evidence

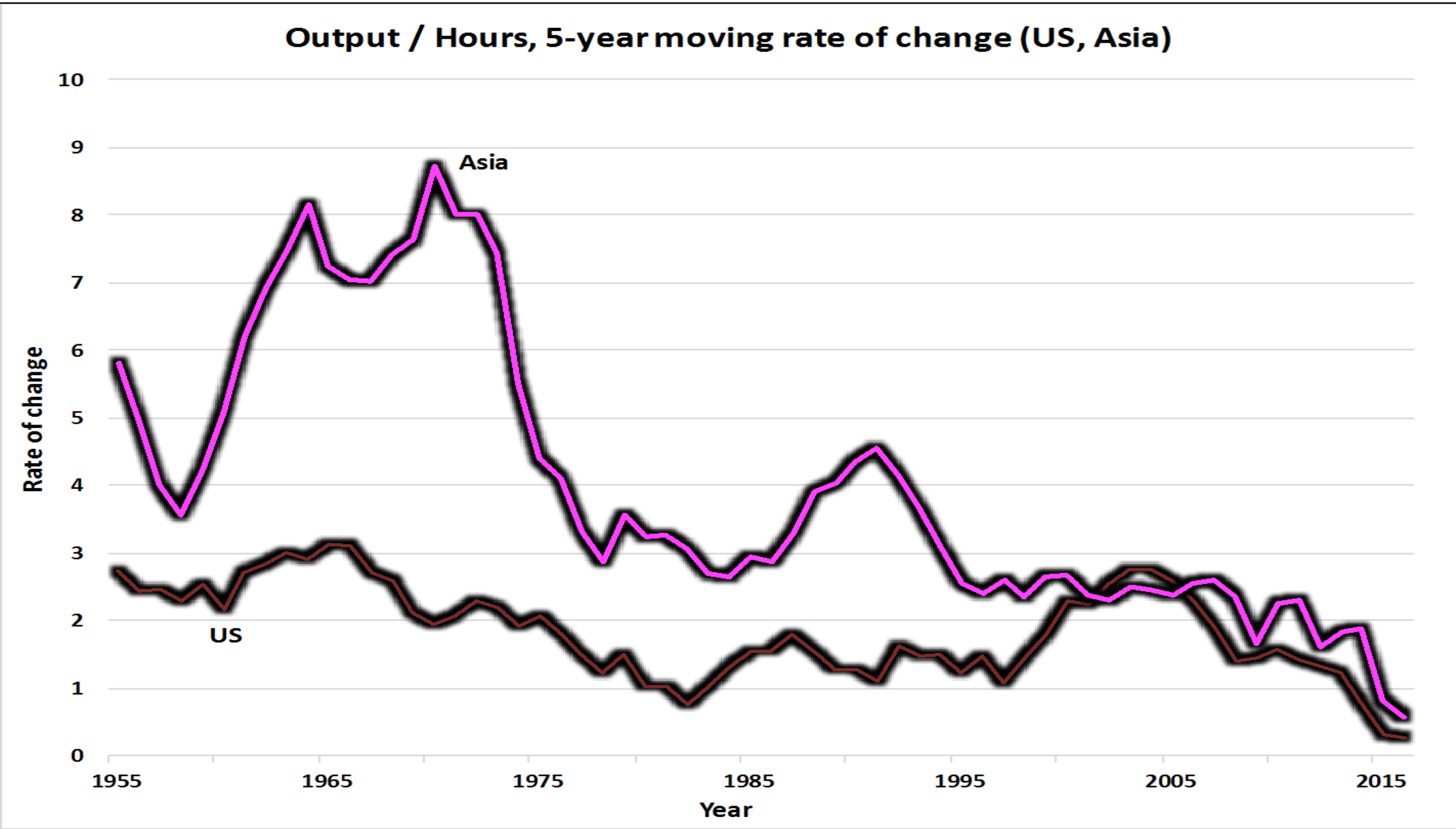
The evidence on productivity: US, Western Europe, and Developed Asia

- The 3rd Industrial Revolution seemed to only affect the US
- But its effects on the US seem to be largely over
- Western Europe and Developed Asia in recent years are also experiencing very low productivity growth rates

Productivity Growth, U.S. vs. Western Europe



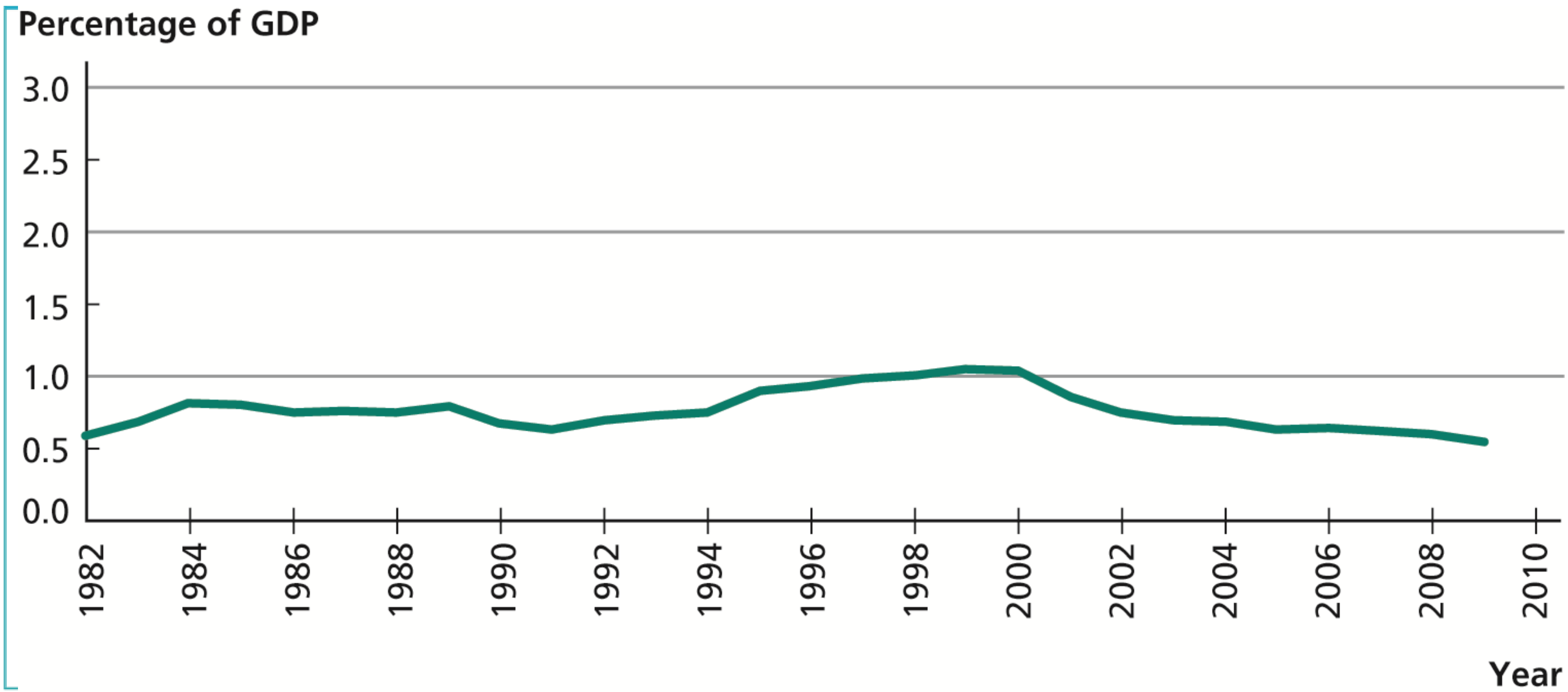
Productivity Growth, U. S. vs. Developed Asia



- If the new economy story is correct, computers and telecommunications must be playing an enormous role in the economy.
- So how important are computers in the aggregate economy?
  - In some sense they are pervasive:
    - Computers play some role in the production of nearly all goods and services
    - Components that use digital technology are found an increasing number of finished goods

- However, the share of output going toward computing is a small number and does not appear to be growing much, if at all, over time

Figure 9.6 Investment in Computers as a Percentage of GDP, 1982–2009

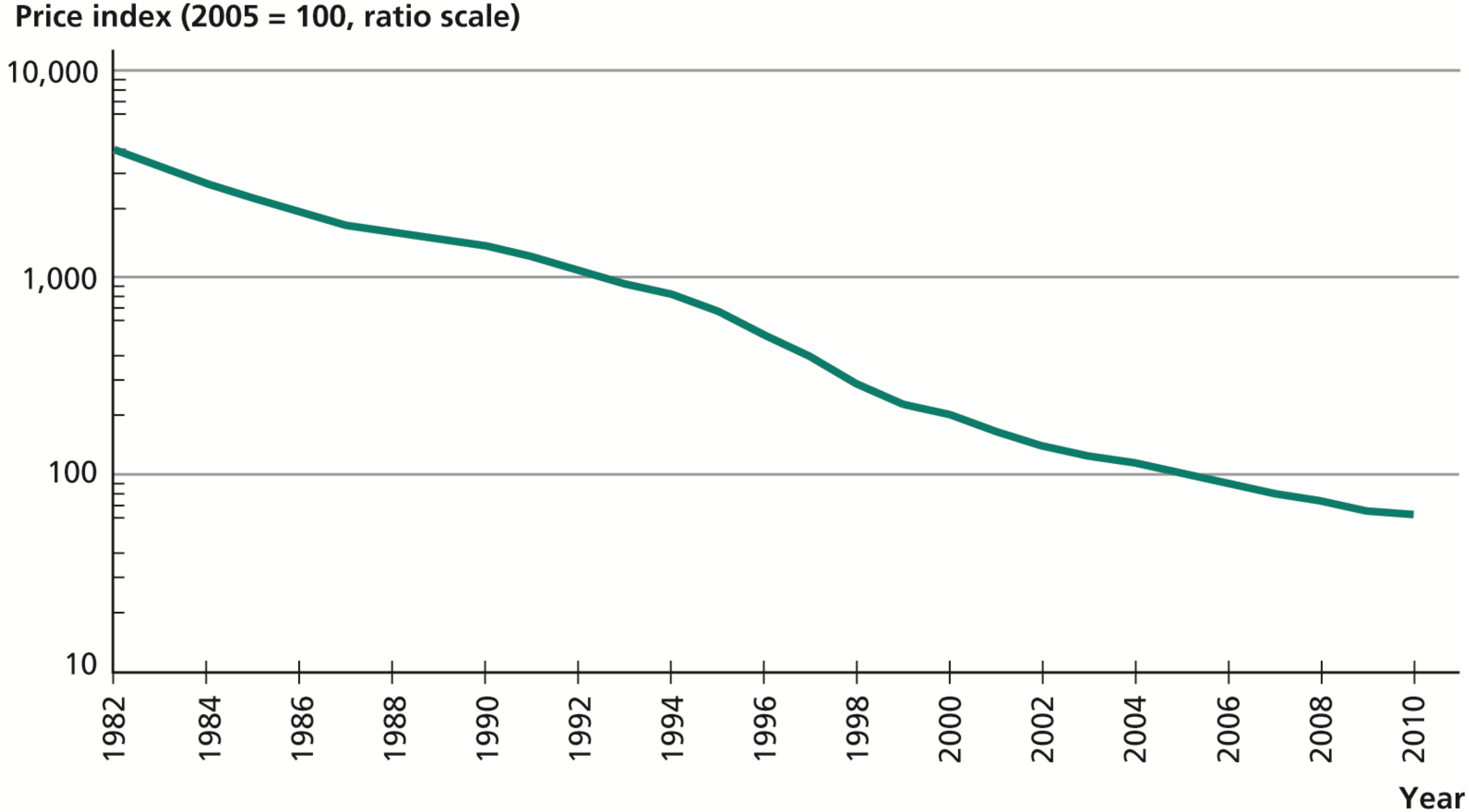


Source: U.S. Department of Commerce, National Income and Product Accounts, Table 5.5.5. Includes both computers and peripherals.

- The fact that the share of income invested in computers is small and shows no trend upward for the last 20 years seems to question the new industrial revolution story

- One interesting finding is technological change can dramatically affect prices in some industries
- The nominal price of a good in an industry with rapid technological advance will often fall.
- Its price relative to the price of a good in an industry with no technological improvement will certainly fall (unless either of the goods would change considerably)

Figure 9.5 Price of Computers, 1982–2010



Source: U.S. Department of Commerce, National Income and Product Accounts, Table 1.5.4. Includes both computers and peripherals.

- Technology does not affect all industries in the same way;
- Some industries experience a lot of technological change some very little
  - In general, aggregate productivity grows faster when a larger sector of the economy has fast productivity growth

- And differences in productivity growth can have interesting effects on the performance of an economy.

- The book examines simple 2-good economies. It makes two different sorts of (extreme) assumptions:
  1. The goods are perfect complements
  2. The goods are perfect substitutes

  While these are extreme assumptions that may not fit exactly, these allow some important points about industrial structure to be easily made

First, suppose goods are perfect complements

- e.g. a bread and cheese economy: assume you eat bread and cheese in fixed proportions

- suppose productivity in bread is growing, but it is not growing for cheese

- Over time, it will take relatively less resources to produce a unit of bread compared to a unit of cheese.
- Since you consume them in fixed proportions, that means a rising share of the economy will have to go into producing cheese and a smaller share into producing bread.
- Eventually the inputs will be largely devoted to cheese production which has no productivity growth.
- Then, in the aggregate, the productivity growth rate will be falling as a rising share of the economy goes to producing cheese which has no productivity growth.

Now, suppose that the two goods are perfect substitutes

- e.g. a butter and margarine economy:

- Assume margarine producers are able to increase productivity at a constant growth rate

- Productivity growth in margarine means that the cost of producing margarine is falling and therefore so is the price.

- If butter manufacturers can't figure out how to increase their productivity, they won't be able to lower the price of butter to stay competitive with margarine. Then if margarine is a perfect substitute, butter producers would go out of business
- Two possible outcomes:
  - If productivity in butter can not be increased, butter is no longer made and the economy becomes a margarine economy
  - If productivity of butter increases at the same rate, we have an economy with both margarine and butter
- In either case, aggregate productivity will grow at the rate of margarine's productivity growth

- We’ve seen evidence of different growth rates of productivity in various sectors of modern economies
  - Most goods producing industries have had productivity rise at a much faster rate, on average, than in services industries

- Some people argued that the slowdown in productivity growth for the US in the 1970s could in part be attributed to the expanding service sectors
  - If true, this requires services to be a complement to goods.
  - Since most services are a complement to goods (E.g. services for home, yard, appliances, car) slower growth in productivity of services can explain some of the productivity growth slowdown
    - As services account for a rising share of output and productivity in services is not growing as fast as productivity in goods, aggregate productivity will grow at a slower rate.
    - This theory can explain why productivity slowed in the 1970s.

- However, the changing share of services can not account for the surge in productivity growth witnessed since the mid-1990s
  - Since the 70s an even larger share of output goes to services than it did before

- Returning to patents and world economic growth
  - There is some evidence that the rest of the world is starting to catch up to the US in terms of technological advance

FIGURE 4.5 PATENTS ISSUED IN THE UNITED STATES, 1880–2010

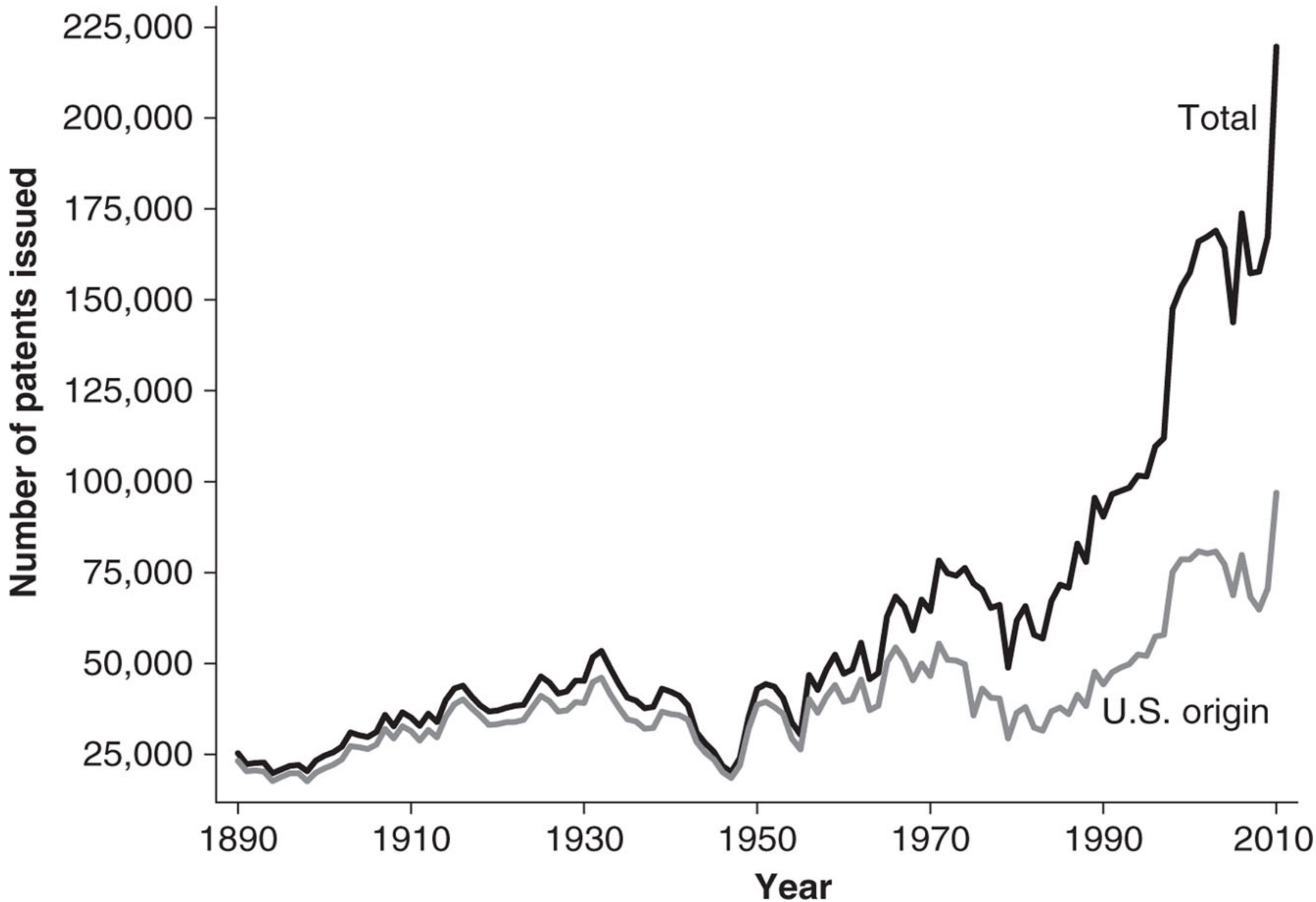


Table 9.2 U.S. Patents and Patents per Million People, 2006

Country	Patents	Patents per Million Residents
Taiwan	7,919	347.6
Japan	39,411	309.1
Israel	1,325	208.6
Finland	1,005	192.1
Switzerland	1,388	184.5
Sweden	1,360	150.8
South Korea	6,509	132.7
Germany	10,889	132.1
Canada	4,094	123.7
Hong Kong	753	108.5
Singapore	469	104.4
Luxembourg	49	103.3
Denmark	546	100.2
Netherland	1,647	99.9
Iceland	24	80.2
Austria	626	76.4
Australia	1,538	75.9
Belgium	720	69.4
France	3,856	60.9
Norway	272	59.0
United Kingdom	3,560	58.6
Ireland	198	48.7
New Zealand	143	35.1
Italy	1,899	32.7

Source: U.S. Patent and Trademark Office at http://www.uspto.gov/web/offices/ac/ido/oeip/taf/cst_all.htm

Table 9.2 U.S. Patents and Patents per Million Residents, 2010

Country	Patents	Patents per Million Residents
Taiwan	9,635	418.5
Japan	46,978	368.2
Israel	1,917	260.7
Finland	1,232	234.4
Switzerland	1,889	247.8
Sweden	1,594	175.7
South Korea	12,508	257.2
Germany	13,633	167.0
Canada	5,513	163.3
Hong Kong	716	101.0
Singapore	633	123.2
Luxembourg	44	88.4
Denmark	766	138.9
Netherlands	1,919	115.8
Iceland	25	80.9
Austria	905	110.2
Australia	2,079	96.6
Belgium	896	86.0
France	5,038	77.8
Norway	448	95.8
United Kingdom	5,038	80.8
Ireland	275	59.5
New Zealand	232	54.6
Italy	2,254	37.1

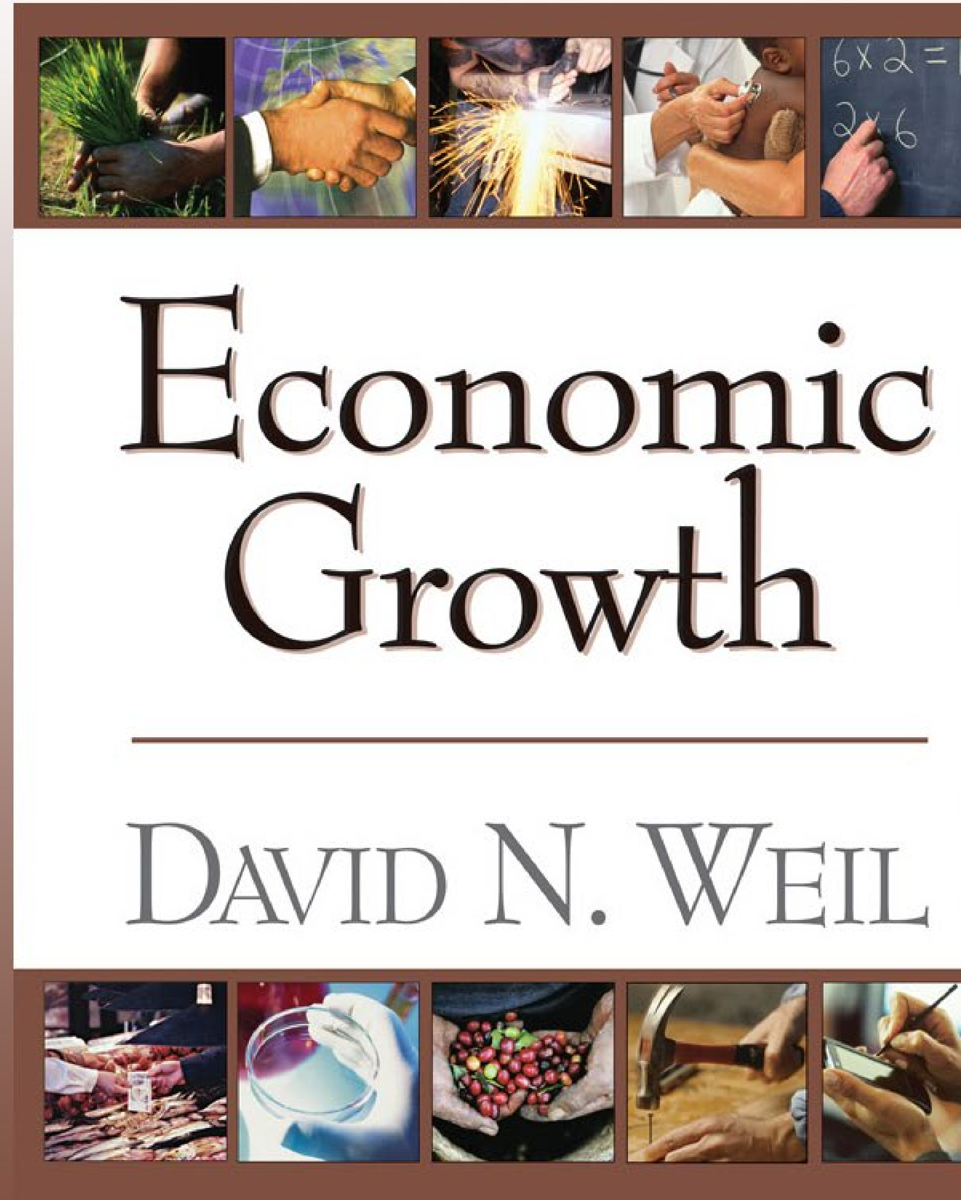
Source: U.S. Patent and Trademark Office, http://www.uspto.gov/web/offices/ac/ido/oeip/taf/cst_all.htm

- In one sense this is bad for the US
  - The increased share of foreign patents in the US suggests we are losing our technological advantages

- But it may actually be good for the US
  - Suppose that growth in population of workers doing R&D for the entire world, not a single country, is what matters for the world's productivity growth
  - Slower growth in US patents indicates either a reduction in the growth of R&D workers in the US or maybe less productive R&D workers in the US. In this case, to maintain a high rate growth in the world's technology would require faster growth in R&D workers from other countries
  - As a world leader we need technological progress to see improvement in our standard of living, and we would be helped by foreign innovations - as well as domestic - innovations.

Chapter 10

Efficiency



PEARSON
Addison
Wesley

- When you go to other countries you often find that the people there are using the same or nearly the same sophisticated technologies that you have gotten used to using in the US
  - This observation implies technology can not explain all the differences in productivity or output per capita across countries
- The effectiveness with which people combine factors and technology is also of great importance.
- This effectiveness is what we mean by the term: Efficiency
  - If two economies have the same levels of technology, human capital per person and physical capital per person, but one of them produces less output per person, then that economy is operating less efficiently that the other country
- How do we decompose productivity into technology and efficiency

$$\text{Productivity} = \text{Technology} \bullet \text{Efficiency}$$

$$A = T \bullet E$$

- From the empirical evidence we can see that there are large differences in productivity between the US and most other countries
- Using the previous equation, we can show that relative differences in productivity are attributable to one or both of the following:
  – Relative differences in technology,
  – Relative difference in efficiency
- It is often difficult to separate the effects of technology from efficiency in the productivity data
  – But a careful data analysis can sometimes lead us to infer the importance of efficiencies or inefficiencies in explaining certain outcomes

$$A_1 = T_1 \cdot E_1$$

$$A_2 = T_2 \cdot E_2$$

$$\underbrace{\left(\frac{A_1}{A_2}\right)}_{\text{WE MEASURE THIS}} = \frac{T_1 \cdot E_1}{T_2 \cdot E_2} = \underbrace{\left(\frac{T_1}{T_2}\right)\left(\frac{E_1}{E_2}\right)}_{\text{DECOMPOSING RELATIVE PRODUCTIVITY IS NOT SO SIMPLE}}$$

CALCULATING THE (T_1/T_2) FROM THE # OF YEARS COUNTRY 1 TRAILS COUNTRY 2 IN TERMS OF TECHNOLOGY

- We know how to measure relative productivity differences, so if we knew how large the technology gap was between two countries we could then infer from our measures of productivity and the previous equation just how large the efficiency gap was between them
  - Problem: We don't usually have precise quantitative measures of how far behind one country's technology is from that of another country
    - However, we often can estimate a plausible range of years that one country lags another country in terms of its technological development
      - In that case we could construct a range of relative efficiencies for a one country relative to another country and so provide an upper bound or a lower bound on relative efficiency

AFTER VISITING INDIA, YOU COULD DETERMINE

$$T_{INDIA,t} = T_{US,t-m}$$

(INDIAN TECH LAGS US TECH BY m YEARS)

$$T_{US,t} = (1+G)\,T_{US,t-1}$$

WE WANT TO KNOW:

$$\frac{T_{INDIA,t}}{T_{US,t}} = \left(\frac{T_{US,t-m}}{T_{US,t}}\right)$$

SO IF $m=1$,

$$RHS = \left(\frac{1}{1+G}\right)$$ (FROM THIS EQN)

IN GENERAL,

$$\left(\frac{T_{INDIA,t}}{T_{US,t}}\right) = \left(\frac{1}{1+G}\right)^m$$

$$T_{US,t} = (1+G)\,T_{US,t-1}$$
$$T_{US,t-1} = (1+G)\,T_{US,t-2}$$

$$\Rightarrow \quad T_{US,t} = (1+G)(1+G)\,T_{US,t-2}$$

$$\frac{T_{US,t-2}}{T_{US,t}} = \left(\frac{1}{1+G}\right)^2$$

$$T_{US,t-2} = (1+G)\,T_{US,t-3}$$

$$\frac{T_{US,t-3}}{T_{US,t}} = \left(\frac{1}{1+G}\right)^3$$

WEIL SETS $G = .0081$

IF INDIA LAGS US TECH BY m YEARS & IF US TECH GROWS AT A RATE OF m (DECIMAL)

THEN $\frac{T_{INDIA,t}}{T_{US,t}} = \left(\frac{1}{1+G}\right)^m$

Table 10.1 Decomposition of Productivity Gap Between India and the United States (Should be M not G)

Years India Lags United States in Technology (*G*)	Level of Technology in India Relative to United States (*T*)	Level of Efficiency in India Relative to United States (*E*)
10	0.94	0.37
20	0.88	0.40
30	0.82	0.42
40	0.77	0.45
50	0.72	0.48
75	0.61	0.57
100	0.52	0.67

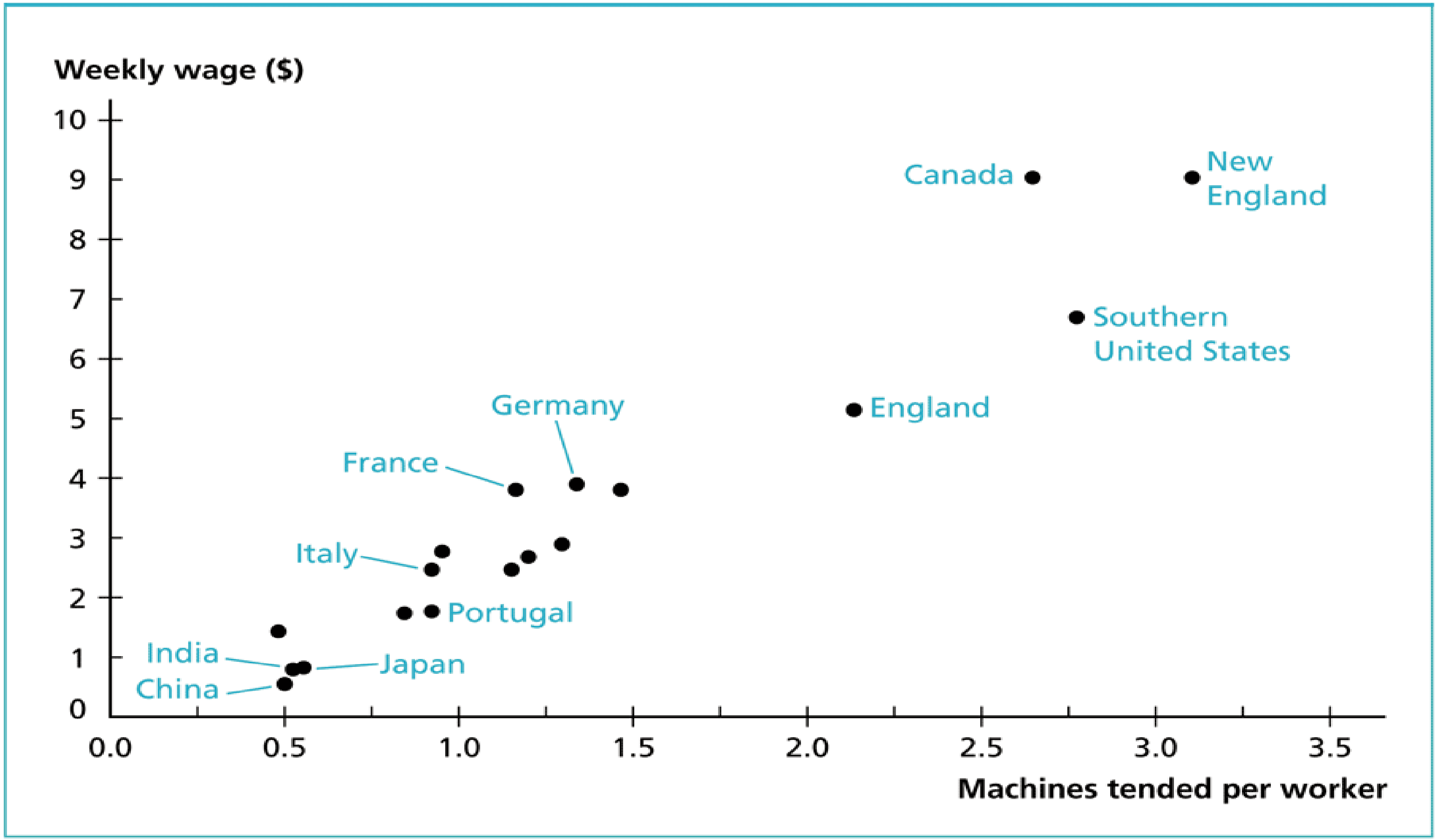
- Some other evidence on differences in efficiency
  - Russian and the USSR (the former Soviet Union)
    - In some industries their technology was comparable to the US
    - Evidence - aggregate data from Russia/USSR
      - In 1985 GDP per capita about 1/3 of US level of y
      - But subsequently, slow growth rate of y
      - In 1999, Russian productivity is only .19 of US level
    - What accounts for inefficiencies? Two favorite explanations:
      - Central planning
      - Limited managerial control of workers

- Another interesting example: The early 20th C. textile industry (data in 1910)
  - Across the world there was a common technology in textile manufacturing and the machines were largely the same, having been produced in Britain
    - Human capital and natural resources can not explain huge differences in wages
    - Workers in the high wage countries tended to operate more machines. What has been used to explain these cross country differences?

      Differences in:

      - factory organization and
      - labor practices

Figure 10.1 Wages and Machines in Textile Industry,1910



Source: Clark (1987).

- We see some large differences in productivity across different industries for the most developed countries
  - Massive differences in technologies can not be the reason

Table 10.2 Productivity in Selected Industries in the Early 1990s

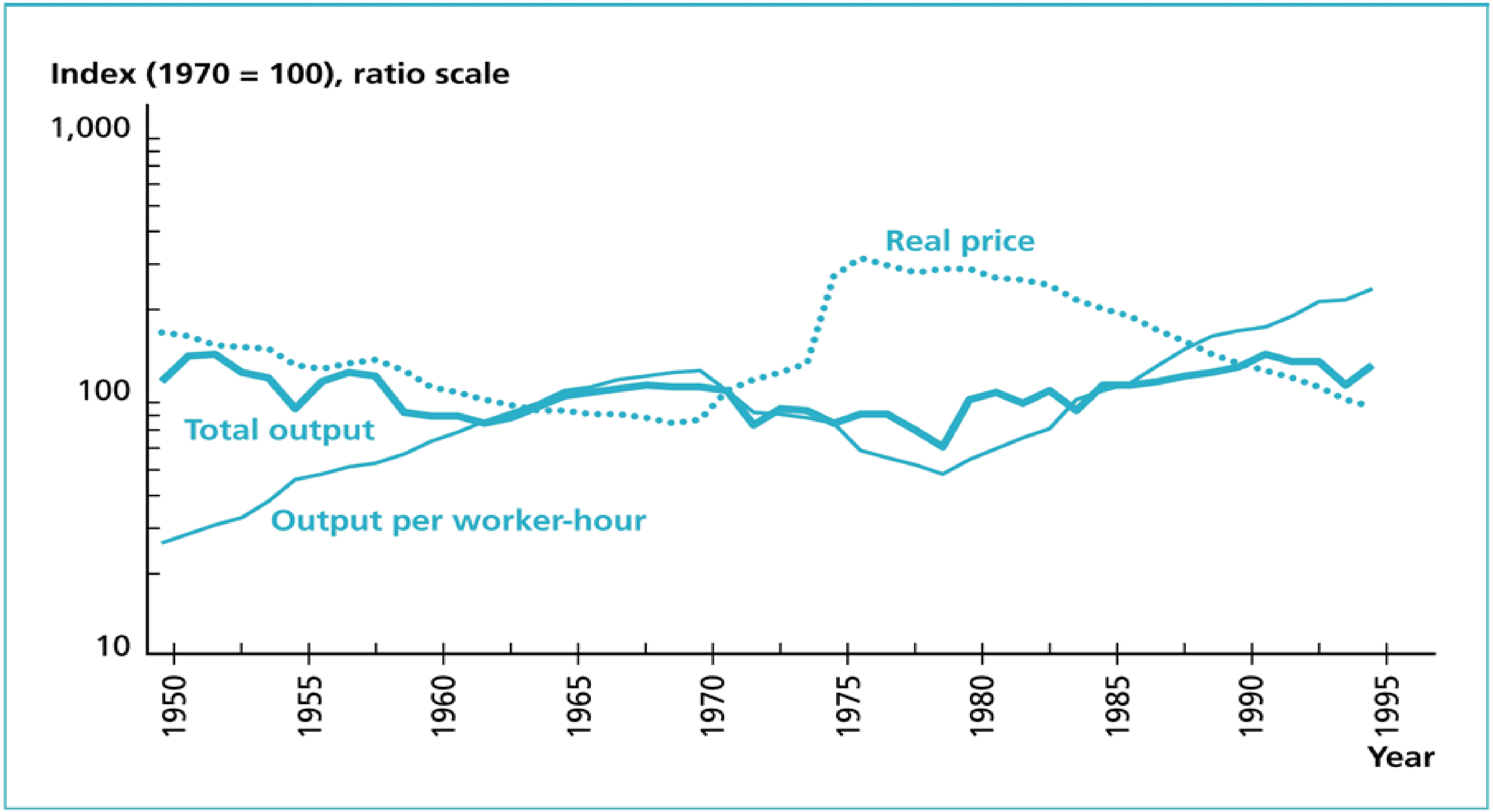
	United States	Japan	Germany
Automobiles	100	127	84
Steel	100	110	100
Food Processing	100	42	84
Telecommunications	100	51	42
Aggregate Productivity	100	67	89

- Can the Japanese be using superior technology for autos and almost 3rd world technology in food processing?
- Can Germany be high-tech in steel but almost 3rd world in technology in telecommunications?

- Neither of these is plausible for such advanced economies

- SKIPPED THIS SLIDE AND THE GRAPH THAT FOLLOWS Coal mining technology was largely unchanged in the postwar period
- The decline in coal output per worker corresponded with a high increase in the relative price of coal
  - Coal labor unions around 1973 gained a strong bargaining position because of the oil price shocks and so they demanded that more workers be hired
  - This was the cause of coal output per worker falling
    - Coal output itself did not really change much at all at this time
    - So output per worker declined because mining firms were forced to adopt less efficient labor practices --- hiring of less skilled and less experienced workers than they would have liked

Figure 10.2 U.S. Subsurface Coal Mining: Output, Price, and Output per Worker-Hour, 1949–1994



Source: Parente and Prescott (2000).

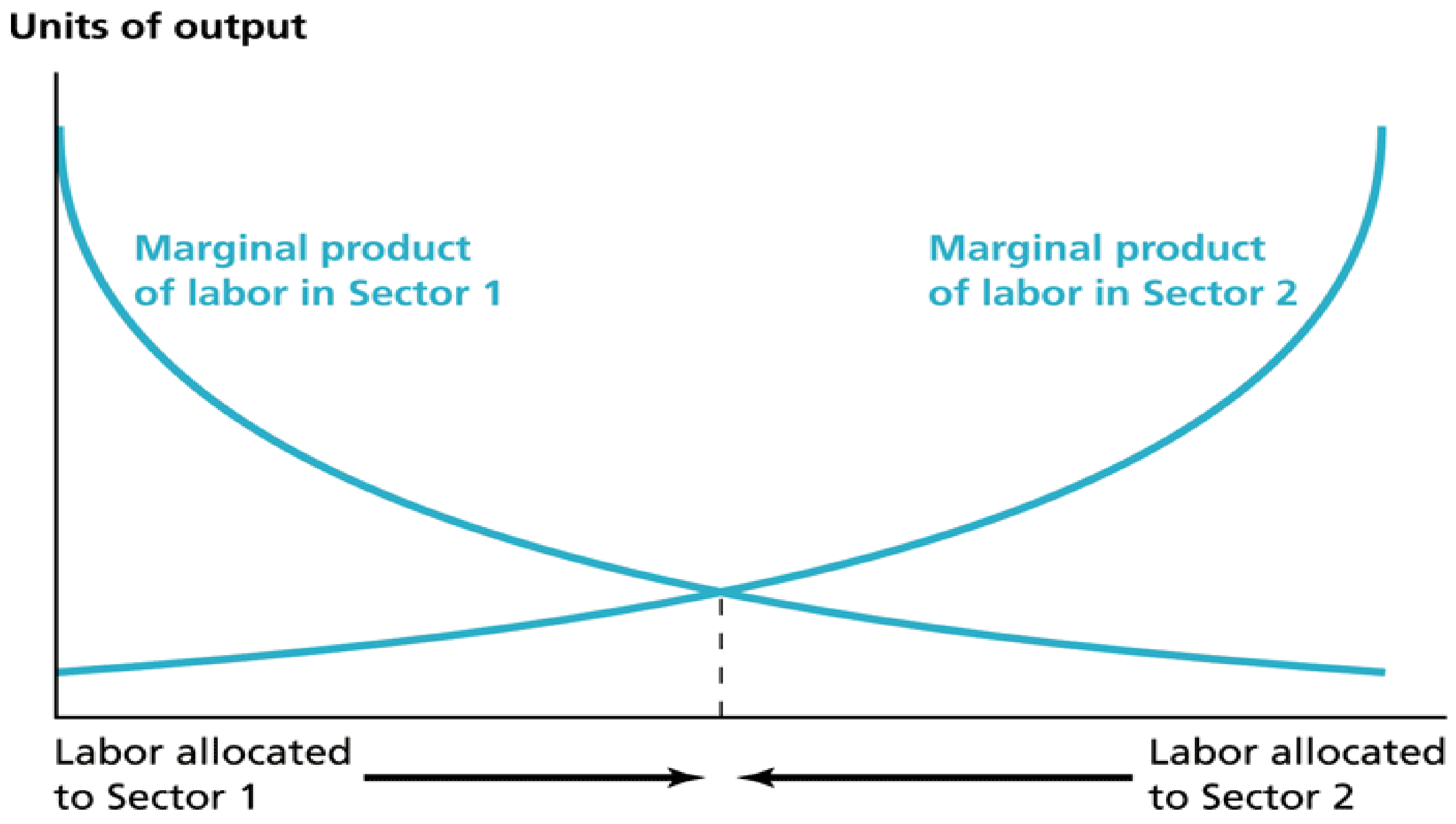
- What are the types inefficiency?
  - Unproductive activities
    - Illegal activities
    - Rent-seeking behavior
  - Idle resources
    - Recessions
    - Regulations
    - Government enterprises
  - Misallocation of factors

- What can types of features in an economy may cause misallocation problems
  - Barriers to mobility of factors
  - Misallocation amongst firms
    - Price fixing
    - Government regulations
    - Monopoly power
  - Blocking technology

Skip the rest of this on Chapter 10 and jump slides for Chapter 11

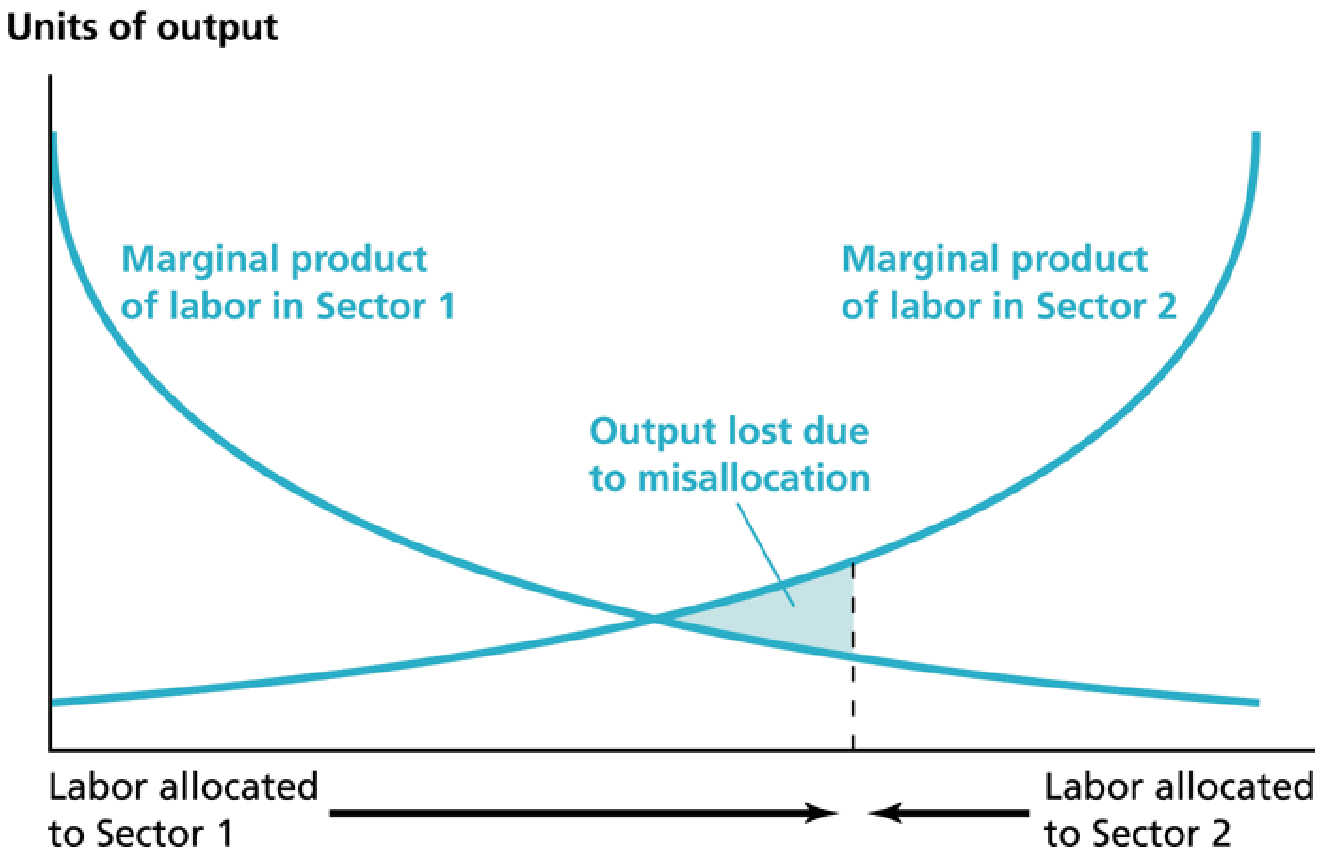
- Suppose we wanted to most efficiently utilize our labor: Here that would mean that we maximize the amount of output that we could produce in society.
  - How would we allocate labor to do this?
    - Note we are taking population, physical capital, human capital and productivity as given
  - The answer: We would allocate labor such that the marginal product of labor is the same across all sectors
  - We use the following graph to help show this
    - The graph assumes:
      - There are only two sectors
      - The marginal product of labor declines as the amount of labor in each sector increases

Figure 10.3 Efficient Allocation of Labor Between Sectors



- The intersection of the two lines indicates the unique labor allocation at which the two marginal products of labor are equal
- Why does this maximize aggregate output in this two sector economy?
  - If we take people out of Sector 2 and put them on Sector 1, then marginal product of the new workers in Sector 1 falls while these workers would have a higher marginal product if they stayed in Sector 2
    - The following graph indicates such an outcome of reallocating workers from the efficient to the inefficient allocation

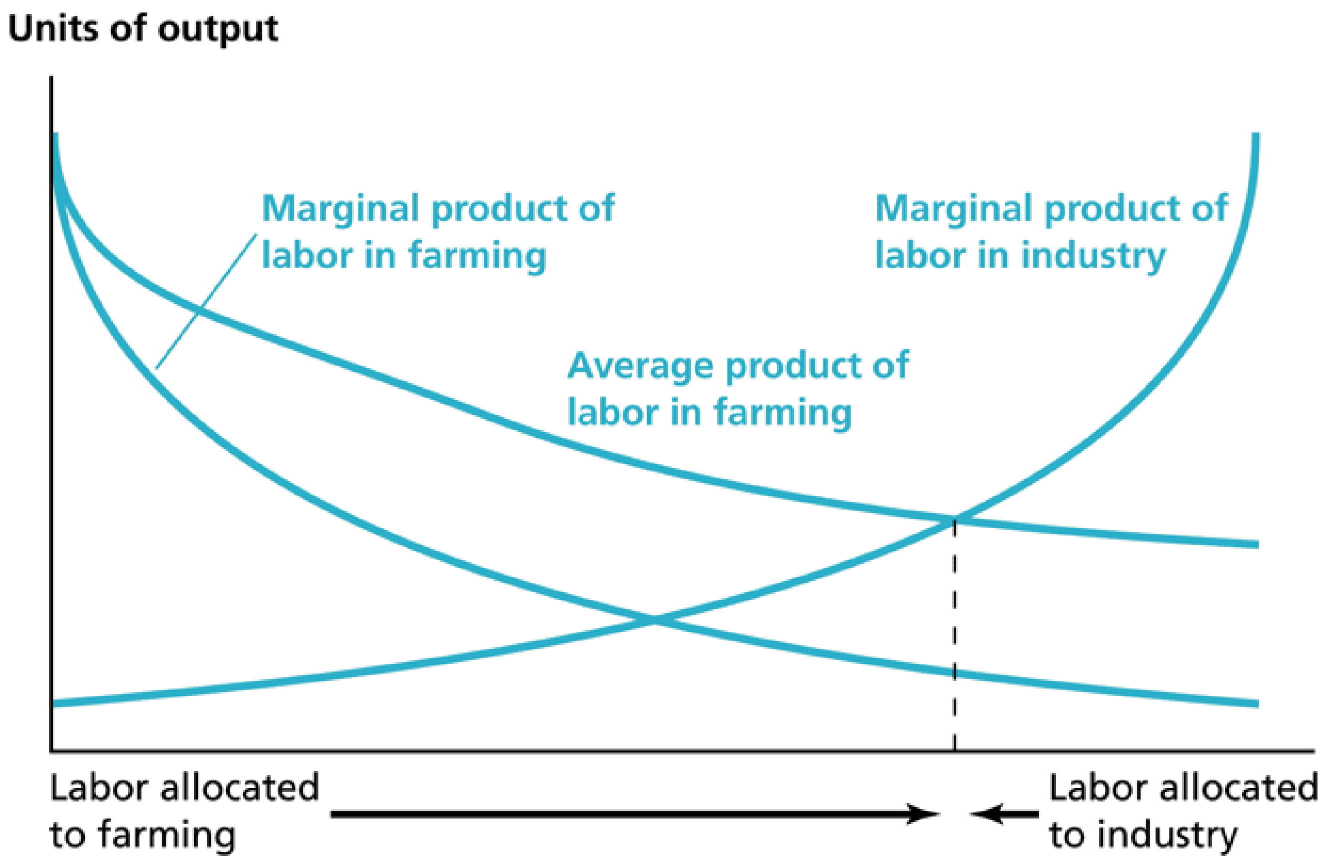
Figure 10.4 Over allocation of Labor to Sector 1



- Another way of thinking about this graph: Suppose we started at the inefficient allocation with a high number of workers in Sector 2 relative to workers in Sector 1
  - We could increase output by shifting workers from Sector 1 to Sector 2
    - The marginal product of workers is higher in sector 2 than in Sector 1 so the output we lose from reducing workers in Sector 1 is smaller than the gain in output from putting them into Sector 2
      - So we raise aggregate output by this shifting of workers
      - We could continue to raise output b the shifting or workers up to the point where the marginal product in each sector are equal to one another

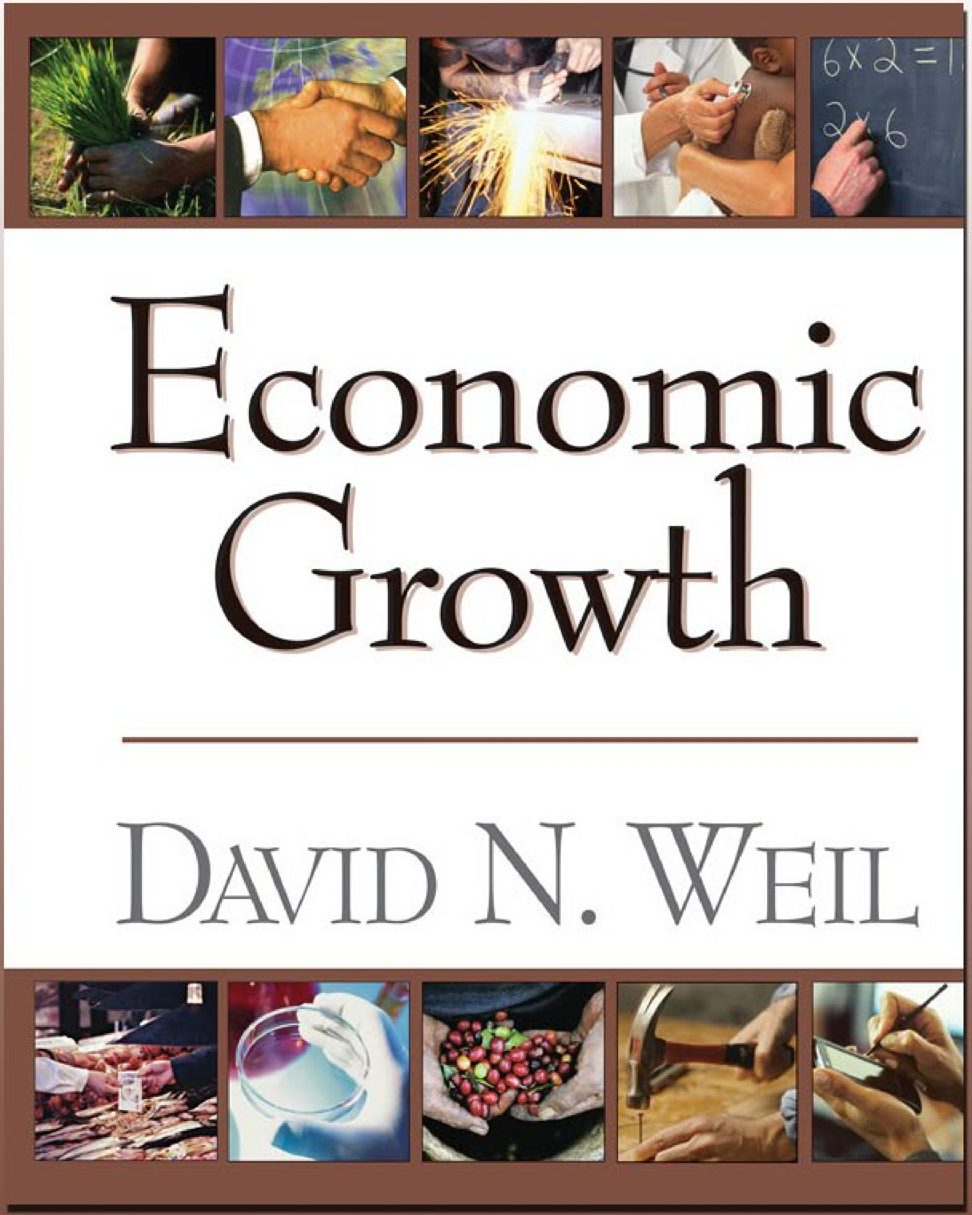
- What can keep us from getting to this point where marginal products are equal
  - Barriers to mobility
  - Misallocation amongst firms
    - Price fixing
    - Government regulations
    - Monopoly power
  - Blocking technology
- Optimal reallocation can have a measurable effect on a country’s economic growth

Figure 10.5 Over allocation of Labor to Farming When Farmworkers Are Paid Their Average Product



Chapter 11

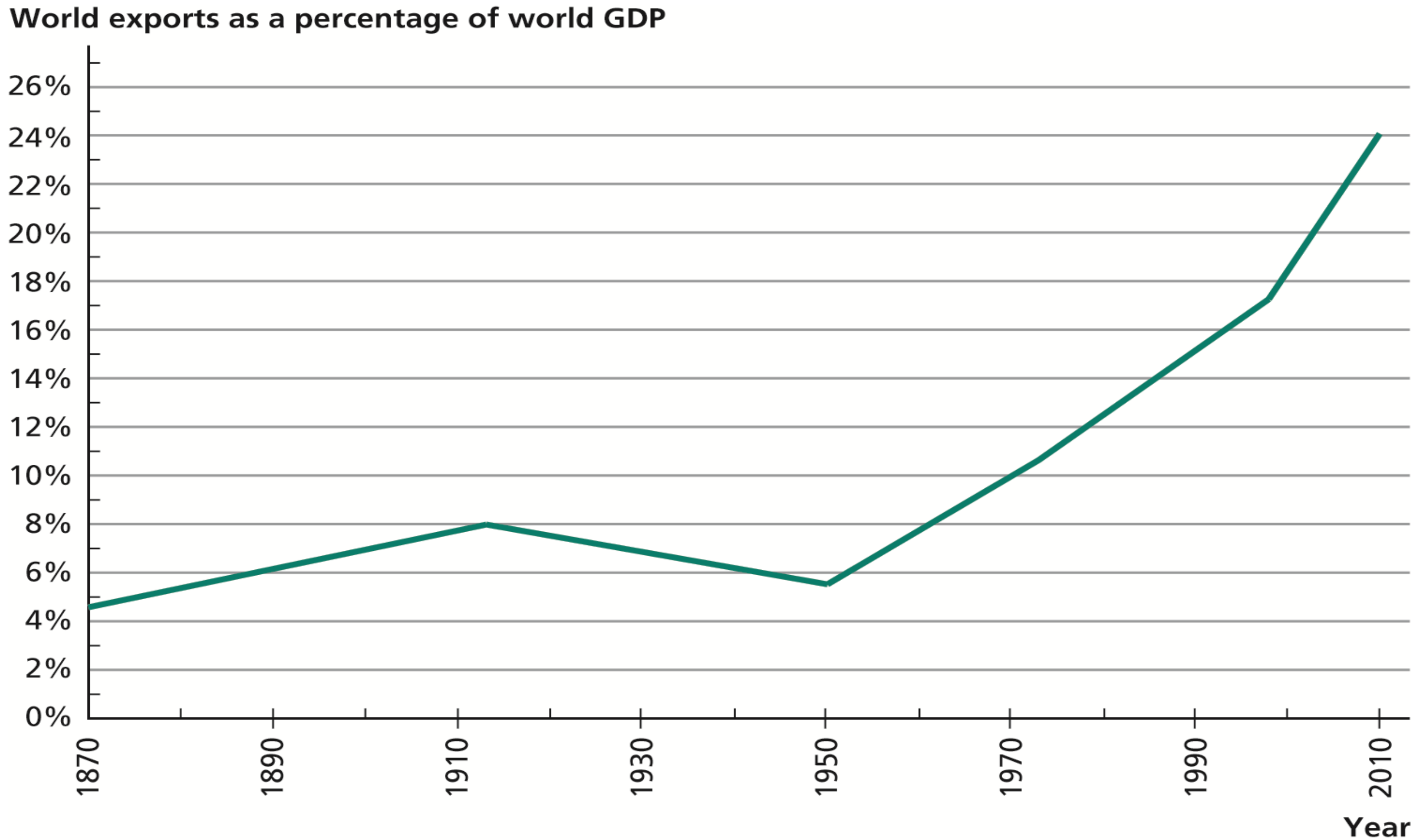
Growth in the Open Economy



PEARSON
Addison Wesley

- World trade relative to world output has been trending upward over time, with the exception of the period from 1910 to 1950

Figure 11.1 Growth of World Trade, 1870–2010



- Trade grew rapidly relative to world GDP from the second half of the 19th century until World War I
  - Countries were trading a rising share of GDP

- A decline in globalization occurred from 1910 to 1950. The drop in world trade as a share of world GDP coincides with the period of World War I, the Great Depression and World War II.
  – War naturally makes international trade more difficult and more expensive
  – The Great Depression reduced spending on all types of goods, but particularly on foreign produced goods
  – At the start of the Great Depression the US government imposed tariffs on US imports (the infamous Smoot-Hawley tariff). Tariffs are a tax on imported goods.
    - About the same time other countries imposed tariffs on US exports. The added costs to buying foreign produced goods significantly reduced world trade

- After World War II ended, trade began to flourish once again
  - Over time exports as a share of output on a world-wide basis rose to an all time high
  - national economies today are more integrated with one another than at any time before
- Recall from a previous examination of data that world GDP has grown fastest since 1950. Thus openness is greatest during the period when world GDP grew fastest

- What accounts for this tendency for increased globalization over time (of course, with the exception of the 1910-1950 period)?

3 key trends are primary factors in increased globalization over time:

- The cost of transporting goods - and people - has fallen over time
- The transmission of information has gotten cheaper and faster over time
- Policies to promote free trade (or at least freer trade) have become more widely implemented

- The declining cost of transporting goods
  - when these costs are high a good produced in one country would have to have a much lower price before it would make any sense to export it to another country
  - More efficiencies in transporting and sometimes fundamentally new transportation systems were developed (e.g. railroads, steamships, computerized freight, air shipping)
  - Greenspan noted that the weight of US shipping has increased only by a little over the last 50 years
    - however the value of shipped goods has grown by a huge amount
    - so even if there had been no decline in the cost of shipping a pound, shipping costs would be lower as a fraction of the total price of imports

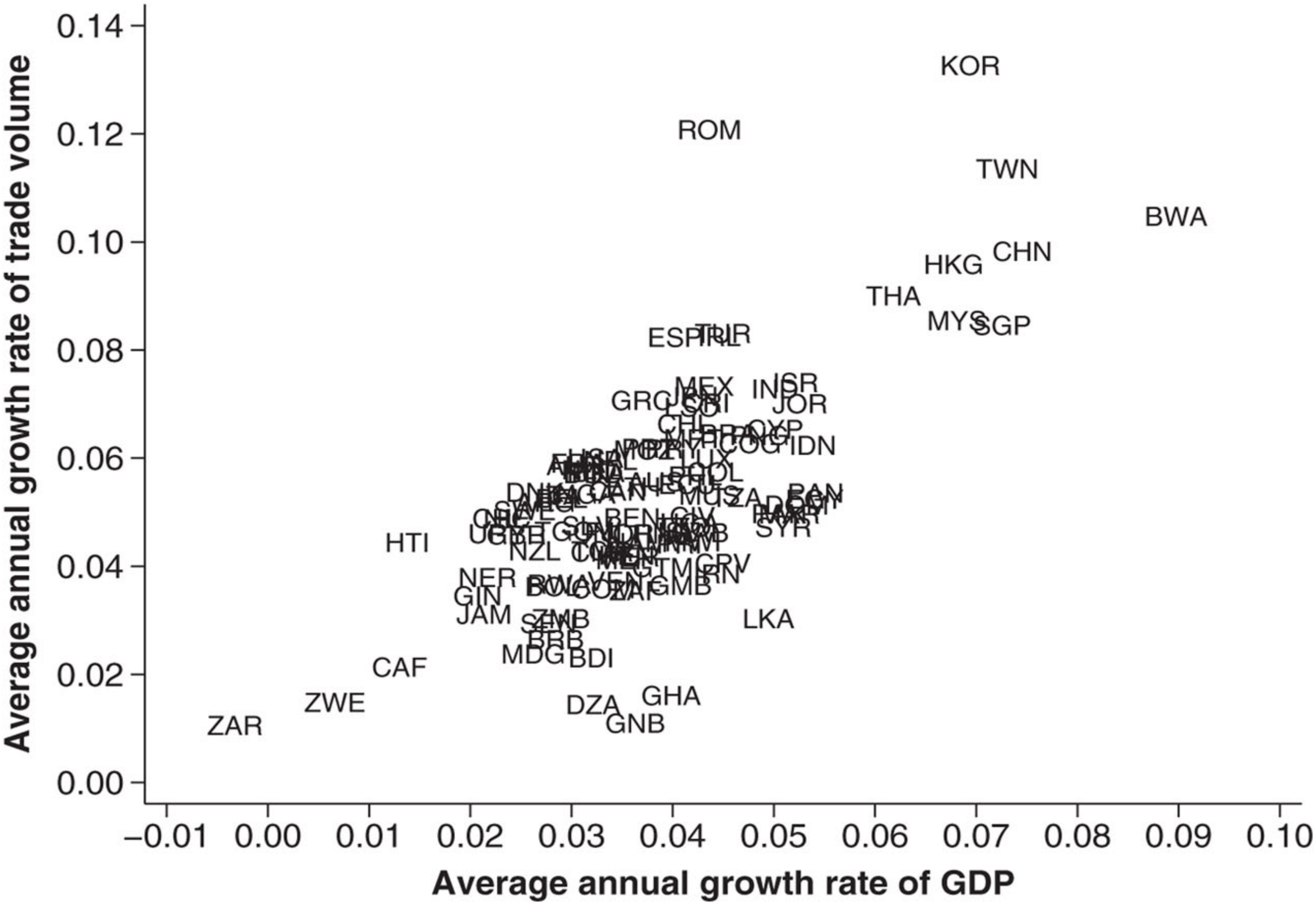
- The declining cost of transmitting information:
  - As it has gotten cheaper and faster, this trend has helped businesses coordinate activities world-wide
  - As this cost of information gets cheaper, this creates new ways of doing business
    - e.g. outsourcing services via the Internet to reduce costs

- Policies to promote freer trade include
  - reducing tariffs,
  - reducing quotas and various other restrictions on trade that governments will sometimes impose.

- More trade directly improves openness of an economy

- Early in the course we looked at a plot that showed empirically a positive relationship across countries between a measure of openness and economic growth

FIGURE 1.5 GROWTH IN TRADE AND GDP, 1960–2008

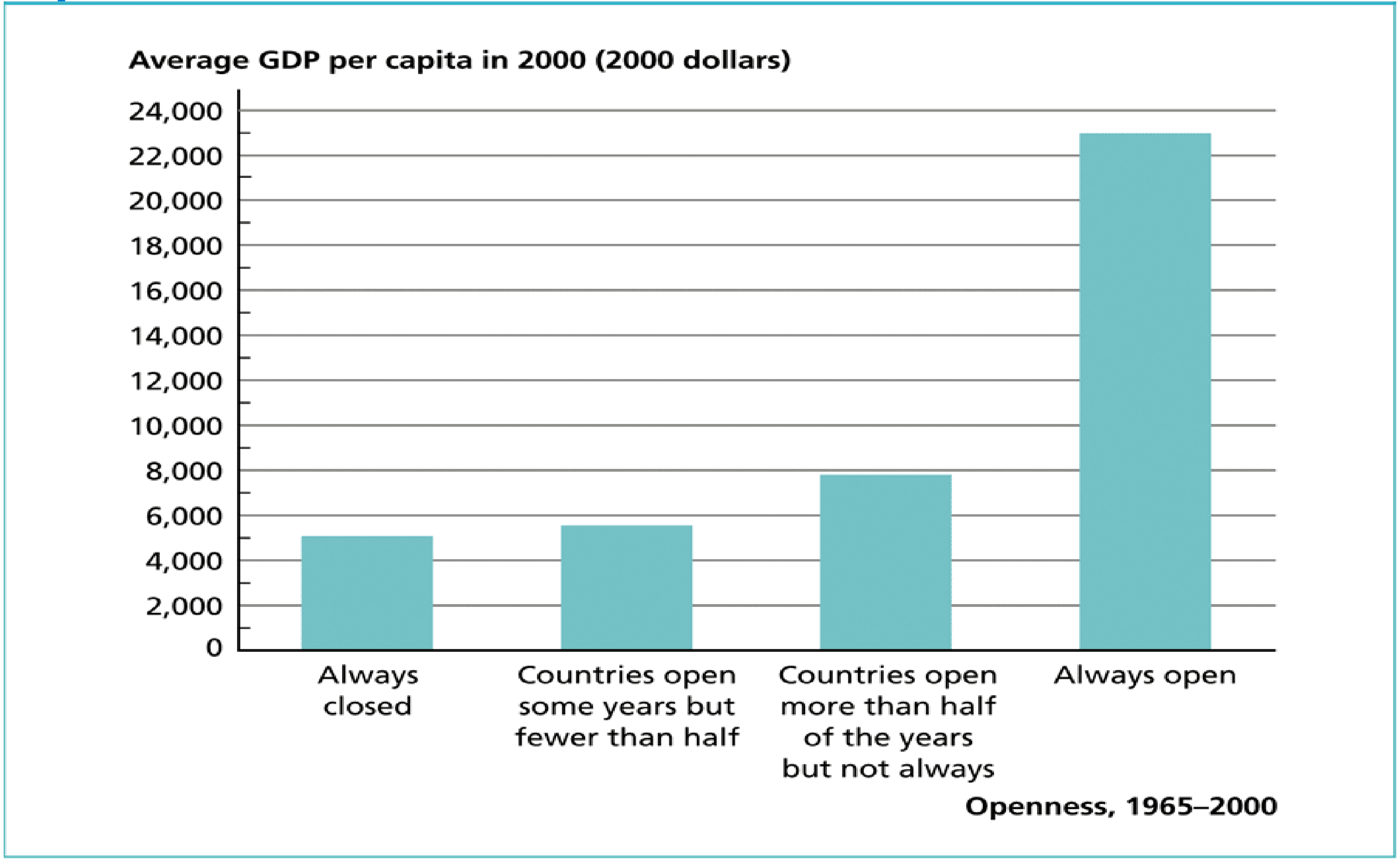


- Here openness is measured by the sum of exports and imports as a share of GDP
  - But exports plus imports as a share of GDP may not be the best measure of openness
  - Reverse causation may explain the relationship. A vibrant fast growing economy:
    - May require more imports as inputs to its growing production
    - May have to export some of its rapidly increasing output

- An alternative and more appropriate index of openness may be needed. Sachs and Warner created such an index in which a country is less open:
  - the higher it sets tariffs;
  - the more it manipulates exchange rates;
  - the more it controls (monopolizes) its export industries

- Sachs and Warner found that countries that are always open tend to have higher standards of living and countries that are almost never open tend to have very low standards of living.
  – This suggests that greater openness tends to allow countries to grow faster and so achieve higher levels of output per capita.

Figure 11.2 Relationship Between Economic Openness and GDP per Capita



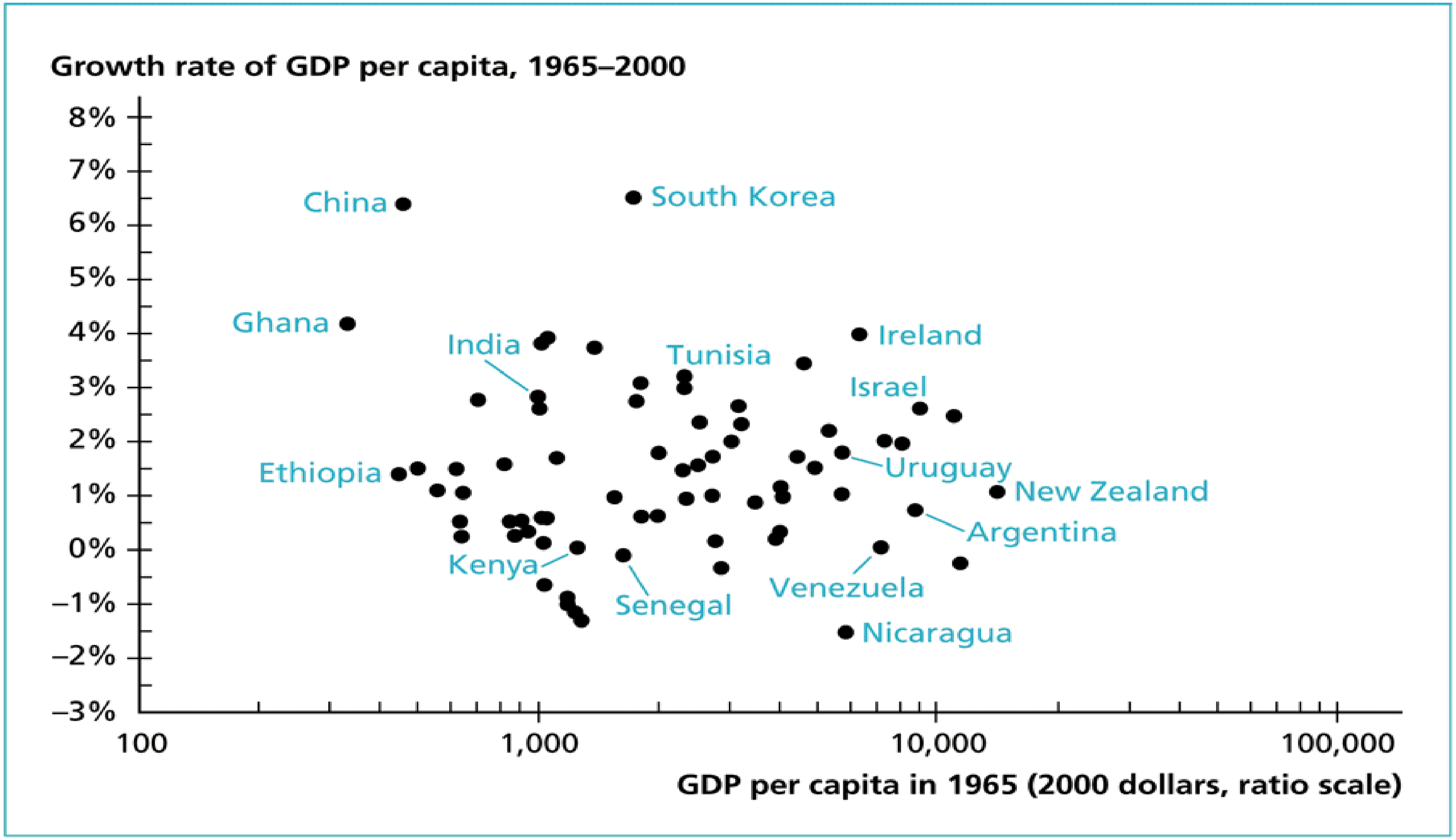
Sources: Sachs and Warner (1995), Wacziarg and Welch (2003).

- But even here one should be concerned about a potential reverse causation
  - If poorer countries more often implement restrictive policies to protect their economies and restrict openness, that could also explain this evidence

- To deal with this simultaneity problem we will break the countries into samples of open and closed economies. Then we can examine
  - The average growth rate for each of these two groups, and
  - Whether there is evidence of convergence in each group
    - Convergence is when countries that are poorer will tend to grow faster than richer countries

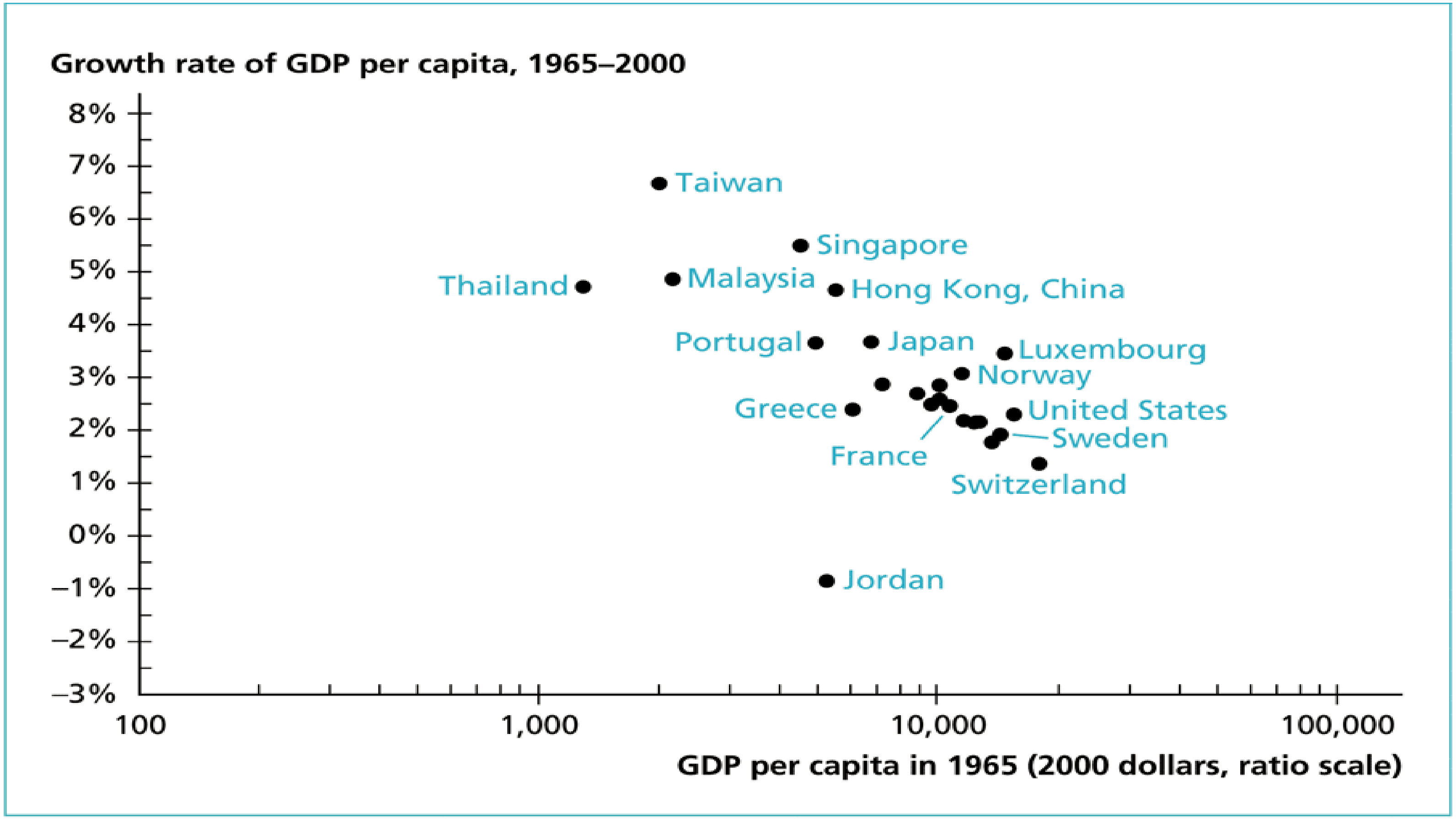
- The findings:
  – Closed economies show no evidence of convergence
    - poorer closed economies don’t show any tendency to grow faster than richer closed economies
  – Open economies show evidence of convergence, in the sense of Solow
    - poorer open economies tend to grow faster than richer open economies
  – Open economies average a higher growth rate of output per capita than closed economies

Figure 11.3 Growth in Closed Economies



Sources: Sachs and Warner (1995), Wacziarg and Welch (2003), Heston et al. (2006).

Figure 11.4 Growth in Open Economies

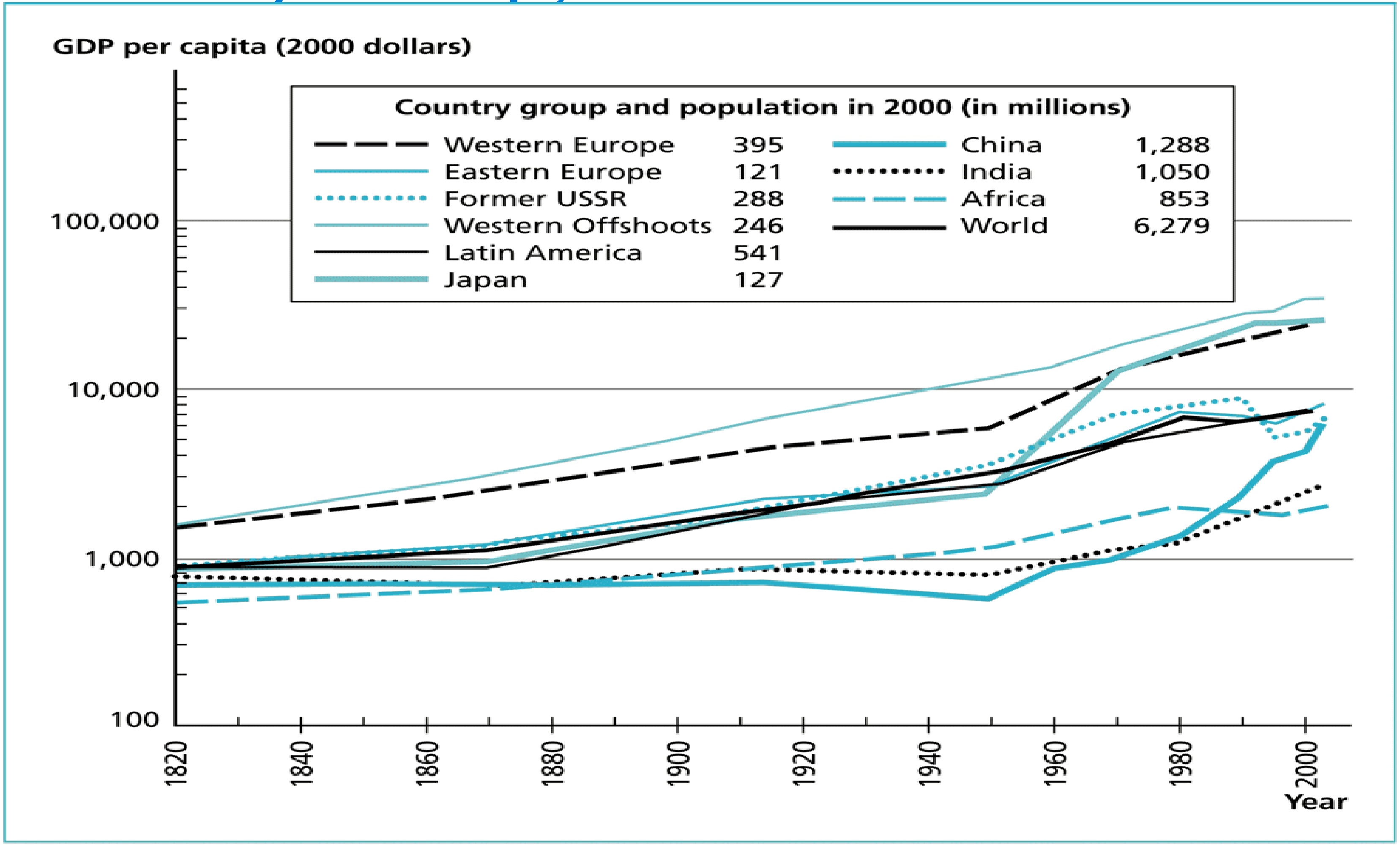


Sources: Sachs and Warner (1995), Wacziarg and Welch (2003), Heston et al. (2006).

- Scientists like to use experimental methods to test hypotheses
  - But, experimental methods are not always feasible in economics
  - When experiments are not an option, and for macroeconomics this is typically the case, economists often try to find “natural experiments”.

- In our context, a natural experiment would be a change in openness that did not result from a change in economic growth
  - South Korea, Uganda and Vietnam are somewhat recent examples where trade was significantly liberalized and subsequently economic growth substantially improved
  - 19th Century Japan is another excellent example. In 1858 Japan revoked its long time policy of isolationism when a new regime took control of the government
    - opening itself up allowed Japanese trade to grew quickly
    - it was not long after trade began to grow rapidly that output growth accelerated. This is seen in the following graph:

Figure 1.7 GDP per Capita by Country Group, 1820–2003



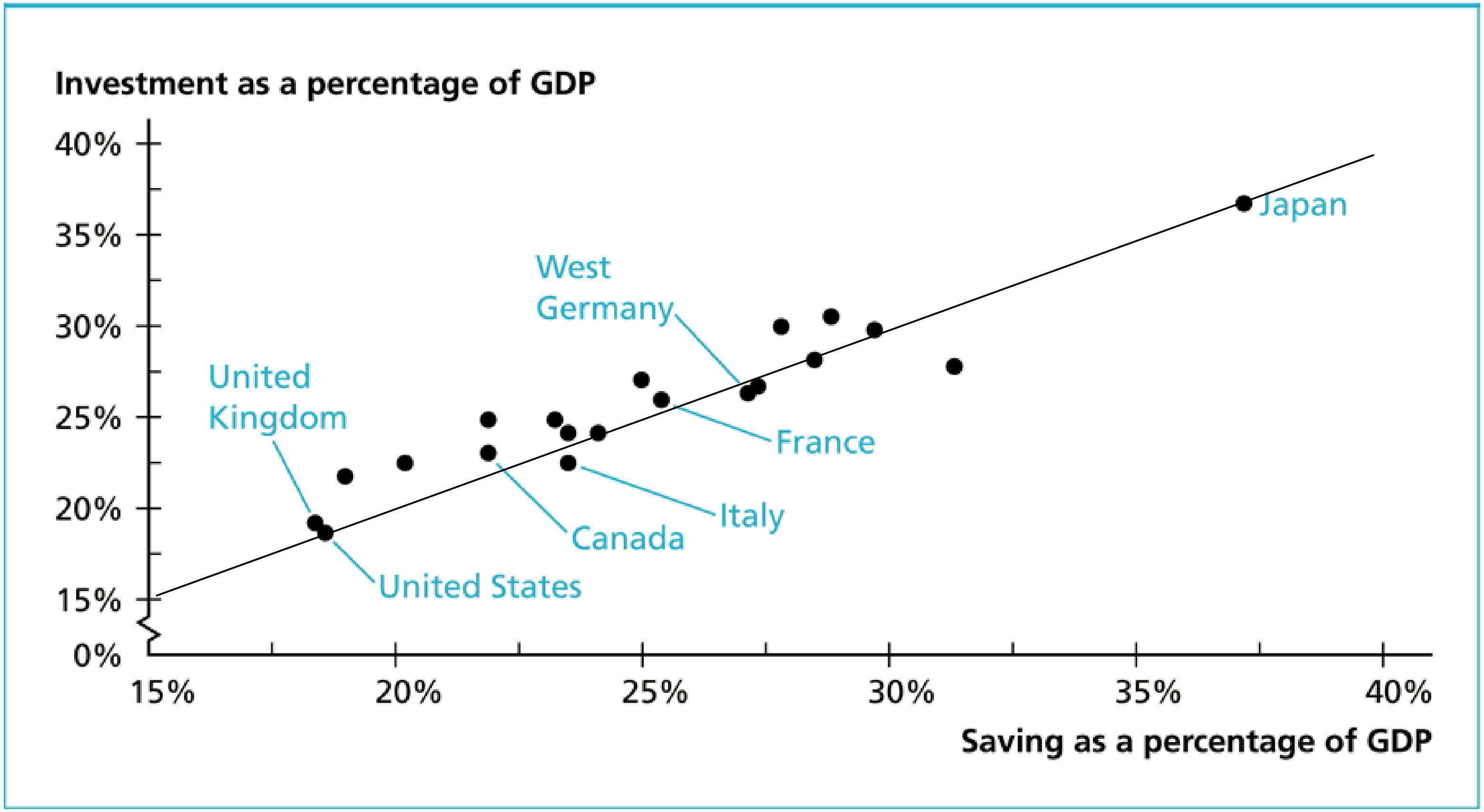
Source: Maddison (2001), Heston, Summers, and Aten (2006).

- Perhaps natural barriers to trade can also be used to determine if trade affects economic growth.
  – economists (Frankel and Romer) found that the amount of trade between two countries partially depends on:
    – how far apart the two countries are
    – if one or the other is a landlocked country
    – how large the countries are (miles, not population)
  - If these geographical factors only affect income by means of their influence on foreign trade then that can be used to estimate the effect of trade on growth
  - Frankel and Romer estimate that trade has a sizeable beneficial effect on income growth

- So if openness has a positive effect on the economic growth of a country, how does this work?
  - Does it enhance a country’s accumulation of factors of production?
  - Does it improve a country’s productivity growth rate?

- Capital flows into and out of economies that are not completely closed-off
  - by means of foreign direct investment and by portfolio investment
- In a world with perfect foreign capital markets there would be no barriers to the flow of capital. In that case, capital would flow to the country that has the highest return on capital (adjusted for risk).
  - high savings countries would send there savings abroad when the return on foreign capital is higher than the return on domestic capital
- Under this perfect market assumption there is no reason for savings rates to be closely associated with investment shares
  - But empirically there is a strong positive cross-country relationship between these two variables, particularly when we look at the industrial economies

Figure 11.5 Saving and Investment Rates of Industrialized Countries, 1960–1974



Source: Feldstein and Horioka (1980).

- Implication: The industrialized countries appear to behave more like closed economies than like countries operating in a world where capital markets are perfectly flexible
- Why? If countries of the world were all closed economies, then savings must equal investment and the savings rate would be precisely equal to the investment share
  - in that case all the data would be on this line I’ve drawn in the picture
- Since the data are reasonably close to lining up on that line capital flows in developed countries do not appear to be the main reason why openness affects income per capita

- Openness does not seem to be affecting economies primarily by its effect on the factors of production …
- … Hence, productivity seems to be the primary means by which openness enhances income per capita.

- In that case, the big question becomes:

How may openness improve productivity?

Three popular explanations for how openness improves productivity

1. trade allows gains from specialization;
2. openness can enhance technological progress;
3. openness can lead to greater efficiency in production

1. trade allows gains from specialization

- if a country produces things it is good at producing and buys from other countries the things it is not as good at producing, the country will produce more output (the theory of comparative advantage)

- There are many examples of this, but lets look again at 19th century Japan
  - before opening up, Japan’s prices for tea and sugar were roughly the same
  - after opening up, the price of tea rose by roughly 50% and the price of sugar fell by half

Table 11.1 Prices in Japan Before and After Opening to Trade

	Price Before Opening (U.S. cents per pound)	Price After Opening (U.S. cents per pound)
Tea	19.7	28.2
Sugar	22.7	11.2

Source: Huber (1971).

- what happened is that opening up its economy allowed the demand for Japanese tea to increase substantially (and thus so did its price) while Japan also found overseas producers who could inexpensively manufacture sugar and sell it at a much lower price in Japan
  - Japan was better off manufacturing tea to buy foreign sugar – an example of comparative advantage – than being closed and having to produce its own sugar

2. openness can enhance technological progress,

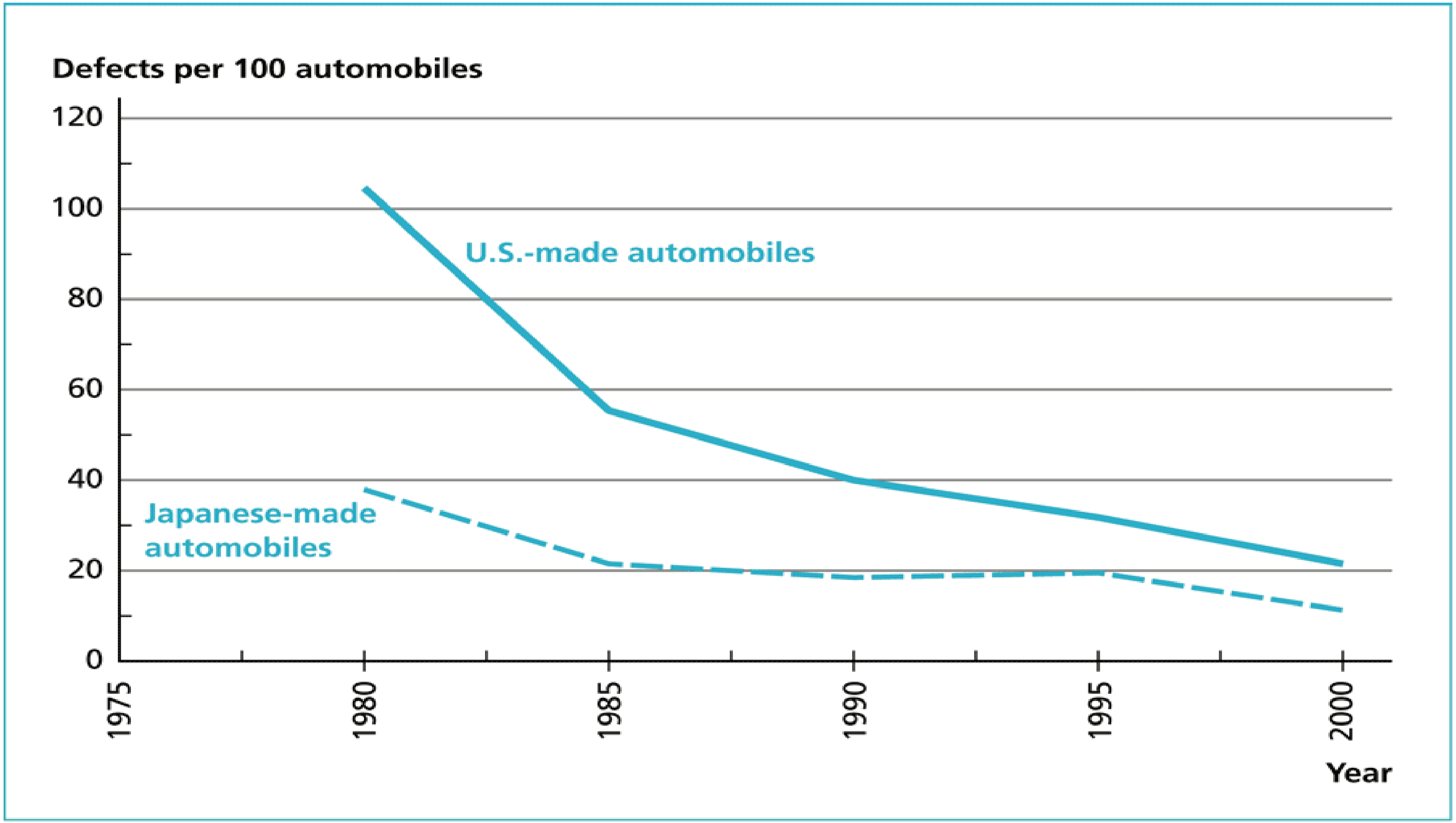
by:

- facilitating technology transfers
  - Access to new ideas:
    - Exposure to new goods,
    - Interacting with new people
- improving the return on technological innovations
  - trade increases the potential market size as foreign markets are opened to an innovative product or a novel idea

3. openness can lead to greater efficiency in production

- competition from foreign firms may force domestic forms to become more efficient
  - the auto industry provides evidence of foreign competition forcing domestic and foreign firms to become more efficient
- When there are returns to scale
  - the industry can expand and take advantage of the benefits of increased size

Figure 11.6 Quality of U.S.- and Japanese-Made Automobiles



Source: "Are Today's Cars More Reliable?" *Consumer Reports* 66(4) (April 2001), p. 12.

- If openness tends to makes a country richer, then why is there often a good deal of opposition to openness?

- While openness is generally good for an economy in the aggregate, it does create economic losers, by which I mean industries that can’t compete with low cost overseas production
  - if the losers have political muscle, they may use that to gain legal protection via trade barriers
  - if the losers have the means to influence public opinion, they may use them to create a backlash against foreigners or foreign produced goods
  - News media tend to focus on people or industries that have large loses and not emphasize the smaller gains everyone receives from increased openness

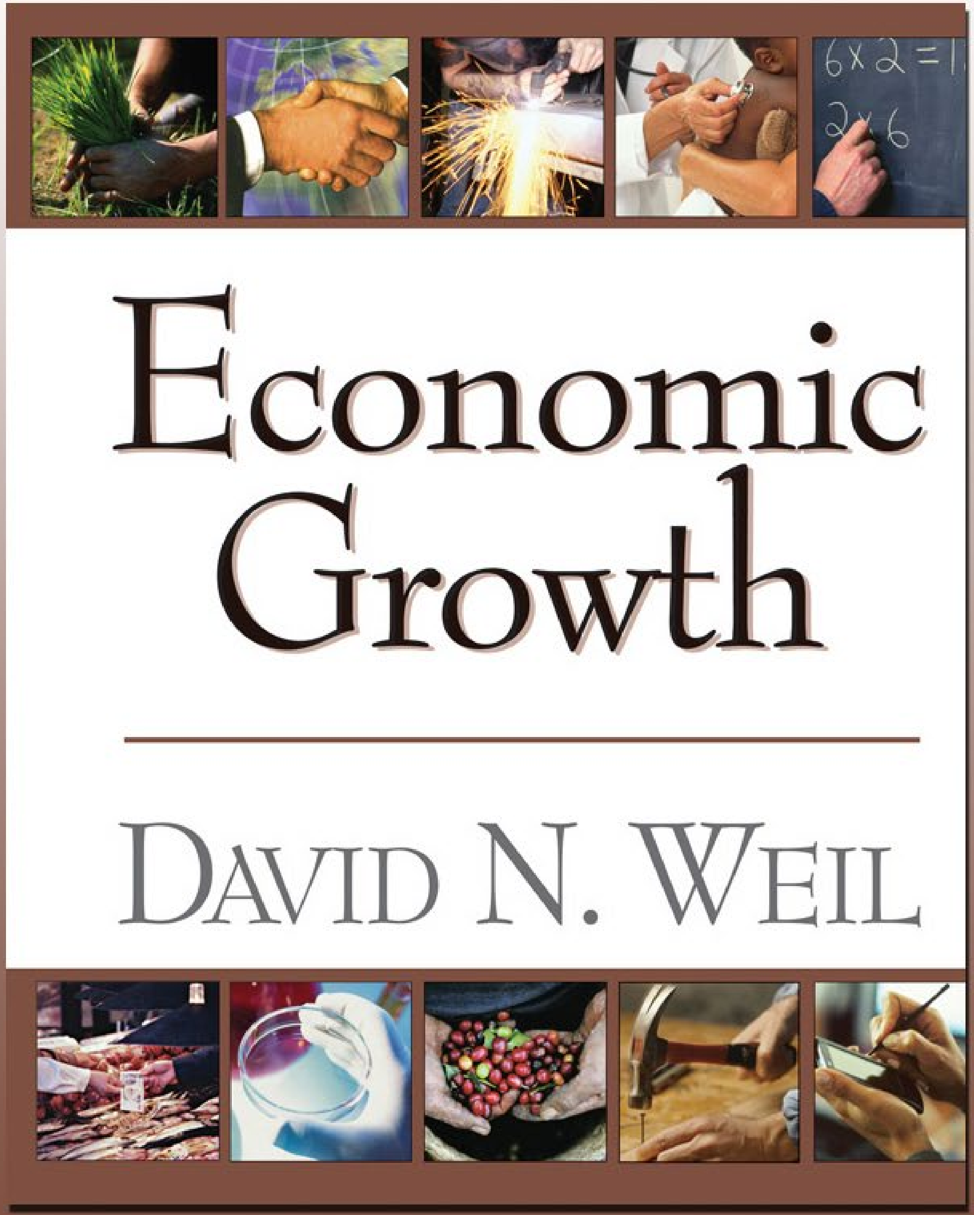
- For example, suppose openness leads to a 10% reduction in the cost of something that everyone buys, but it wipes out a domestic industry
  - wide-spread unemployment in an industry gets significant media attention
  - The 10% reduction in cost is probably not front page news. But this cost reduction frees up income that can
    1. buy more of other goods that we produce, thus creating jobs in some of our other industries,

       OR

    2. be saved, eventually leading to increased investment in plant and equipment which also yields an increased demand for workers in other industries
  - If the 10% reduction in prices is noted by the media, it will likely be attributed to some unexplained reduction in costs or to productivity enhancement, even when these improvements are the direct result of greater openness

Chapter 12

Government



PEARSON Addison Wesley

- The most important questions in (macro)economics are about economic policy.
  - Can a policy make us better off? If so, how best can policy be used to do that?
- For this course a crucial question is: Can government policy have a beneficial effect on the standard of living or growth rate of an economy?

- **Government policies pertain to:**
  1. taxation (tax rates, tax credits, capital depreciation allowances, etc.)
  2. income transfers (social security, Medicaid, Medicare, unemployment benefits. etc.)
  3. tangible government capital (roads, bridges, seaports, airports, highways, the information superhighway, etc.)
  4. intangible government capital (property rights, human rights, justice, national defense, etc.)

- Monetary policy is also available to governments, but it is not thought to have important long-run effects on an economy
  - Yes, hyperinflations do have negative long-run effects on the level of output and perhaps even its growth rate.
    - But, perhaps contrary to your intuition, hyperinflation is NOT the result of monetary policy.
    - Hyperinflations are instead caused by out of control spending, leading to massive fiscal deficits that are financed by printing money

- **How can we determine if government has mattered?** One was: Look at examples where a nation splits into two separate countries.
  - Separations serve as natural experiments if at the time of the split, the new countries initially have similar levels of human capital, physical capital and productivity
  - In that case, different outcomes after the split are attributable to the different economic structures, different political structures, or possibly both
- 3 relevant natural experiments:

1. Germany split into East and West Germanys after World War II ended

- West Germany adopted a democratic government and a market based economic structure and became one of the largest and most developed economies of the world
- East Germany adopted communism. After the split, East Germany fell way behind West Germany in all measures of aggregate economic performance

2. Korea split into North and South Koreas in 1953 after the fighting in Korea stopped

- South Korea adopted a market oriented approach and went on to become one of the Asian Tigers --- the group of fastest growing countries in the world until China growth surpassed all others
- North Korea was taken over by communists and it has become an economic disaster

3. At one time, Hong Kong and Taiwan were part of China. After separating, both countries jumped ahead of China in terms of output-per-worker or output-per-person. This was gradual for Hong Kong, and very rapid for Taiwan.

- Britain took control of Hong Kong in 1841. the British returned Hong Kong to Mainland China in in 1997, but Hong Kong has maintained many of the economic and political freedoms it adopted from Britain.

- Taiwan separated from Mainland China in 1949 after the Communist Revolution which drove Chiang Kai-shek from power. Then Taiwan developed a more market based economy.

- Of course, more recently things have been changing for China
  - It has grown more rapidly that any country over the last few decades
    - This change is associated with the switch from overbearing state control to allowing greater economic freedoms (if not so much political freedom) following the death of Chairman Mao Zedong
    - In the future, China may one day compete with the US in terms of per capita measures of output. But that will almost certainly require changes in political and economic freedoms along they lines they been changing over recent decades
  - And it is one of the largest two economies in the World today,
    - But currently it owes this stature more to the immense size of its population, but its output per capita is also rising rapidly

- **What justifies government involvement in the economy?**
- A primary reason would be if there is some type of market failure, because
  - If markets obtain the most efficient outcome on there own,
    - there is no need for government to get involved

      and
    - government involvement could not make things better and would likely make things worse
- The question is: What are there market failures?

- **Types of market failure that may create incentives for government intervention**

1. public goods
   - these are goods that a private market is unable to provide or will not provide an adequate amount of:
     - e.g. national defense, rule of law, a system to handle civil disputes, interstate highways

2. externalities

- An externality is a cost or benefit which affects a person or firm who did not choose to incur that cost or benefit. It occurs when the choice of a person or firm affects another party by some means other than through a market price.
- Externalities may be positive or negative. Examples:
  - Positive externality: A technical innovation that will help other people or firms come up with new ideas
  - Negative externality: Pollution that the producer of it would not have to worry about without government involvement
- When there is a positive externality, too little of that item is produced without government intervention
  - If innovators can not claim the full social return for their ideas, they will produce fewer innovations. Patents and other government rules allow innovators to be compensated by others who benefit from their ideas
- When there is a negative externality, too much of the item is produced without government intervention
  - If firms do not pay the full cost of pollution, they will emit more pollution. Government taxes and regulations cause polluters to internalize those costs so that others do not have to suffer those costs.

3. monopolies

- In general, we know that a market with a single producer (the monopolist) will tend to have a higher price and produce less output than it would have if it had more than one producer
- A monopoly may arise as a natural market outcome (e.g. at times Microsoft has been called a natural monopoly).
  - Government typically regulates a monopolized industry out of concern that a monopolist will have too much economic power for the good of consumers
    - Government will also regulate an industry which has only a few producers because of concern that these firms will collude about pricing
- However, sometimes a monopoly is thought to be the most efficient way to provide some good and a government may designate a monopoly to a single firm in an industry
  - e.g. a local monopoly on electricity transmission is typically granted to a company
  - Consequently, the government will need to regulate this energy company so that prices do not get excessively high, since that would lead to energy usage that is excessively low

4. income redistribution policies

- Income redistribution may be used to correct inequities of the market system,
  - taxing the rich to give to the poor
  - taxing workers to subsidize unemployed workers, the medical costs of people who are unable to care from themselves or provide income to retired people, for example.

5. coordination failure problems

- if economic activities could somehow be better coordinated between a set of firms, the output of the firms might be improved, the cost of production may go down or some combination of the two

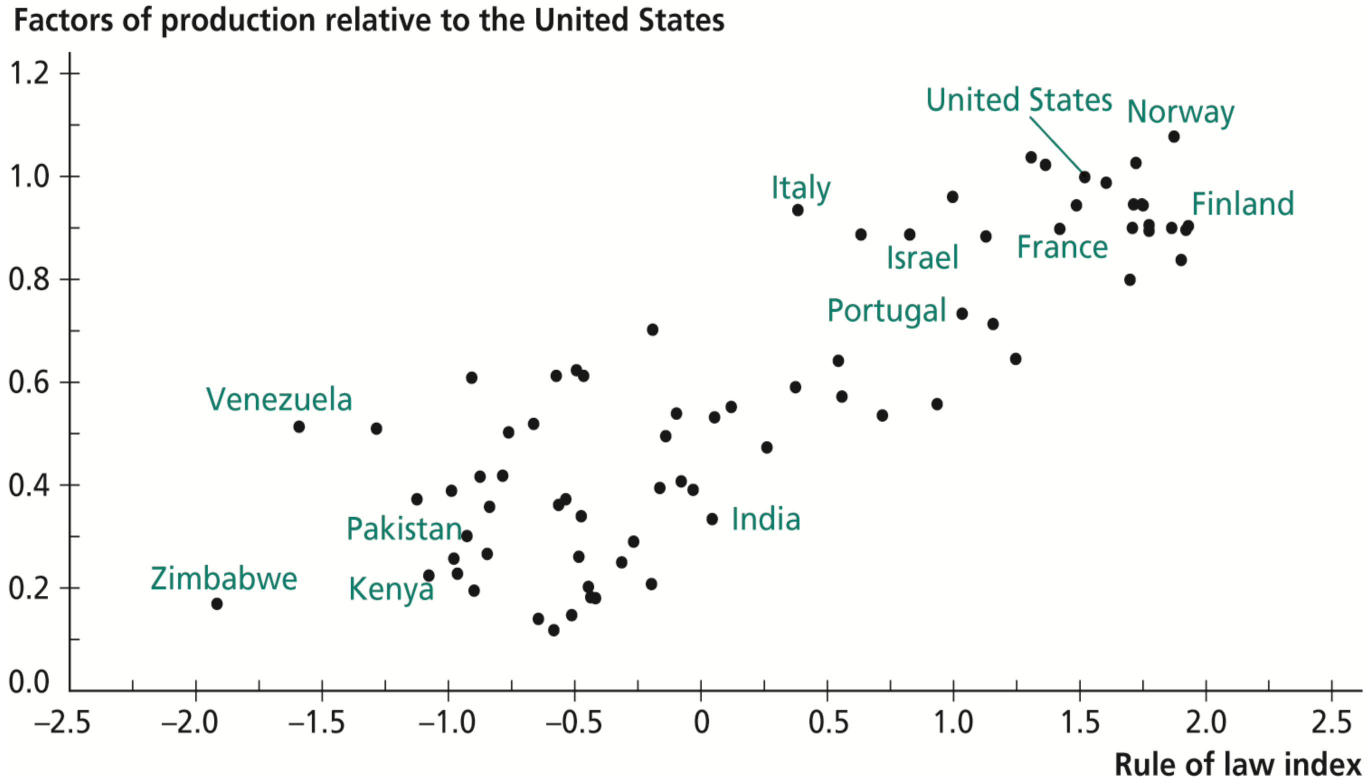
- **But government intervention may not always be warranted. Government failure can occur:**
  - When the government tries to do something the private sector can actually do more efficiently
    - there has been a recent trend internationally toward having less government involvement in the economy .
    - For example:
      - privatizing of formerly nationalized industries
      - reducing the amount of regulation in industries
  - When the politically expedient choice is made rather than what is economically the best thing. Examples are:
    - When the government gives business to a firm that donated a lot of money to a politician’s campaign
    - When a government official demands a bribe before
      - Giving a government business contract or
      - Allowing some government service to be provided

- **The rule of law is apparently very important for economic growth**
  - the rule of law increases economic activity because
    - contracts can then be established, since they are enforced by the legal system, and contracts promote business-to-business arrangements, borrower-lender relationships, etc.
    - protection of property rights gives reason for firms to build stores to inventory and sell goods and for firms to build factories to produce goods. It also gives people reason to invest in human capital.

- How might we measure the rule of law?
  - one example, an index that combines
    - enforceability of contracts
    - effectiveness and predictability of the judiciary
    - the incidence of crime
- Modern cross country evidence shows a strong positive relationship between the rule of law and both
  - the factors of production

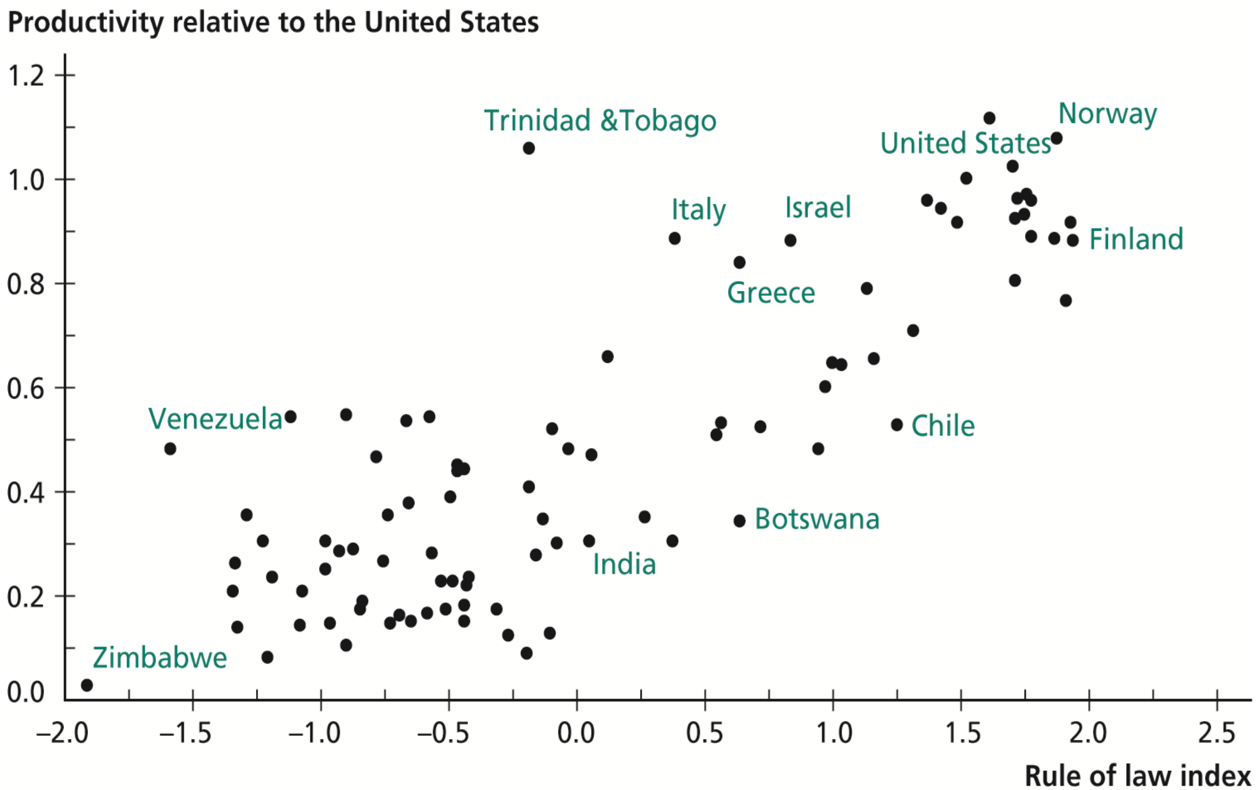
    and
  - productivity
    - these two variables are measured in the same way as we did before, relative to the US

Figure 12.1 Rule of Law and Factor Accumulation, 2009



Source: Kaufmann, Kray, and Mastruzzi (2010). Data are scaled to have a standard deviation of 1.

Figure 12.2 Rule of Law and Productivity



Source: Kaufmann, Kray, and Mastruzzi (2010). Data are scaled to have a standard deviation of 1.

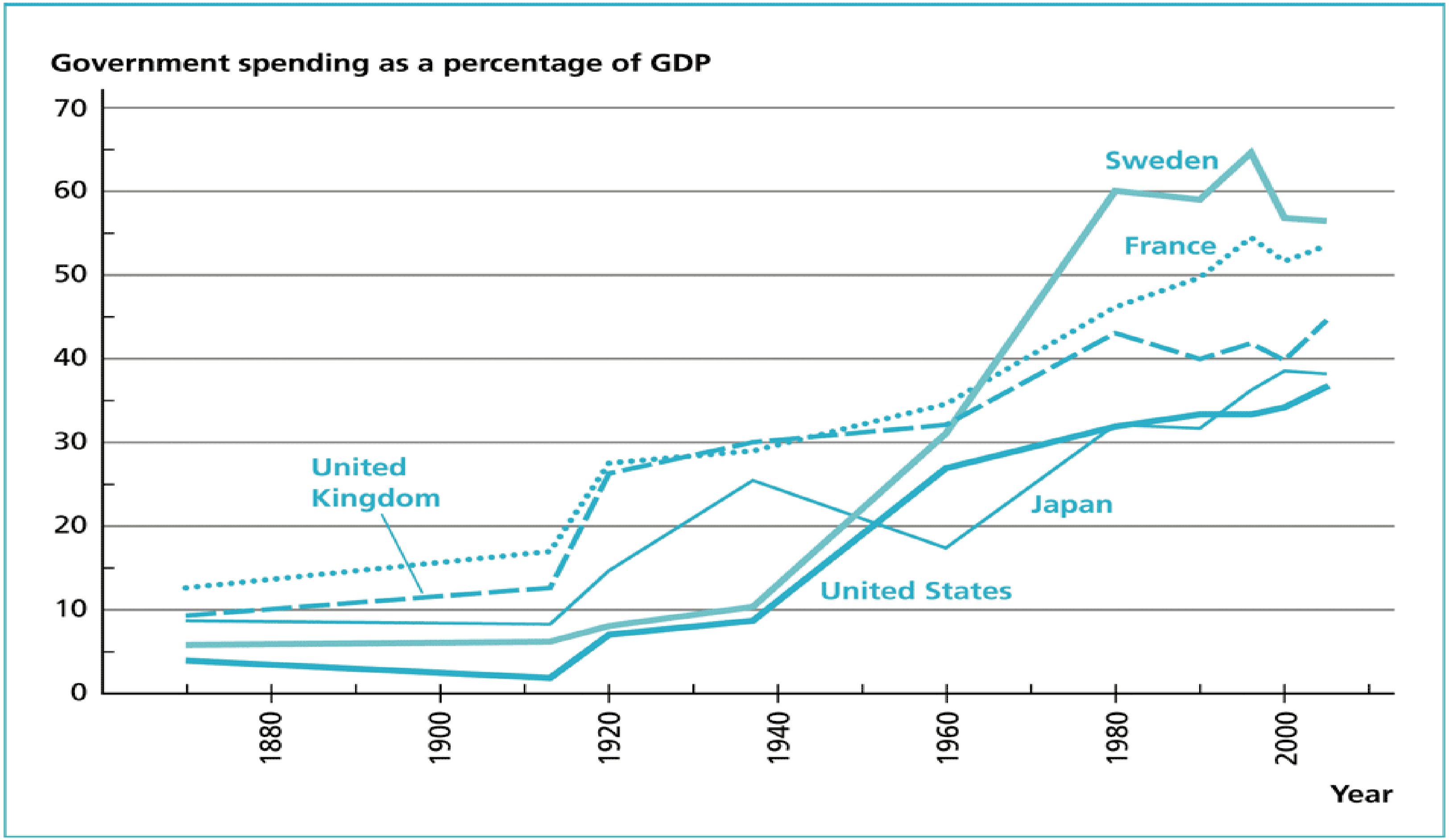
- Since factors and productivity are both positively related to output per capita, that means rule of law is also positively related to output per capita.

- Therefore, if changes in rule of law for countries are largely independent from the level of output, this correlation establishes that improved rule of law causes more factor accumulation and greater productivity of a country
  - Of course, there is still concern about the infamous and pervasive “simultaneity problem”.
  - But recall that the industrial revolution started in Britain following fundamental changes in human rights and property rights that were unrelated to output.
    - Thus, the Industrial Revolution serves as a natural experiment for how an improvement in the rule of law can raise the level of output for a society, according to Nobel Prize in Economics recipient Doug North

- **Other ways government matters**
  - tax rates and government spending are thought to have significant effects on an economy
- In fact, the amount of taxation is related to the amount of government spending (outlays)
  - While taxes aren't always equal to outlays - because governments can run surpluses or deficits - there is a tendency for taxes and outlays to move in similar ways over the long run

- Lets examine how outlays have behaved over long periods of time for a sample of countries

Figure 12.3 Growth of Government Spending, 1870–2005



Source: "The Future of the State," *The Economist*, September 20, 1997, *OECD*.

- government (outlays) spending have been trending upward for about the last century, when measured as a share of GDP
- in the late 19th century the measure tended to be about 10% of GDP or less for these advanced countries
- It began rising with World War I or World War II in these developed countries
- by the late 20th century the measure has increased a large amount in developed countries

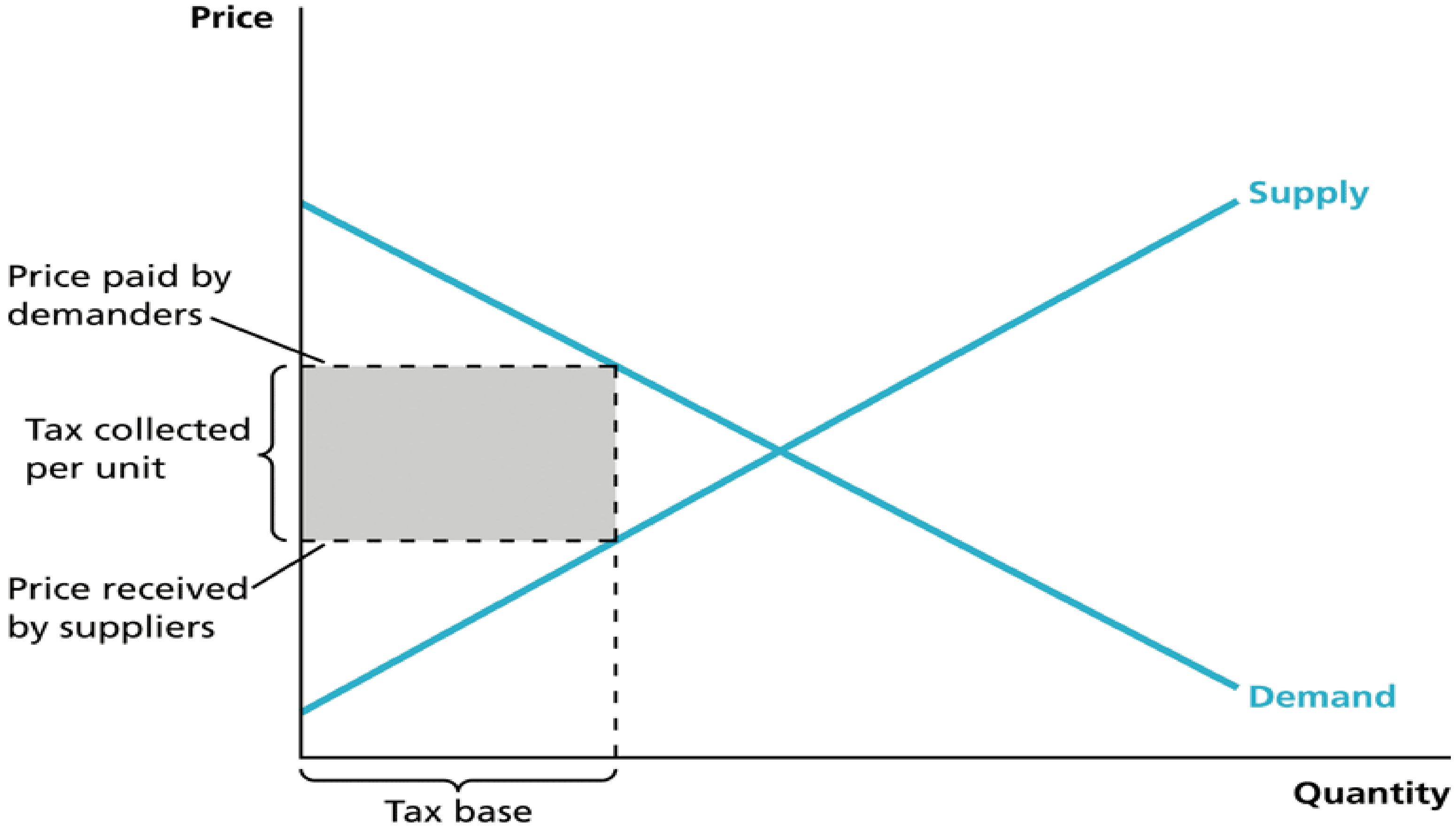
- Since the late 1800s these economies have been growing at a similar rate even as the size of government sector continued to rise

- **Government shares rising means government spending has been growing faster than GDP.**
- Why? Some reasons offered to explain this trend in government's share of output are:
    - wealthier countries require more complex regulations
    - people in wealthier countries demand an increasing amount of public goods
        - wealthier countries may require more spending on national defense, broader and deeper government safety nets, more extensive judicial systems, etc.

- To balance its budget a government would have to take in an amount of taxes as a share of GDP that is equal to the amount of government outlays as a share of GDP
- most taxes are assessed as a rate on something (income tax, sales tax, estate tax, etc.)
- this means that countries with government outlays that are higher as a share of GDP will tend to have higher tax rates, and vice versa.

- **Can higher tax rates adversely affect output in the long-run?**
  - Yes!
  - Consider the following graph – for any market
    - first assume there is no tax. In that case, market equilibrium occurs where supply and demand curves intersect
    - now suppose there is a tax on this good that applies to every unit of the good that is sold.
    - For simplicity, assume the tax is paid to government by the company after they sell the good to the consumer

Figure 12.4 Effect of a Tax



- So when there is a tax, the price that buyers pay is different from price the seller receives after taxes.
  - the difference is known as a tax wedge
  - the market equilibrium quantity of the good is at the unique point in the graph where the gap between the supply and demand curves is equal to the tax wedge.
  - An implication of this graph: The higher the tax rate, the less quantity of goods is sold and so the less will be produced

- The implication - higher taxes create less production
  - the amount produced declines as the tax rate rises
  - in the aggregate, higher tax rates lead to a decline in GDP
- This is why government spending requires cost benefit analysis decision making:
- Are the benefits from government programs worth the cost of financing them by taxes?

Industrial Policies

- Examples:
  - state-run enterprises
  - state direction of productive resources
  - trade restrictions
- Industrial policies have not always been a failure, though in many cases, perhaps most, they have made things worse
- Japan’s industrial policies after World War II have sometimes been cited as a successful example of industrial policy

- Japan, after World War II and until 1990, was highly successful in terms of output per capita growth
  - Many people attributed these economic successes to Japan's industrial policy and wanted to implement the same in the US
  - But perhaps Japan would have grown just as fast - or even faster - without government industrial policies.

- The post-World War II market reforms were a major structural change to Japan’s economy that were likely to be the key impetus to growth in Japan.
- But some questioned whether the market would have made the same or even better decisions than Ministry of International Trade and Industry (MITI) about how to allocate capital to industries in Japan
  – MITI’s role has been taken over by METI (Ministry of Economy, Trade and Industry)

- And some argued industrial policies were a factor in Japan’s long post-1990 slow down in growth.
  - Over time, industries learned how to manipulate the government to obtain loans.
    - Crony-capitalism, is a term often used to describe the operation of Japan’s financial markets
      - Firms with the best access to government were able to obtain bank loans
      - They were not necessarily the most innovative firms or the firms with the most profitable investment opportunities

- However, there are some who believe an underdeveloped or developing country's government must actively assist that economy to reach a high level of development more rapidly.
- in his book: *The Quest for Prosperity: How Developing Economies Can Take Off*, Justin Yifu Lin former Chief Economist of the World Bank strongly advocates that the use of industrial and other policies instrumental in trying to bring an underdeveloped economy up to the level of modern developed economies like the US

- Lin’s book argues there are certain key things leaders can do to help guide developing economies more rapidly achieve high levels of prosperity. He argues:

- The optimal industrial structure varies over time – i.e. must be upgraded – if an economy wants to move from one level of economic development to the next.
- The appropriate levels of government infrastructure (tangible and intangible government capital) evolve with each stage of development.
- Growth is impeded by:
  - Large externalities in terms of firm transaction costs and the returns to capital investment associated with industrial upgrading
  - Difficulties in coordinating various improvements industrial structure needed at each stage of development.
- To hasten growth, the government should help coordinate industrial improvements and compensate firms for the externalities while simultaneously cultivating effective market mechanisms.

- Like all things in government, whether or not to develop an industrial policy is a cost-benefit analysis
  - Balancing the potential rewards (better economic performance) with the potential risks (abuse of a government program) is the key question

- **Why do governments do things that can have bad consequences for the economy**?
  1. there may be enough benefits from certain policies to warrant the costs
     - government spending on goods and services provide for national defense that has a benefit of protection, but the cost is that the higher tax rates needed to finance the spending will cause the economy to be less productive.
     - government regulations that make workers safer, or consumers safer or cause a reduction in pollution have societal benefits, but these also will effectively act like a tax on firms (because they increase the cost that firms must pay to produce and thus lead to less production)
     - society may think that income redistribution is correct under some conditions but the cost is the tax some group pays to help another
       – these policies will result in less efficiency in production, but may serve to correct a perceived inequity (e.g. taxing the rich to help the poor to survive)

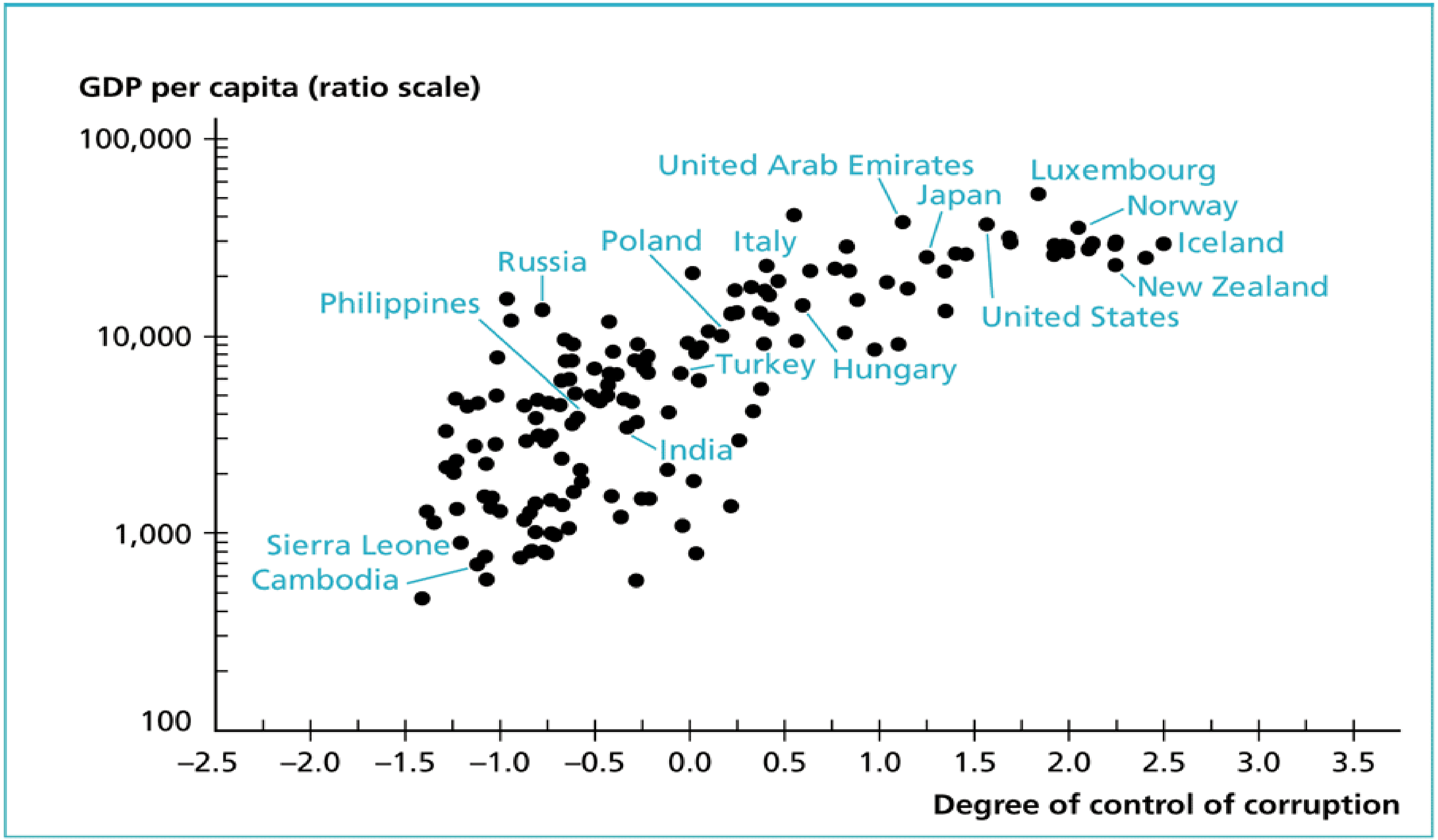
2. governments may do things that are in their own self-interest

- misuse of a position of political power for personal gain – in short, corruption
  - corruption can:
    - raise costs of production essentially like a tax
    - reduce resources that are allocated to some desired social purpose
- rulers may not want to have rapid change or foreign influence for fear that these would unsettle the people and lead to their demise

- **Why do poor countries tend to have bad governments?**

- There is a close connection between government corruption and poor economic outcomes

Figure 12.5 Government Corruption Versus GDP per Capita, 2005



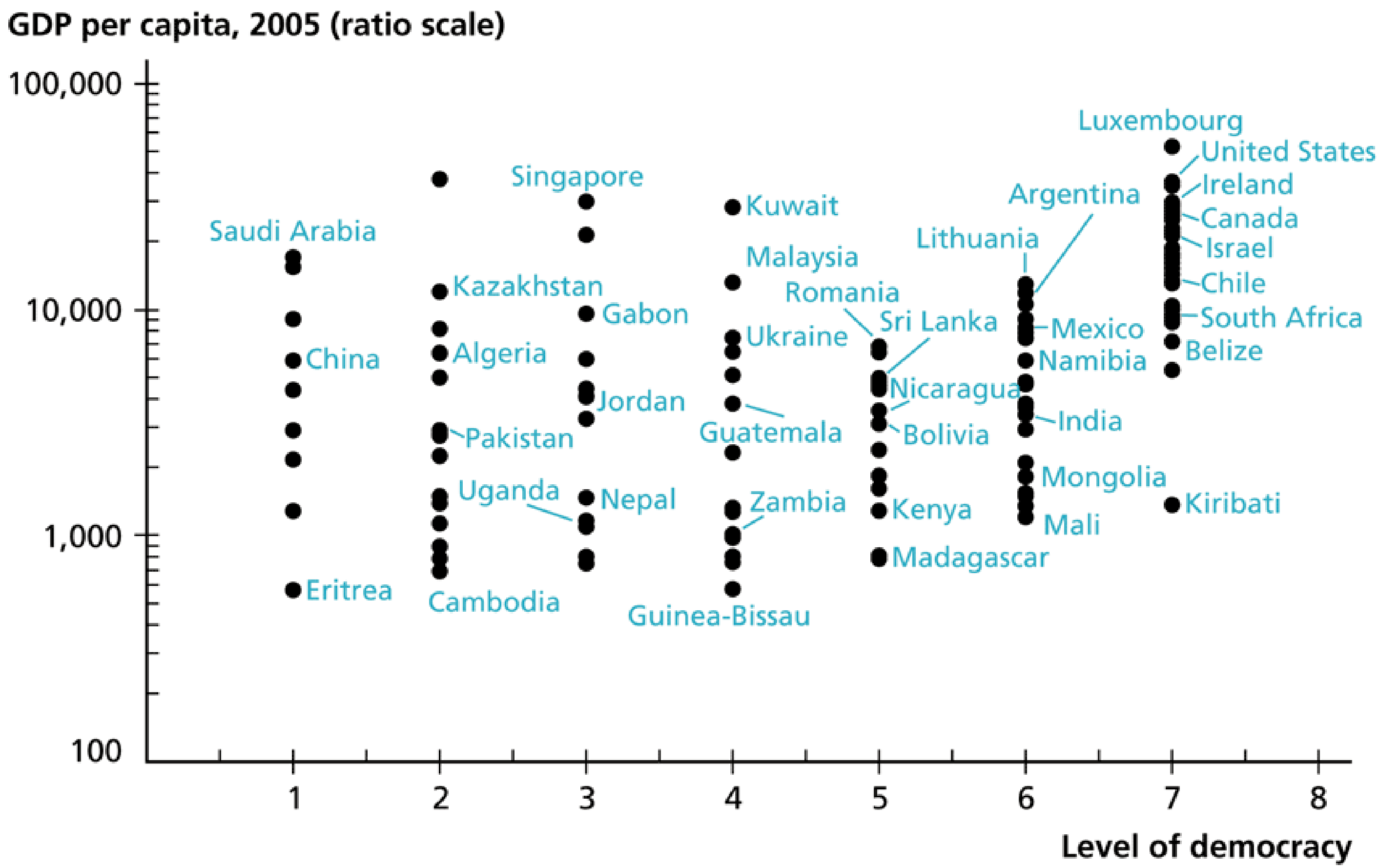
Source: Kaufmann, Kray, and Mastruzzi (2007).

- Could be another case of simultaneity
  - the income level affects government quality
    - there is evidence that rising income levels can cause governments to improve
      - wealthier countries can pay government workers a higher salary
      - when a country doesn’t grow that means that the only way one person’s income rises is for another person’s income to fall. When the economy is growing everyone can have their income rise at the same time
  - government quality can affect income level
    - government promotion of its own interest can reduce the performance of an economy
      - there are many examples of corrupt regimes in the poorer countries

- Many former colonies of European countries have both bad governments and bad economic performance
  - The extraction of resources that was done in these colonies required a strong central control.
  - When European’s left a new government administered matters with strong central control just like they learned from Britain and other colonial powers
- In contrast, the colonies established in places that later became the US, Canada, Australia and New Zealand established legal systems more like what British people lived under

- **Does democracy affect standard of living?**
  – American intuition says this effect must be positive
  – However, cross-country evidence finds no strong relationship between Democracy and standard of living

Figure 12.6 Democracy and GDP per Capita

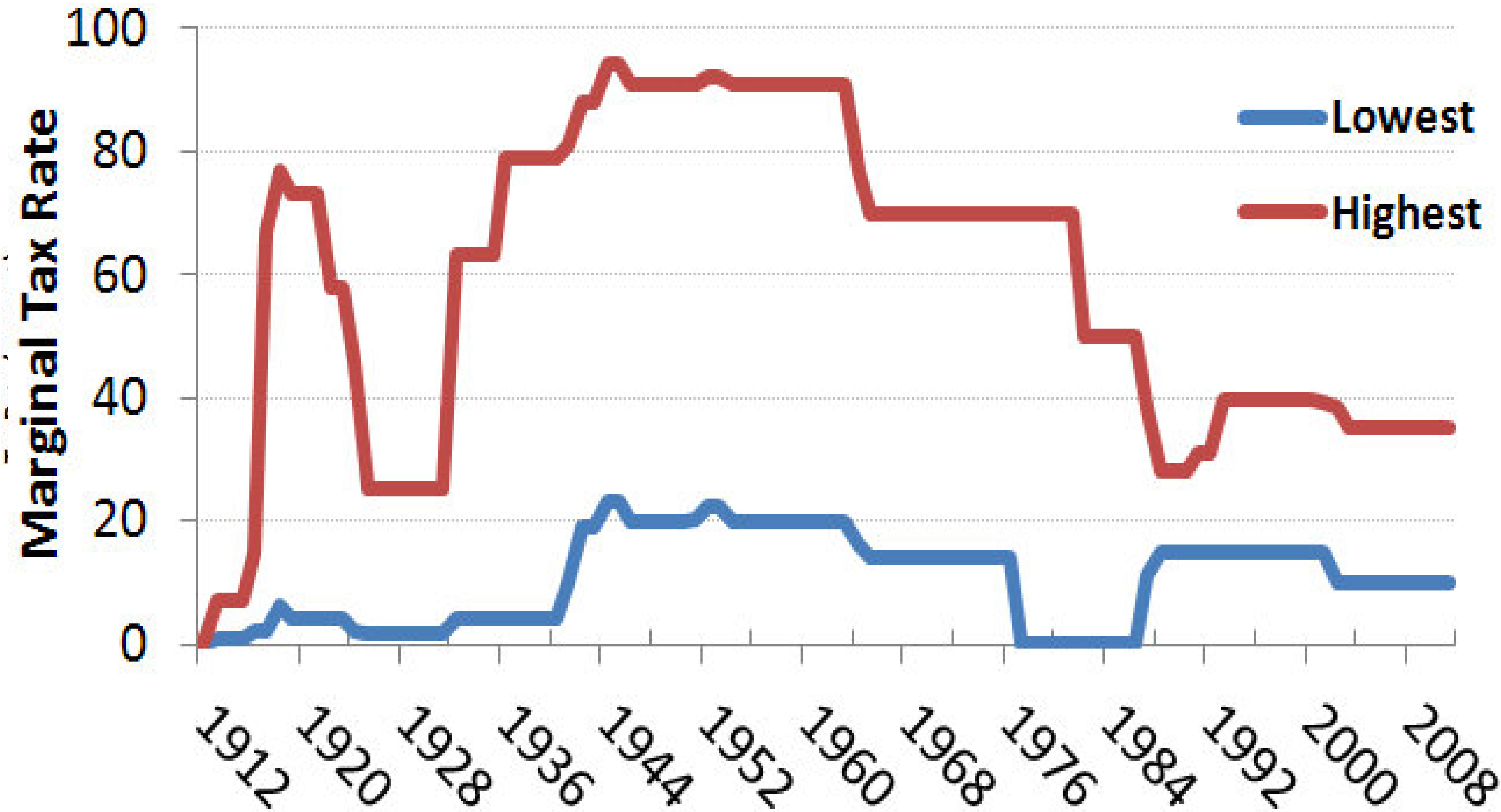


Source: Freedom House (2005).

How are Tax Rates and GDP Growth Related in the Data?

- There is evidence of a temporary increase in growth from a lowering of tax rates and a temporary lowering of economic growth when tax rates are raised.
- Highest marginal tax rate seems to have no effect on real growth in the long run for the US

Historical Marginal Tax Rates for Highest and Lowest Income Earners



Source: Tax Foundation

Stopped here for the Final Exam

For the Remaining Slides, All you need to know is:

- Shumpeterian Growth Models predict higher tax rates will lower the long run growth rate of real GDP per capita
- In data, tax rates are almost unrelated to long-run GDP per capita growth
- Greater Human Capital per person (h) increases long-run growth of real GDP per capita for a particular set of structural assumptions (interesting idea, but it has not yet been formally tested)

Outline of the last three things I'll discuss for the Final Exam

- Adding Human Capital to the Romer-Jones Growth Model
- How are Tax Rates and GDP Growth Related in the Data
- A Schumpeterian Growth Model

The Chapter 9 Growth Model

- This Model is a version of the Romer model, modified by Jones
- So lets call it the Romer-Jones Model
- The model begins with this production function for new ideas (where λ and Θ are each positive, but less than one):

$$\hat{A} = \frac{L_A^{\lambda} A^{-\theta}}{\mu}$$

- we showed before (take logs and then the time derivative) how this equation means that if A has a steady state growth rate, then it must equal:

$$\hat{A} = \frac{\lambda \hat{L} - \hat{\mu}}{\theta}$$

- For growth in A to be positive at least one of the following must occur:
  - $\hat{L}$ must be positive, OR
  - $\hat{\mu}$ must be negative

- But Population growth ($\hat{L}$) is expected to reach roughly zero in about 50 years
- And we can not expect the Cost of Innovating (μ) to continually shrink
- Thus this model has an unpleasant prediction: Productivity growth will eventually stop!
  – Incomes will stop growing, wealth will stop increasing and political unrest will become wide-spread as people demand a return to the good old days when productivity was growing

Can we modify the model so it no longer has this dire prediction?

- The model ignores potentially important factors in the idea creation process
- Physical capital is certainly used in idea creation (as it does in output production)
- For example, write the idea production function as:

$$\hat{A} = \frac{L_A^{\lambda} K_A^{\rho} A^{-\theta}}{\mu}$$

- Under this assumption the same implication holds - productivity growth will stop eventually unless population growth is positive or the cost of innovating is shrinking
  – Using the fact that K/AL reaches a steady state in the long-run - which it generally will – allows us to transform the equation to show this (THIS IS NOT REQUIRED OF YOU)

Human Capital

- Suppose human capital per person (h) multiplies labor in the idea production function:

$$\hat{A} = \frac{(hL_A)^{\lambda} A^{-\theta}}{\mu}$$

- Thus h is entering this idea creation function multiplicatively

- In this case, if h settles down to a steady state in the long-run – like it appears to have done for the US recently - then h has no long-run effect on growth of A.
- We could show that without growth in h this this model obtains the same unpleasant prediction – no productivity growth without growth in population or continual shrinkage in the cost of innovating

A different assumption for h

- Suppose human capital affects the elasticity of idea growth with respect to the stock of ideas
- More human capital increases the rate at which new ideas are formed from a given set of ideas
  - Similarly, less human capital reduces the rate at which new ideas are derived from an existing body of knowledge

- One way to write this new specification is as follows

$$\hat{A} = \frac{L_A^{\lambda} A^{-\theta+\beta\left(h/\hat{A}\right)}}{\mu}$$

- The exponent on A as a function of $h/\hat{A}$ not simply h. Why do we divide h by $\hat{A}$?
  - This means the more rapidly technology advances, a given level of human capital will produce a smaller number of new ideas

- Intuitively, as the technological frontier progresses at a faster rate, workers must have a greater amount of human capital to maintain a given rate of productivity growth
    - To sustain a higher rate of technological advance, more experience and more education are required

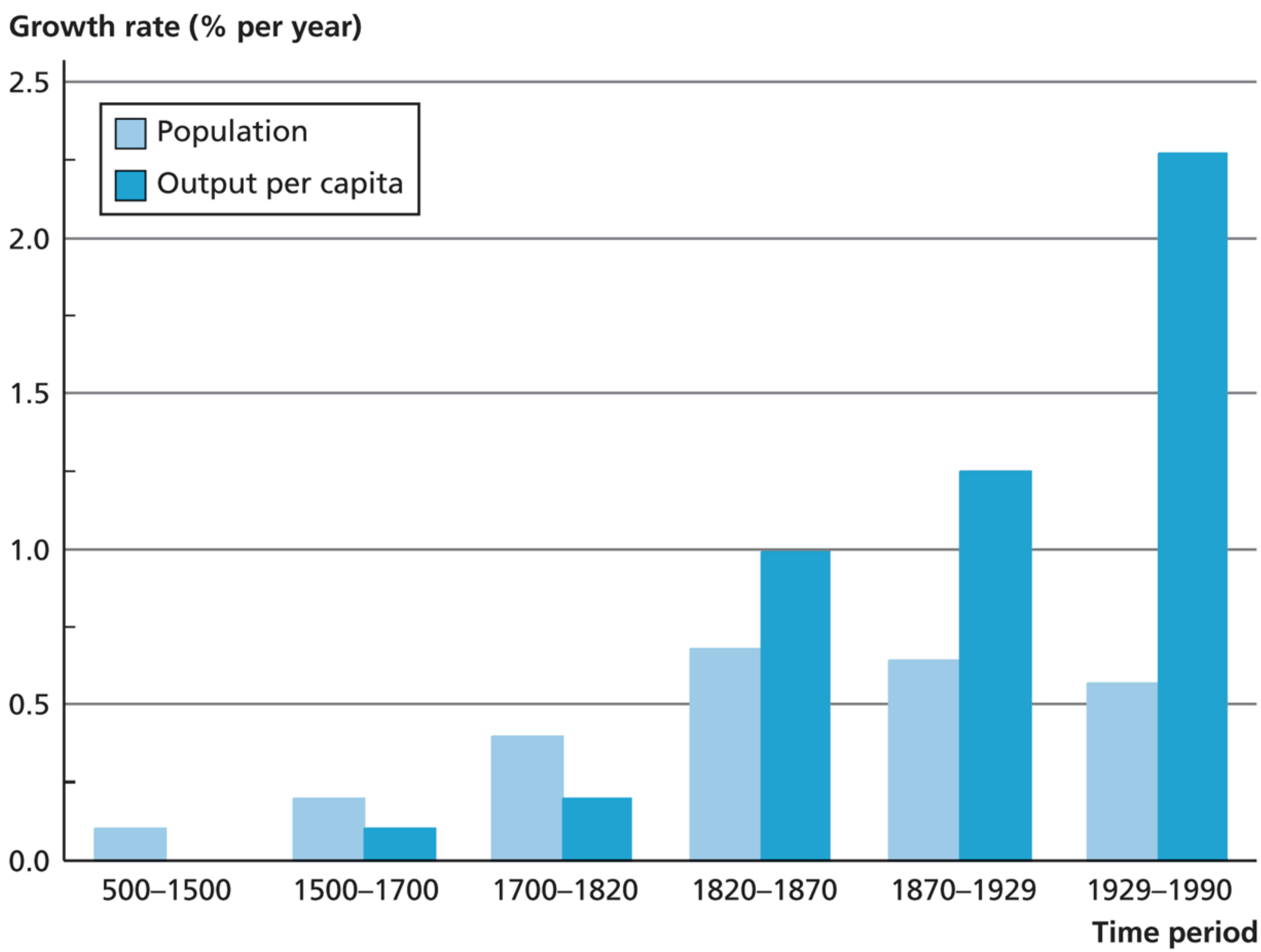
- So (taking the logarithm of last equation, assuming economy is in the steady state, and then taking the derivative with respect to time) one can show that in the steady state:

$$\hat{A} = \frac{\lambda \hat{L} + \beta h - \hat{\mu}}{\theta}$$

- This equation has many of the same implications. Faster productivity growth arises from either of the following:
  – Higher Population Growth
  – A Falling Cost of Innovating
- But now when these two factors go to zero, productivity growth still occurs because of the human capital we've accumulated
- This model holds out hope for a brighter future where strong productivity growth may be maintained by a high level of h

- This model also has the ability to capture an empirical effect found in some economies
- Sometimes productivity growth actually rises at a faster rate (or at least does not shrink) when population growth falls
  - See the following slide, Fig 4.6 from Weil, for data on Western Europe
- Romer-Jones models are inconsistent with this prediction

FIGURE 4.6
Breakdown of the Malthusian Model in Western Europe



Source: Galor and Weil (2000).

- Why would population growth and GDP per capita growth move in opposite directions in this new model.
  - Suppose when people have smaller families they put more resources (time, wealth, etc.) into providing opportunities for their children to develop human capital
  - Smaller families mean a slower rate of population growth which our model says will lower the growth rate of productivity.
  - But more human capital raises the growth rate of productivity in this model.
  - If this rise in productivity growth from human capital exceeds the reduction caused by falling population growth, productivity will grow faster

Schumpeterian Growth Models

- Joseph Schumpeter emphasized creative destruction in his theoretical work.
- This is also a key element in newer growth models called Schumpeterian growth models
  - While interesting, these creative destruction models are somewhat intricate, and it will be unnecessary for us to fully describe them
- However, a key feature in these models is the assumption that expenditures on research and development are an essential element to the creation of new ideas

A Simple Schumpeterian Model of Economic Growth

- Idea Creation Function
  - Depends on the amount of Spending on Research and Development

$$\Delta A = \sigma(R\,\&\,D\ Spending)$$

- Where σ is a parameter that indicates how productive R&D spending is
- Now, assuming
  - $\phi_{R\&D}$ is the income share going to R&D and
  - R&D spending is measured as spending per worker

$$(R\,\&\,D\ Spending) = \phi_{R\&D}\left(\frac{Y}{L}\right)$$

- Plugging the last equation into the first one and dividing by A yields

$$\hat{A} = \frac{\Delta A}{A} = \sigma \phi_{r\&d} \left(\frac{Y}{AL} \right)$$

  - Which tells us the growth rate of productivity (growth of new ideas)

- Now let the production function be:

$$Y = K^{\alpha} (ALh)^{1-\alpha}$$

  - Divide this by AL:

$$\frac{Y}{AL} = \left(\frac{K}{AL} \right)^{\alpha} h^{1-\alpha}$$

– Now define: $\tilde{k} = \left(\frac{K}{AL} \right)$

– And insert the last equation from the last page into first equation from last page to obtain what we will call the SHUMP Curve:

$$\hat{A} = \sigma \phi_{r\&d} \tilde{k}^{\alpha} h^{1-\alpha}$$

– Next we will use the Solow model to derive another equation in terms of

$\tilde{k}$ and $\hat{A}$

- From the Solow Model we have:
  - the capital accumulation equation

$$\Delta K = I - \delta K$$

  - Savings Function: $S = \gamma Y$
  - And the national income accounting identity for a closed economy $S = I$
  - We know from earlier analysis we can derive from this set of equations:

$$\hat{K} = \frac{\Delta K}{K} = \gamma \left(\frac{Y}{K} \right) - \delta$$

- Recall the production function:

$$Y = K^{\alpha}(ALh)^{1-\alpha}$$

– And inserting this equation into the capital growth equation from the last slide yields:

$$\hat{K} = \gamma\left(\frac{K^{\alpha}(ALh)^{1-\alpha}}{K}\right) - \delta$$

– Then notice that:

$$\left(\frac{K^{\alpha}(ALh)^{1-\alpha}}{K}\right) = K^{\alpha-1}(ALh)^{1-\alpha} = \left(\frac{K}{AL}\right)^{\alpha-1} h^{1-\alpha}$$

- Thus we obtain::

$$\hat{K} = \gamma \left(\frac{K}{AL} \right)^{\alpha-1} h^{1-\alpha} - \delta$$

  – Or:

$$\hat{K} = \gamma \tilde{k}^{\alpha-1} h^{1-\alpha} - \delta$$

- Now recall the definition:

$$\tilde{k} = \left(\frac{K}{AL} \right)$$

  - A more advanced treatment of the Solow model would show that $\tilde{k}$ settles down to a steady state level. And in this model we will find $\tilde{k}$ reaches a steady state.
    - From our growth rate rules, a steady state for $\tilde{k}$ means that:

$$\hat{K} = \hat{A} + \hat{L}$$

i.e. that growth rate of capital equals growth rate of productivity plus growth rate of labor

- Taking the last result and plugging it into the last equation from two slides back - which is given by:

$$\hat{K} = \gamma \tilde{k}^{\alpha-1} h^{1-\alpha} - \delta$$

  - And then we obtain the SOLOW Curve:

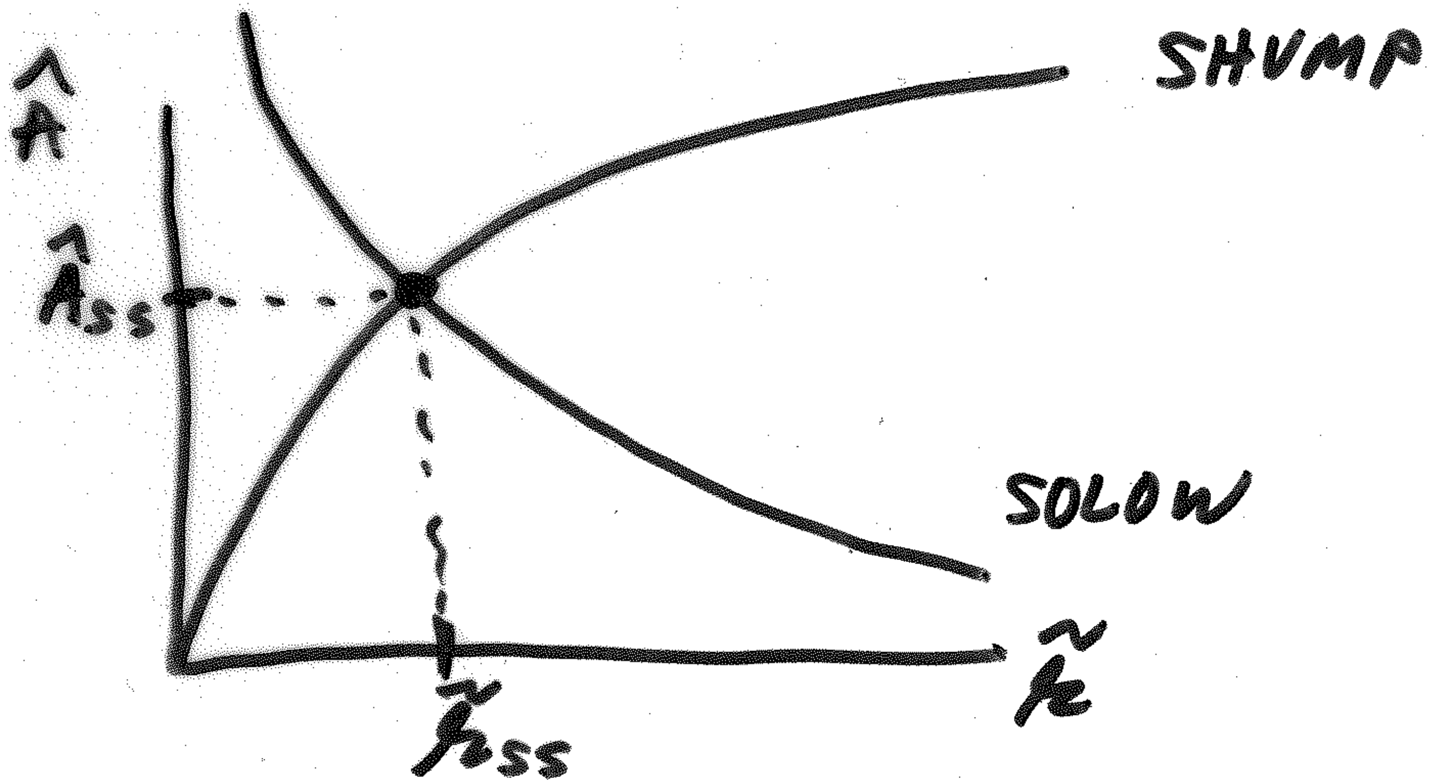
$$\hat{A} = \gamma \tilde{k}^{\alpha-1} h^{1-\alpha} - \delta - \hat{L}$$

  - Now we can graphically combine this curve with the SHUMP Curve:

$$\hat{A} = \sigma \phi_{R\&D} \tilde{k}^{\alpha} h^{1-\alpha}$$

RECALL: $\cancel{\hat{A} = \sigma \cdot \Phi_{R+D} \cdot}$

$\hat{A} = \sigma \cdot \Phi_{R+D} \cdot \tilde{k}^{\alpha} h^{1-\alpha}$ SHUMP



RESULTS:

$\uparrow \sigma, \uparrow \phi_{RVD} \rightarrow \uparrow \hat{A}_{SS}$ [SHIFTING SHUMP UP]

$\uparrow \gamma, \downarrow \delta, \downarrow \hat{L} \rightarrow \uparrow \hat{A}_{SS}$ {SHIFTING SOLOW UP}

$\uparrow h \rightarrow \uparrow \hat{A}_{SS}$ {SHIFTING BOTH UP}

- Problematic predictions from this model
  - We DON'T observe strong evidence that higher investment rate (γ) leads to faster long-run productivity growth ($\hat{A}$)
  - We DON'T observe evidence that higher population growth ($\hat{L}$) is associated with lower long-run productivity growth ($\hat{A}$)
  - We DON'T observe that a higher share of spending in R&D ($\phi_{R\&D}$) is associated with faster productivity growth ($\hat{A}$) across countries

- Another common prediction from Schumpeterian models is that lower tax rates will have a positive effect on the long-run growth rate of the economy.
  - For example, we could have higher taxes on personal savings (or income) that reduce γ (GAMMA), or fiscal policies that stimulate R&D spending (raise $\phi_{R\&D}$)
- The data do not support these findings. Evidence suggests tax rates have no effect on the long-run growth of an economy, or at most a very small effect

A very brief conclusion to the course

- Growth remains an exciting field of study - if we can grow faster the welfare of people will improve more rapidly
- Economists still need to develop better models of growth.
  - My view is some form of a Romer-Jones type model holds out the most promise.
  - But unexpected innovations will sometimes revise one's perspective.

SHUMPETERIAN GROWTH MODEL

IDEA CREATION FUNCTION

$$\Delta A = \sigma \cdot [\text{R+D SPENDING}]$$

IDEA PROD. PARAM.

$$\text{R+D SPENDING} = \phi_{R+D} \cdot \left(\frac{Y}{L}\right)$$

$$\Delta A = \sigma \cdot \phi_{R+D} \cdot \left(\frac{Y}{L}\right)$$

$$\hat{A} = \frac{\Delta A}{A} = \sigma \cdot \phi_{R+D} \cdot \left(\frac{Y}{AL}\right)$$

$$Y = K^{\alpha}(hLA)^{1-\alpha}$$

$$\frac{Y}{AL} = \frac{K^{\alpha}(hLA)^{1-\alpha}}{A^{\alpha+1-\alpha} \cdot L^{\alpha+1-\alpha}}$$

$$= \left(\frac{K}{AL}\right)^{\alpha} h^{1-\alpha} \quad , \quad \text{DEF} \quad \tilde{k} = \frac{K}{AL}$$

$$\hat{A} = \sigma \cdot \phi_{R+D} \cdot \tilde{k}^{\alpha} h^{1-\alpha}$$

~~SCHUMP~~ SHUMP.

SOLOW MODEL GIVES

$$\left\{\begin{aligned} S &= \gamma \cdot Y \\ \Delta K &= I - \delta \cdot K \\ S &= I \end{aligned}\right.$$

$$\Delta K = \gamma \cdot Y - \delta \cdot K$$

$$\hat{K} = \frac{\Delta K}{K} = \gamma \cdot \left(\frac{Y}{K}\right) - \delta$$

DATA SUGGEST $\hat{K}$ and $\left(\frac{Y}{K}\right)$

DO <u>NOT</u> GROW OVER TIME,

SO S.S. FOR THEM IS REASONABLE

$$\frac{Y}{K} = \frac{K^{\alpha}(hLA)^{1-\alpha}}{K^{\alpha+1-\alpha}} = \frac{h^{1-\alpha}}{\left(\frac{K}{AL}\right)^{1-\alpha}}$$

$$= \tilde{k}^{\alpha-1} h^{1-\alpha}$$

$$\therefore \quad \hat{K} = \gamma \cdot \tilde{k}^{\alpha-1} h^{1-\alpha} - \delta$$

IF $\tilde{k}$ IS IN S.S.)

$\tilde{k}$ = CONSTANT

$$\tilde{k} = \frac{K}{AL}$$

THEN $\hat{K} = \hat{A} + \hat{L}$

$\therefore \quad \hat{A} = \gamma \cdot \tilde{k}^{\alpha-1} h^{1-\alpha} - \delta - \hat{L}$ SOLOW

Chapter 13

INCOME INEQUALITY

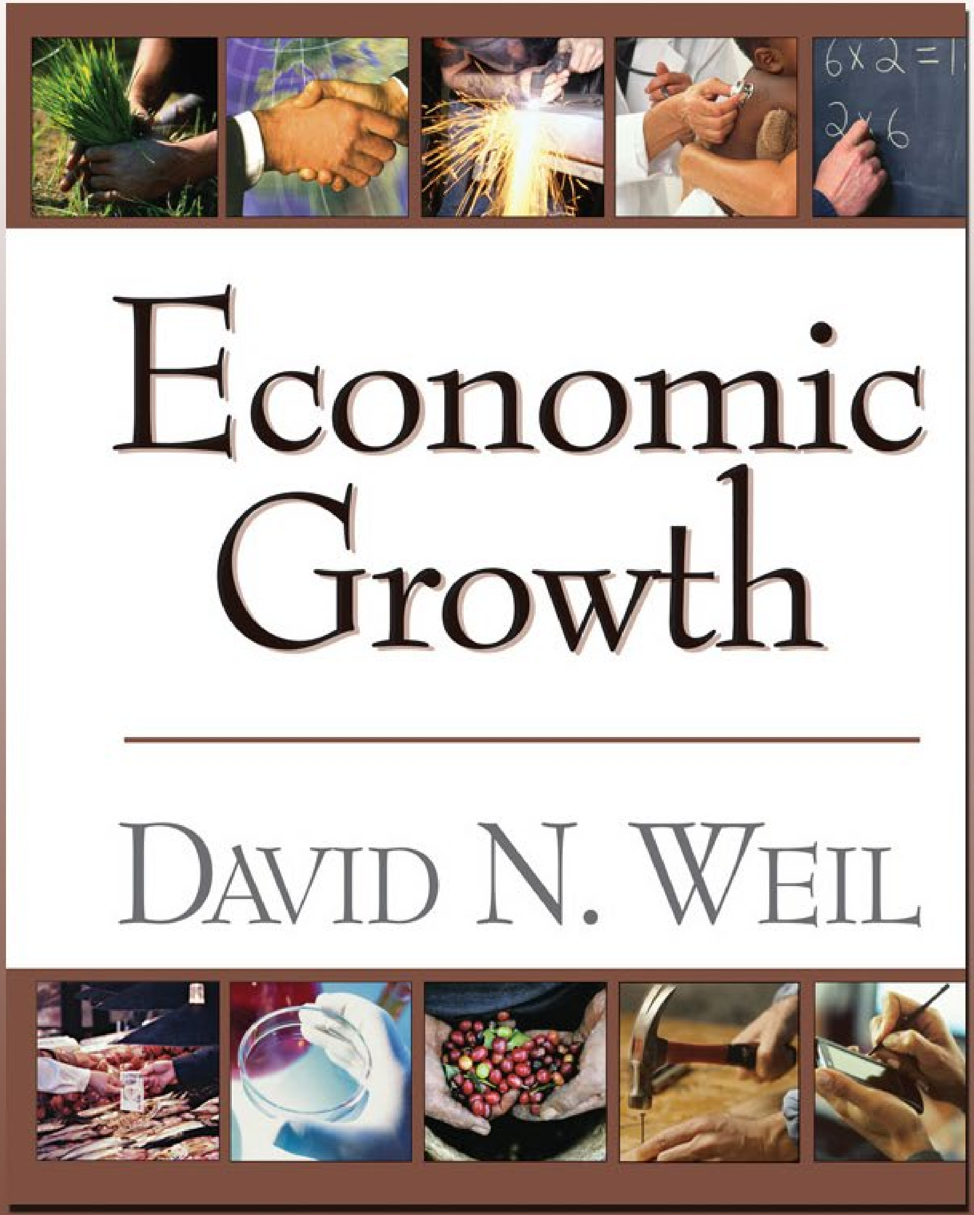
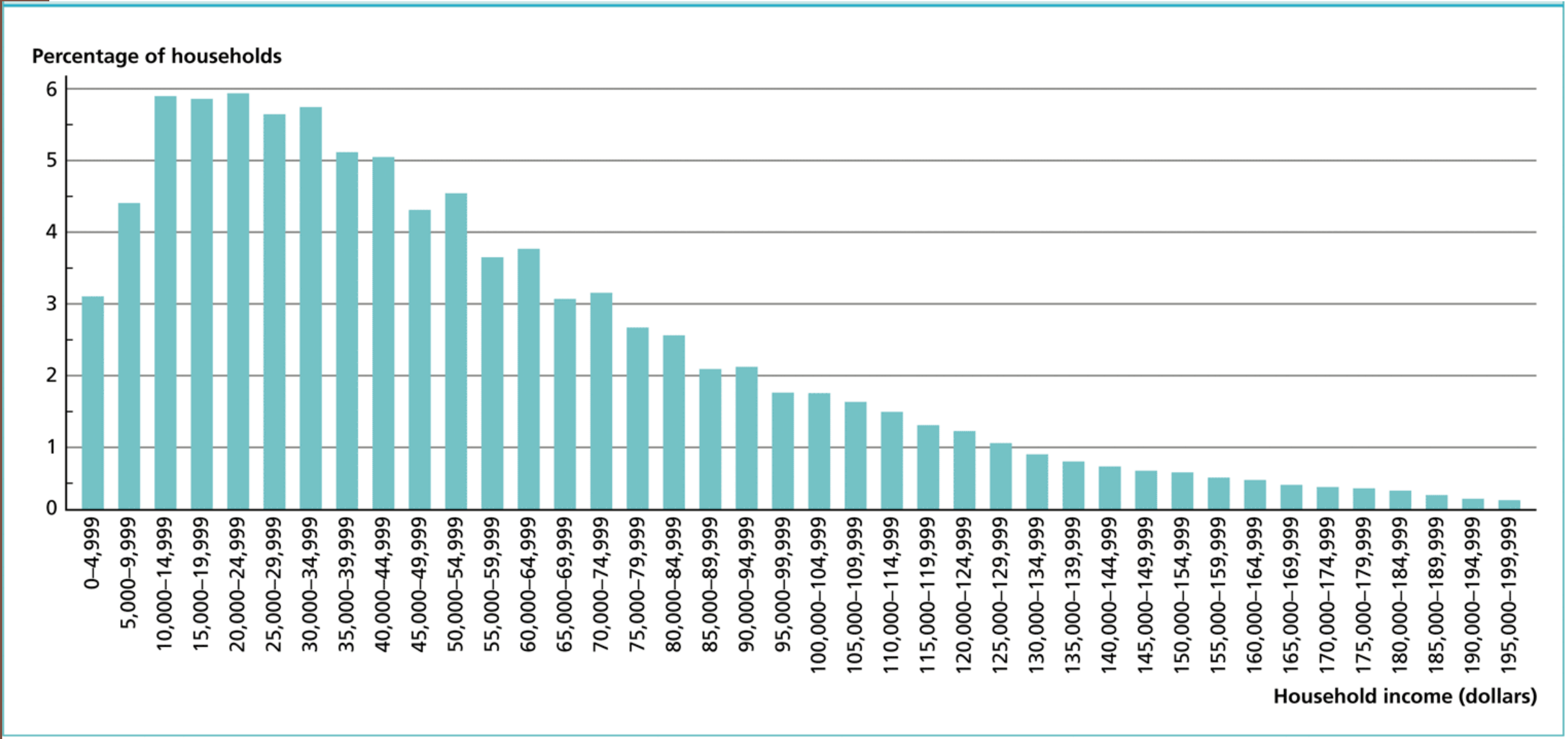


Table 13.1 Household Income in the United States by Quintiles, 2006

Quintile	Average Household Income	Share of Total Household Income (%)
1st (Lowest)	$11,352	3.4
2nd	$28,777	8.6
3rd	$48,229	14.5
4th	$76,929	22.9
5th (Highest)	$168,170	50.5

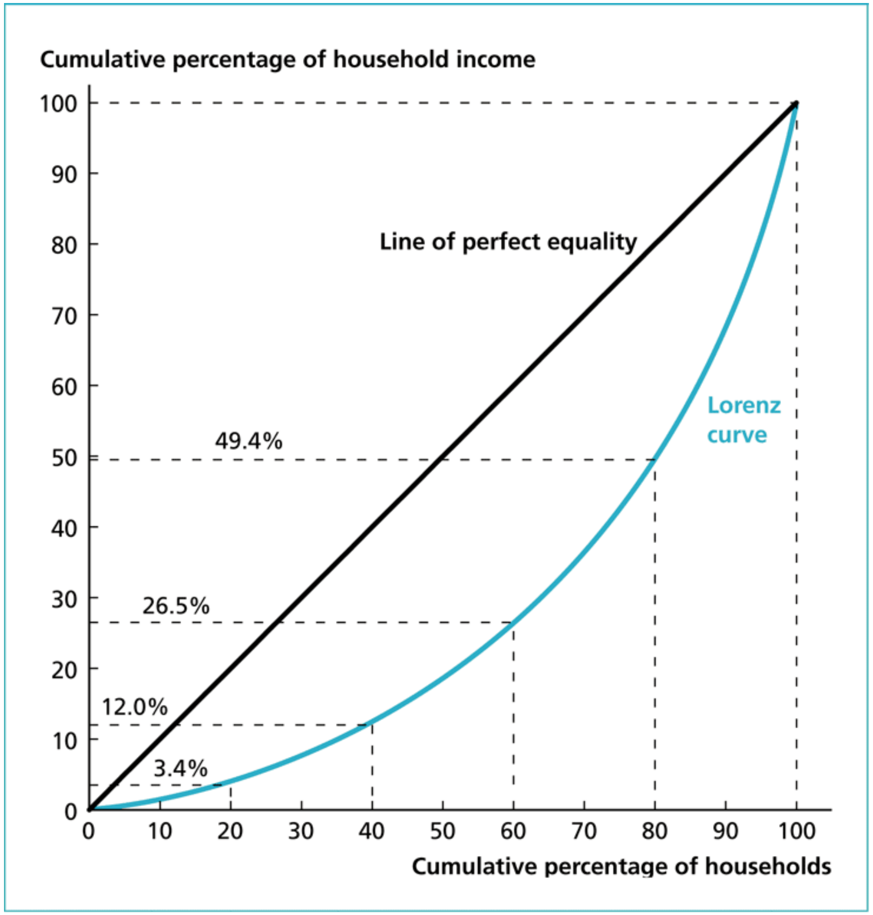
Source: DeNavas-Walt, Proctor, and Smith (2007).

Figure 13.1 Income Distribution in the United States, 2006



Source: DeNavas-Walt, Proctor, and Smith (2006).

Figure 13.2 The Lorenz Curve for the United States, 2006



Source: De Navas-Walt, Proctor, and Smith (2007).

Figure 13.3 The Kuznets Curve

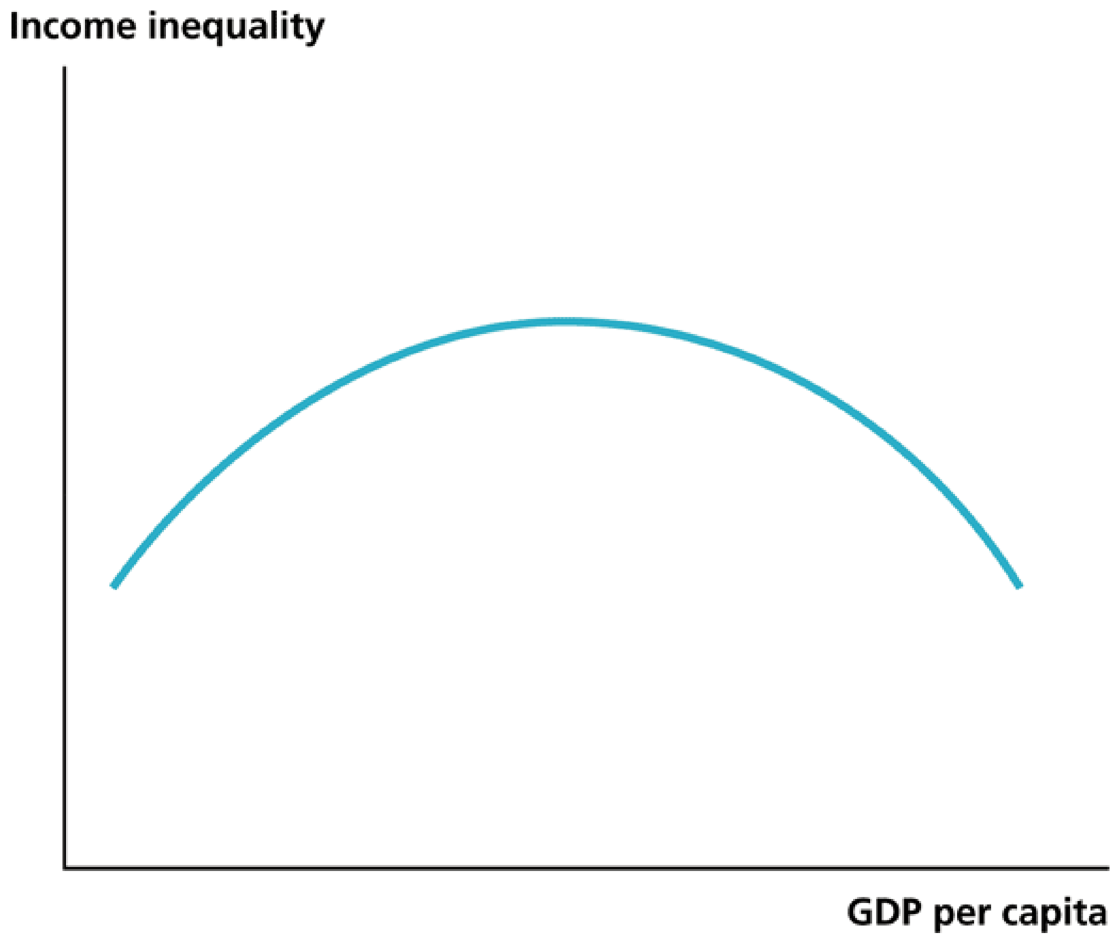
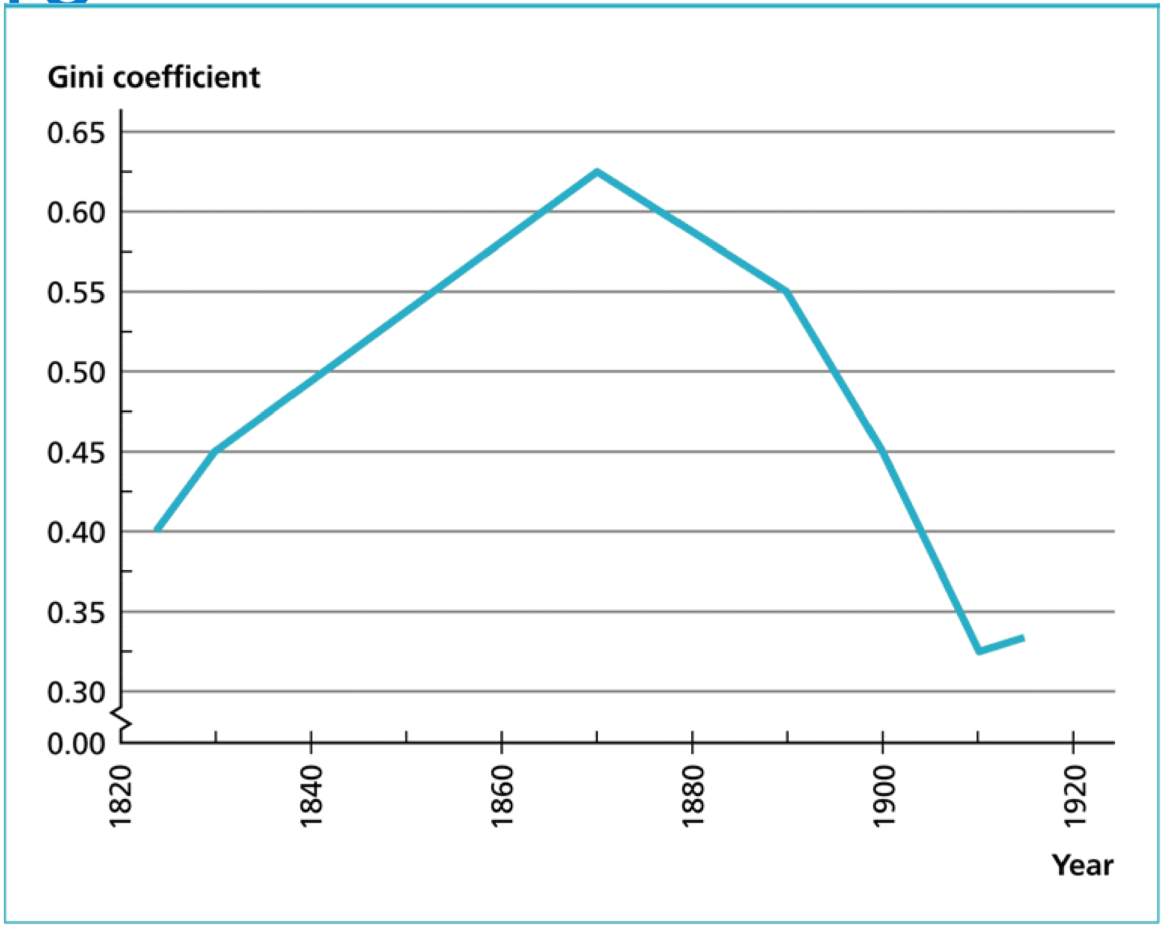
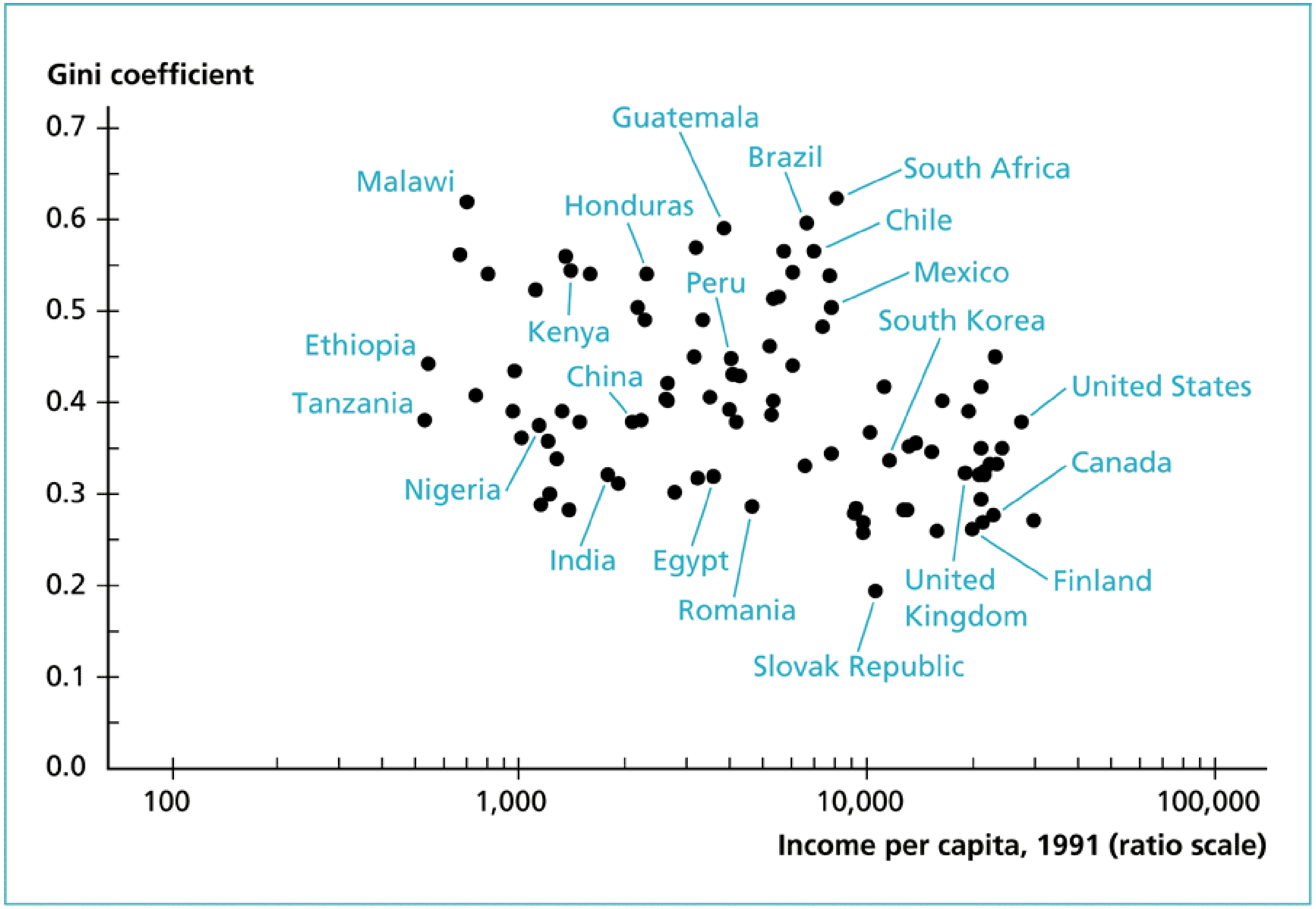


Figure 13.4 The Kuznets Curve in England and Wales, 1823–1915



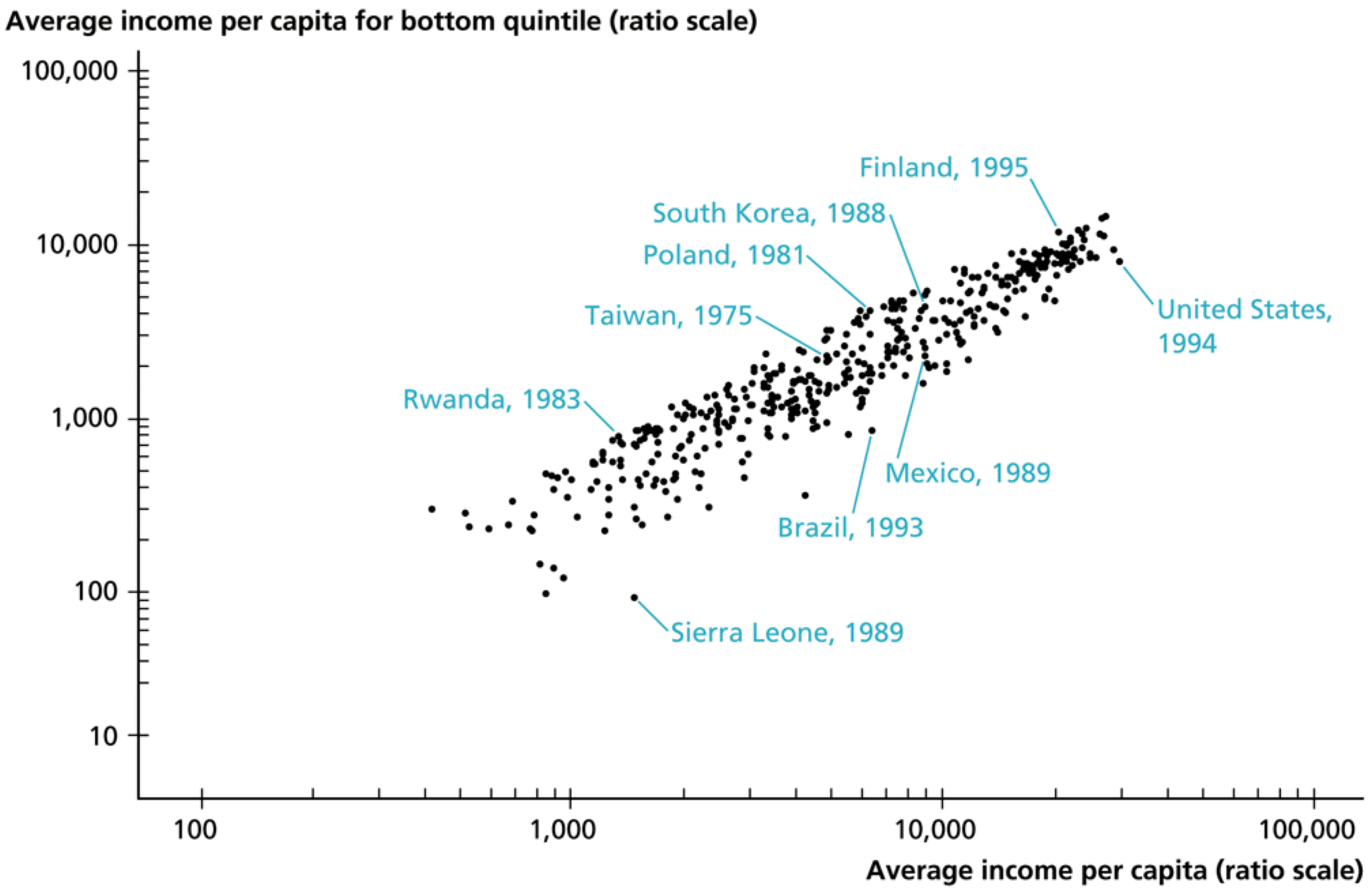
Source: Williamson (1985).

Figure 13.5 Income per Capita Versus Inequality



Source: Deininger and Squire (1996), Heston et al. (2002).

Figure 13.6 Income per Capita Versus Income of the Bottom Quintile



Source: Dollar and Kraay (2002).

Figure 13.7a Determination of Income Inequality

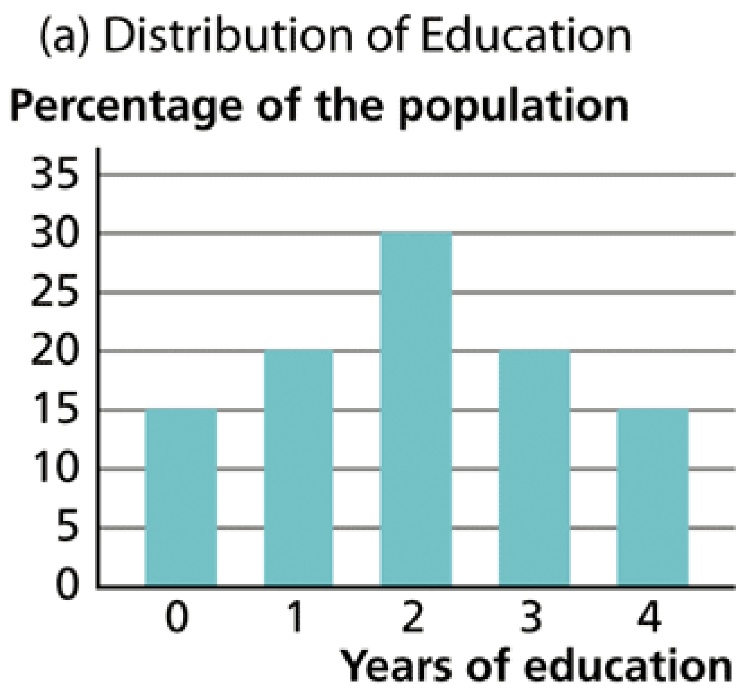


Figure 13.7b Determination of Income Inequality

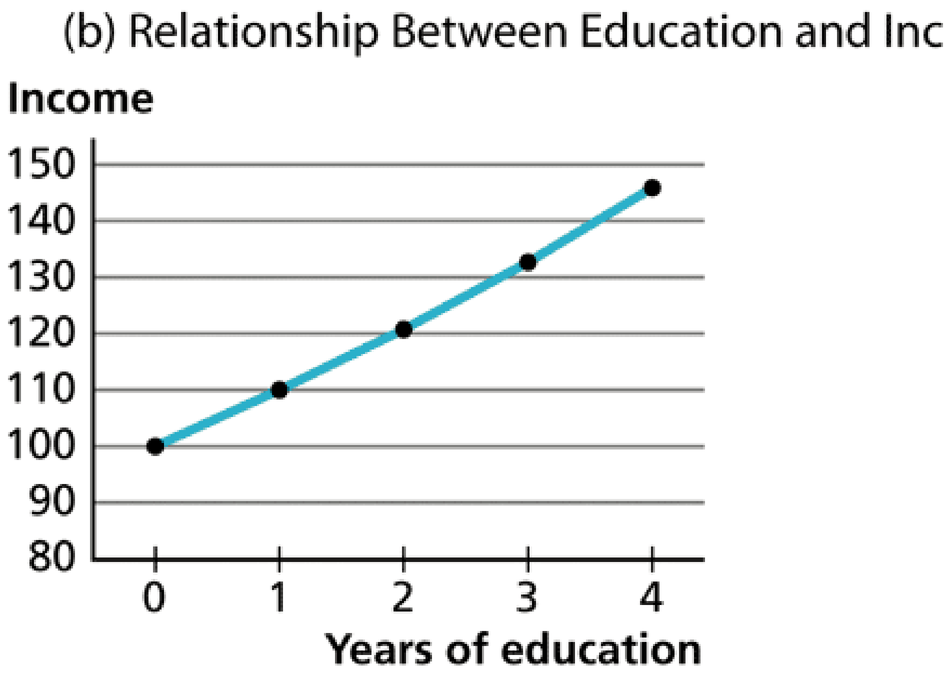


Figure 13.7c Determination of Income Inequality

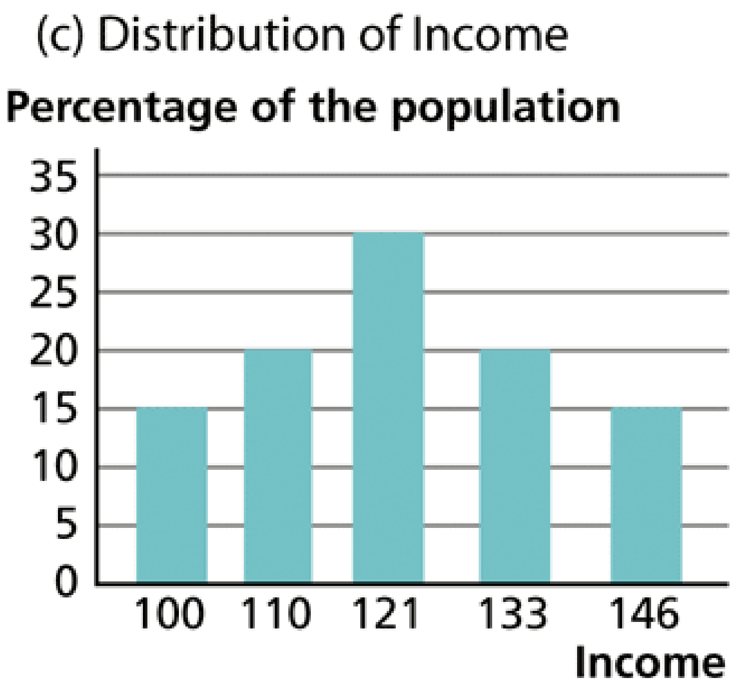


Figure 13.8a How the Return to Education Affects the Distribution of Income

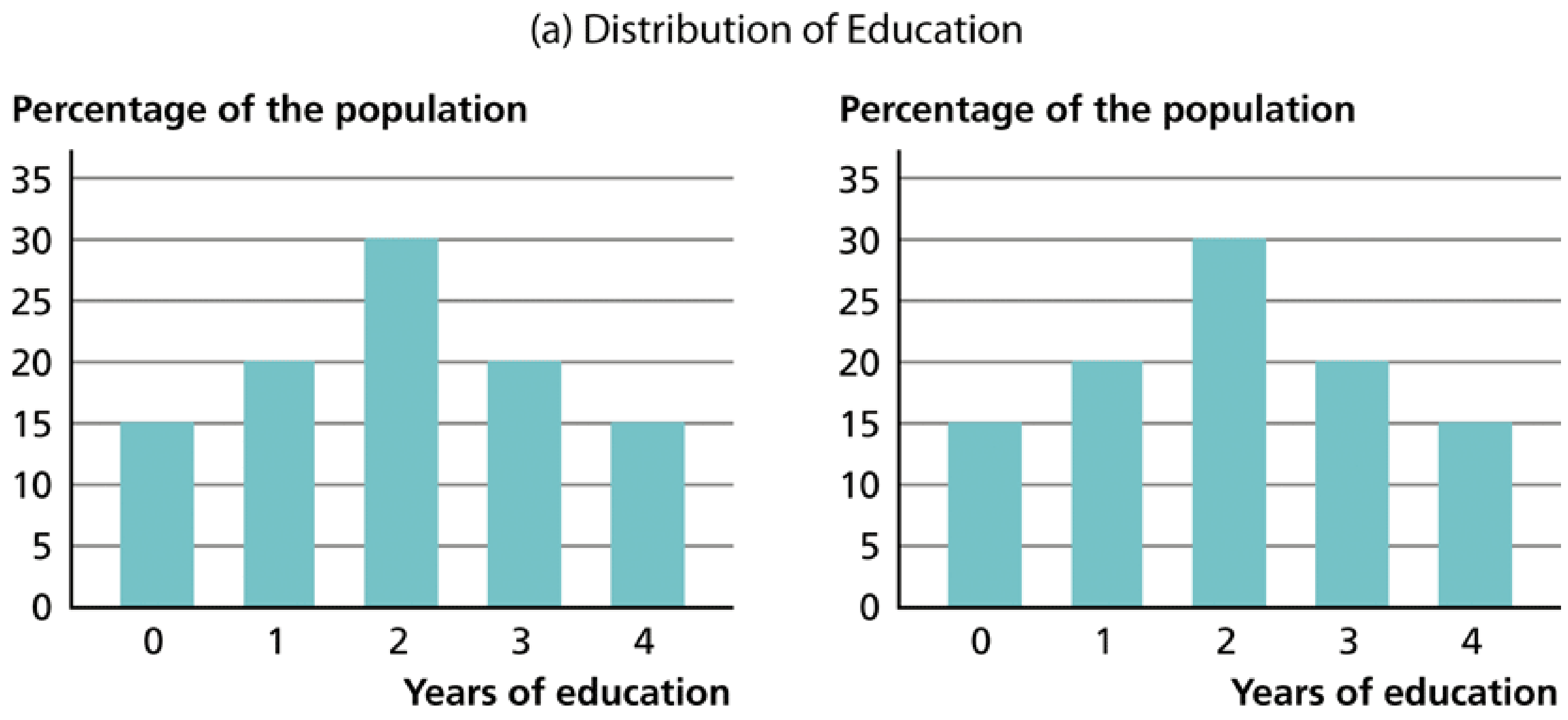


Figure 13.8b How the Return to Education Affects the Distribution of Income

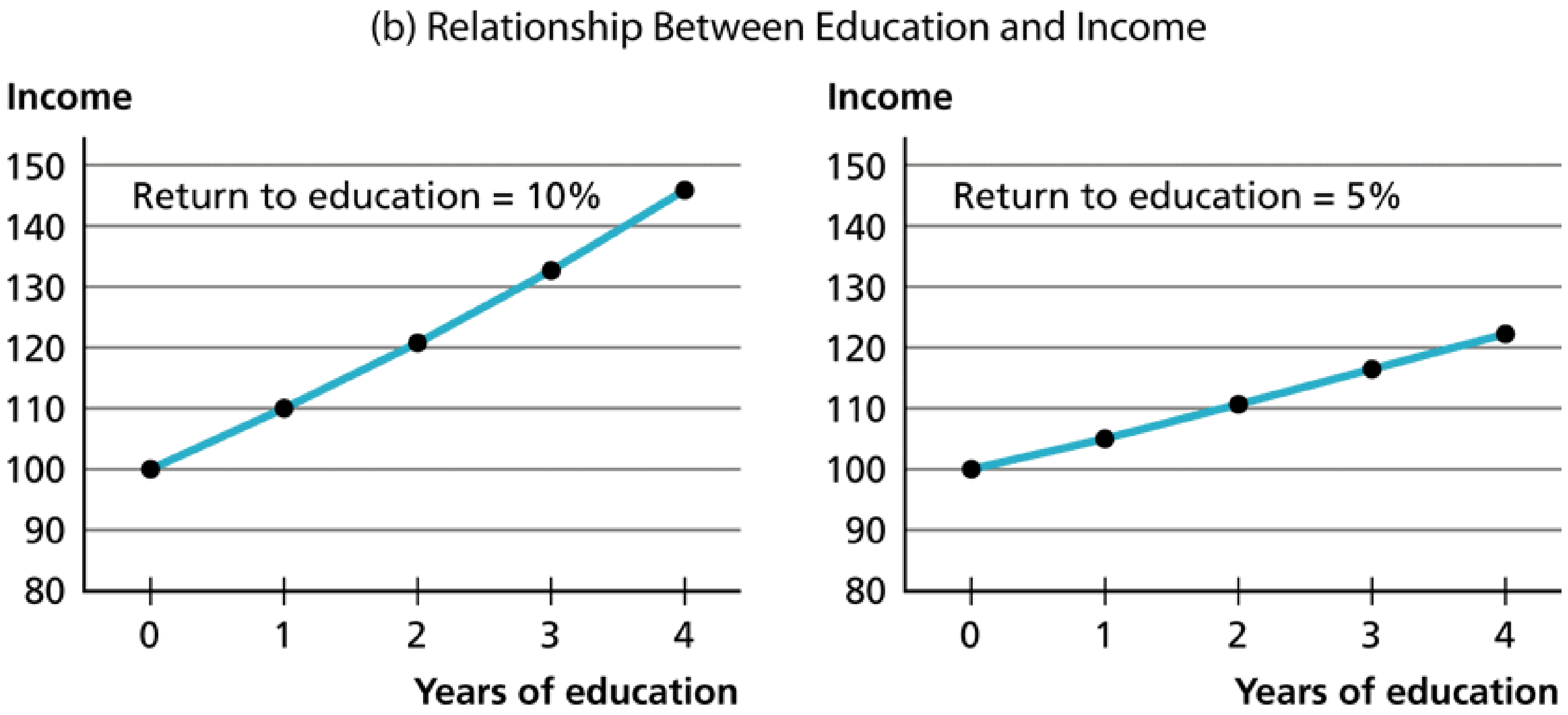


Figure 13.8c How the Return to Education Affects the Distribution of Income

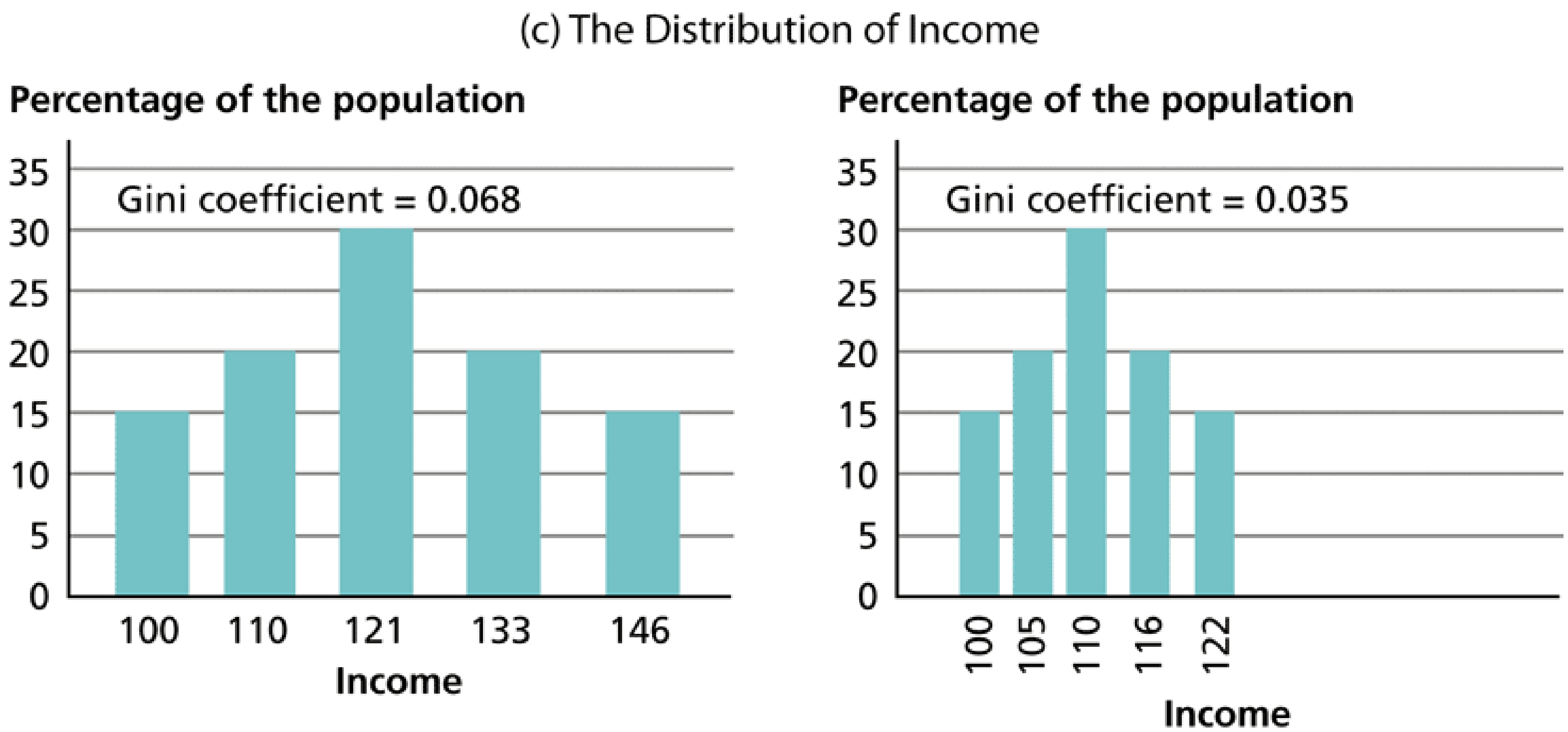


Figure 13.9a How the Distribution of Education Affects the Distribution of Income

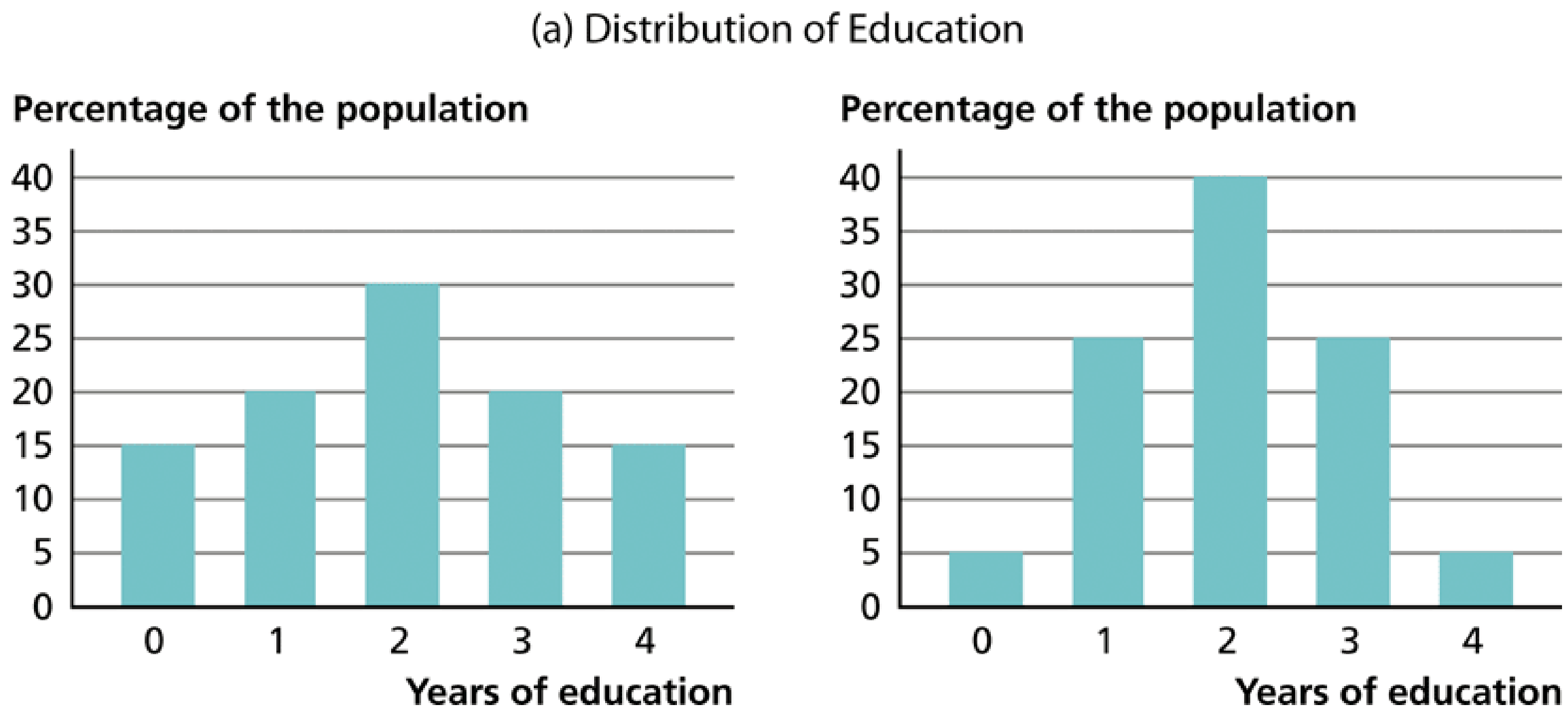


Figure 13.9b How the Distribution of Education Affects the Distribution of Income

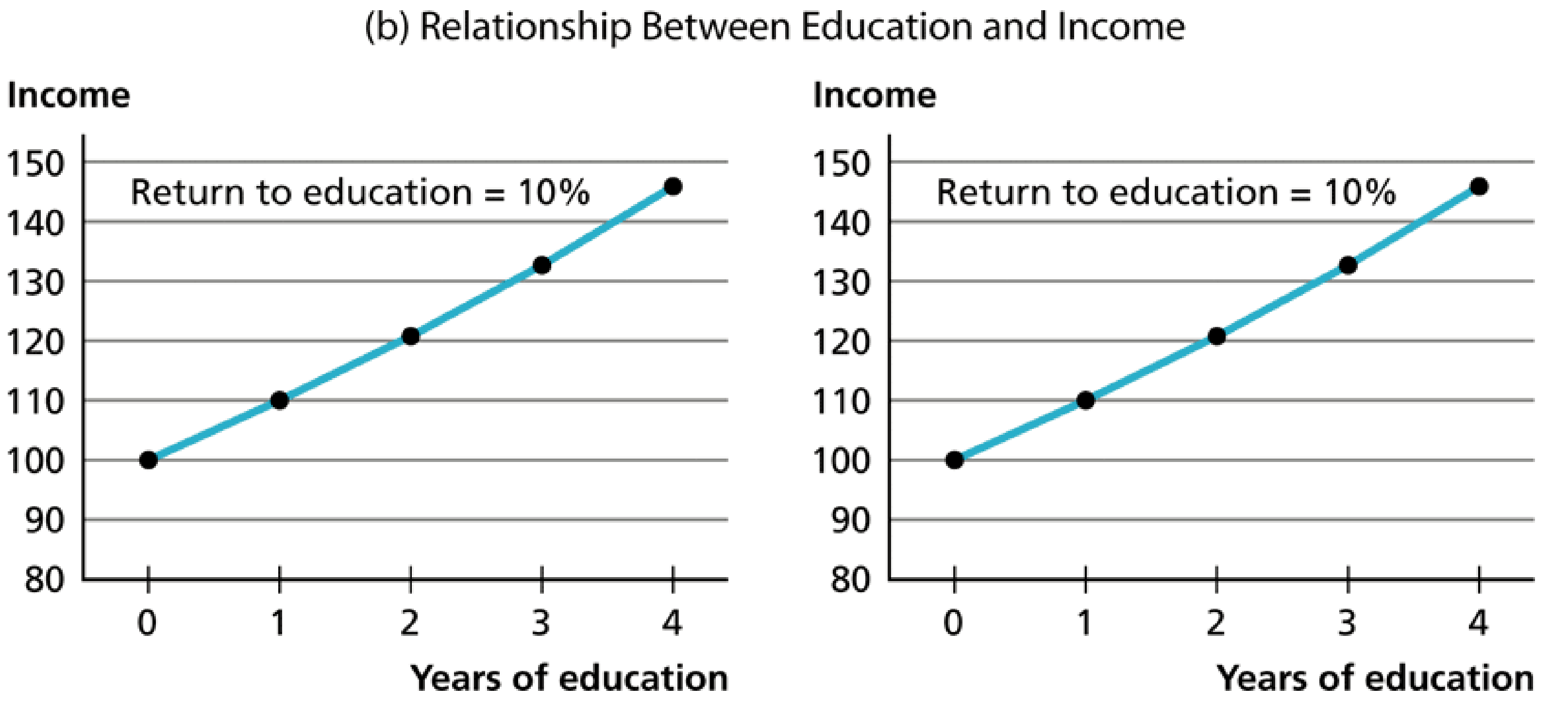


Figure 13.9c How the Distribution of Education Affects the Distribution of Income

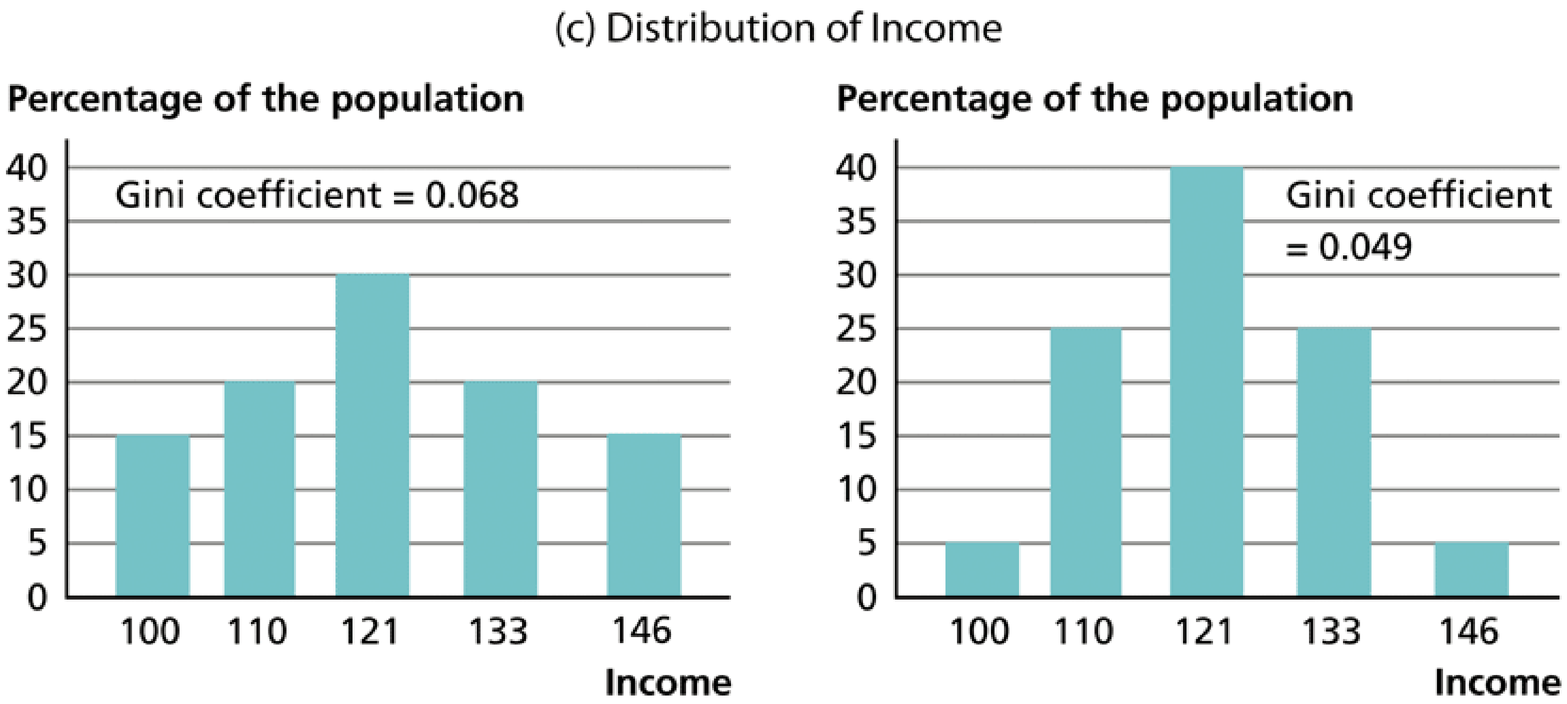
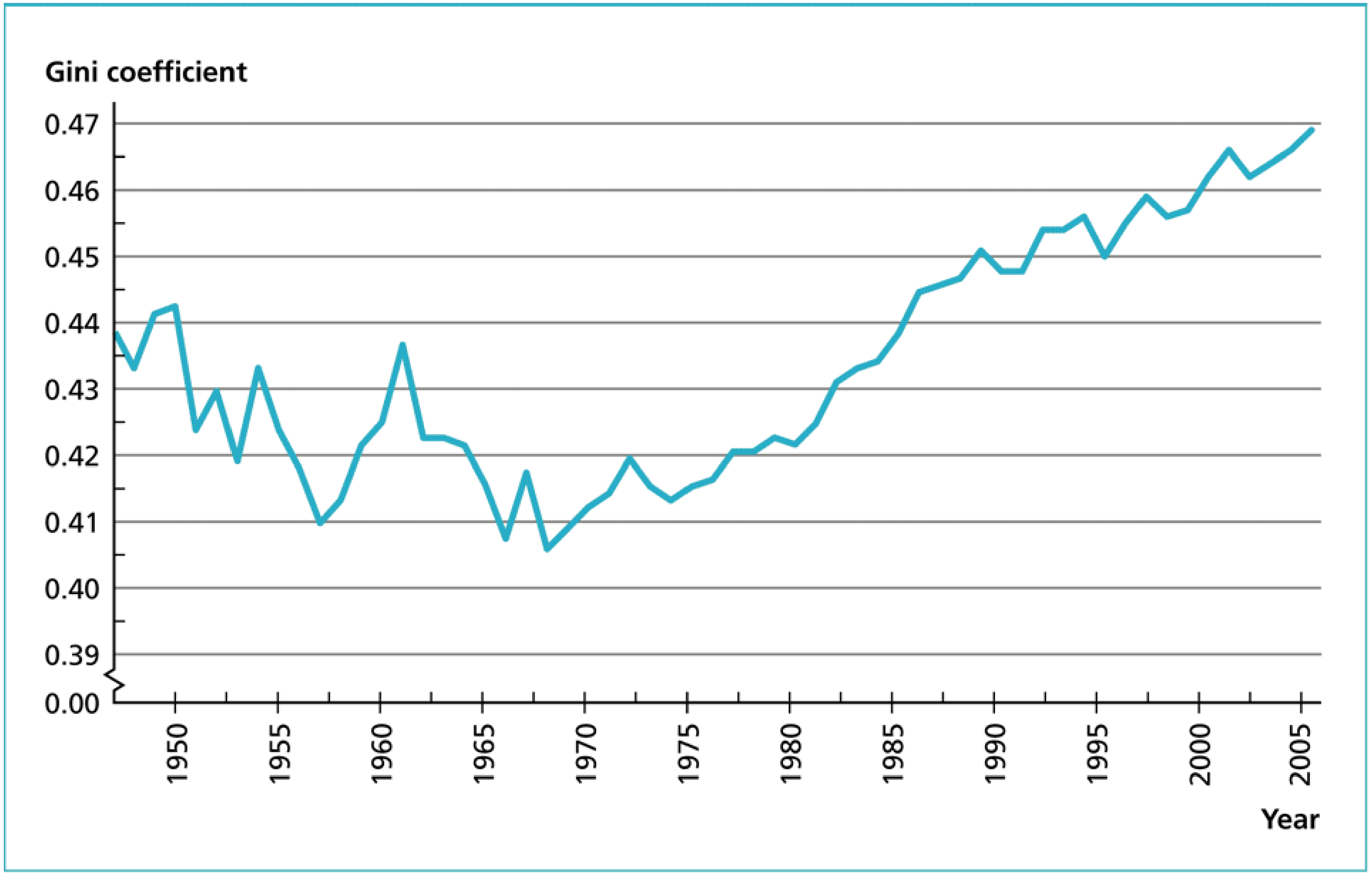


Figure 13.10 Income Inequality in the United States: 1947–2005



Sources: Weinberg (1996); Jones and Weinberg (2000); DeNavas-Walt, Proctor, and Smith (2007).

Table 13.2 Saving Rates by Income Quintile, 2003

Income Quintile	Median Saving Rate
1 (Lowest)	9.0%
2	13.5%
3	17.2%
4	19.2%
5 (Highest)	24.4%

Source: Dynan, Skinner, and Zeldes (2004), Table 3. Data are for households with heads aged 30–59.

Figure 13.11 Marginal Products of Physical and Human Capital

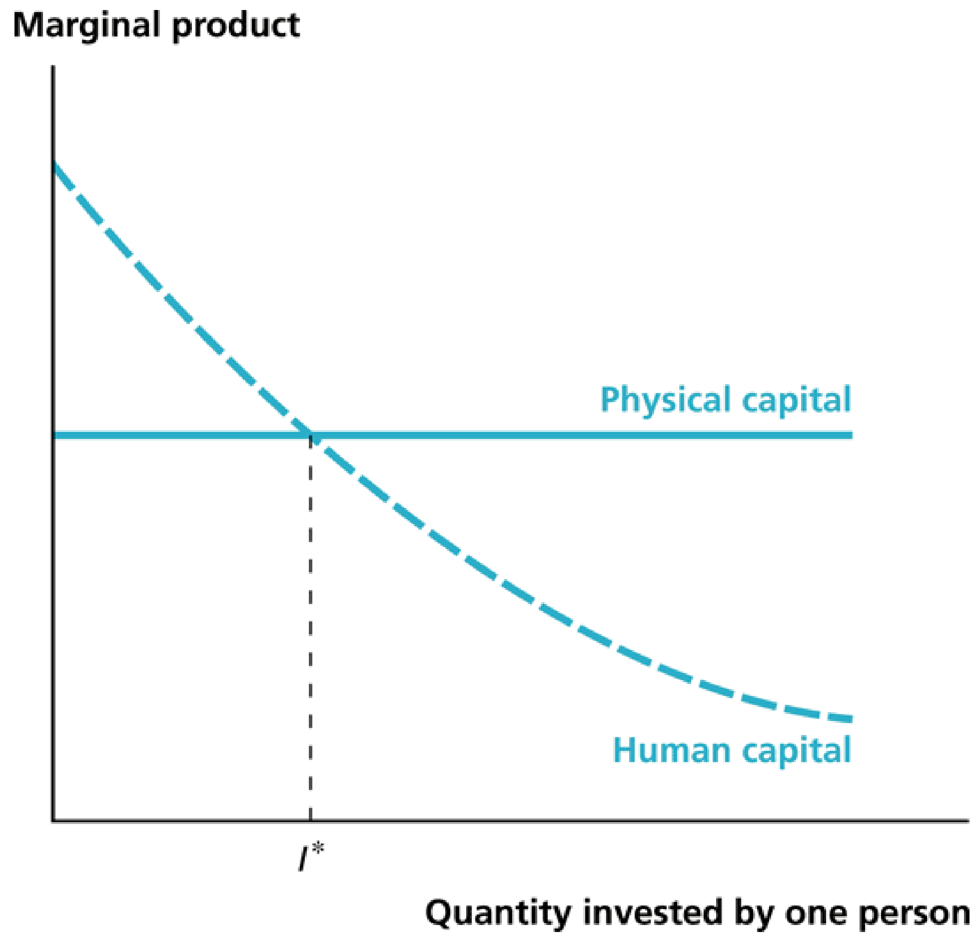


Figure 13.12 Relationship Between Income Inequality and the Desired Tax Rate

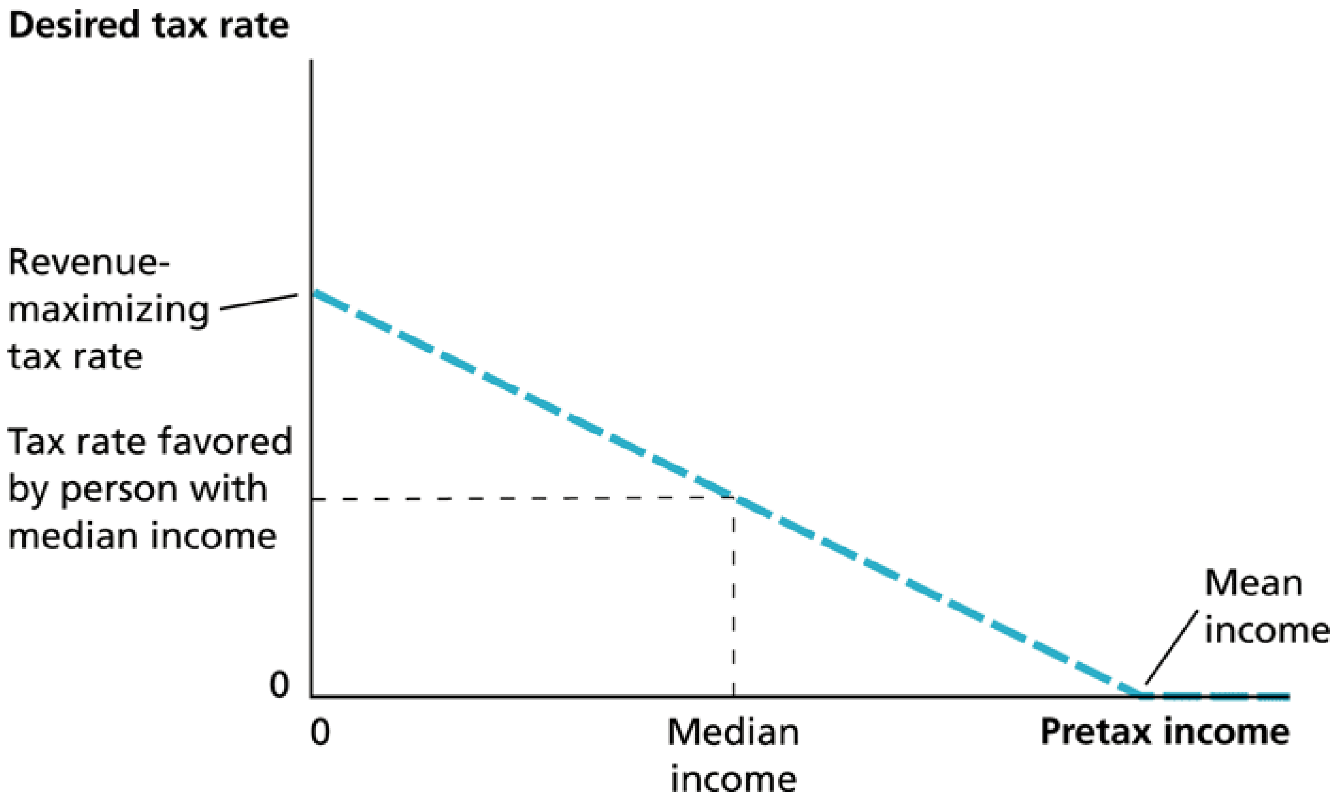


Figure 13.13 How an Increase in Income Inequality Affects the Desired Tax Rate

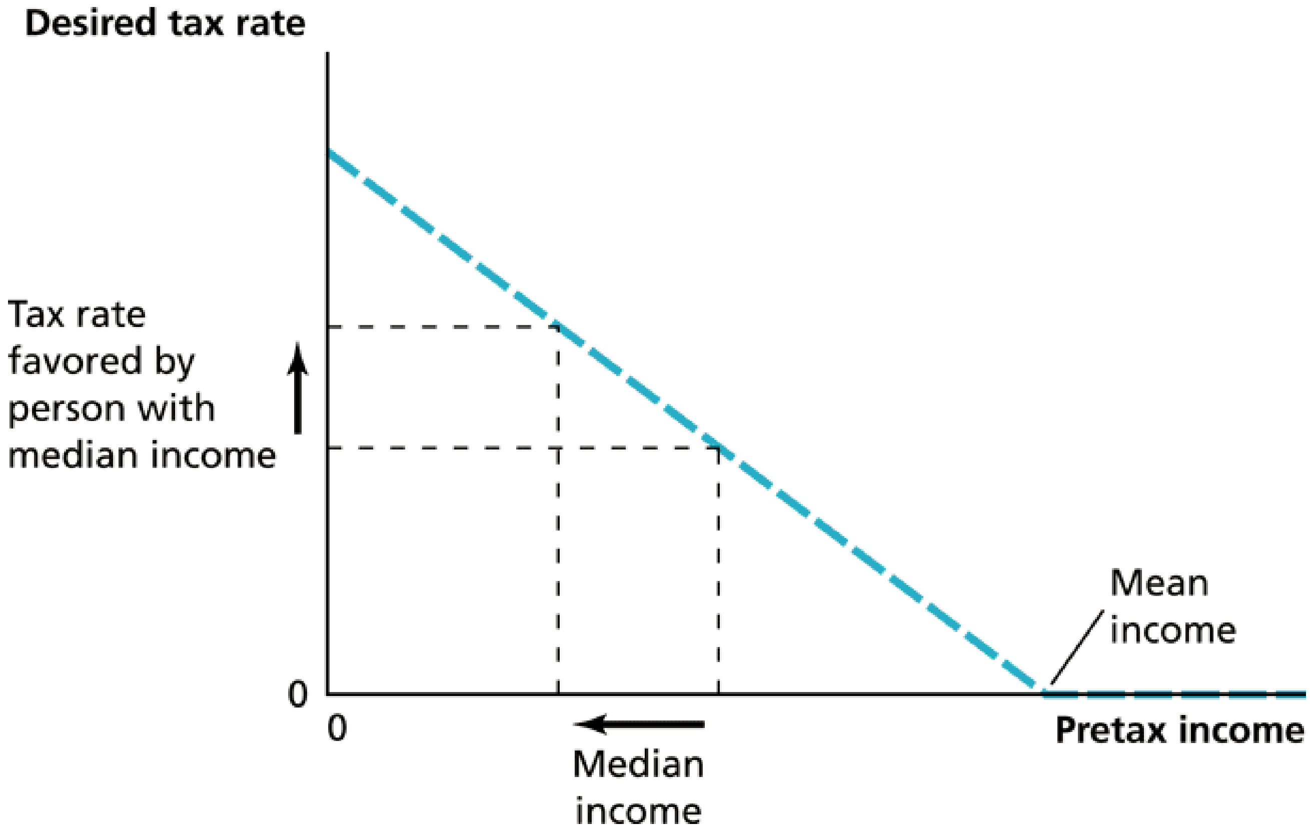
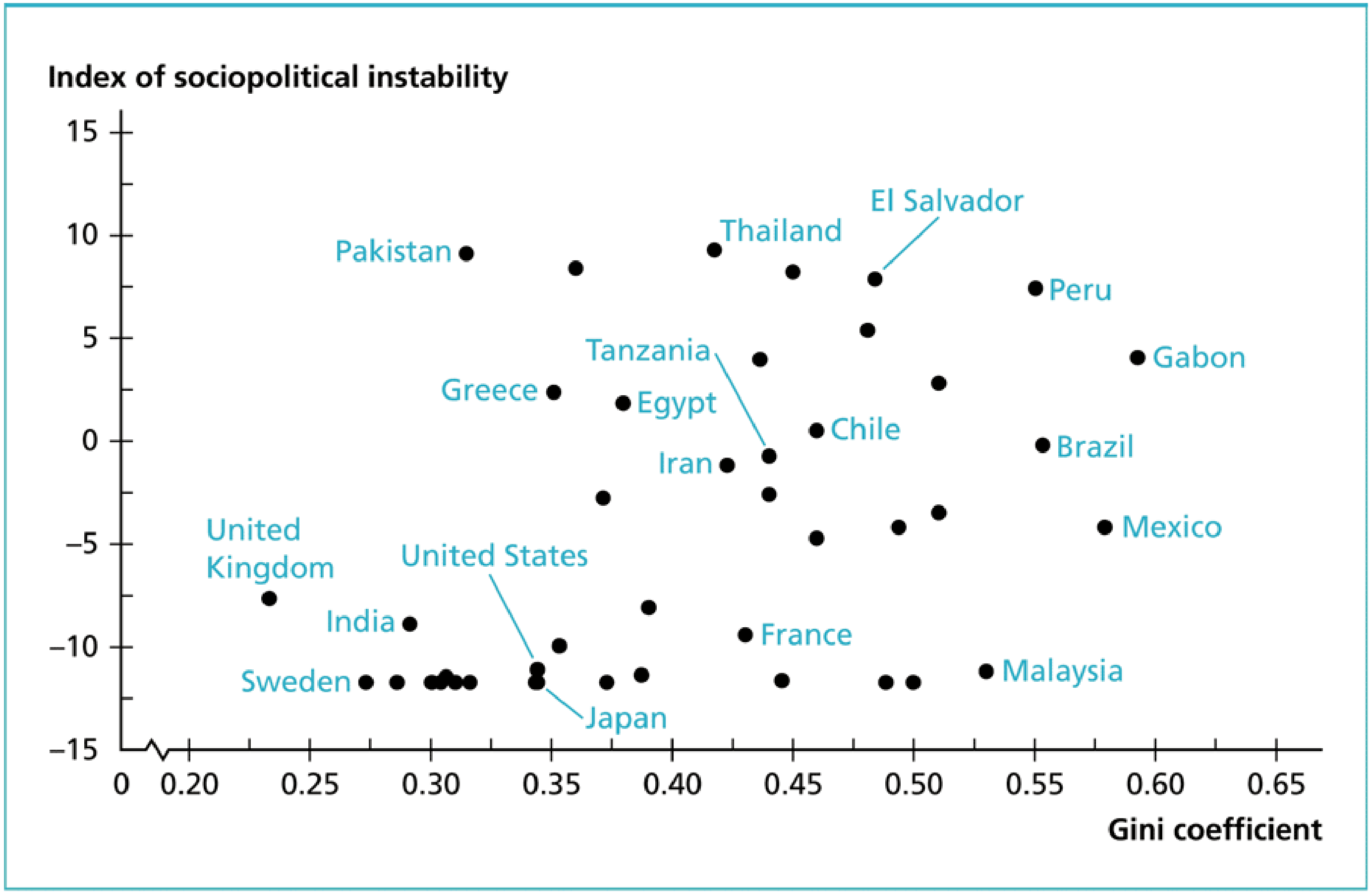


Figure 13.14 Relationship Between Income Inequality and Sociopolitical Instability



Sources: Alesina and Perotti (1996), Deininger and Squire (1996).

Table 13.3 Intergenerational Income Mobility in Canada

Father's Earnings Quartile	Son's Earnings Quartile			
	1st (Bottom)	2nd	3rd	4th (Top)
1st (Bottom)	.33	.28	.22	.17
2nd	.25	.27	.26	.21
3rd	.22	.24	.27	.27
4th (Top)	.20	.21	.25	.35

Source: Corak and Heisz (1998).

Chapter 14

CULTURE

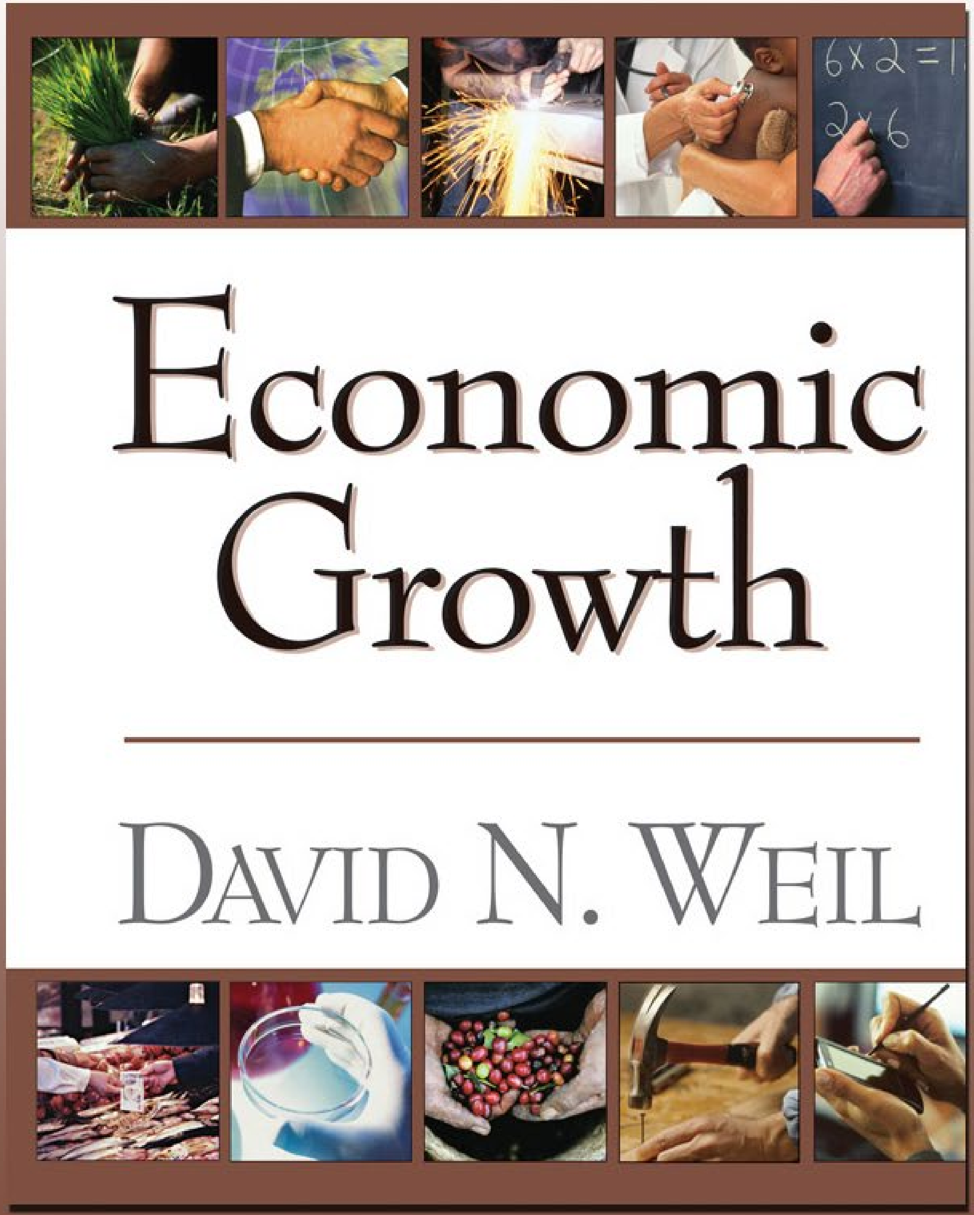
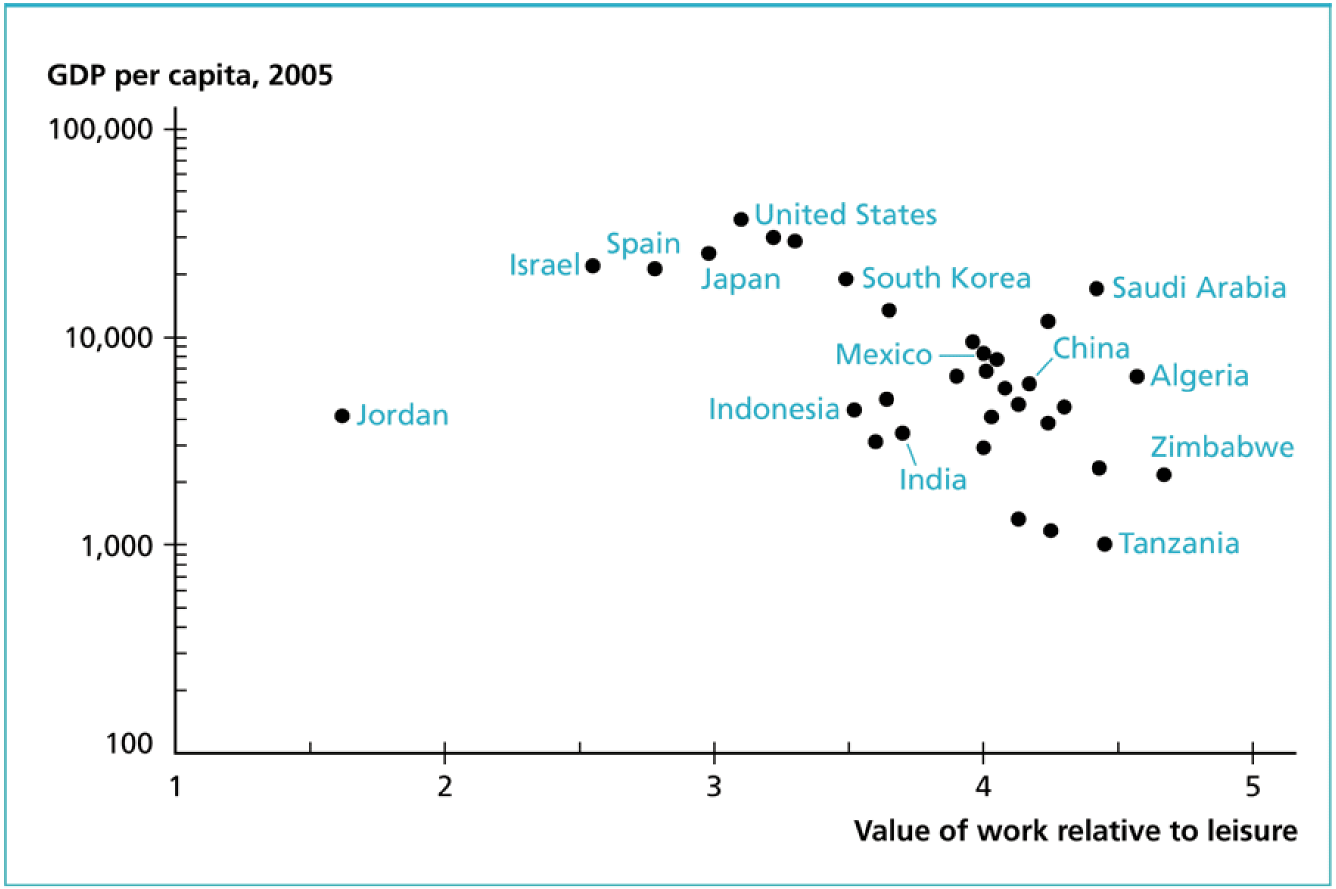


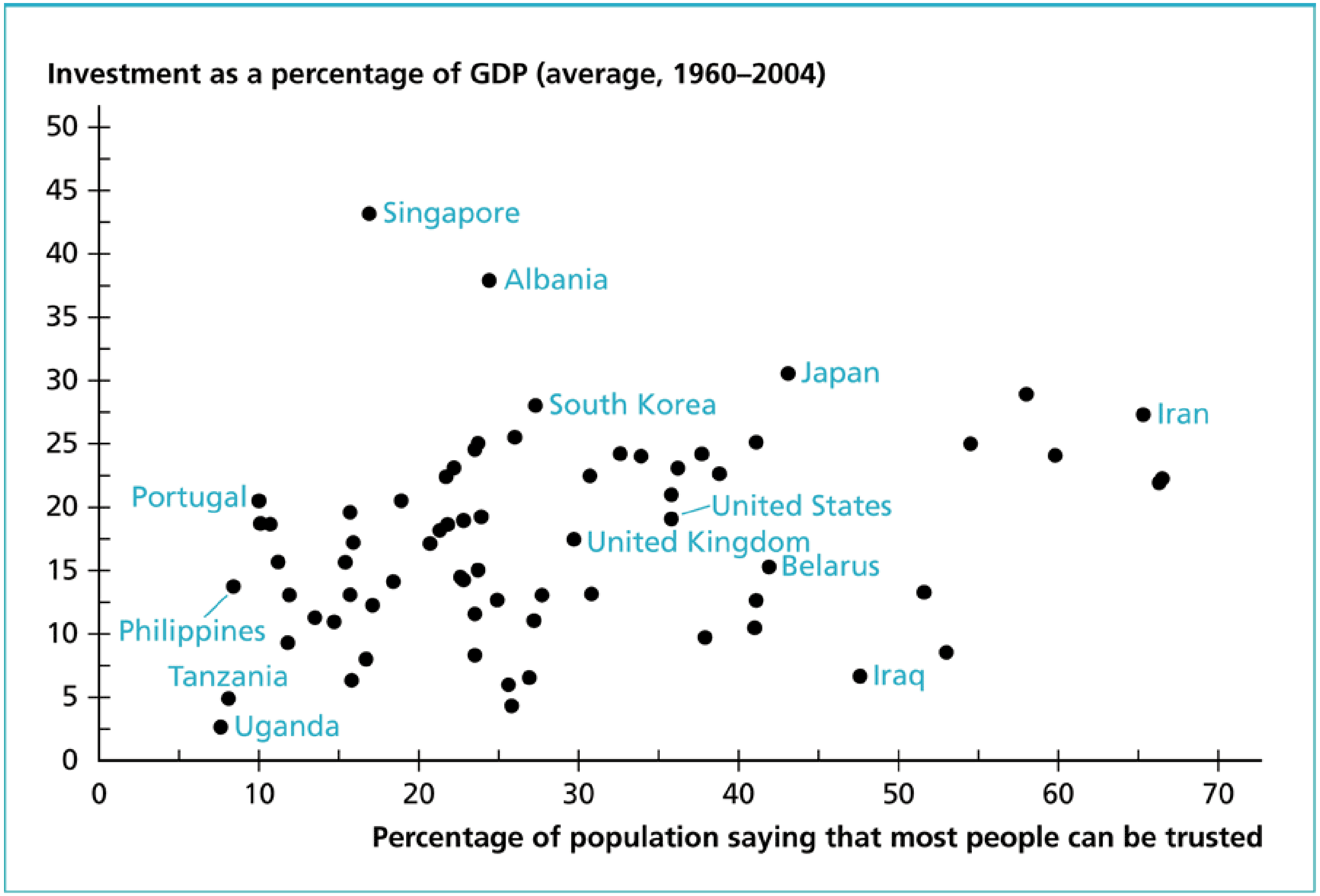
Figure 14.1 Value of Work Versus GDP per Capita



Source: World Values Survey

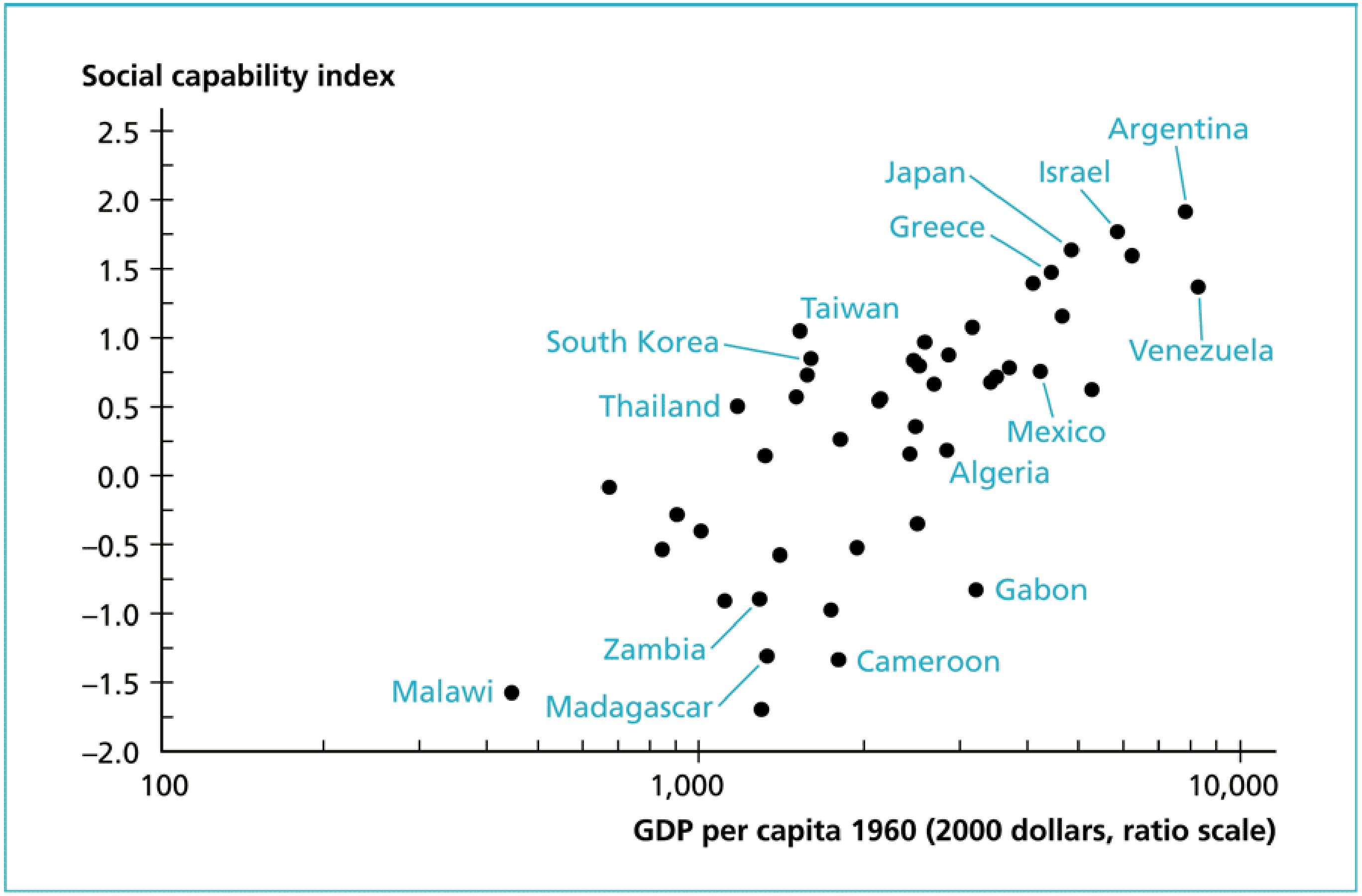
*Scored on a 5-point scale where 1 indicates higher value on leisure, and 5 indicates higher value on work.

Figure 14.2 Relationship Between Trust and Investment



Sources: Knack and Keefer (1997), Heston et al. (2006).

Figure 14.3 Social Capability Versus GDP per Capita in 1960



Sources: Temple and Johnson (1998); Heston, Summers, and Aten (2006).

Figure 14.4 Social Capability and Economic Growth

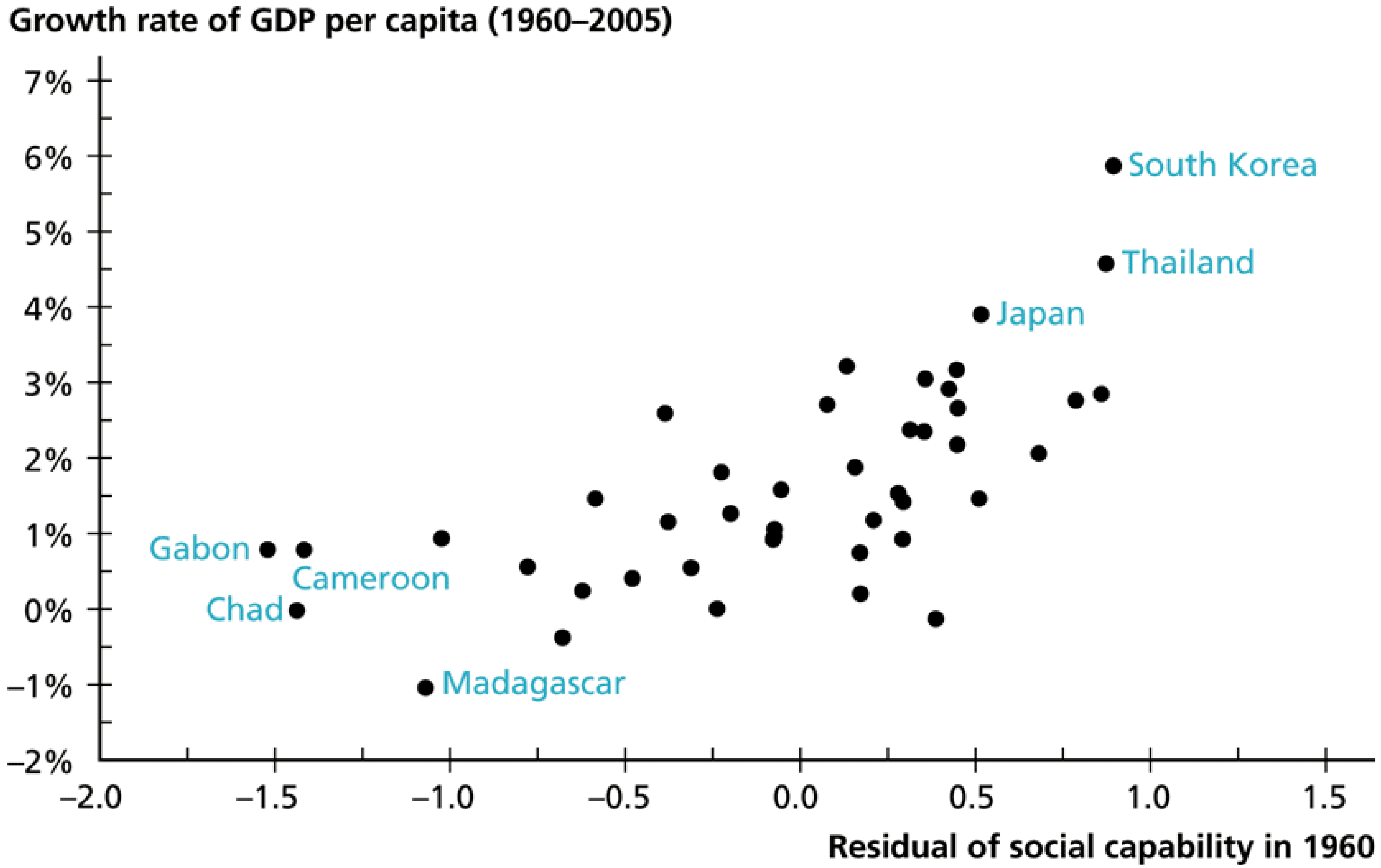
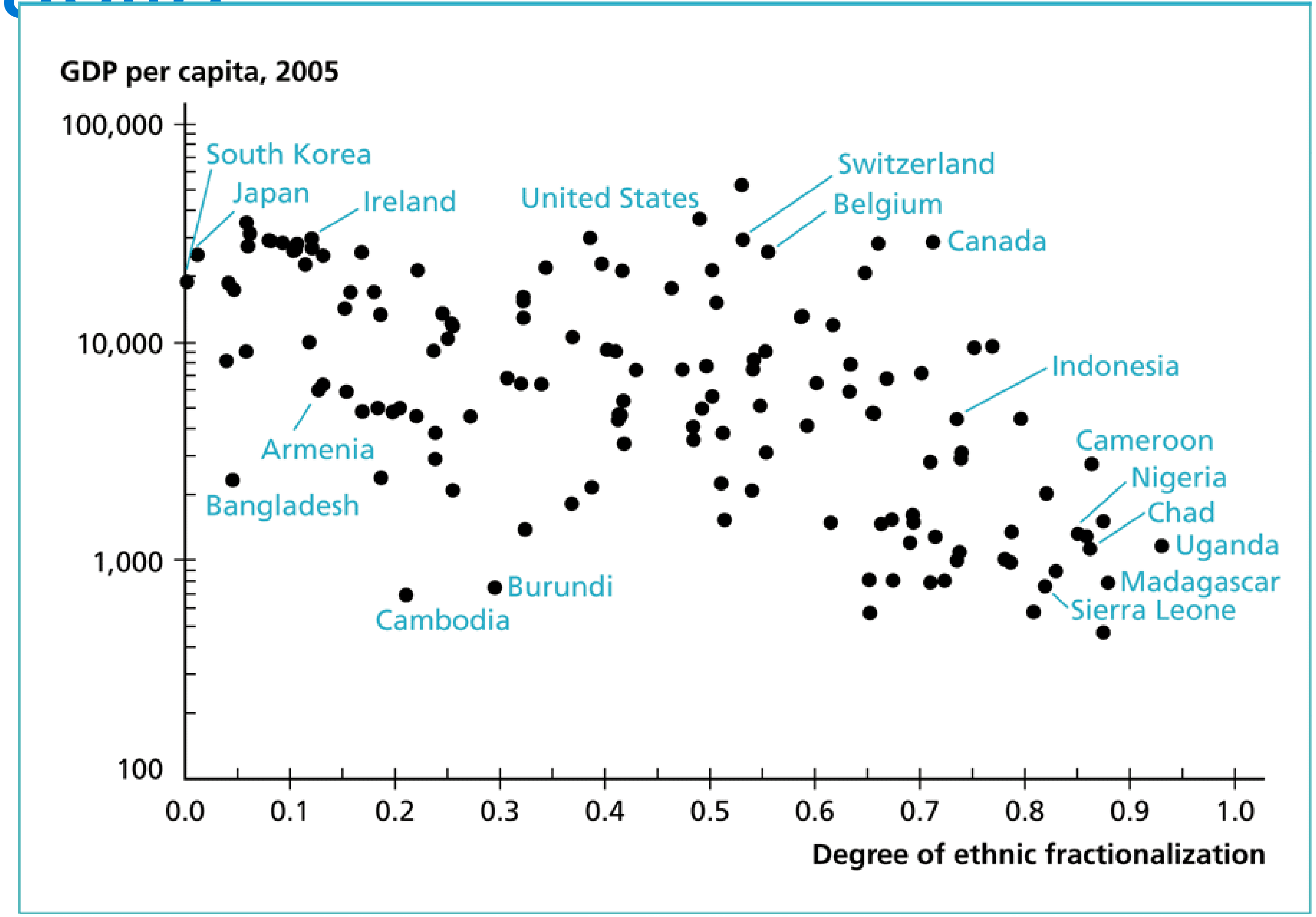
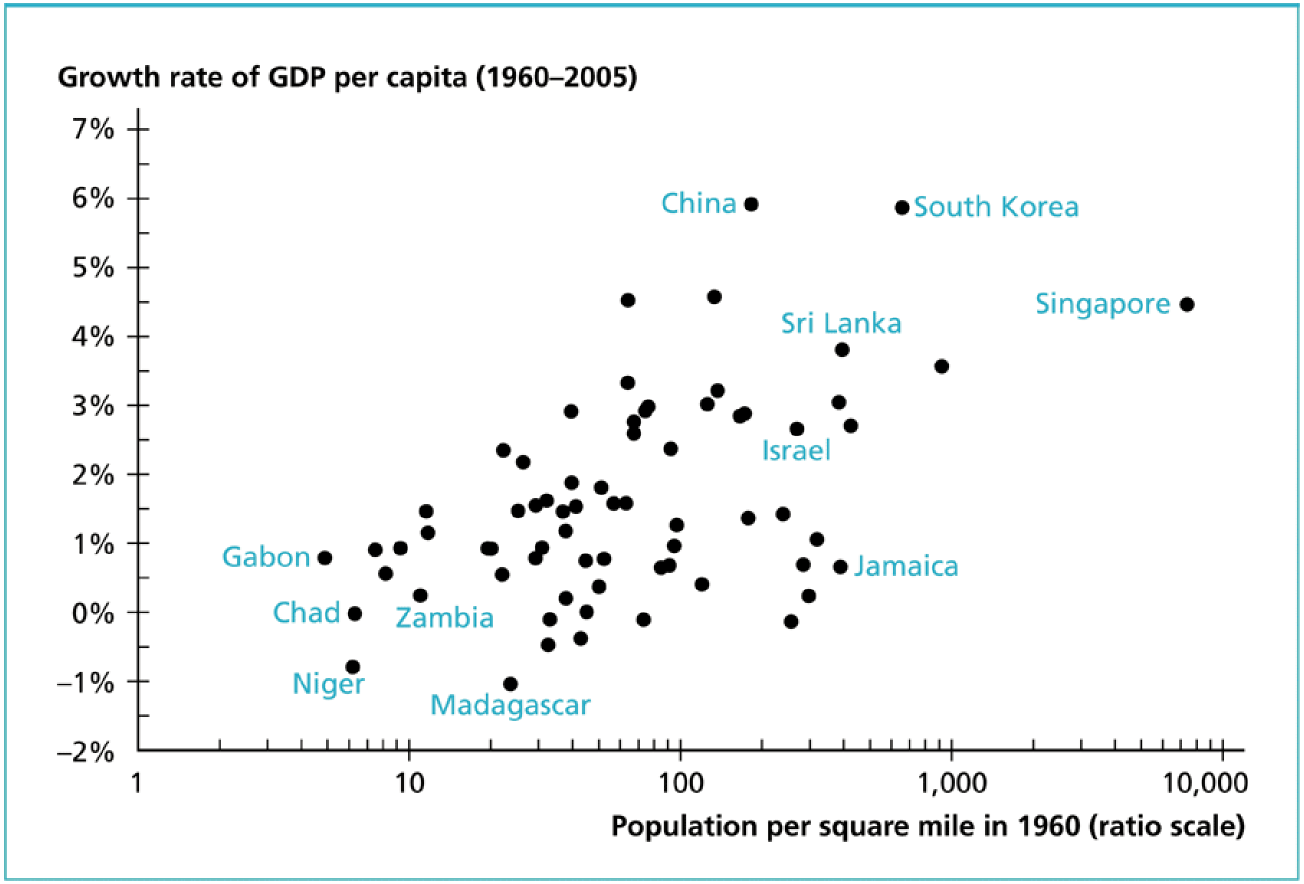


Figure 14.5 Ethnic Fractionalization Versus GDP per Capita



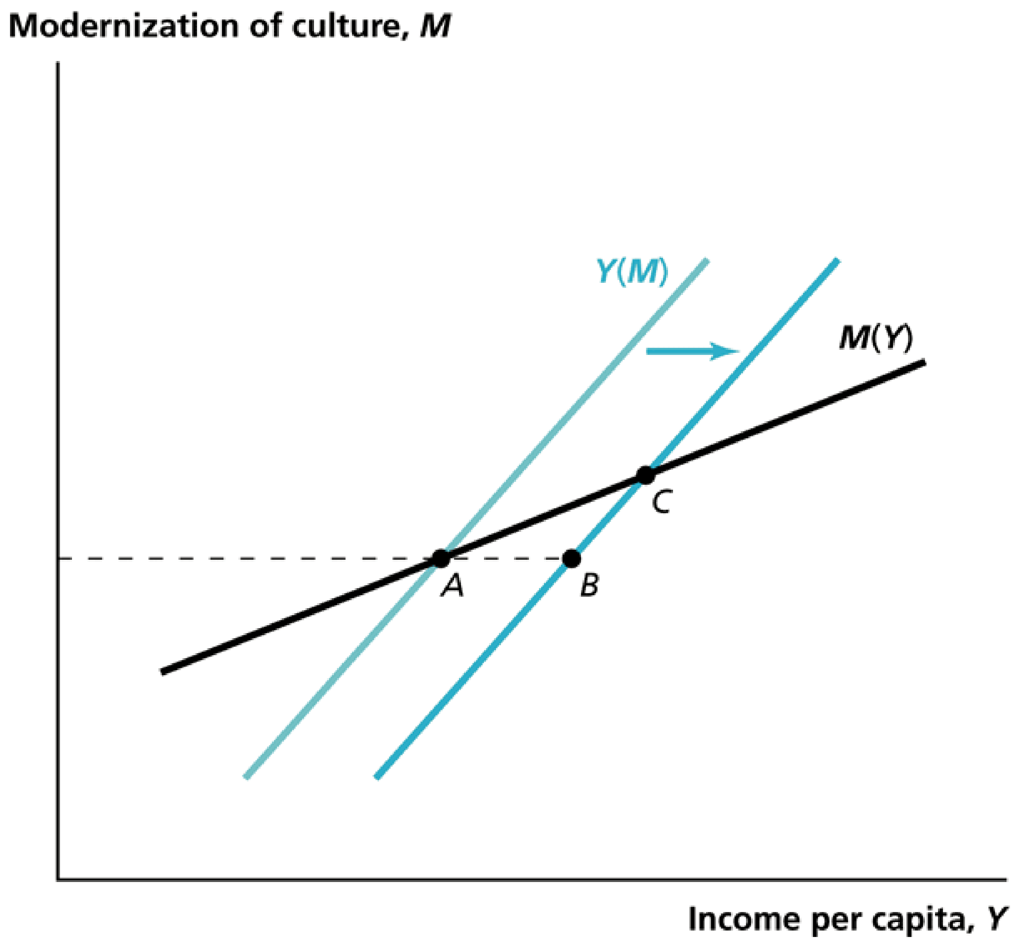
Source: Alesina et al. (2003).

Figure 14.6 Population Density Versus Economic Growth



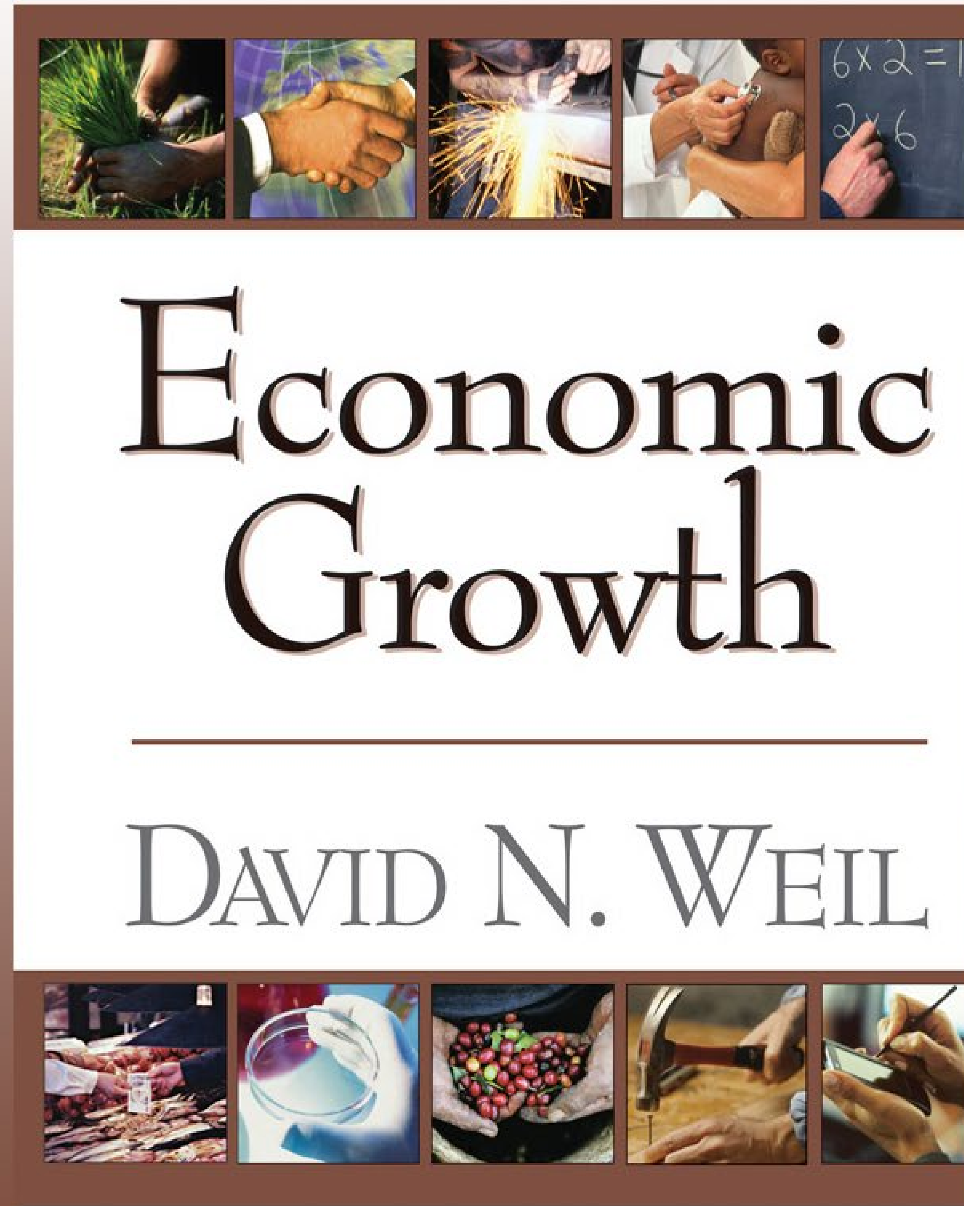
Source: Burkett, Humblet, and Putterman (1999).

Figure 14.7 Simultaneous Determination of Income and Modernization



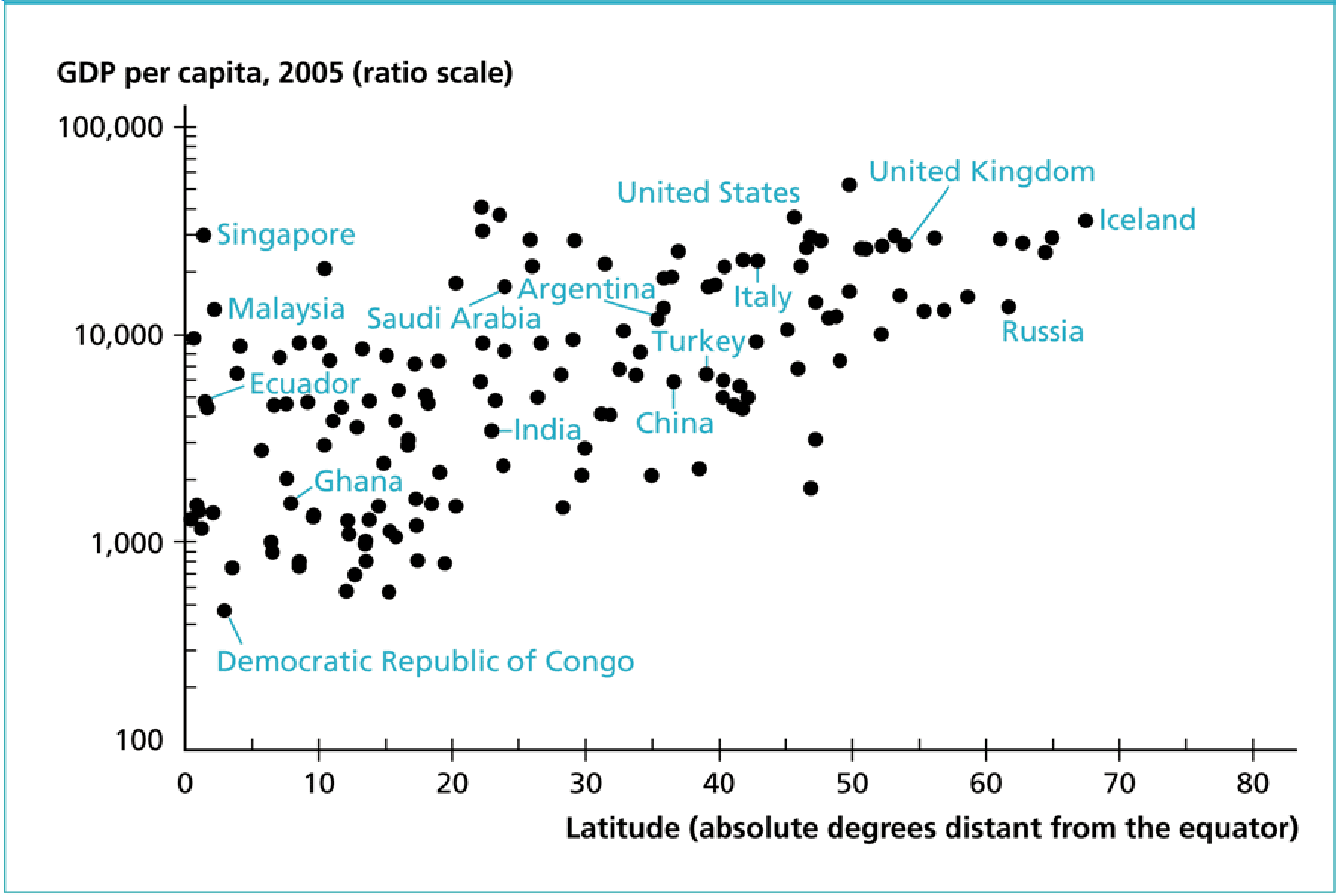
Chapter 15

GEOGRAPHY, CLIMATE, AND NATURAL RESOURCES



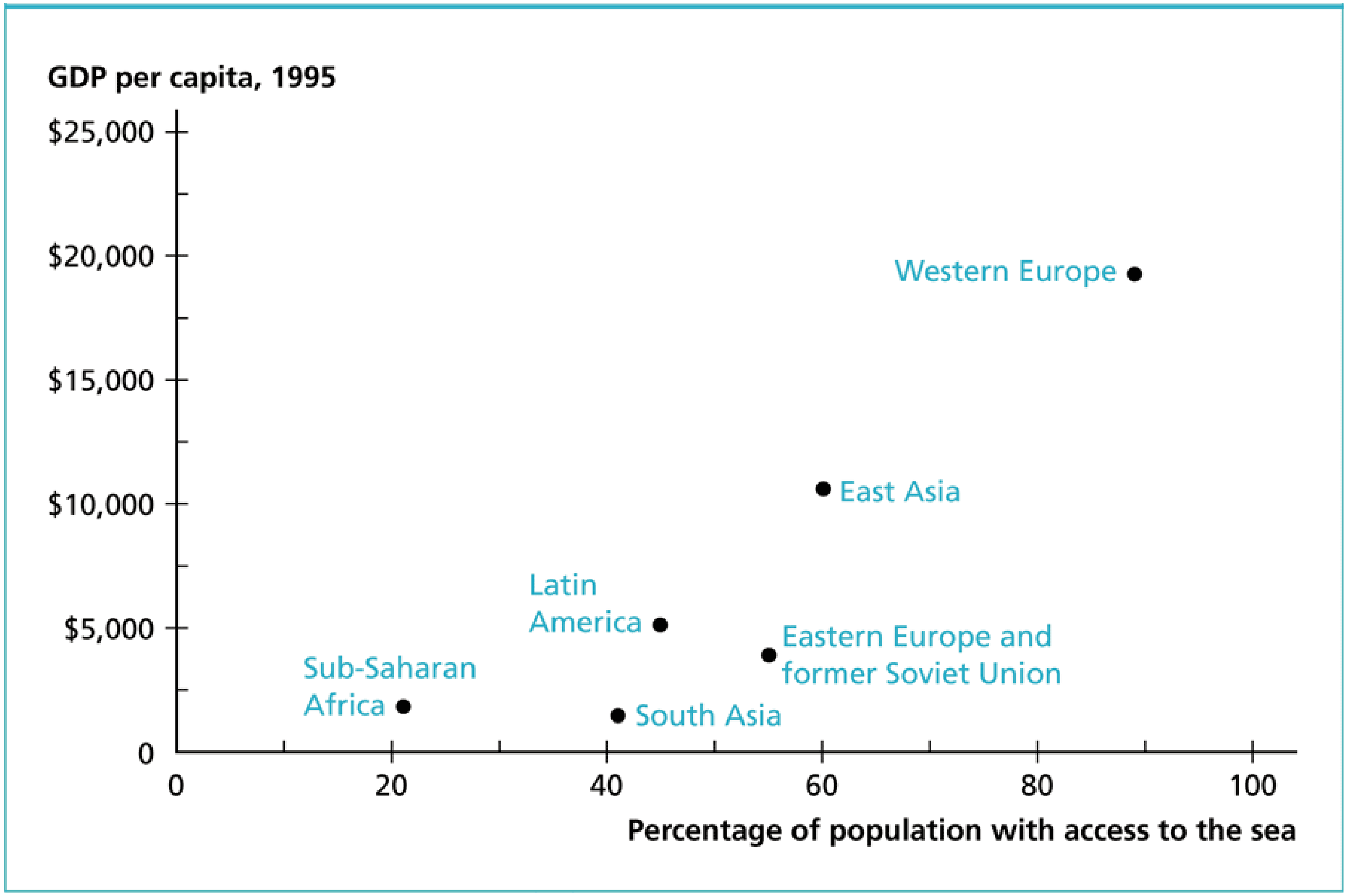
PEARSON
Addison Wesley

Figure 15.1 Relationship Between Latitude and Income per Capita



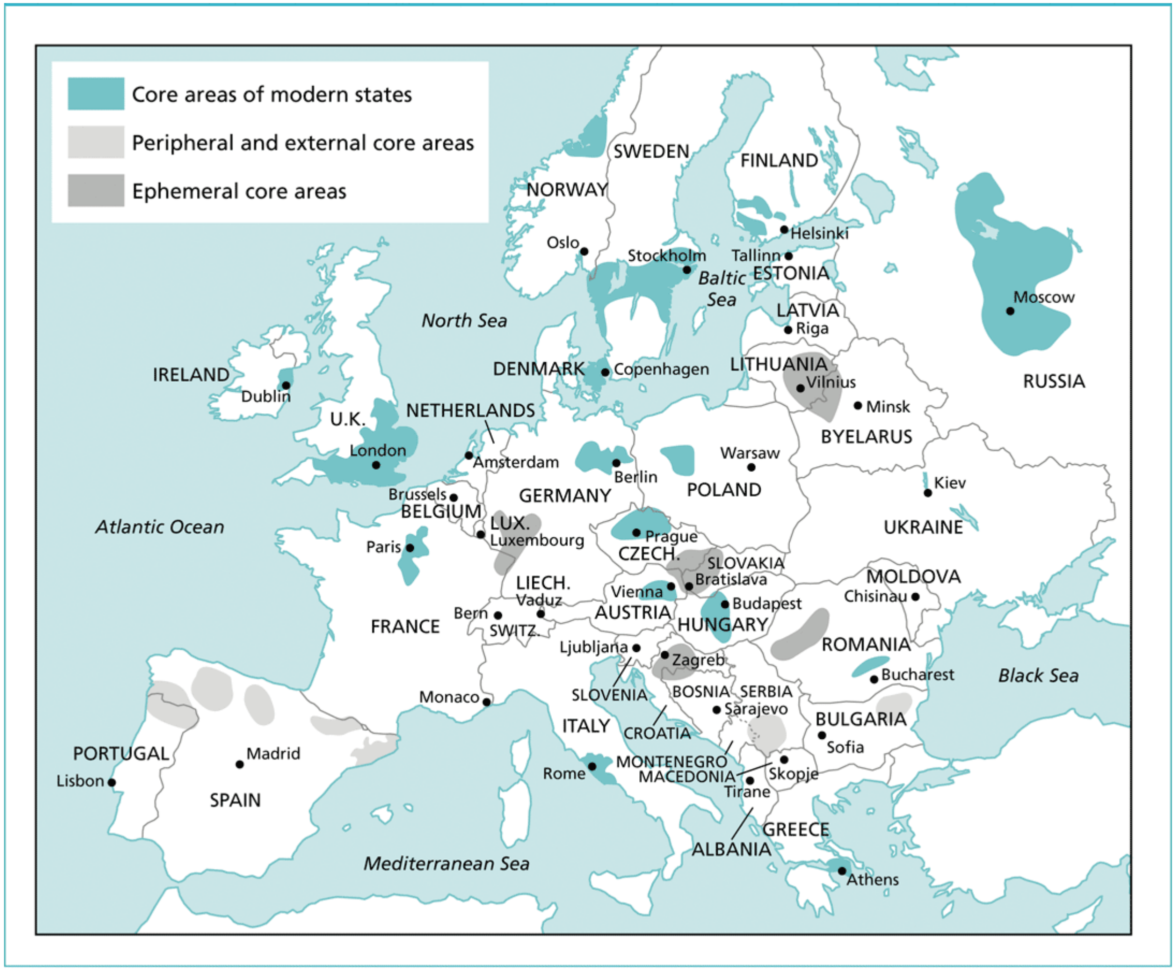
Sources: Heston, Summers, and Aten (2006); World Bank (2007a).

Figure 15.2 Regional Variation in Income and Access to the Sea



Source: Gallup, Sachs, and Mellinger (1998).

Figure 15.3 Core Areas in Preindustrial Europe



Source: Pounds and Ball (1964).

Figure 15.4 Core Areas in Preindustrial China

Source: Stover (1974).

Table 15.1a World Climate Zones

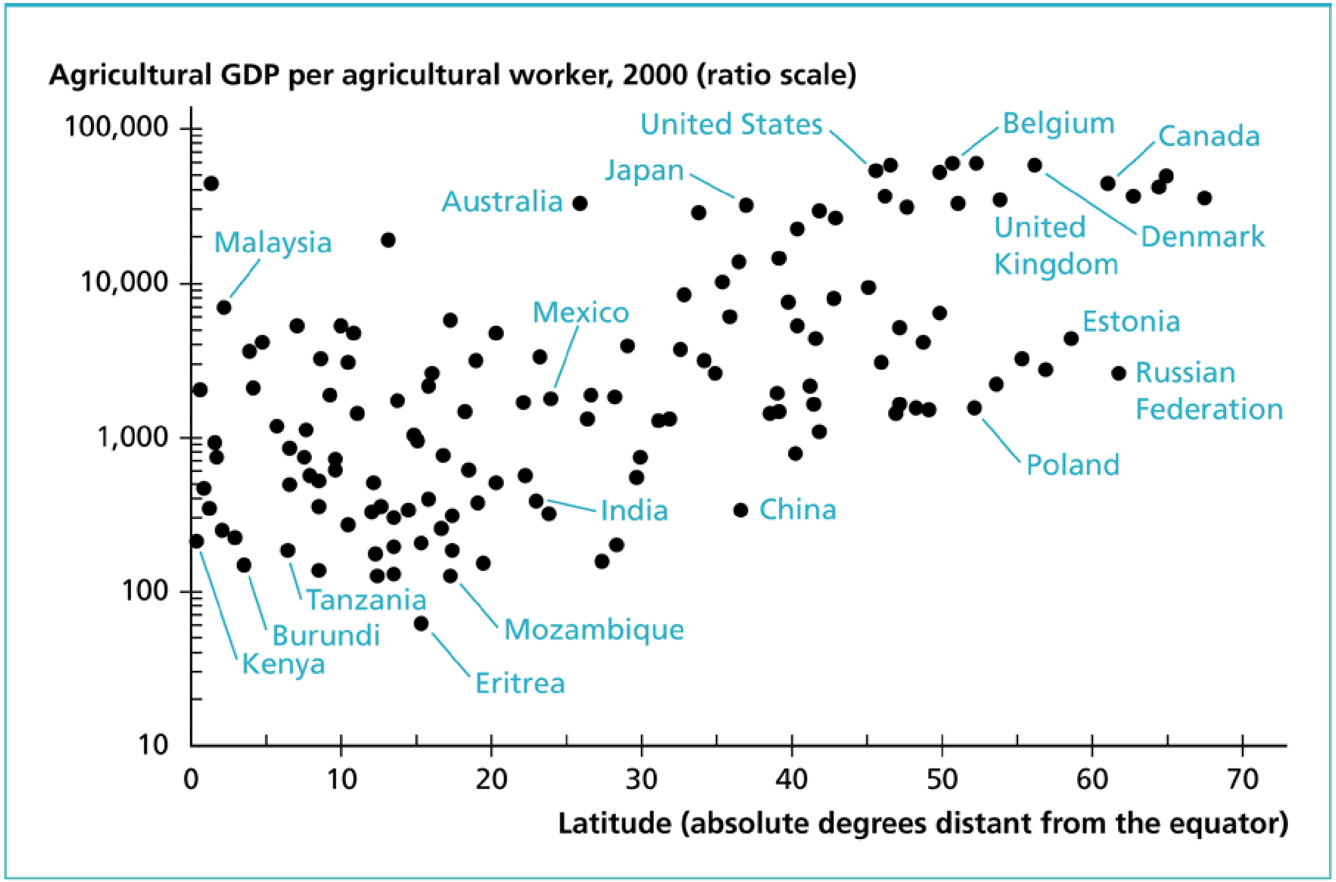
Climate Zone	Description	Representative Cities	Percentage of World Landmass	Percentage of World Population	GDP per Capita Relative to World Average
Af	Tropical Rain Forest	Jakarta, Indonesia Manaus, Brazil	4.0	4.4	0.64
Am	Tropical Rain Forest with Seasonal Monsoon	Manila, Philippines Cochin, India Belém, Brazil	0.8	2.4	0.41
Aw	Tropical Savannah	Dhaka, Bangladesh Kinshasa, Congo Havana, Cuba	10.8	17.5	0.38
Cw	Subtropical: Mild Humid with Dry Winter	Hanoi, Vietnam Kanpur, India Lilongwe, Malawi	4.3	16.0	0.44
Cf	Mild Humid Climate with No Dry Season	New York, USA Paris, France Shanghai, China Sydney, Australia	7.7	19.5	2.24
Cs	Mediterranean Climate: Mild, Humid with Dry Summer	San Francisco, USA Rome, Italy Santiago, Chile	2.2	4.3	2.10

Table 15.1b World Climate Zones

Df	Snowy-Forest Climate with No Dry Season	Chicago, USA Moscow, Russia	23.0	5.8	1.90
Dw	Snowy-Forest Climate with Dry Winter	Seoul, South Korea Vladivostok, Russia	6.2	5.3	0.64
BS	Semi-arid Steppe	San Diego, USA Odessa, Ukraine	12.3	11.8	0.55
BW	Desert: Annual Precipitation Less than 15 in. (38 cm)	Cairo, Egypt Karachi, Pakistan	17.3	6.2	0.58
H	Highlands	Mexico City, Mexico	7.3	6.8	0.78
E	Ice Climates: Average Temperature in Warmest Month Less Than 50°F (10°C)	Nuuk, Greenland	4.0	<0.1	–

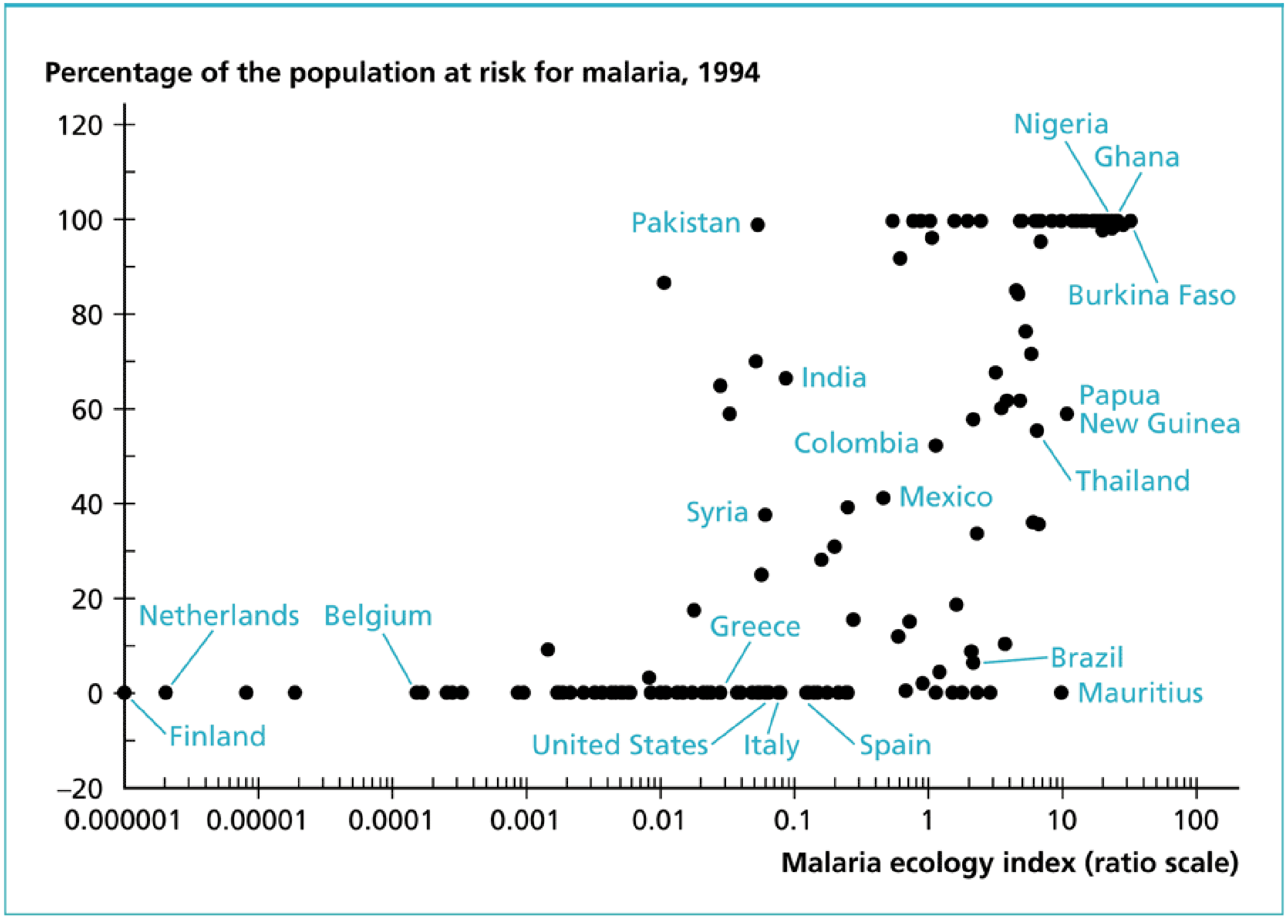
Source: Data on landmass, population, and GDP per capita are from Mellinger, Sachs, and Gallup (1999).

Figure 15.5 Latitude Versus Agricultural GDP per Agricultural Worker



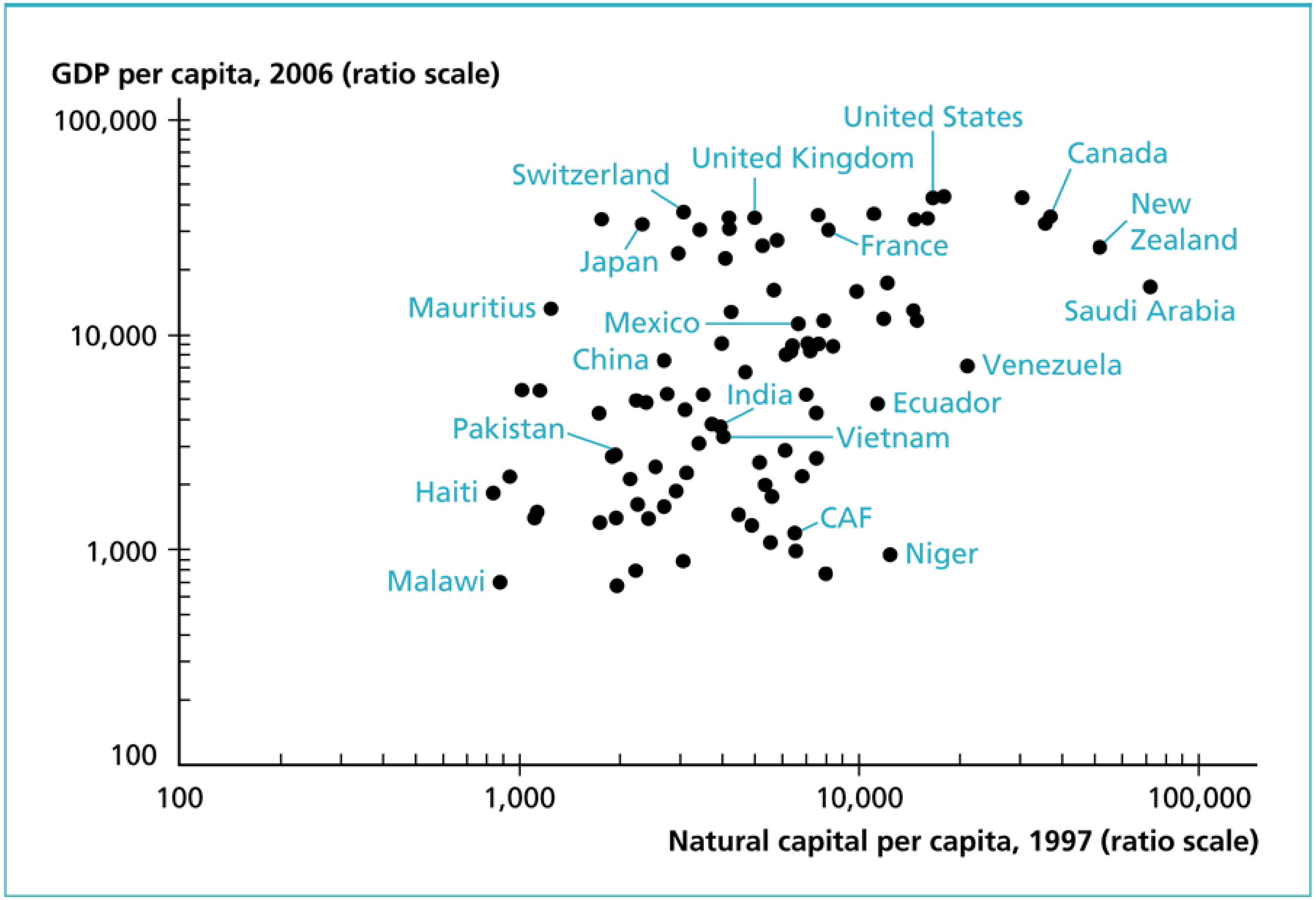
Source: United Nations Food and Agriculture Organization (2003).

Figure 15.6 Malaria Ecology Versus Incidence of Malaria



Sources: Kiszewski et al. (2004).

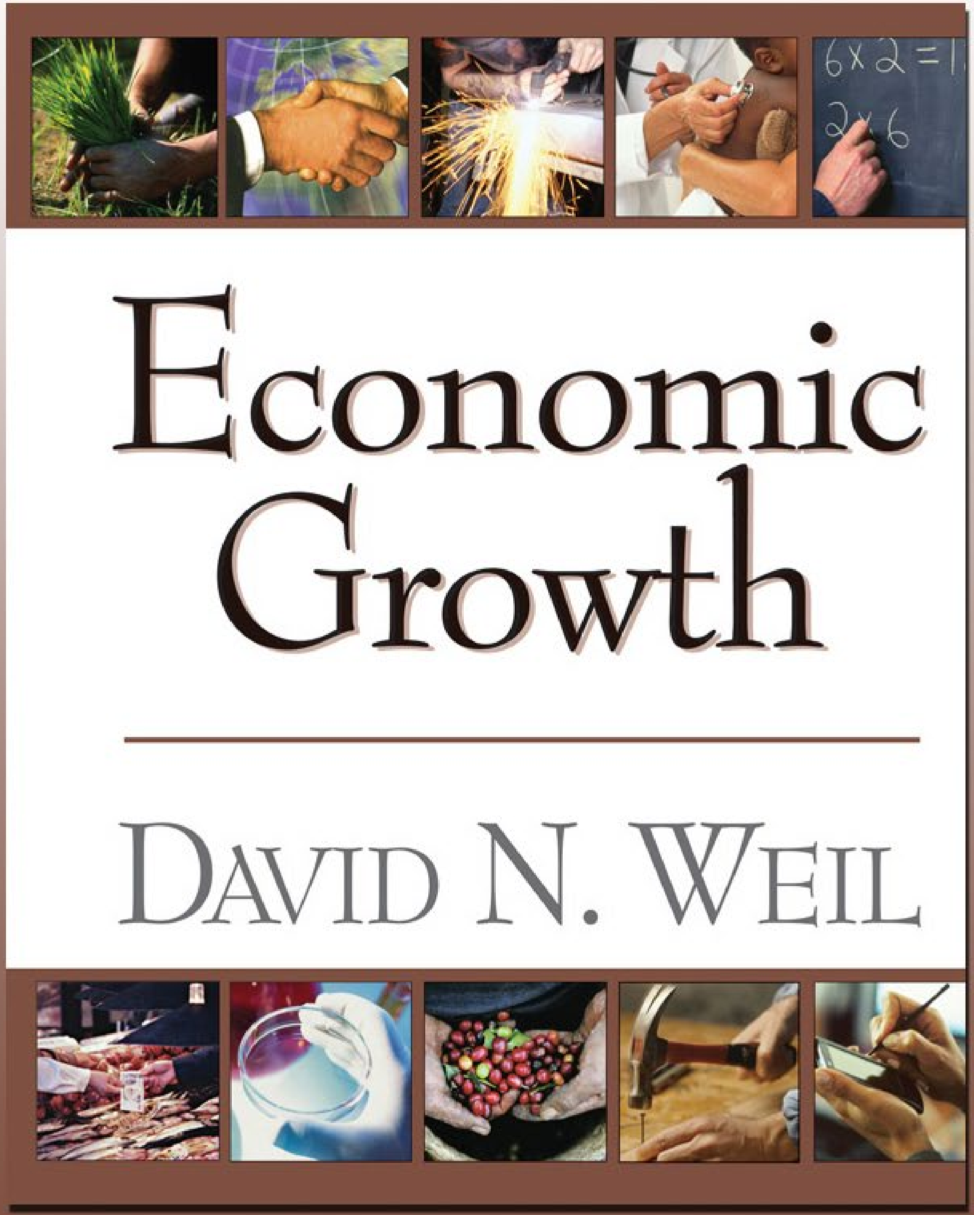
Figure 15.7 Natural Capital Versus GDP per Capita



Sources: World Bank (1997, 2007a); Heston, Summers, and Aten (2006).

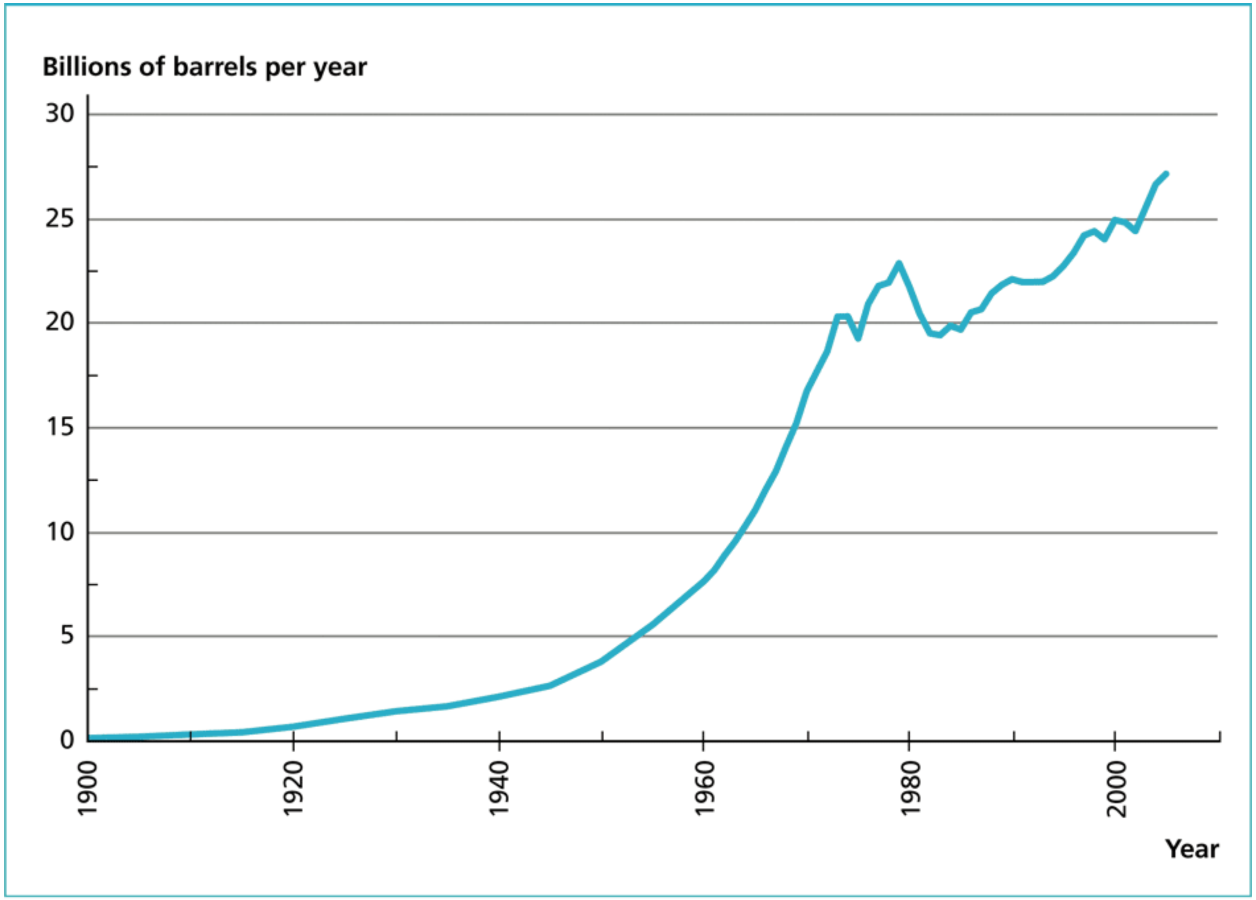
Chapter 16

RESOURCES
AND THE
ENVIRONMENT
AT THE GLOBAL
LEVEL



PEARSON
Addison
Wesley

Figure 16.1 World Crude Oil Production, 1900–2005



Sources: Jenkins (1977), p. 85 and Table 2; U.S. Department of Energy, Energy Information Administration (2007), Chapter 11.

Table 16.1 World Crude Oil Production and Reserves (Billions of Barrels)

Figure 16.2 Growth of a Renewable Resource

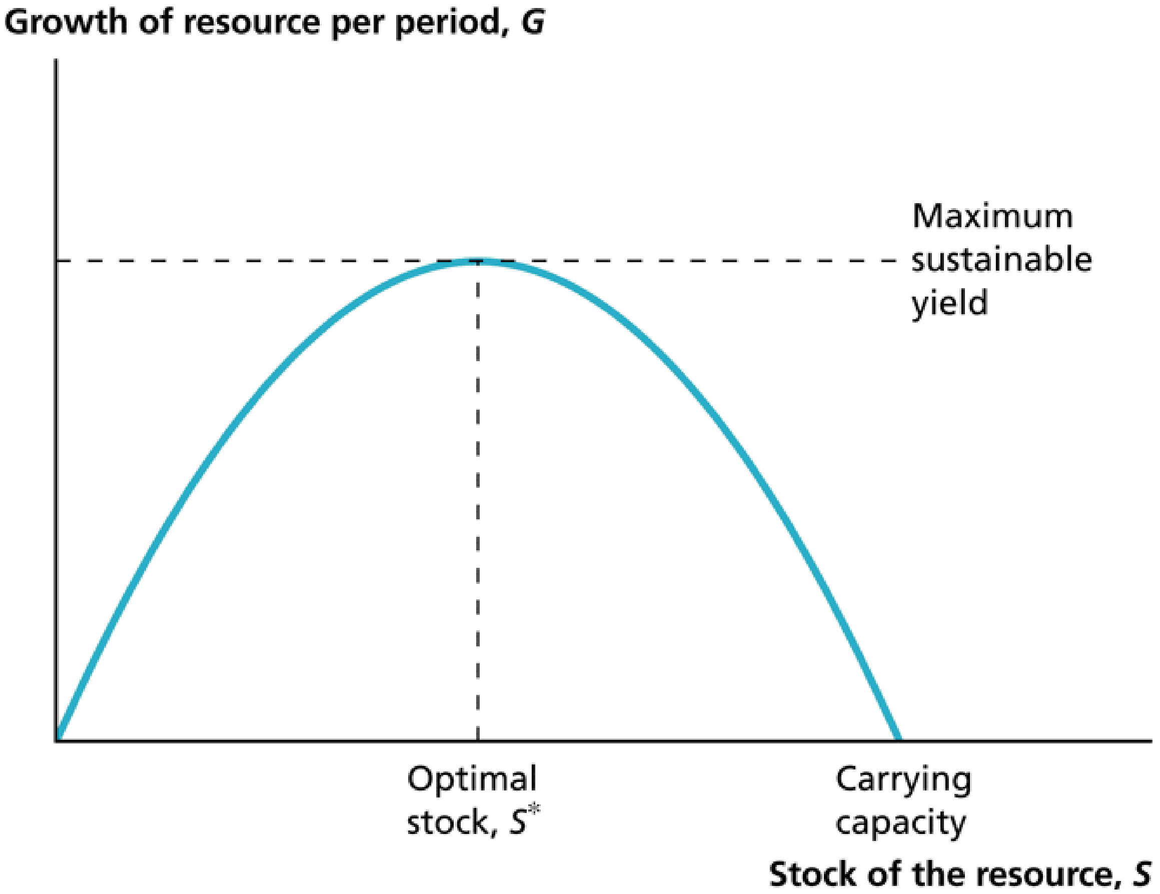


Table 16.2 Energy Use by Different Country Groups

Country Group	Population (Millions)	GDP per Capita ($)	Commercial Energy Use per Capita (Kg of Oil Equivalent)	Energy Intensity (Kg of Oil Equivalent per $ GDP)
Low Income	2,319	2,086	510	0.24
Lower Middle Income	2,236	5,224	1,159	0.22
Upper Middle Income	798	8,788	2,221	0.25
High Income	1,017	28,600	5,502	0.19

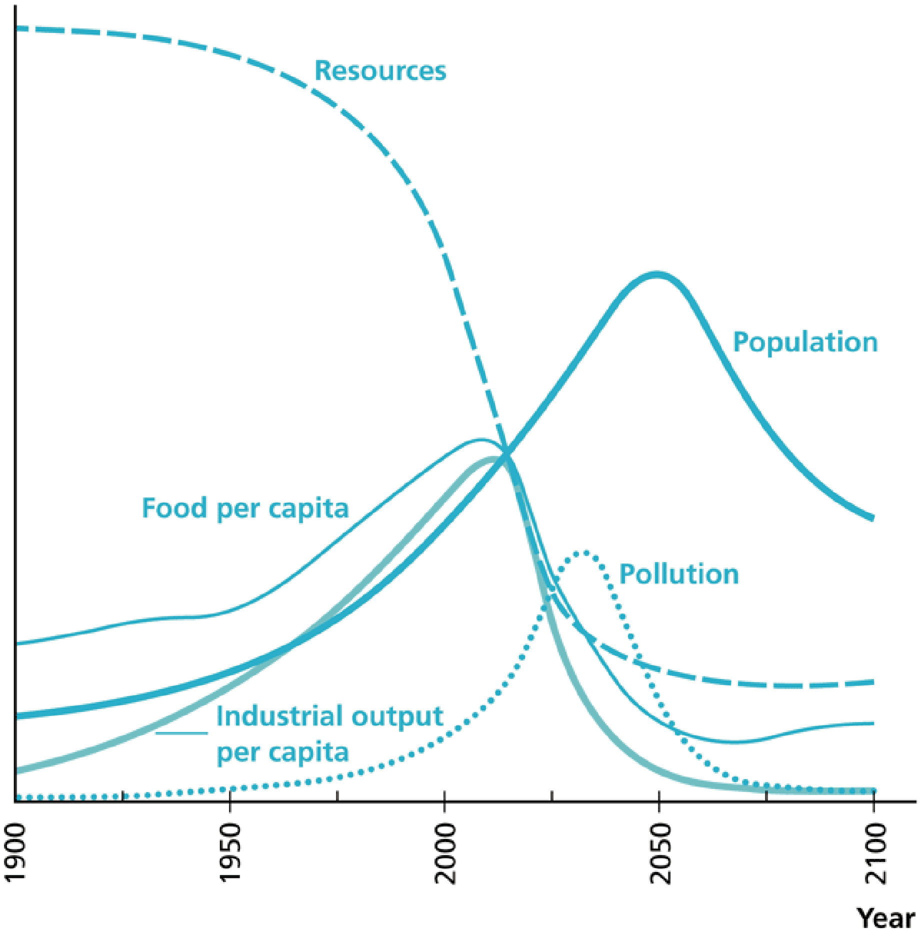
Source: World Bank (2007a).

Table 16.3 Calculation of the Value of Depletion for the 14 Most Important Minerals

Mineral	World Consumption (Thousands)	Price per Unit ($)	Production Cost per Unit ($)	In-Ground Price per Unit (Price – Production Cost) ($)	Value of Exhausted Resource (Consumption × In-ground Price) ($ Million)
Crude Oil	3,012,984	113	56.6	56.4	169,932
Natural Gas	95,925	2,133	958.3	1,174.7	112,683
Hard Coal	3,967,054	40	32.6	7.4	29,356
Brown Coal (Lignite)	1,119,937	11	9.4	1.6	1,792
Bauxite (Aluminum)	132,315	33.8	14.5	19.3	2,554
Copper	9,539	2,330	1,385.2	944.8	9,012
Iron Ore	604,679	40	23.9	16.1	9,735
Lead	2,718	679	658.1	20.9	56.8
Nickel	783	6,278	5,239.9	1,038.1	812.8
Phosphate	136,482	38	31.7	6.3	859.8
Tin	166	5,428	4,209	1,219	202.4
Zinc	6,964	1,033	894.4	138.6	965.2
Gold	1.74	12,346,000	10,822,700	1,523,300	2,652
Silver	10	169,872	129,763.5	40,108.5	401.0
Total					341,015

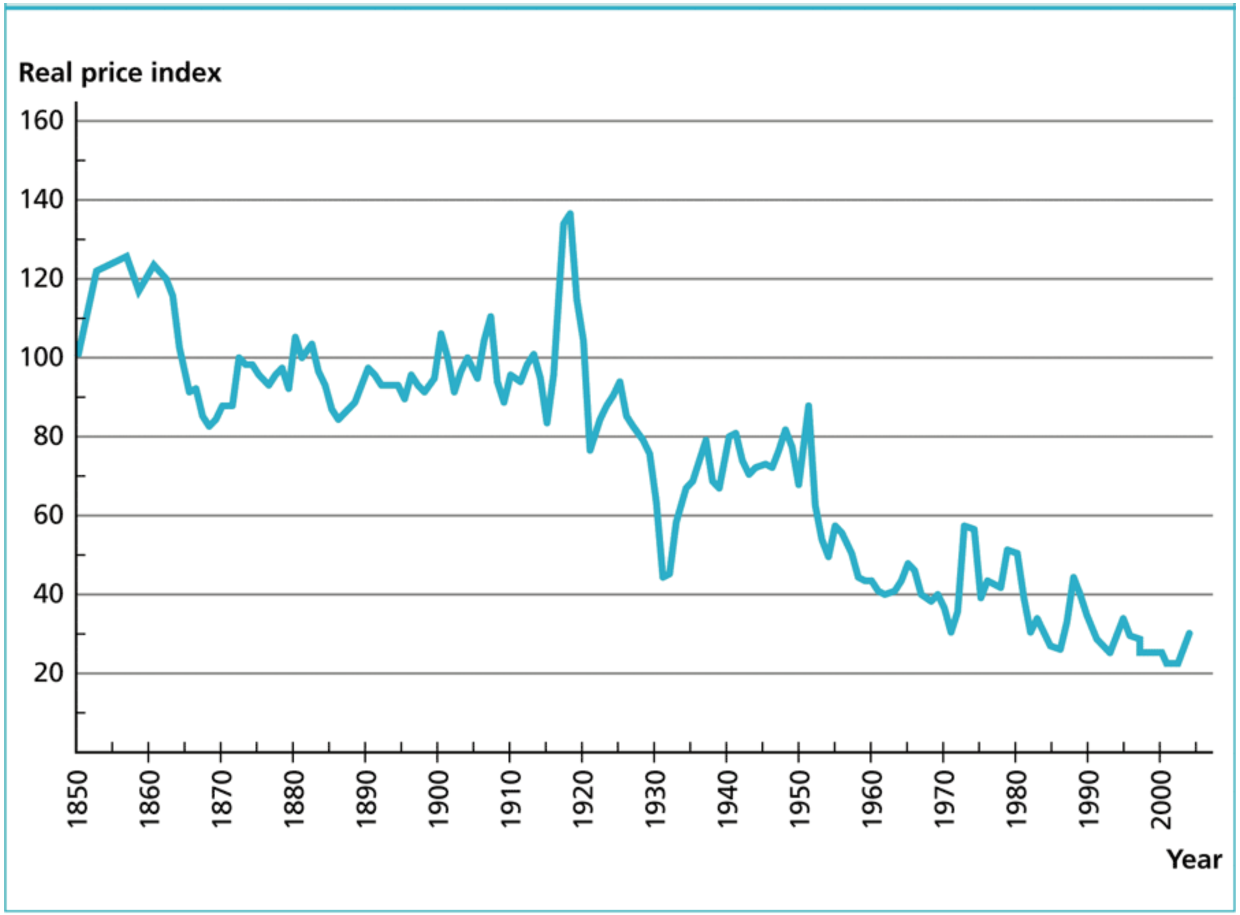
Source: Weitzman (1999). Quantities are all metric tons, except for natural gas, which is measured in trillions of joules. Prices correspond to the unit of quantity used. Data are for 1994.

Figure 16.3 Growth Forecast from *The Limits to Growth*



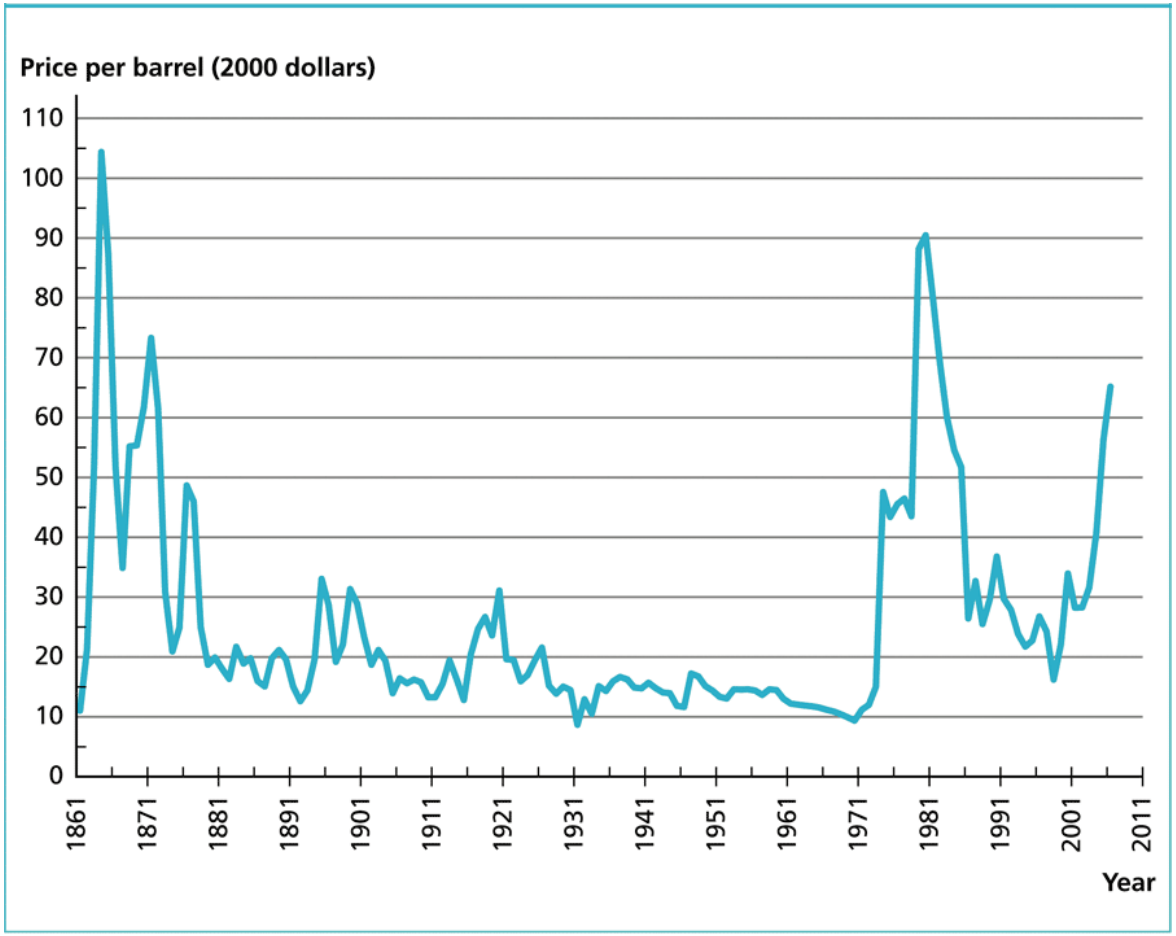
Source: Meadows et al. (1972), Figure 35.

Figure 16.4 Natural Resource Prices, 1850–2005



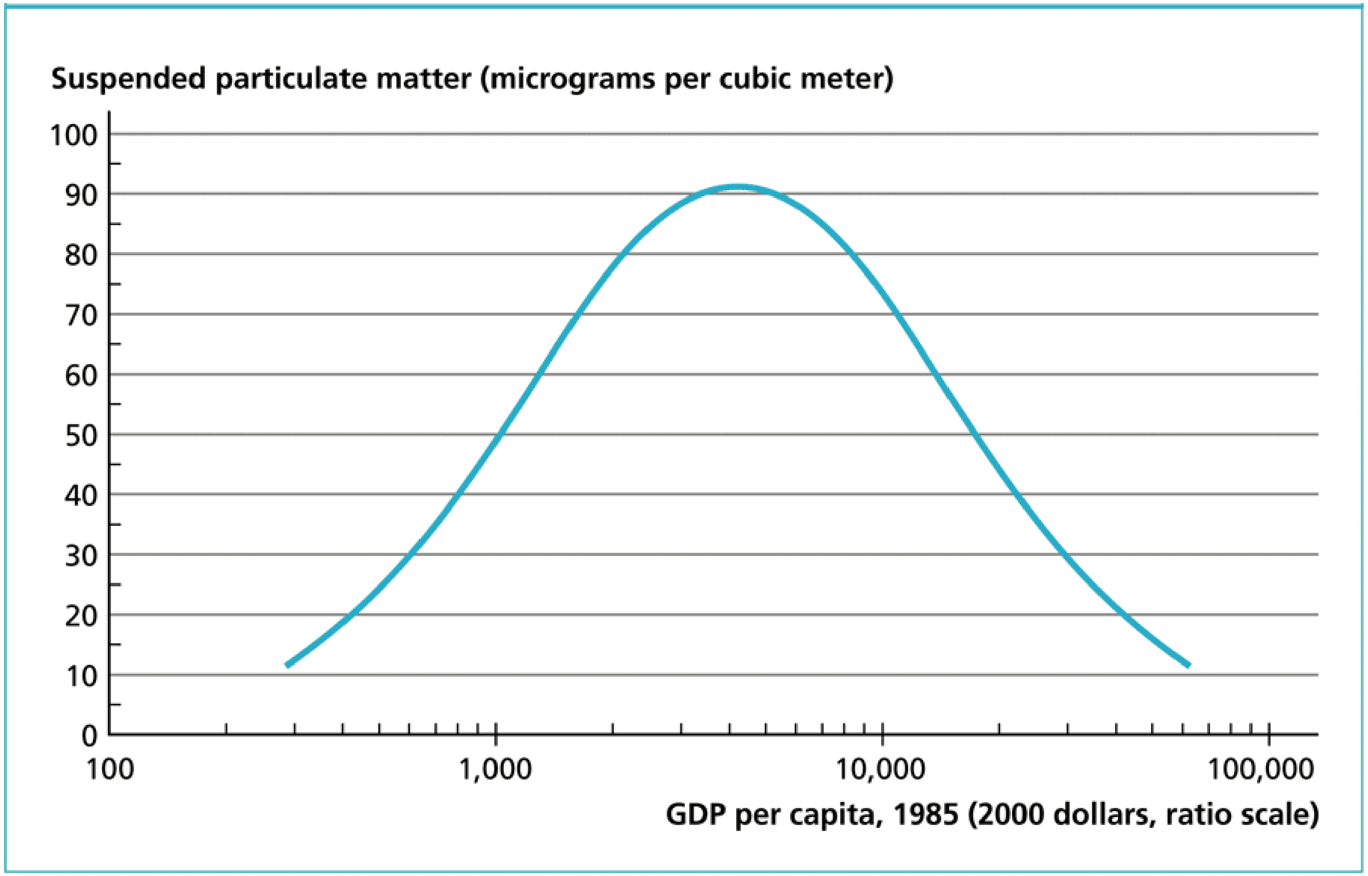
Source: Cashin and McDermott (2002). Original data are from *The Economist* industrial commodity price index.

Figure 16.5 Real Price of Oil, 1861–2006



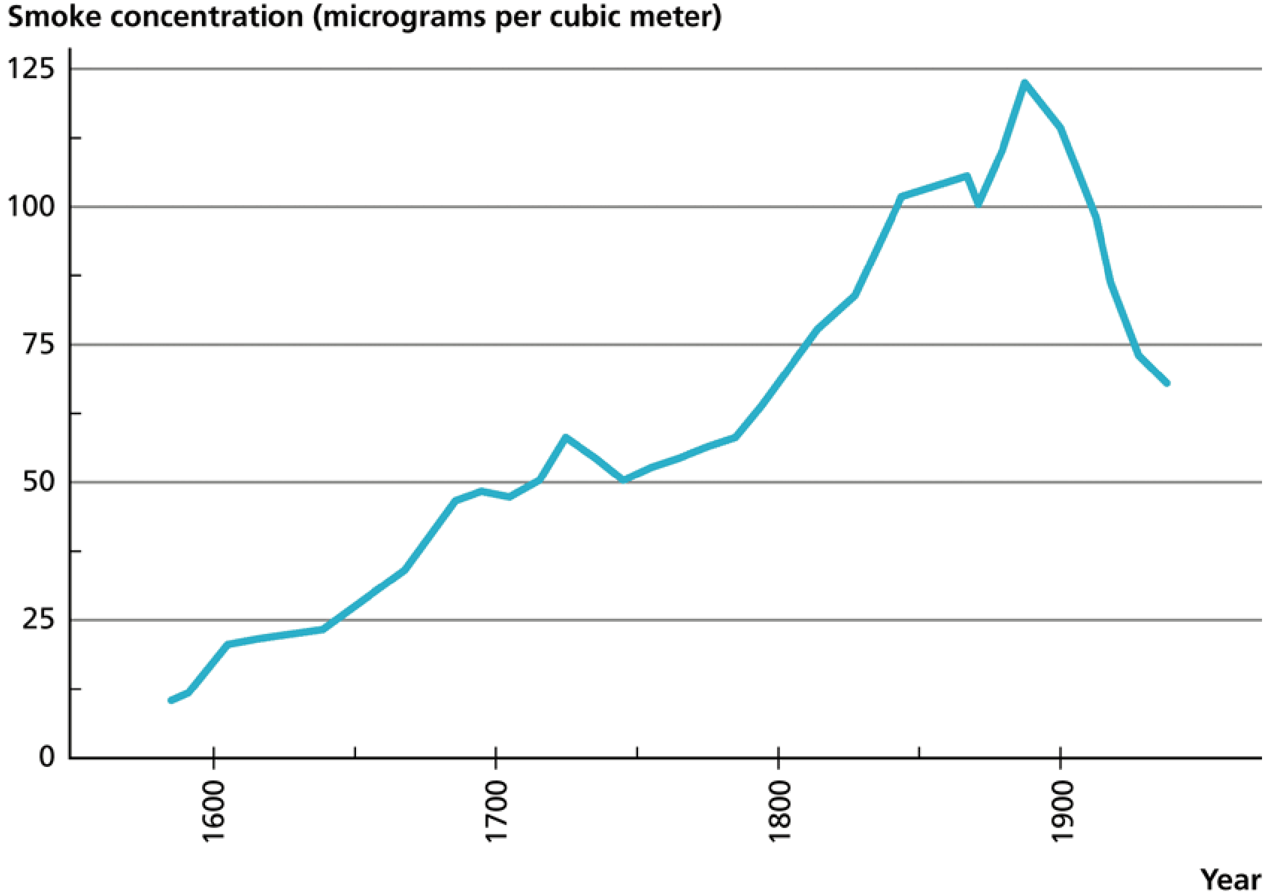
Source: BP (2007).

Figure 16.6 An Environmental Kuznets Curve



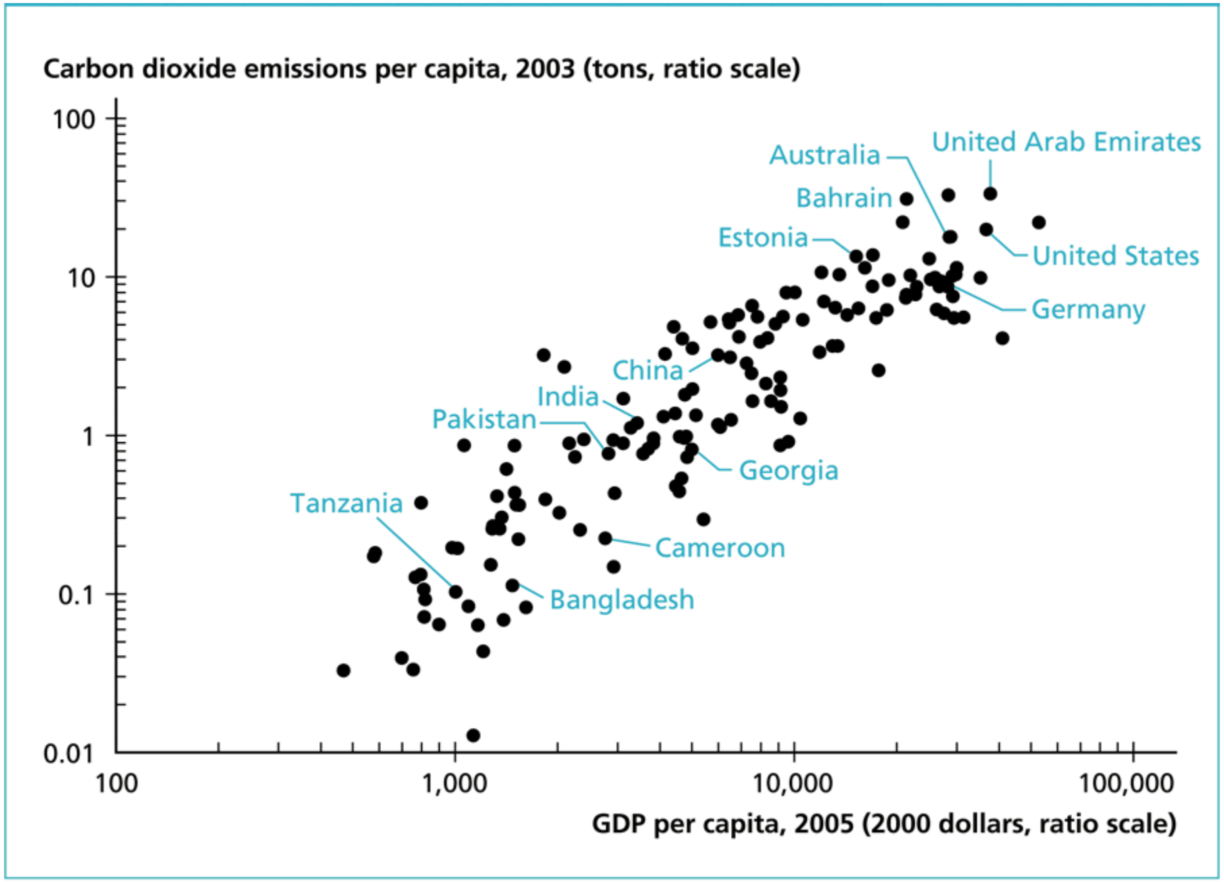
Source: Shafik (1994).

Figure 16.7 Smoke Concentration in London, 1585–1940



Source: Brimblecomb (1977), Figure 5.

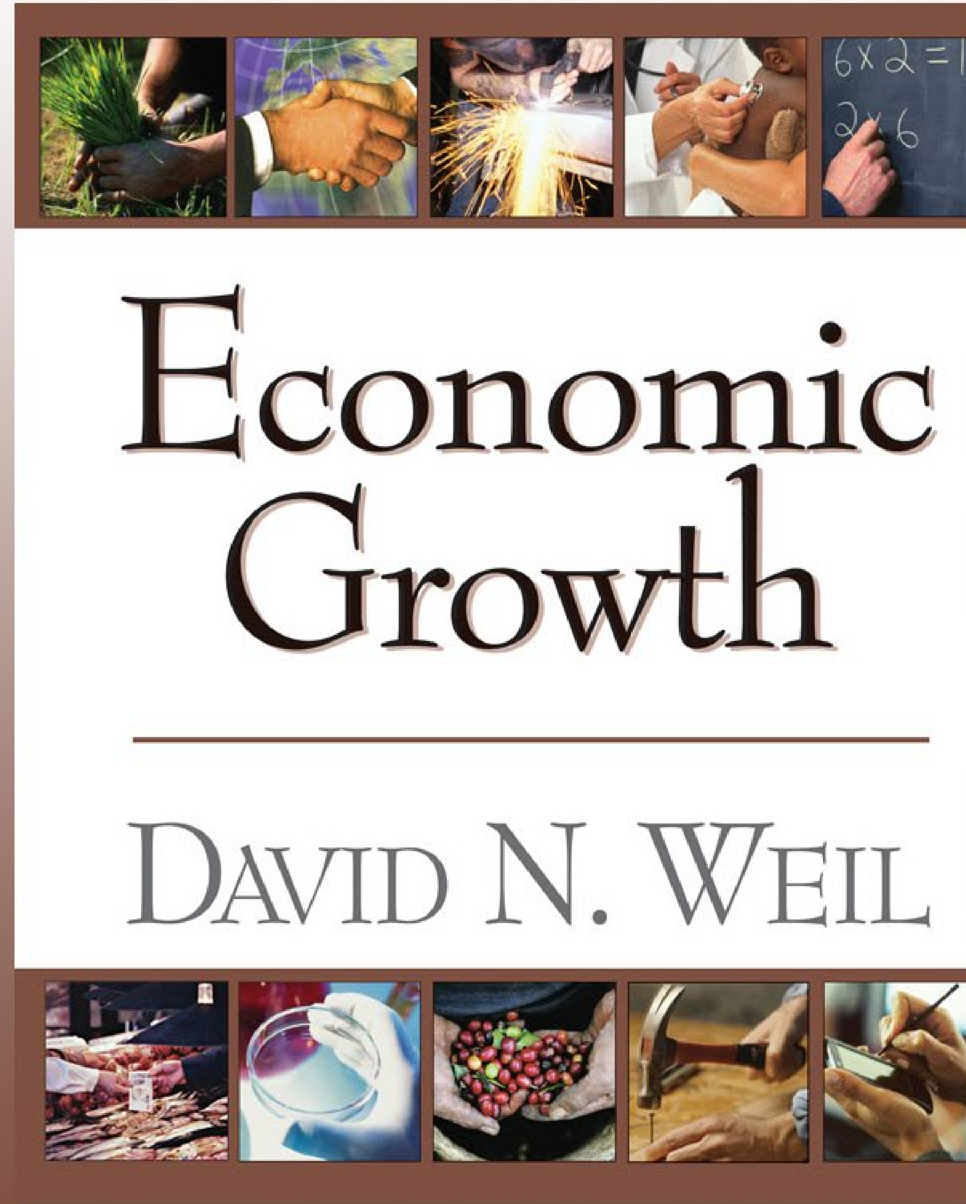
Figure 16.8 GDP per Capita Versus Carbon Dioxide Emissions per Capita



Sources: Heston, Summers, and Aten (2006); World Bank (2007a).

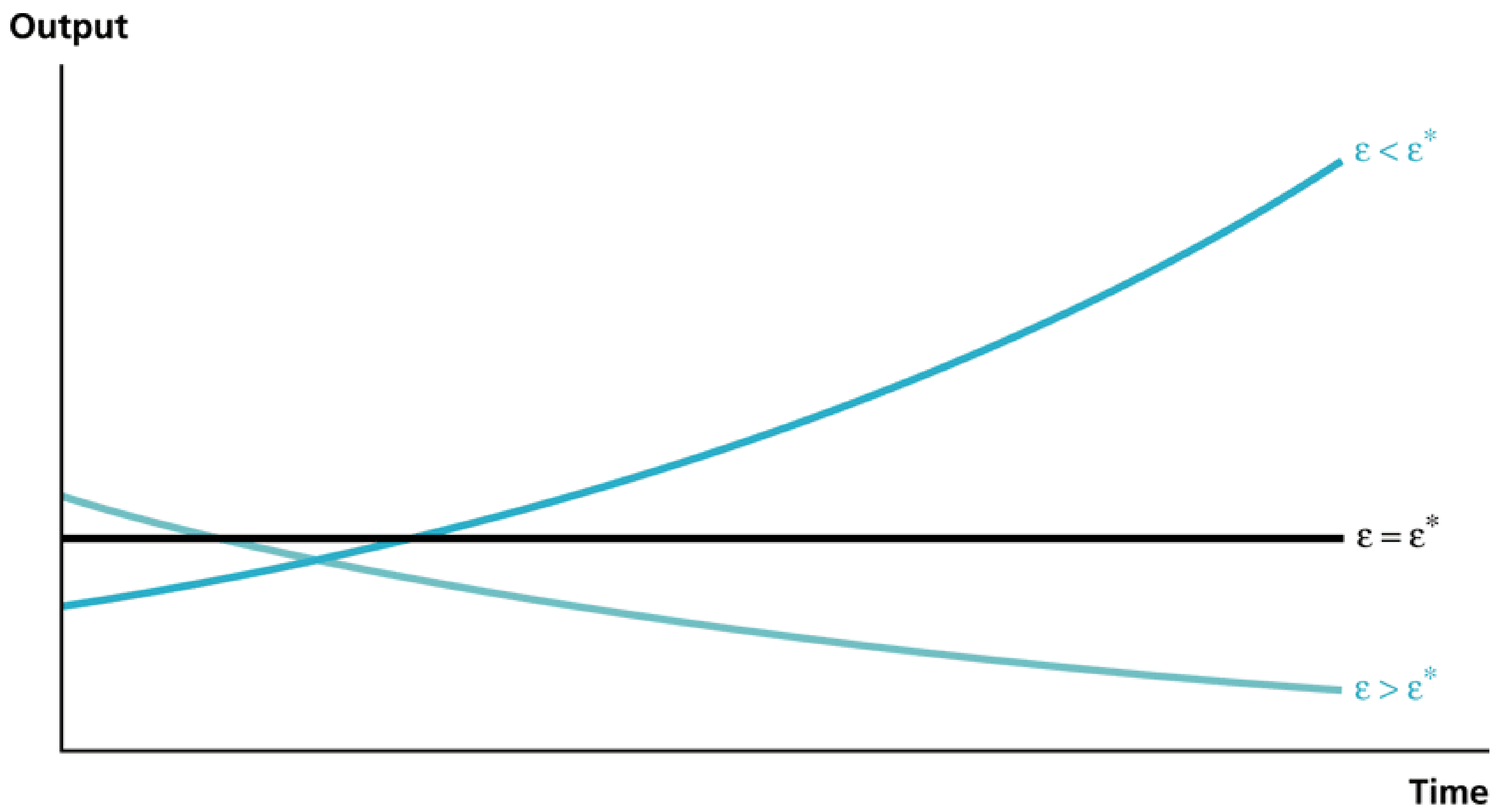
Chapter 16

Mathematical Appendix: Technological Improvement Versus Resource Depletion



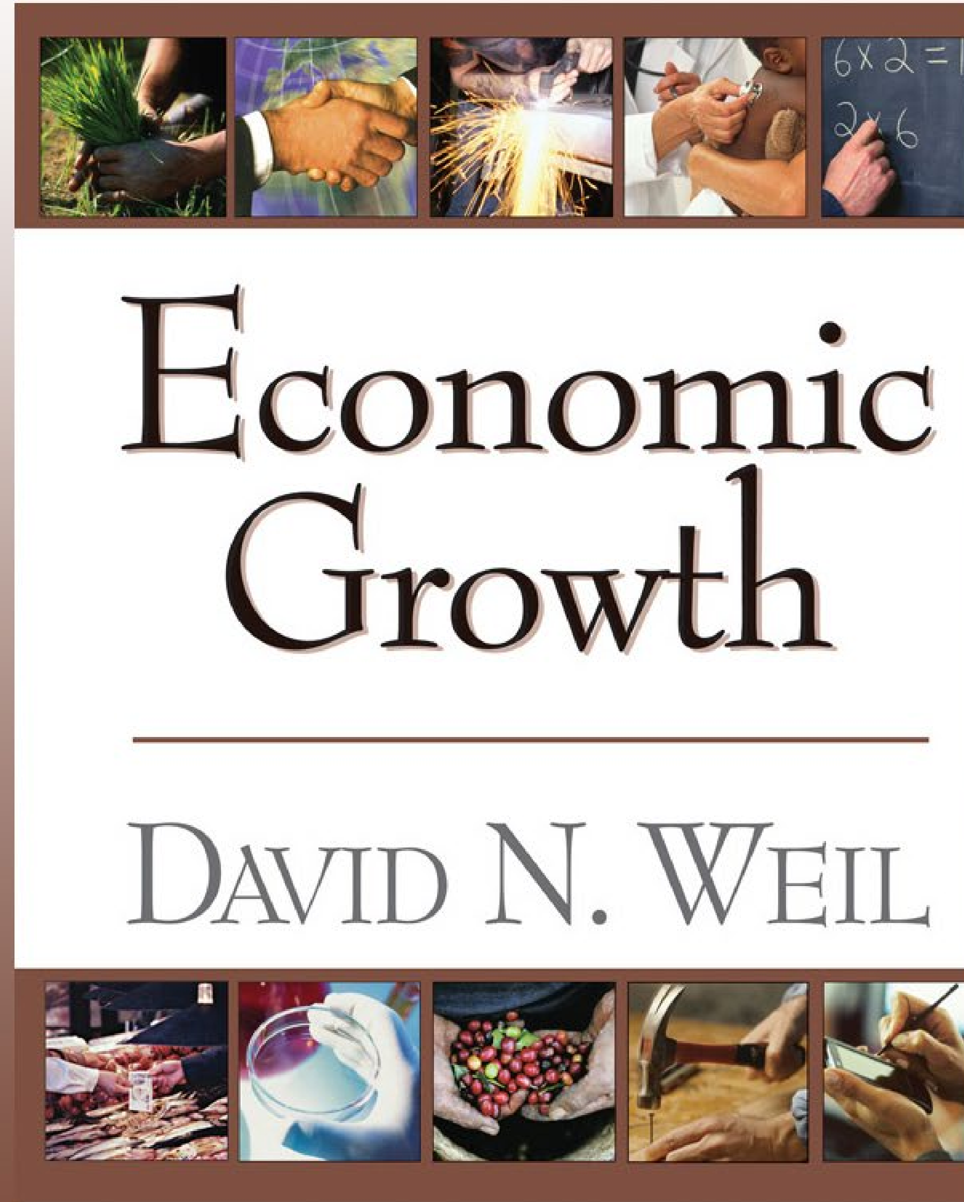
PEARSON Addison Wesley

Figure 16.9 Relationship Between Resource Use and Growth



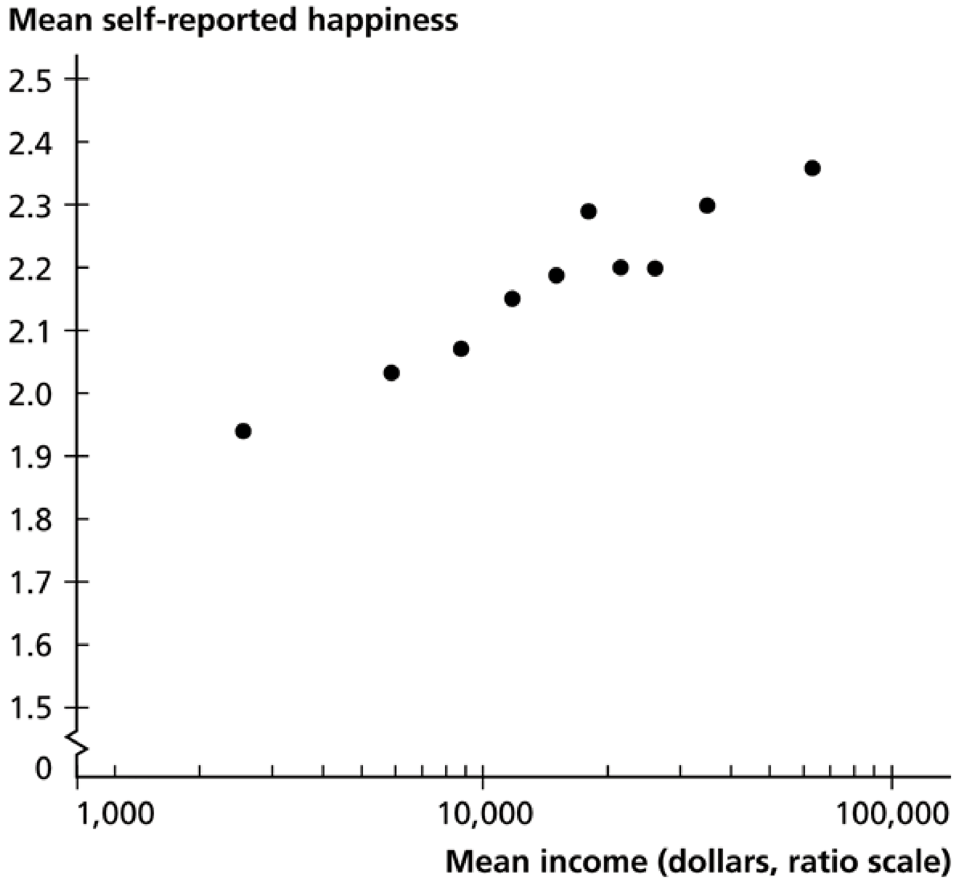
Chapter 17

WHAT WE HAVE LEARNED AND WHERE WE ARE HEADED



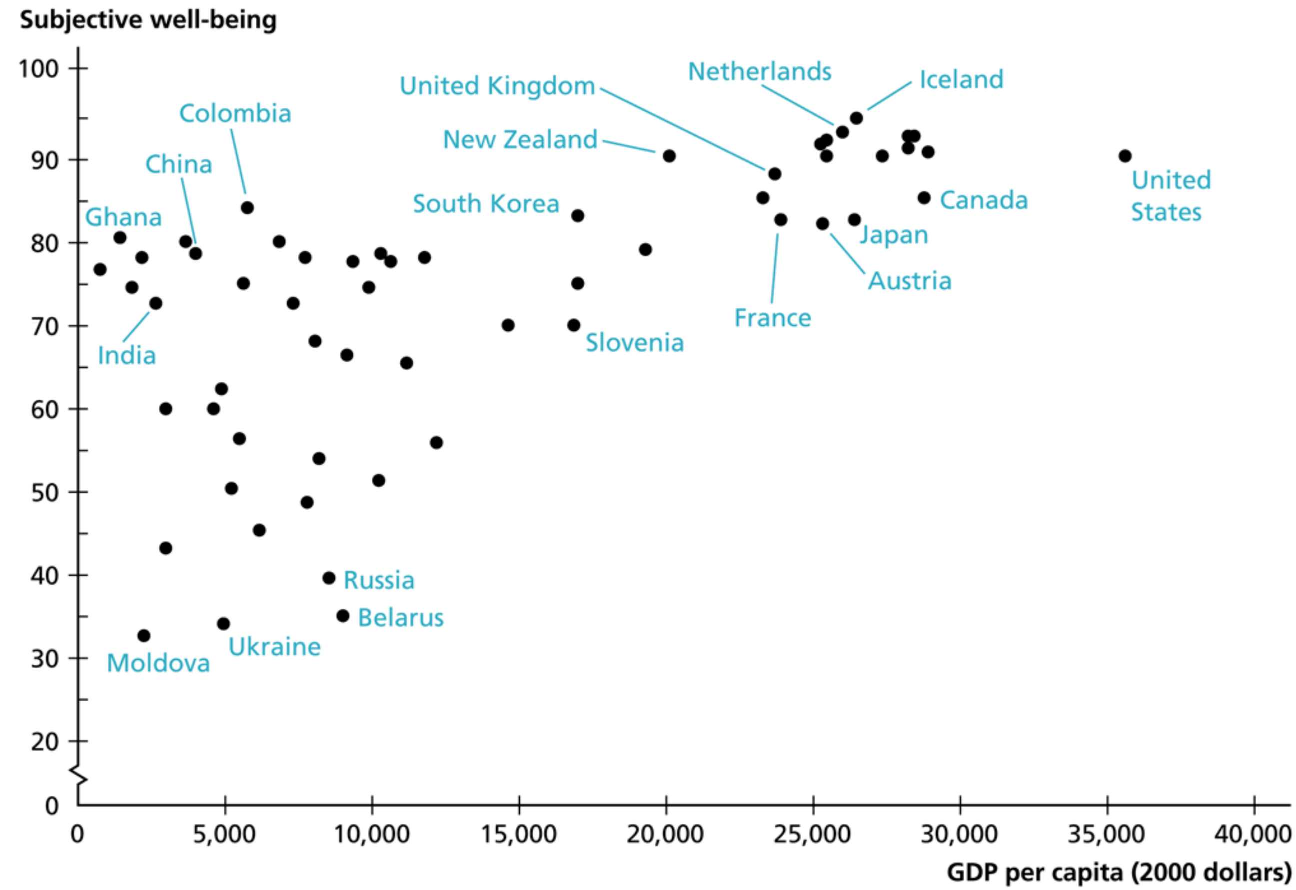
PEARSON
Addison Wesley

Figure 17.1 Relationship Between Income and Happiness in the United States



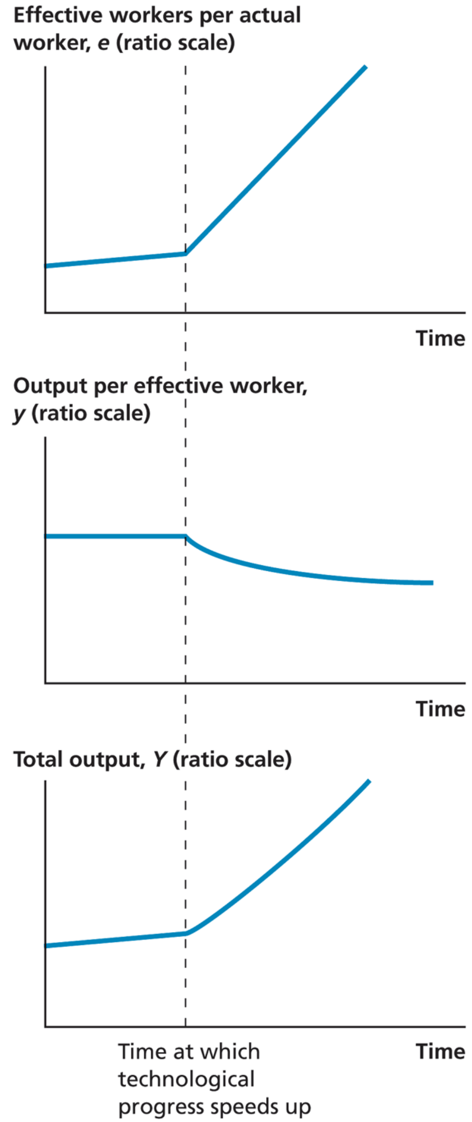
Source: Frey and Sturtzer (2002). Data are for deciles of the income distribution.

Figure 17.2 Relationship Between Income and Happiness in a Cross-Section of Countries



Source: Inglehart and Klingerman (2000), Table 7.1.

FIGURE 8.8
Effect of an Increase in Technological Progress



PPP and a Broad Sample of Countries GDP

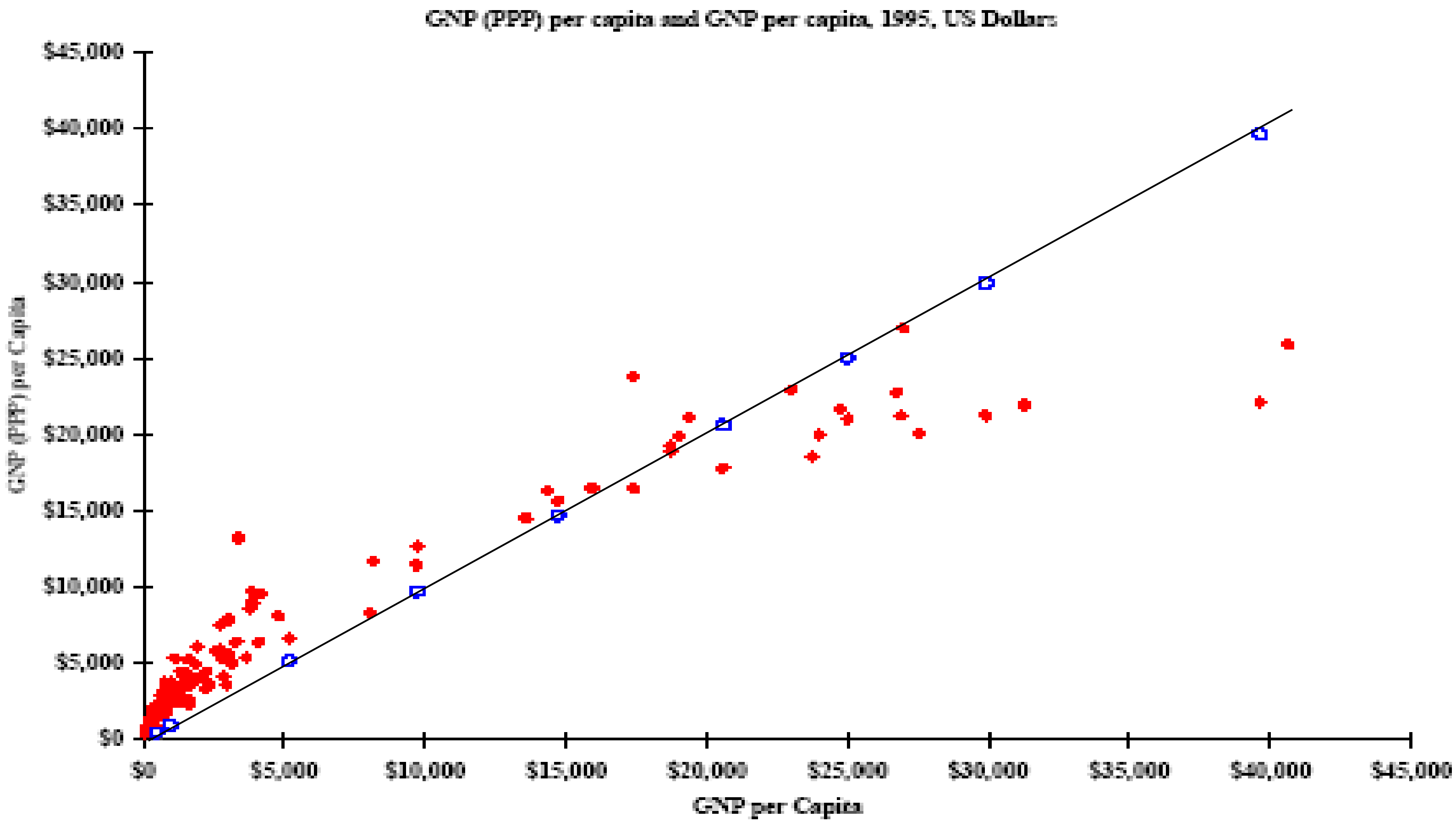


FIGURE 2.3

Relationship Between Latitude and Income per Capita

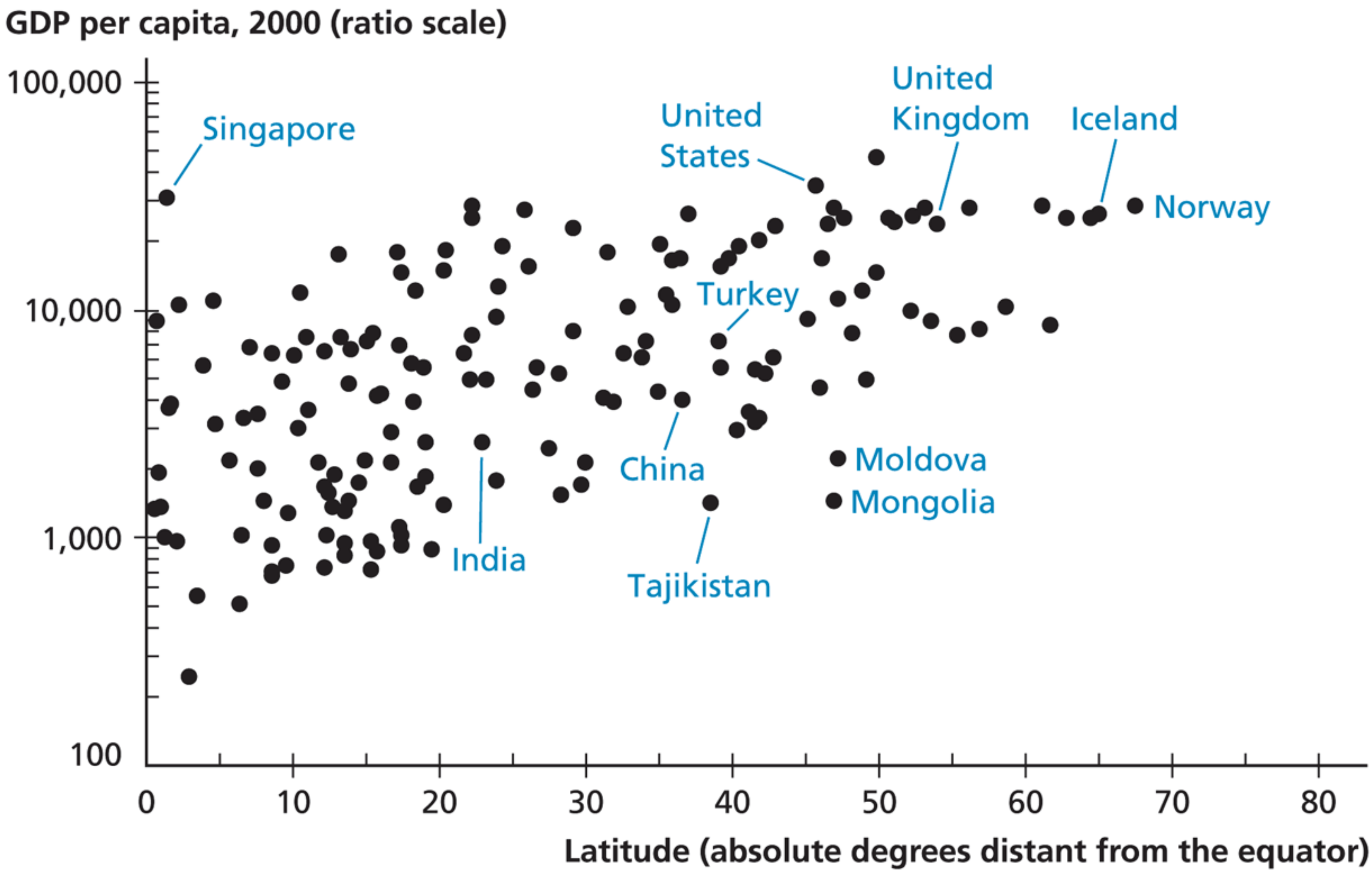


Figure 2.4
Relationship Between Income per Capita and Population Growth

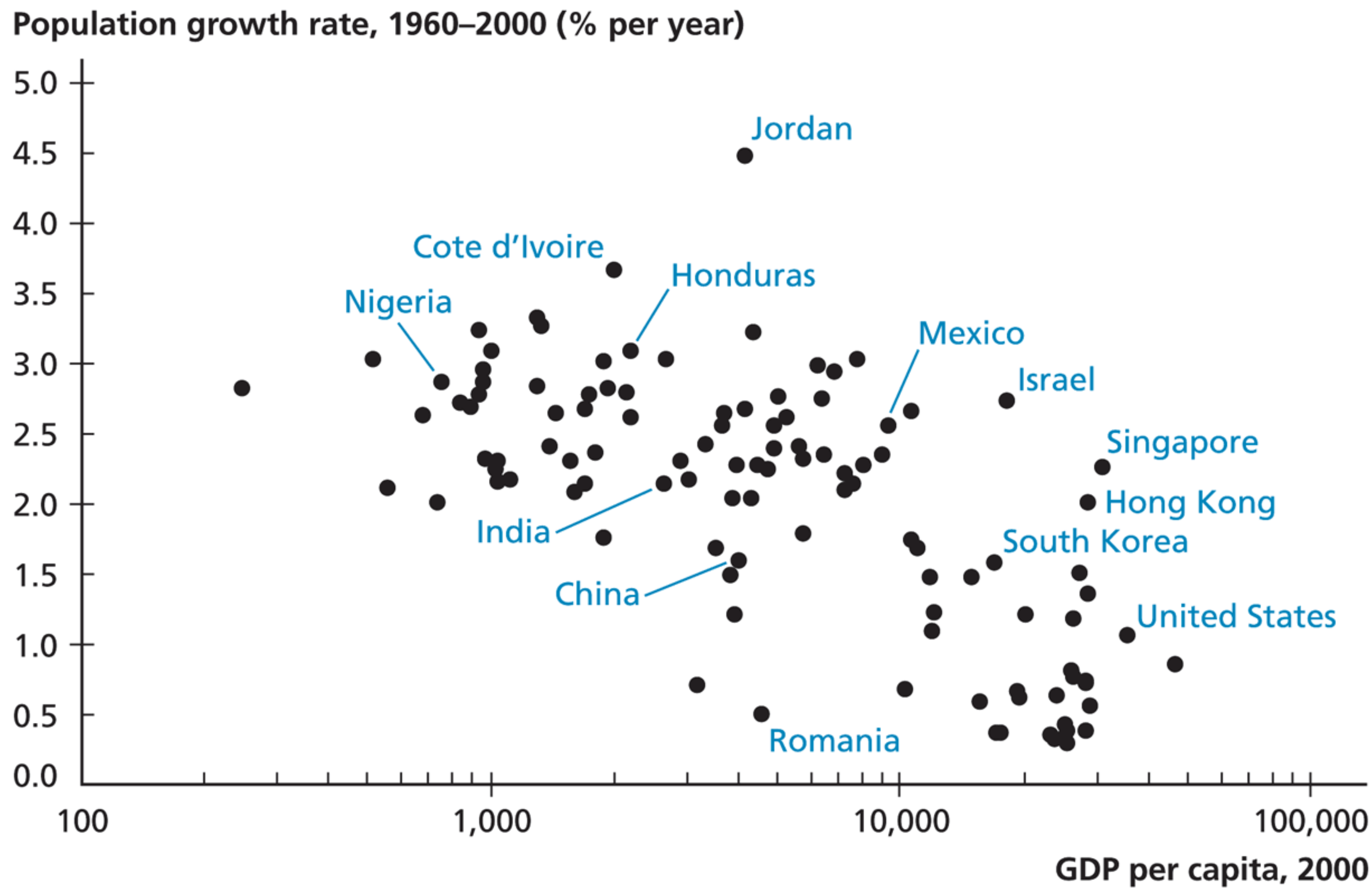
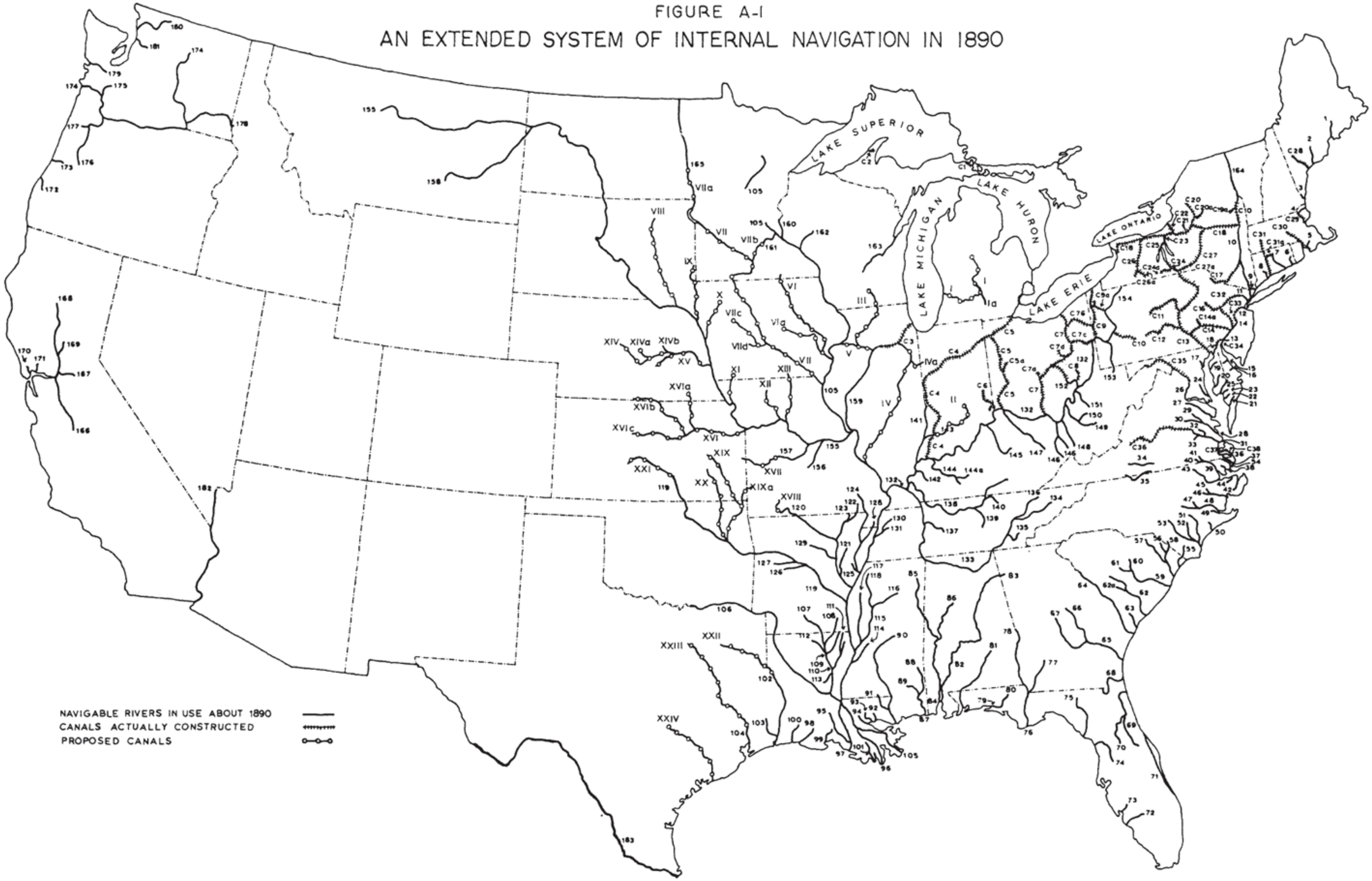


FIGURE 2.5
Fogel's Map of a Potential Water Transport Network for 1890



Source: Fogel (1964).