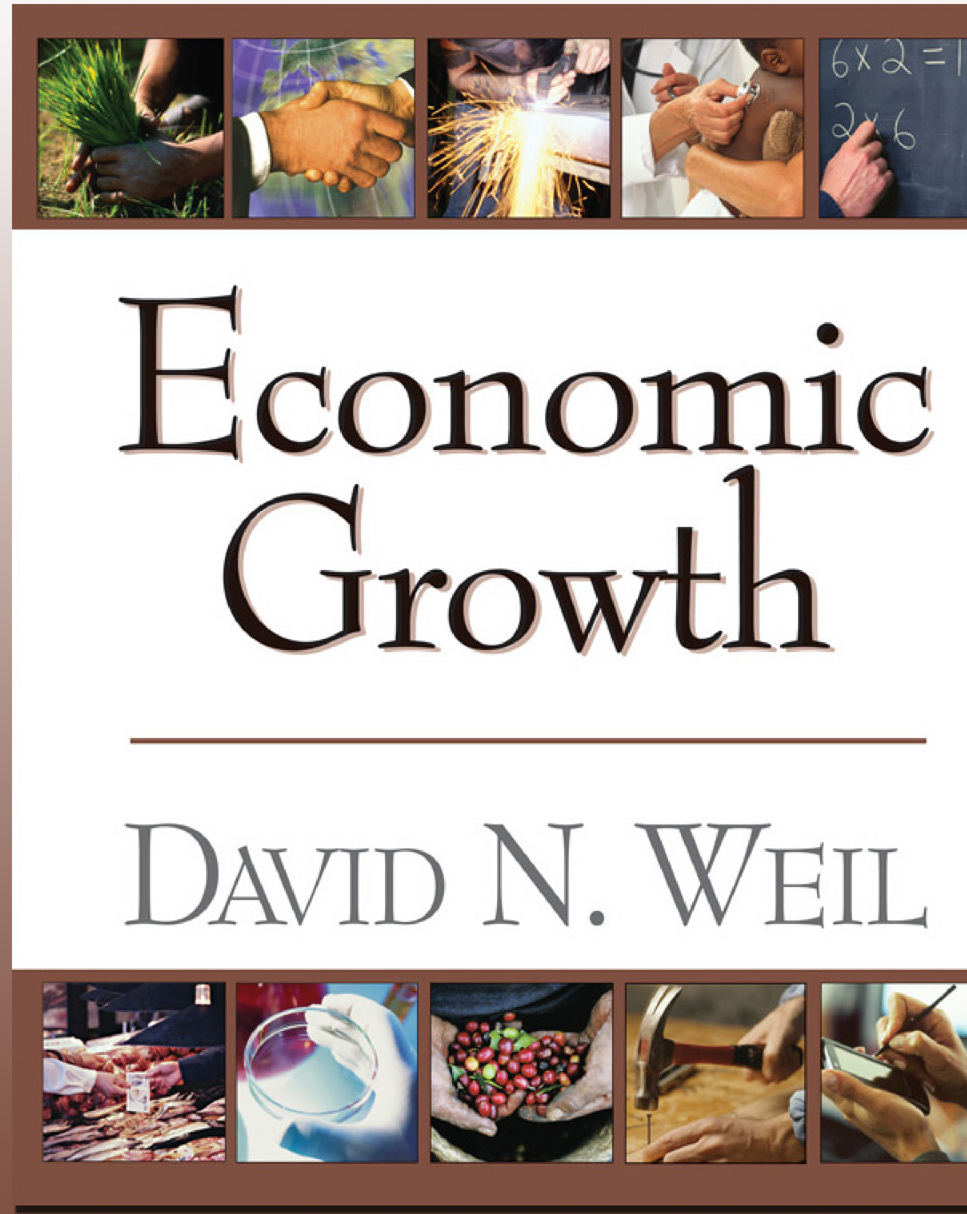
# Chapter 16

## Resources and the Environment at the Global Level



# Key Questions

- Will the limited natural resources pose a constraint to growth?
- What is the best way to manage natural resources?
- How to deal with global warming?

# 16.1 Natural Resources Concepts

- **Nonrenewable resources** – exists in fixed quantity, and once consumed it is gone forever. Examples: oil, coal, gold,…
- **Renewable resource** – replenishes itself by natural process. Examples: plants and animals, atmosphere,…
  - Problem: if too much is used, they may not renew themselves.

# Questions

- How long will the **nonrenewable** resources last? In particular how long will the oil reserves last?
- What is the best way to use **renewable** resources?

# How long will a nonrenewable resource last?

- $S_0$ – current stock
- $U_0$ – current usage
- g – annual growth rate of usage
- T – time when the resource is gone

$$S_0 = \sum_{t=0}^{T} U_0 (1+g)^t$$

$$\left( \text{Recall}: \sum_{t=0}^{T} q^t = \frac{1-q^{T+1}}{1-q} \right)$$

$$S_0 = U_0 \frac{1-(1+g)^{T+1}}{1-(1+g)}$$

$$-g \frac{S_0}{U_0} = 1-(1+g)^{T+1}$$

$$(1+g)^{T+1} = \left( 1 + g \frac{S_0}{U_0} \right)$$

$$(1+g)^{T+1} = \left(1+g\frac{S_0}{U_0}\right)$$

$$(T+1)\ln(1+g) = \ln\left(1+g\frac{S_0}{U_0}\right)$$

$$T = \frac{\ln\left(1+g\frac{S_0}{U_0}\right)}{\ln(1+g)} - 1$$

# Example: when will the oil run out?

In 2002:

$S_0$ = 1428 (billion barrels)

$U_0$ = 25 (billion barrels)

g = 1.2%

$$T = \frac{\ln\left(1 + 0.012\frac{1428}{25}\right)}{\ln(1+0.012)} - 1 = 42.763$$

# Distribution of proved (oil) reserves 1984,1994, 2004

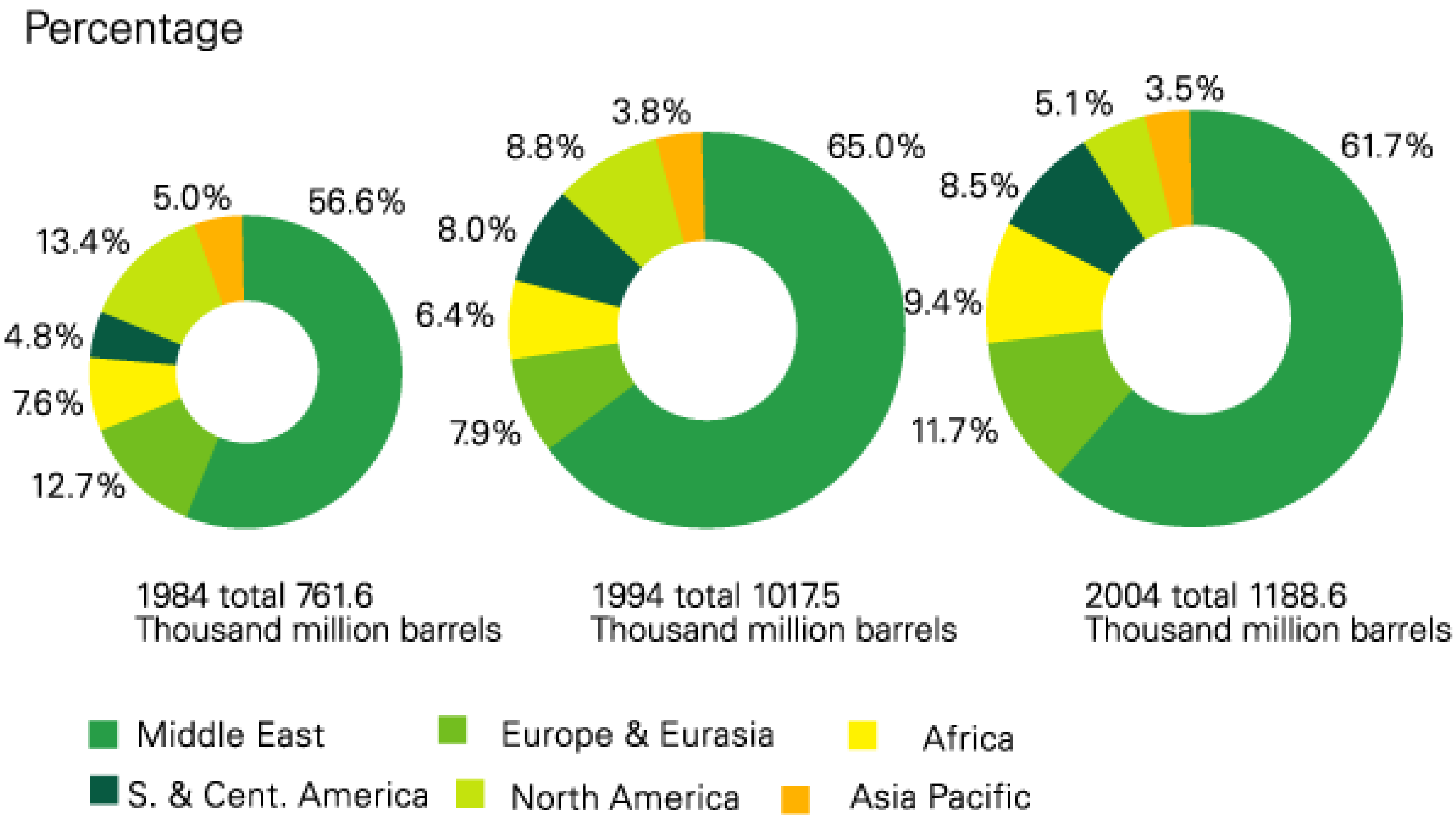
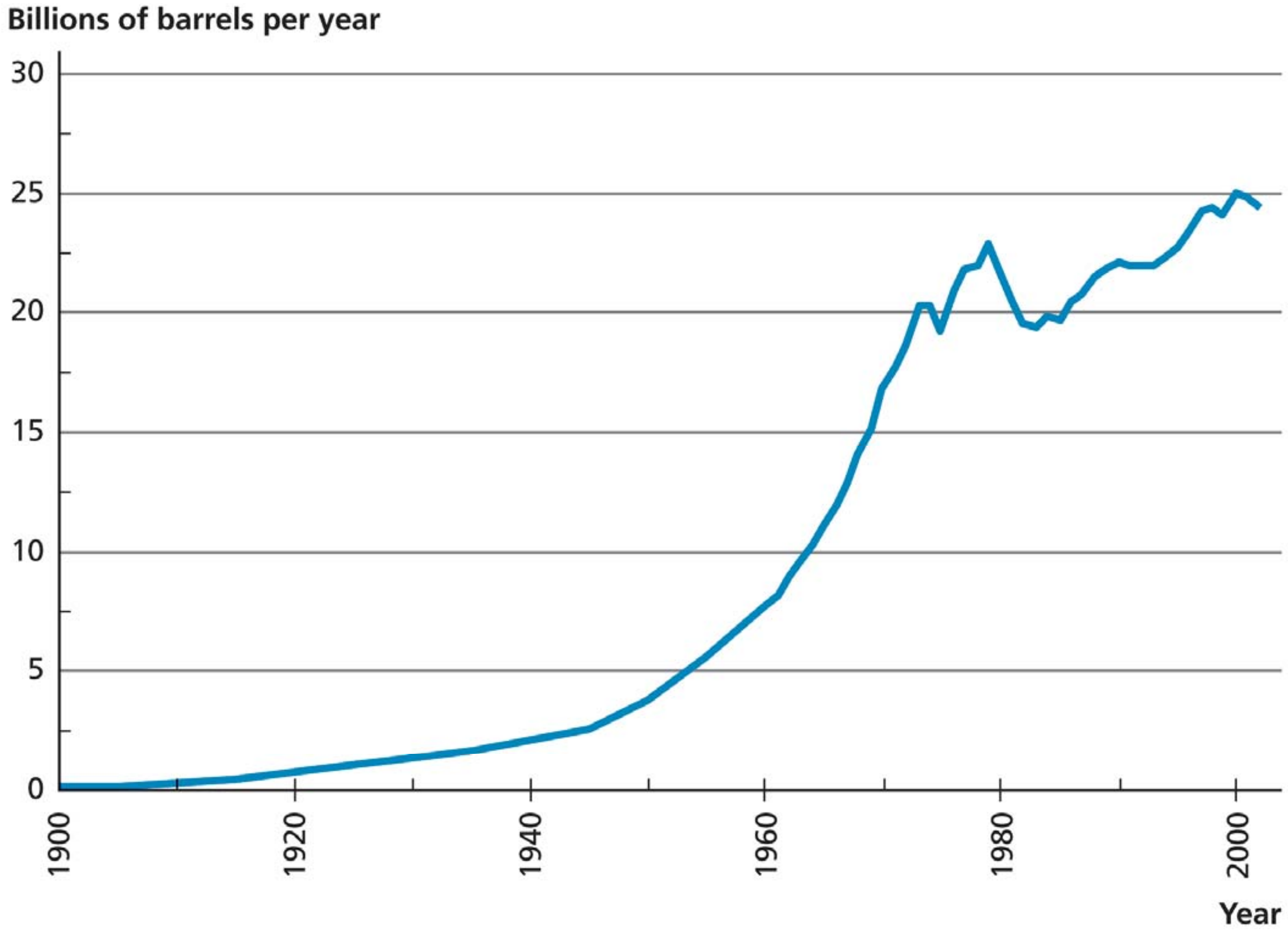


**Figure 16.1**
**World Crude Oil Production, 1900–2002**



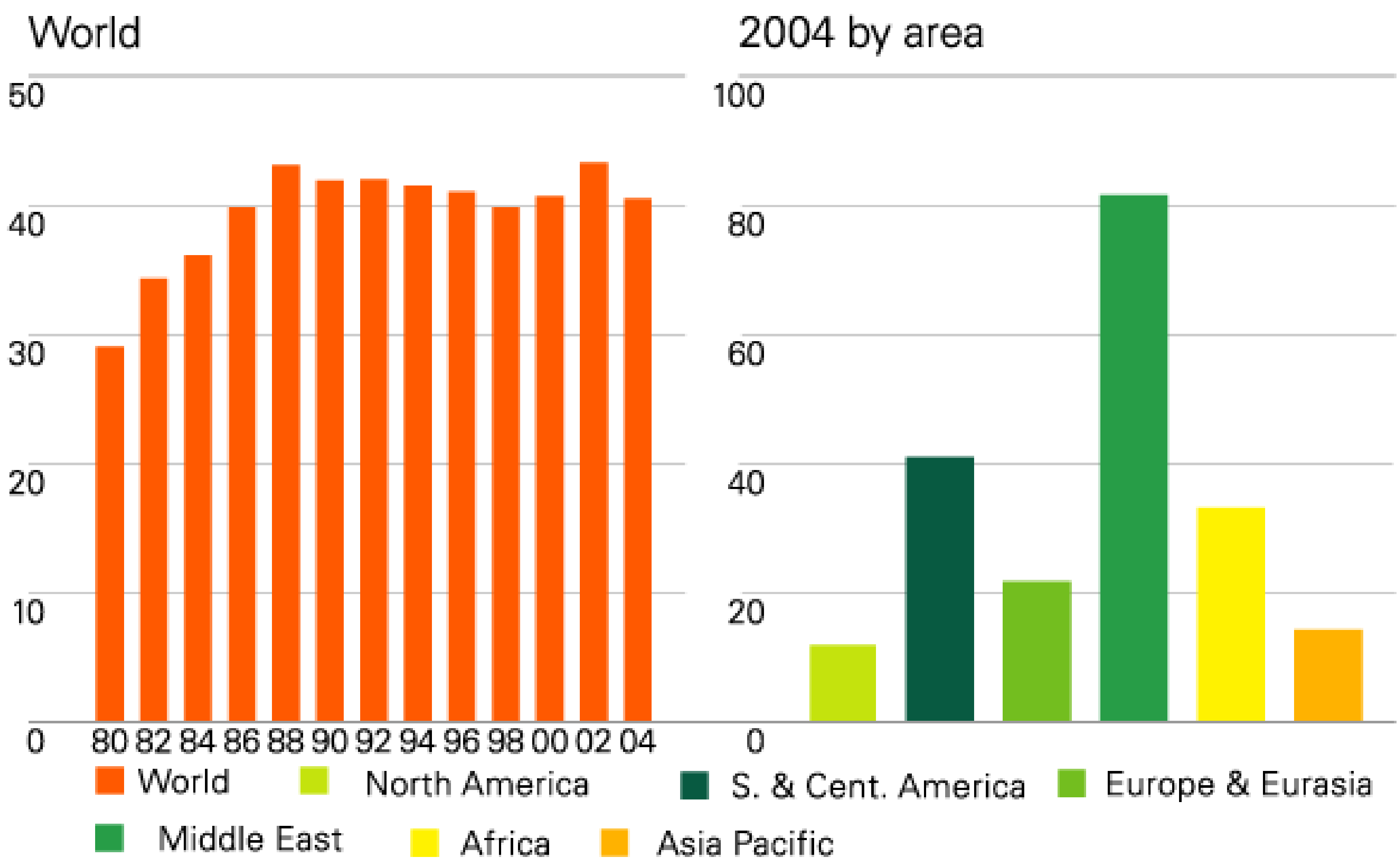

Sources: Jenkins (1977), p. 85 and Table 2; U.S Department of Energy, Energy Information Administration (2003), Chapter 11.

# Who will run out of oil first?

- The higher is the ratio of reserves to usage (*S/U*), the longer the oil will last.

$$T = \frac{\ln\left(1 + g\,\frac{S_0}{U_0}\right)}{\ln(1+g)} - 1$$

# Oil reserves-to-production (*S*/*U*) ratios




The world's oil reserves-to-production ratio fell to 40.5 years in 2004, down from 43.3 in 2002. Reserves have continued to increase and now stand 17% above the 1994 level; production is 20% higher.

## Table 16.1

### World Crude Oil Production and Reserves (Billions of Barrels)

| | 1945–1960 | 1961–1970 | 1971–1980 | 1981–1990 | 1991–2002 |
|---|---|---|---|---|---|
| Reserves at Beginning of Period | 51 | 291 | 611 | 649 | 1,009 |
| − Production | 77 | 119 | 205 | 217 | 307 |
| + Additions to Reserves | 318 | 439 | 242 | 577 | 346 |
| = Reserves at End of Period | 291 | 611 | 648 | 1,009 | 1,048 |

Sources: Adelman (1995), Table 2.2; BP (2003).

# Renewable resources

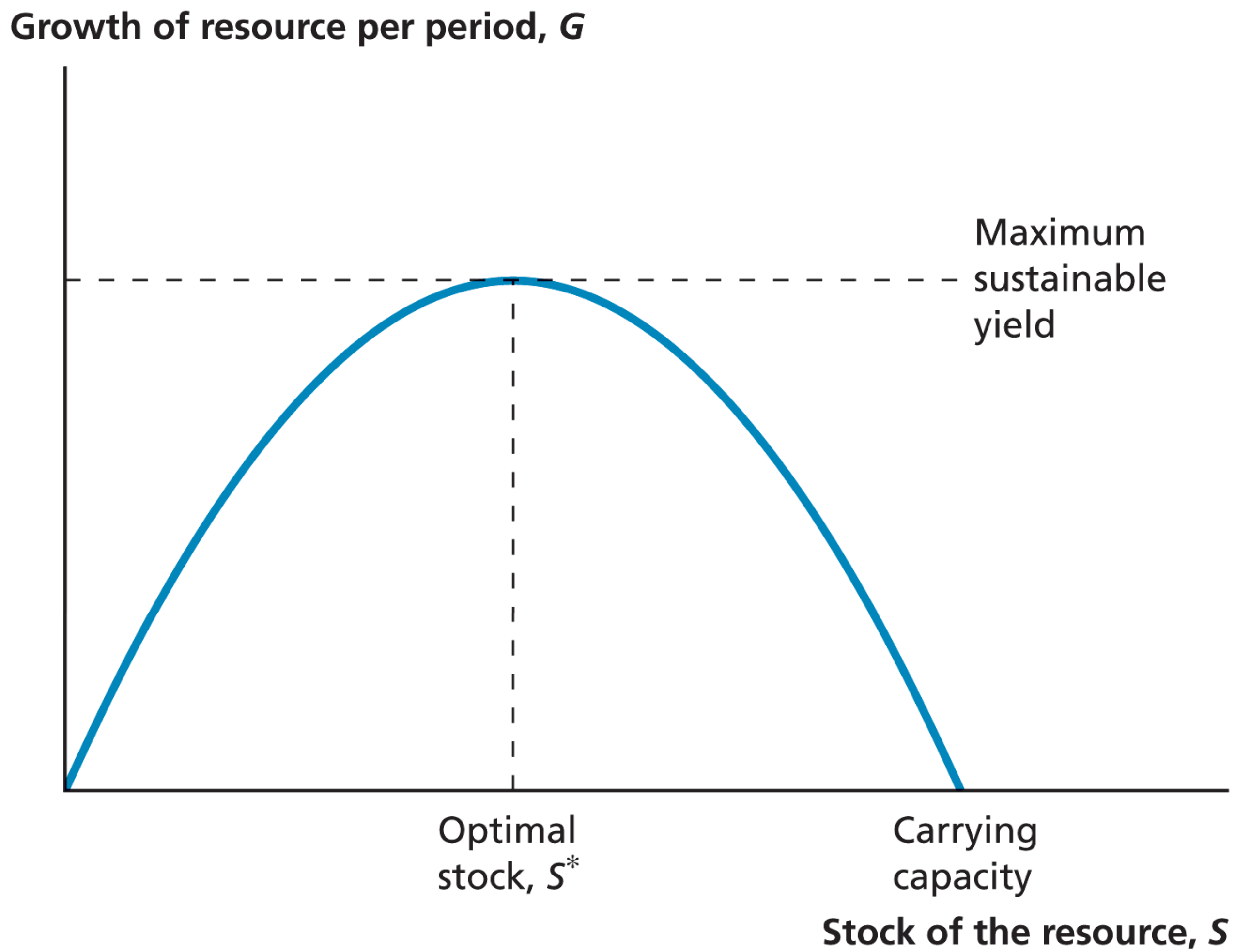
- **Renewable resource** – replenishes itself by natural process. Examples: plants and animals, atmosphere,…
- Problem: if too much is used, they may not renew themselves.

# Law of motion of renewable resource

- $S_t$ – *stock at time t*
- $G_t$ – *quantity that grows at time t*
- $H_t$ – *quantity harvested at time t*

$$S_{t+1} = S_t + G_t - H_t$$

## Figure 16.2
## Growth of a Renewable Resource



# Example: find the optimal stock and the optimal harvest.

$$G_t = \frac{S_t(100 - S_t)}{100}$$

$$\max_{S_t} 100S_t - S_t^2$$

$$100 - 2S_t = 0$$

$$S_t^* = 50$$

$$G_t^* = \frac{50(100-50)}{100} = 25$$

# Property rights over resources

- **Tragedy of the commons** – tendency to overexploit resources that are common property (whale, lakes, rivers, sea and ocean, atmosphere,…).

# Example

- There are 10 people in a village. Each person can work in the local lake or in the city. The wage in the city is $59. The revenue R, the average revenue AR and the marginal revenue MR as a function of number of fishermen is given in the next table. Assume that all the fishermen have the same skill, so that everybody will catch the same amount of fish.

# Example continued

| L | R | AR | MR |
|---|---|---|---|
| 1 | 100 | 100 | 100 |
| 2 | 190 | 95 | 90 |
| 3 | 270 | 90 | 80 |
| 4 | 340 | 85 | 70 |
| 5 | 400 | 80 | 60 |
| 6 | 450 | 75 | 50 |
| 7 | 490 | 70 | 40 |
| 8 | 520 | 65 | 30 |
| 9 | 540 | 60 | 20 |
| 10 | 550 | 55 | 10 |

# Example continued

1. If the lake is a common property, find the allocation of workers and the total income of the villagers.

- Villagers will join the lake as long as AR is greater or equal to the city wage. Thus, 9 will be fishermen and 1 will work in the city. Total income is 540 + 59 = 599.

# Example continued

2. If the lake is privately owned by one of the villagers, find the allocation of workers and the total income of the villagers.

The owner of the lake will employ fishermen as long as MR is greater or equal to the city wage (**to maximize the profit from the lake**). Thus, 5 will be fishermen and 5 will work in the city. Total income is 400 + 5*59 = 695, which is greater than in the case the lake is a common property. The reason is that when the lake is common, each additional fisherman neglects the negative externality that he has on other fishermen, i.e. the others catch less fish. When the lake is private, the owner takes these externalities into account.

# Challenging question

- In practice, we often cannot assign property rights over natural resources. But, we can achieve optimum by using government regulation, such as permits. In the previous example, find the size of the permit that would result in optimal allocation of workers between fishermen and city workers.

# Answer

- Let the required permit be T. We want the fifth fisherman to want to work in the lake, but the sixth should prefer to work in the city. Thus,

$$80 - T \geq 59$$

$$75 - T < 59$$

$$\Rightarrow 16 < T \leq 21$$

# Solutions to Inefficient Use of Commons

1. Private ownership
2. Permits

- Can these solutions be used for global warming?

# 16.2 Natural Resources and Growth

- Q: Will natural resources constrain growth?
- A: It depends.

## 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 | 2,462 | 2,110 | 569 | 0.27 |
| Lower Middle Income | 2,144 | 4,500 | 1,206 | 0.27 |
| Upper Middle Income | 497 | 8,500 | 1,805 | 0.21 |
| High Income | 950 | 26,480 | 5,430 | 0.21 |

# Resource intensity

- $R$ – resource use, $I$ – resource intensity, $y$ – GDP/cap, $L$ – population.
- Suppose that output per capita grows at 2%. If resource intensity is fixed, and population grows at 1%, then resource use must grow at 3% per year.

$$I = \frac{R}{yL}$$

$$R = IyL$$

$$\hat{R} = \hat{I} + \hat{y} + \hat{L}$$

$$or$$

$$\hat{y} = \hat{R} - \hat{I} - \hat{L}$$

# Resource Disaster: Easter Island

# Resource Disaster: Easter Island

- 400 A.D. 40 settlers
- Main resource: palm trees
- 1100-1400 A.D. 10,000 population
- 1722 A.D. 3,000 population, no trees

# Green GDP

- **Green GDP** = GDP – (value of natural capital depleted during the year).
- Green GDP only slightly smaller than the official GDP.

**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 |

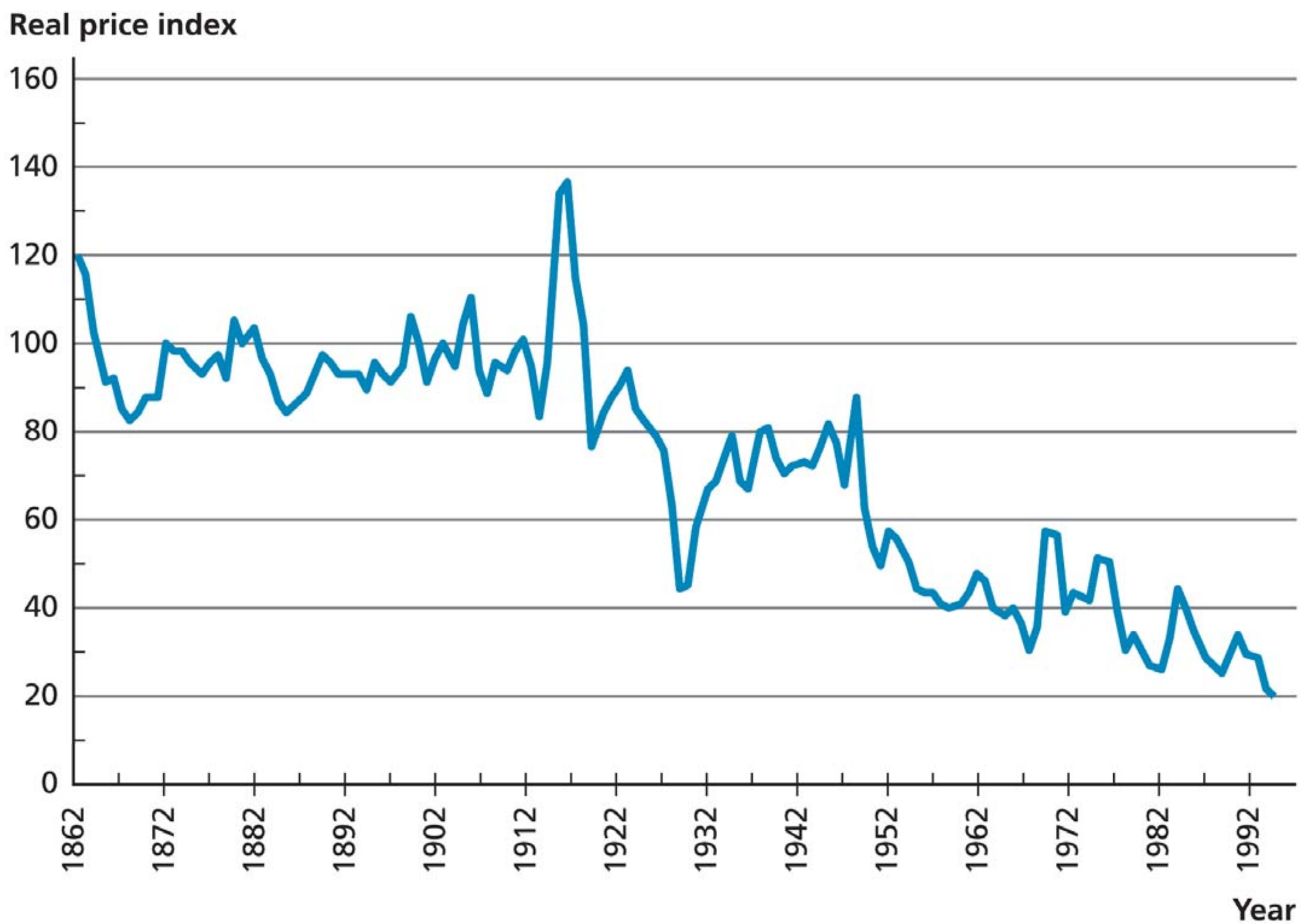
Source: Weitzman (1999). Quantities are all metric tons, except for natural gas, which is measured in trillions of joules. Prices correspond to the unit of quantity used. Data are for 1994.

# Resource prices

- **Resource prices are important:**

1. Higher prices give incentives to find substitutes.
2. High price increases the potential gain for inventing technological fix.

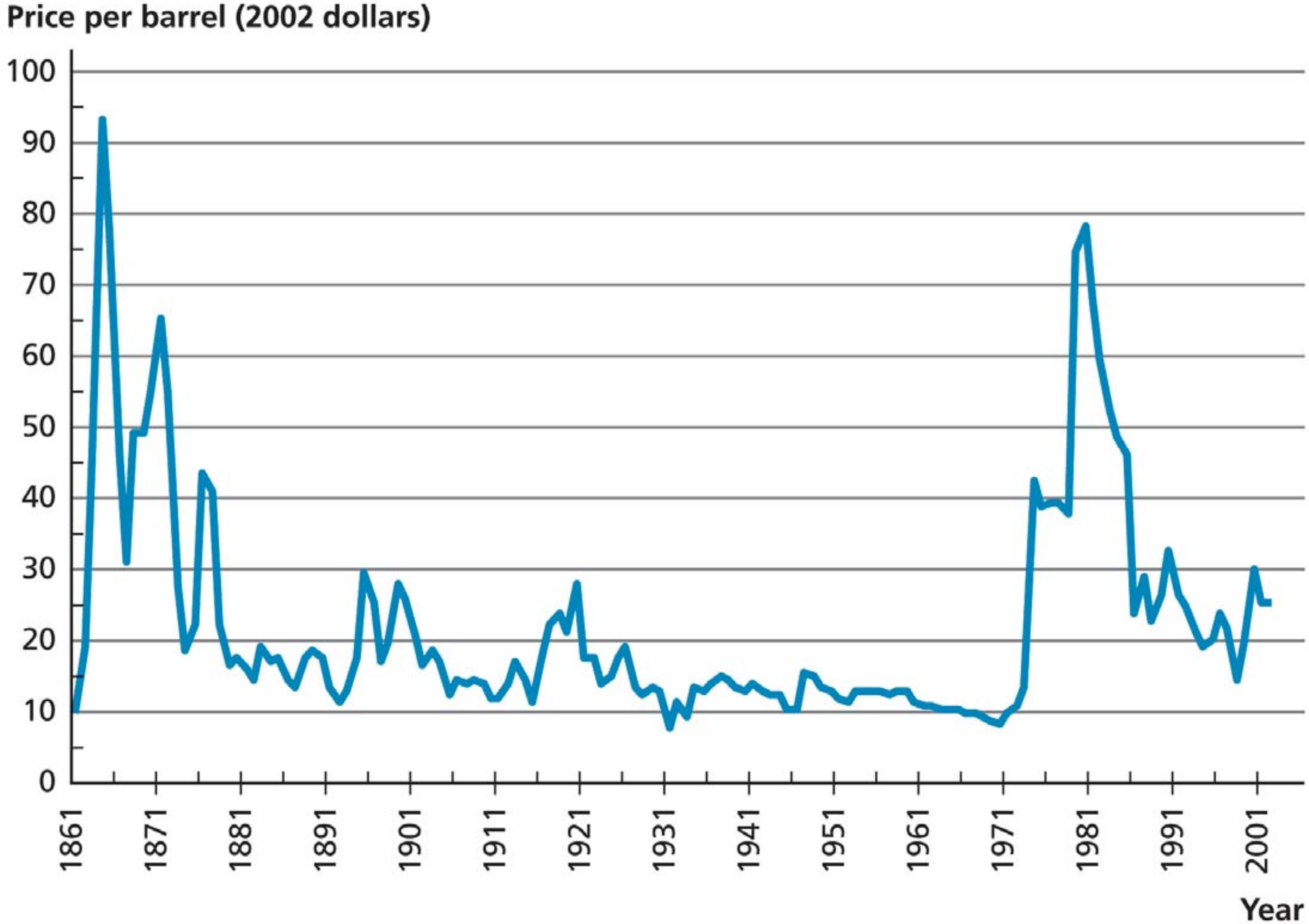
**FIGURE 16.4**
**Natural Resource Prices, 1862–1999**




Source: Cashin and McDermott (2002). Original data are from *The Economist* industrial commodity price index.

**Figure 16.5**

**Real Price of Oil, 1861–2002**




Source: BP (2003).

# Why resource limitations do not prevent economic growth?

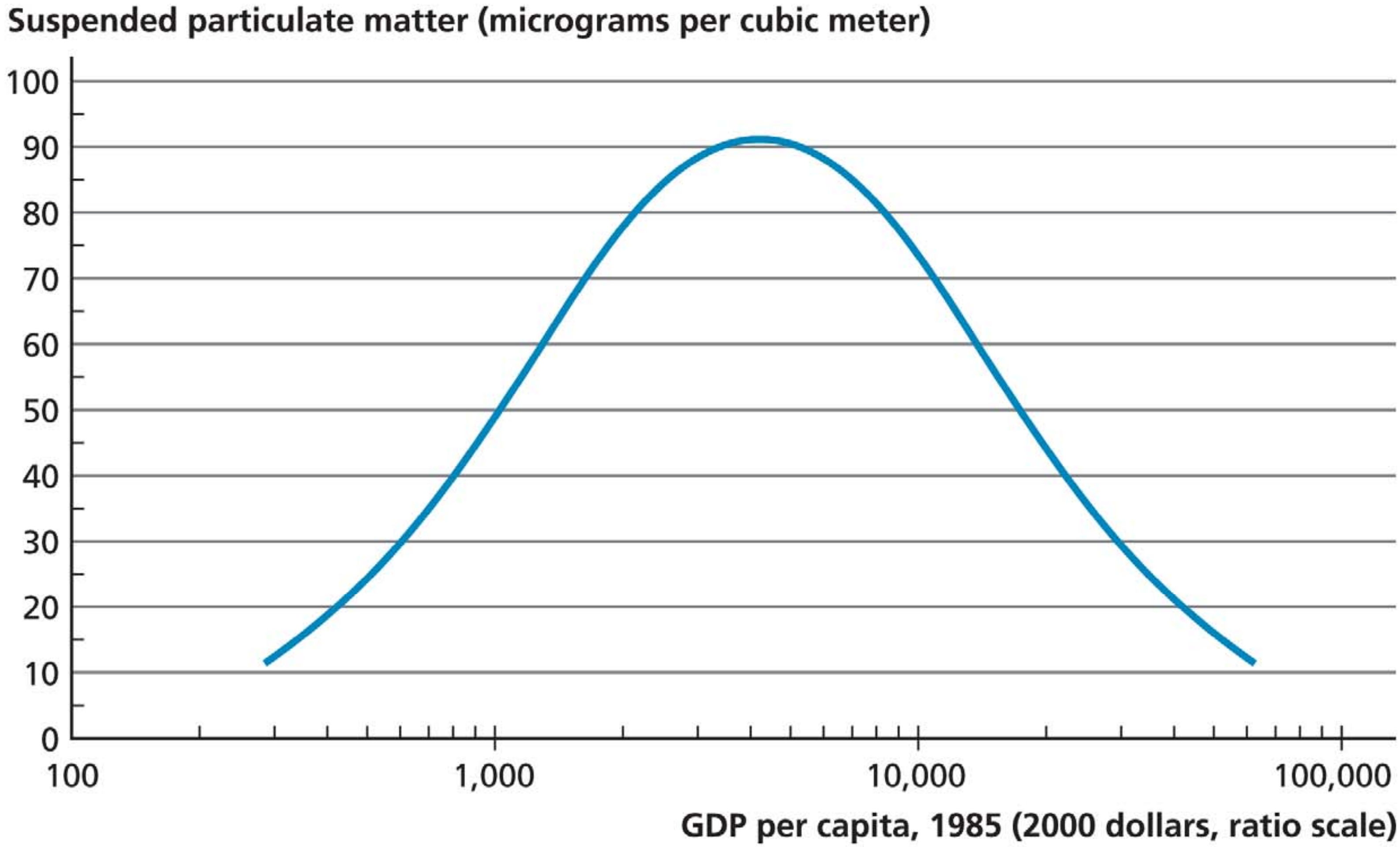
1. **Substitution.** Example: whale oil was primary source of illumination until mid 19 century. **Price elasticity of demand** – bigger in the long run.
2. **Technological progress.**

# Environmentalists vs. Economists

- **Environmentalists:** resource limitations pose constraint on growth ☹
- **Economists:** if resource prices reflect their scarcity, then when the resources run out people will find substitutes ☺

# 16.3 Growth and the Environment

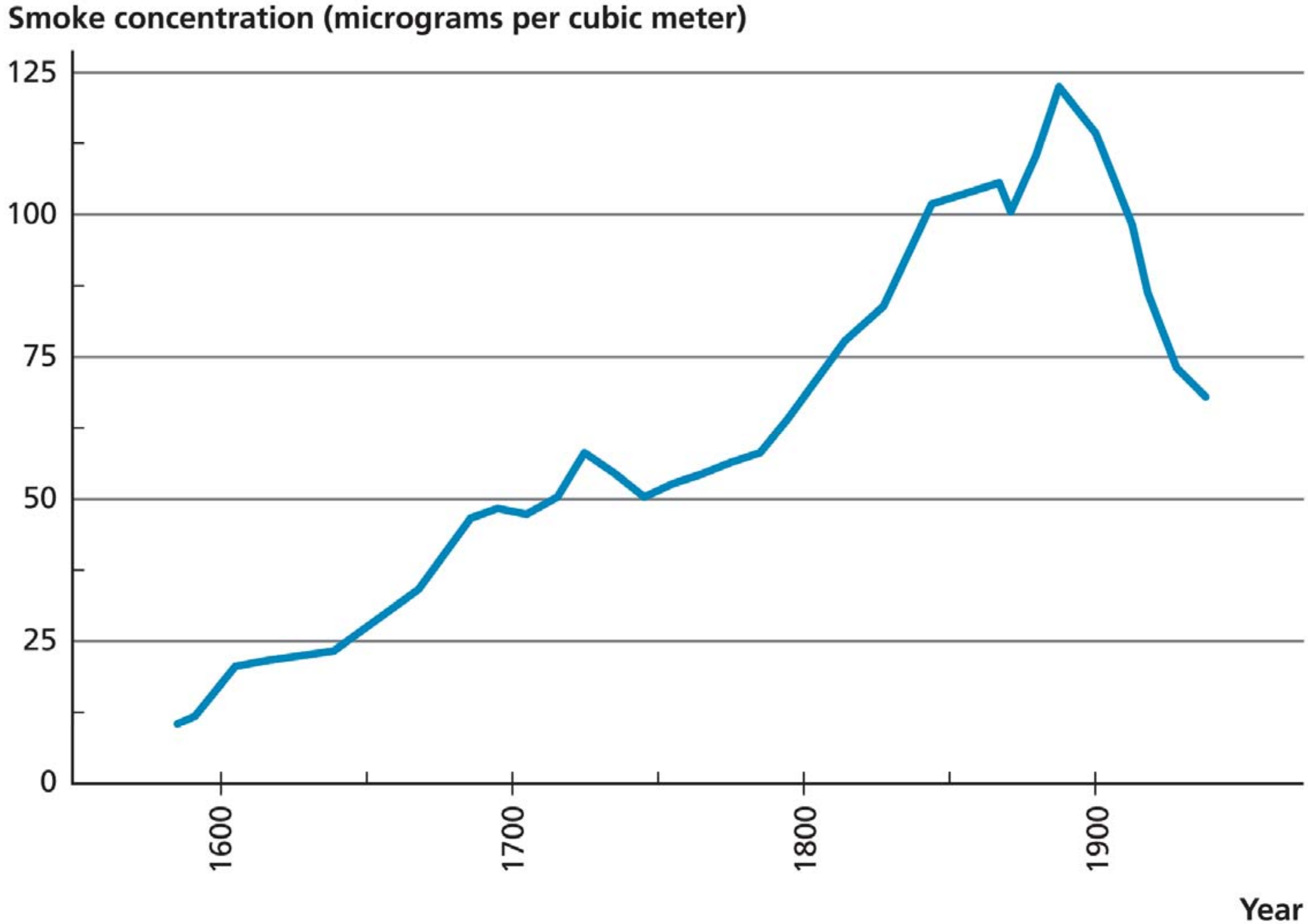
## FIGURE 16.6
### An Environmental Kuznets Curve




Source: Shafik (1994).

**FIGURE 16.7**

## Smoke Concentration in London, 1585–1940.




Source: Brimblecomb (1977), Figure 5.

# Exporting polluting industries to developing countries

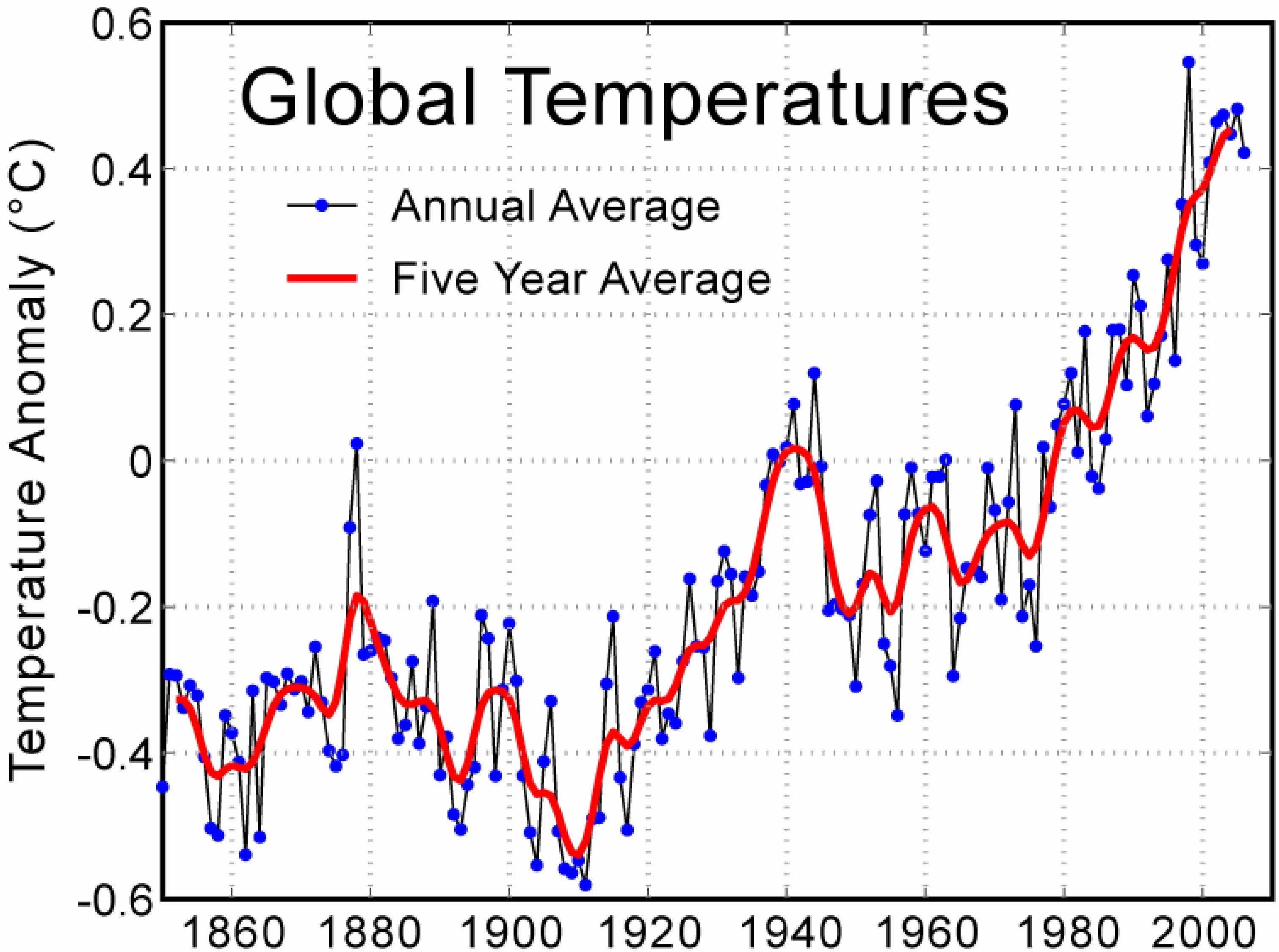
Both rich and poor countries can benefit from moving polluting industries from rich to poor:

- Clean environment is a “luxury good”, thus rich countries put higher dollar value on reducing pollution.
- The health cost of pollution are increasing in the level of pollution. Thus, the developing countries rather have the jobs and the pollution of those industries, than neither.

# Global warming

- **Global warming** – the rise in the temperature near earth in the last 100 years.

# Global warming



# Greenhouse gases in the atmosphere

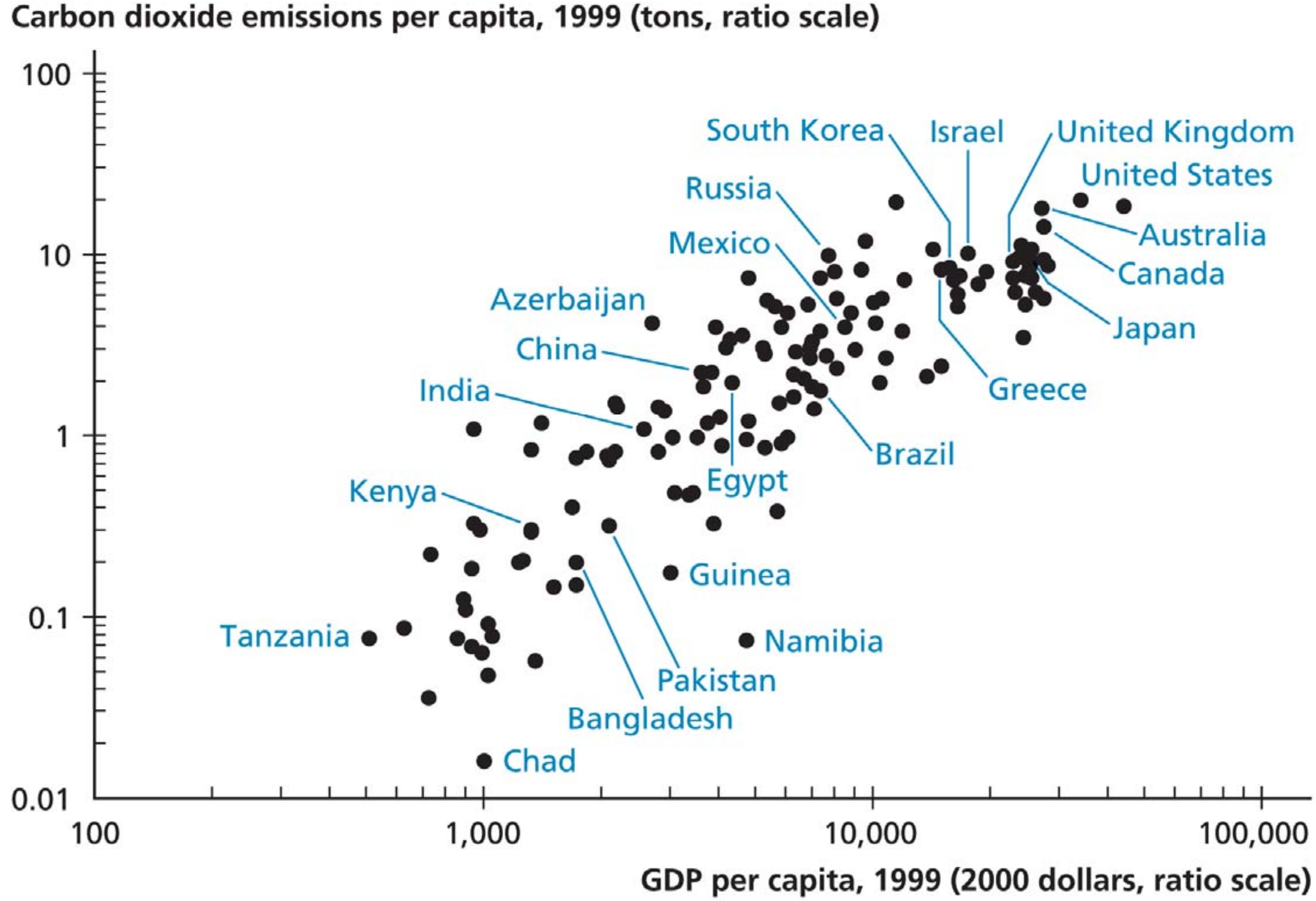
- It is the process by which absorption and emission of infrared radiation by atmospheric gases warms a planet's atmosphere and surface.
- On Earth, the major natural greenhouse gases are water vapor, which causes about 36–70% of the greenhouse effect (not including clouds); carbon dioxide (CO2), which causes 9–26%; methane (CH4), which causes 4–9%; and ozone, which causes 3–7%.

# Global warming

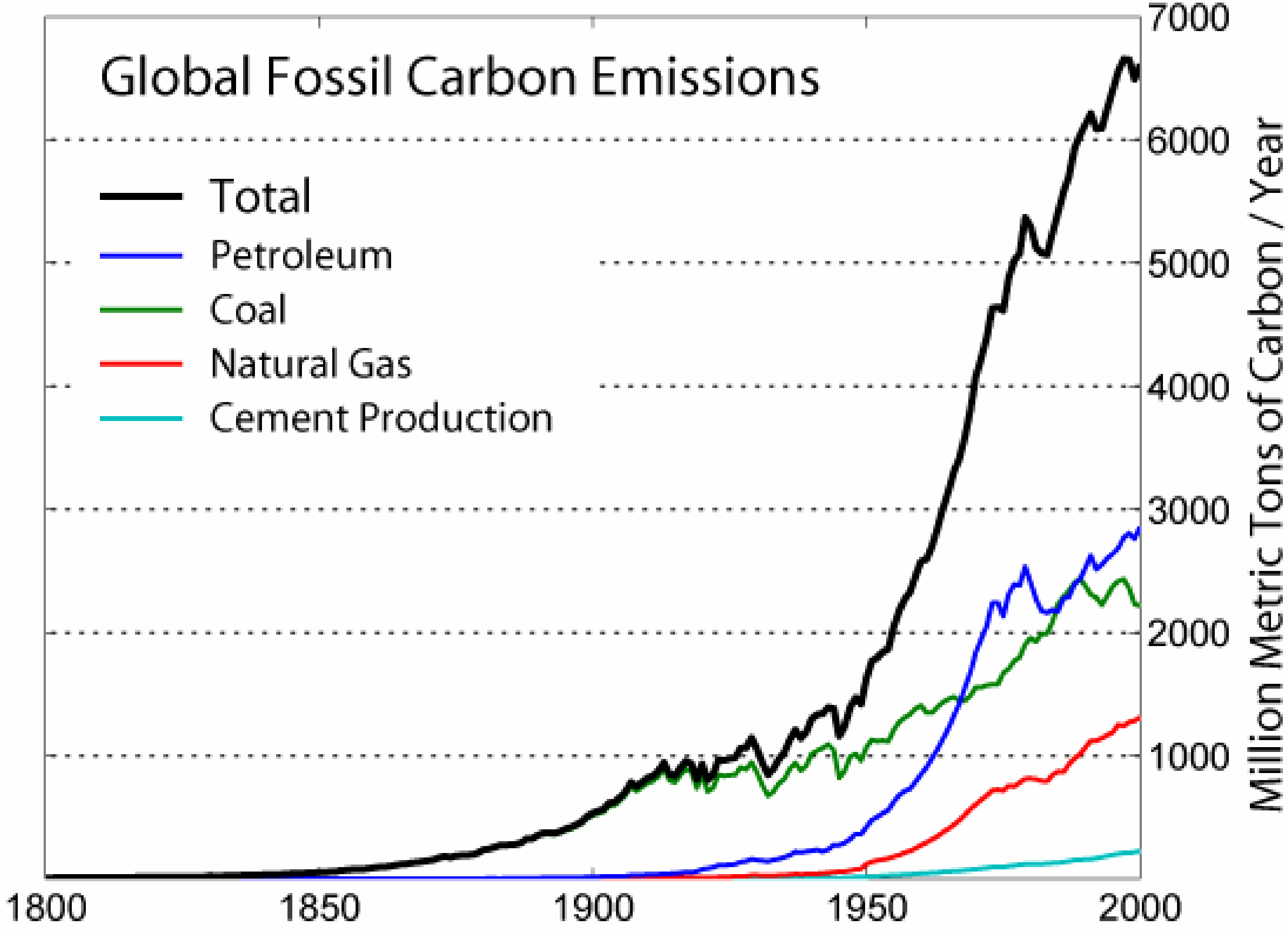
- Atmosphere is a common good, over which we cannot assign property rights. Thus, the atmosphere suffers from the **tragedy of the commons**. The problem is more severe because of the global aspect of the global warming: emissions by one country cause damage in other countries.

**Figure 16.8**

## GDP per Capita Versus Carbon Dioxide Emissions per Capita




Source: World Bank (2003b), Heston et al. (2002).



Global Fossil Carbon Emissions
Total
Petroleum
Coal
Natural Gas
Cement Production
7000
6000
5000
4000
3000
2000
1000
Million Metric Tons of Carbon / Year
1800
1850
1900
1950
2000

# Policies to reduce $CO_2$ emissions

- Key idea – need to attach a price to pollution, e.g. **carbon tax**. This tax will work just like the permit to fish in the lake. The permit makes the price of fishing to take the negative externalities into account. Higher price of emissions will encourage us to look for substitutes to fossil fuels.

# Conclusions

- So far, shortages of natural resources had little effect on growth. The key to overcoming the problem of limited resources is **prices**. As resource becomes scarce, its price goes up, increasing the incentive to find substitutes. In the absence of property rights when the resource is common, there is no price. **Governments** can and should intervene and attach a price to the resource.