MEETING 5:

"RESOURCES: SCARCITY AND ABUNDANCE"

Outline

- The supply of non-renewable resources
- Physical supply and economic supply
- Economic theory of non-renewable resource use
- Internalizing environmental costs of resource recovery
- The economics of recycling

The supply of non-renewable resources

- The planet holds a fixed quantity of non-renewable resources, including metal and non-metal minerals, oil, coal and natural gas.
- Limited non-renewable resources can not last forever but issues regarding their use are complex, involving changes in resource supply and demand as well as the wastes and pollution generated in their consumption.
- These issues are related with the concept of "entropy"
  - increased use of energy and resources (low entropy) is usually associated with greater pollution and waste generation (high entropy).

** Entropy: a measure of the unavailable energy in a system*

The supply of non-renewable resources

- **This meeting will focus on the specific aspects of the overall process that is referred as resource throughput.**
- **The first part of throughput is the extraction of non-renewable resources from available planetary supplies.**
- **What economic principles govern this process?**

Physical supply and economic supply

- The economic supply of a non-renewable resource differs from its physical supply.
- The physical supply (in the earth's crust) is finite but generally not precisely known.
- The economically recoverable reserves provide the measure most commonly used in, for example, calculations of resource lifetime. However, this figure changes over time for three main reasons:
  1. The resource is extracted and used over time, diminishing reserves,
  2. New resource deposits are discovered over time, increasing reserves,
  3. Changing price and technological conditions can make more (or less) of the known reserves economically viable. These factors make predictions of resource lifetimes an inexact science.

Physical supply and economic supply

- **A mineral resource such as copper is classified through a combination of geologic and economic measures.**

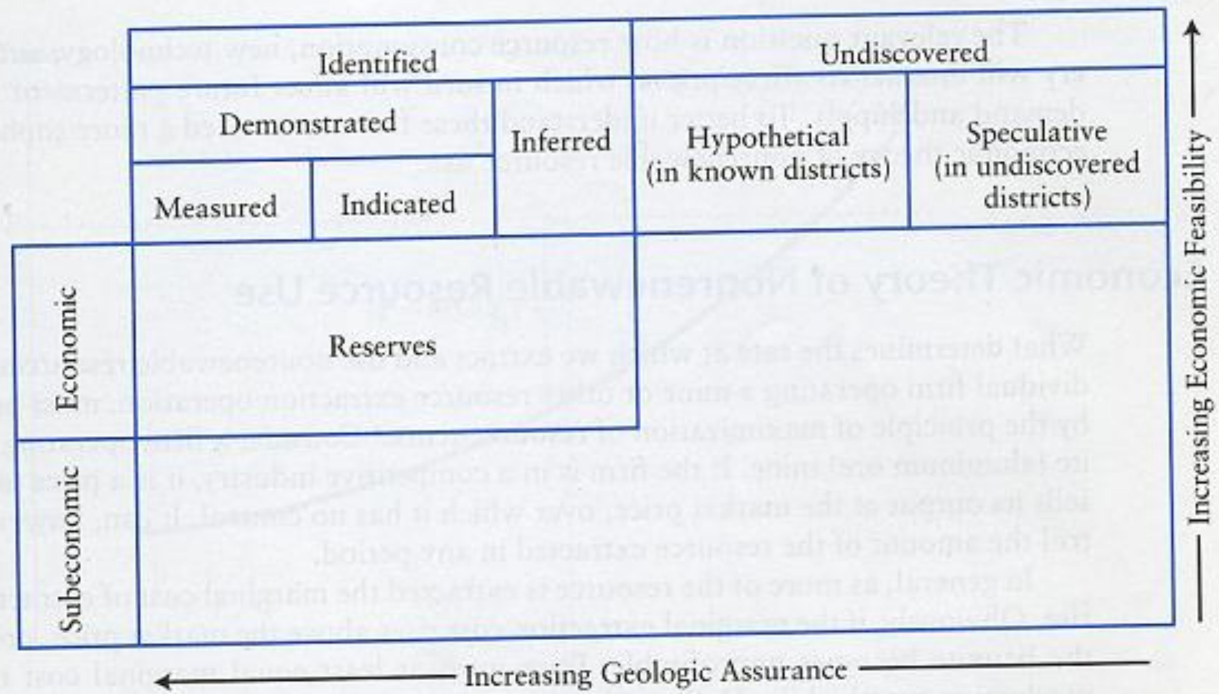


FIGURE 12-1 *Classification of Nonrenewable Resources*

Source: Adapted from U.S. Bureau of Mines and U.S. Geological Survey, *Geological Survey Bulletins 1450-A* and *1450-B*, 1976. Available at http://www.usgs.gov.

Physical supply and economic supply

- **In geological terms, resources are classified by available quantities. Identified reserves are those whose quantity and quality are already known.**
- **A portion of these identified reserves have been measured within a 20 percent margin of error; another portion are indicated or inferred based on geological principles. In addition, hypothetical and speculative amounts of the resource are yet undiscovered, but likely to exist in certain geological conditions.**

Physical supply and economic supply

- <u>Economic factors</u>, create another dimension to resource classification, shown in Figure 12-1, with the most economically profitable resources toward the top.
- Only some identified resources are of high enough quality to be profitably produced. These are identified as economic reserves.
- Subeconomic resources are those whose costs of extraction are too high to make production worthwhile.
- However, if prices rise or extraction technologies improve, these deposits may become profitable.

Physical supply and economic supply

- The fact that economic reserves can be explained in both geological and economic dimensions renders projections using a static reserve index unreliable. A static reserve index divides economic reserves by the current rate of use for an estimate of resource lifetime.

$$\text{Expected Resource Lifetime} = \frac{\text{Economic Reserves}}{\text{Annual Consumption}}$$

- With growing population and economic output, we can expect non-renewable resources use to grow. An exponential reserve index assumes that consumption will grow exponentially over time, leading to more rapid resource exhaustion.

Physical supply and economic supply

- The relevant question is how resource consumption, new technology and discovery will interact to affect prices, which in turn will affect future patterns of resource demand and supply.
- To better understand these factors, we need a more sophisticated economic theory of non-renewable resource use.

Economic theory of non-renewable resource use

- **What determines the rate at which we extract and use non-renewable resources?**
- **An individual firm operating a mine or resource extraction operation, must be guided by the principles of maximization of resource rents!**
  - ***Economic rent: is the income derived from ownership of a scarce resource. In a resource-extracting industry, the usual principle of profit maximization thus becomes the maximization of resource rents.***
- **Consider a firm operating an aluminium ore. If the firm is in a competitive industry, it is a price taker and sells its output at the market price, over which it has no control. It can, however, control the amount of the resource extracted in any period.**

Economic theory of non-renewable resource use

- **In general, as more of the resource is extracted the marginal cost of extraction will rise. If the marginal extraction cost rises above the market price, producing the aluminium becomes profitable. Price must at least equal marginal cost to make production worthwhile.**
- **Unlike other competitive industries where price equals marginal costs in equilibrium, resource-extracting firms typically operate at an output level at which price exceeds marginal cost (Figure 12-2). Such firms must seek to maximize the value of rents not just in one period, but over an extended period of time.**

Economic theory of non-renewable resource use

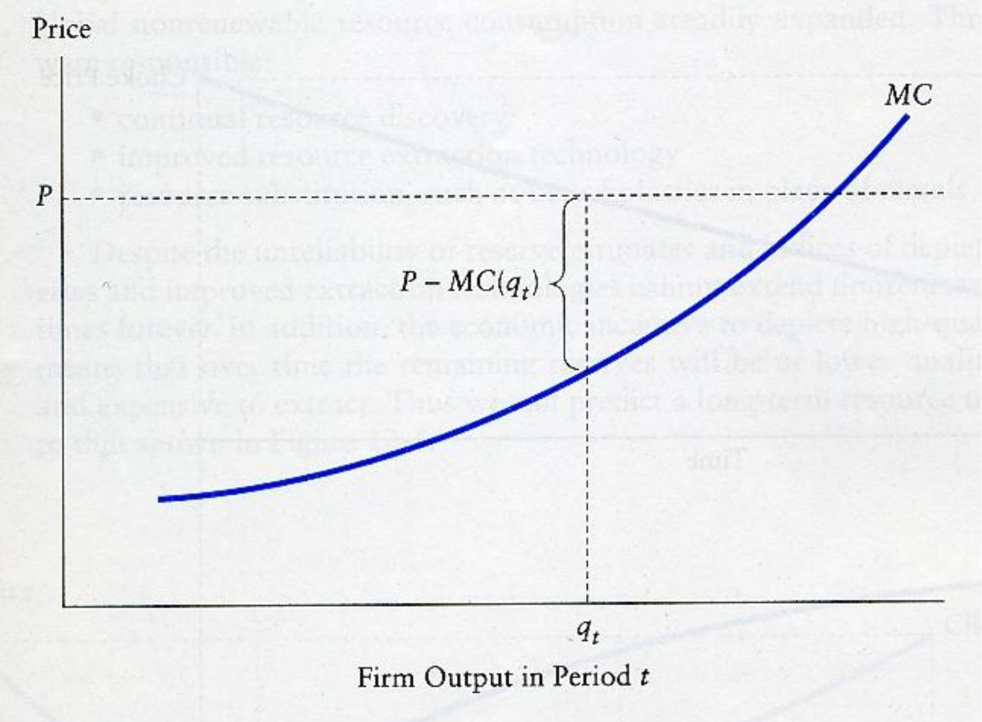


FIGURE 12-2 *Resource Rent for the Competitive Firm*[6]

- **The present value of a stream of rents extending into the future is given by:**

$PV\ [R] = R_0 + R_1/(1+r) + R_2/(1+r)^2 + R_3/(1+r)^3 + \ldots + R_n/(1+r)^n$

where R_i is the rent accruing to the firm in the i^{th} period.

Economic theory of non-renewable resource use

- **To maximize the present value of the rent stream, the firm must adjust the extraction quantity in each period until the rent rises at a rate equal to the discount rate, so that the present value of the rent in each period is the same, or:**

$$R_0 = R_1/(1+r) = R_2/(1+r)^2 = R_3/(1+r)^3 = \ldots = R_n/(1+r)^n$$

When all the firms in a resource-extracting industry operate in this principle, the rent, or net price (price – extraction costs) must rise over time.

This means: if production is very profitable today, firms will produce more. However, the increased production will lower today's price while the reduced reserves available for future production will raise expected future prices!

Economic theory of non-renewable resource use

- If marginal extraction costs fall over time, perhaps due to improved technology, net price may rise while the market price of the resource declines. However, if extraction costs are stable, we would expect the market price of the resource to rise over time.
- The principle of rent maximization has a more immediately relevant implication: higher-quality resources will be exploited first! Why? …
  - Resources that are subeconomic today can become economic in the future, possibly increasing the amount of economically recoverable reserves – at the same time that extraction has diminished the physical reserves.

Economic theory of non-renewable resource use

- The basic theory of non-renewable resource extraction also implies that limited resource stocks will be exploited to exhaustion. So long as the price continues to rise, delaying some production will remain profitable. But every resource has some maximum price, called the choke price, at which the quantity demanded falls to zero.
- By the time the choke price is reached, producers will have extracted and sold all economically viable reserves. Figure 12-3 shows the price path and extraction path for a resource stock being exploited to exhaustion.

Economic theory of non-renewable resource use

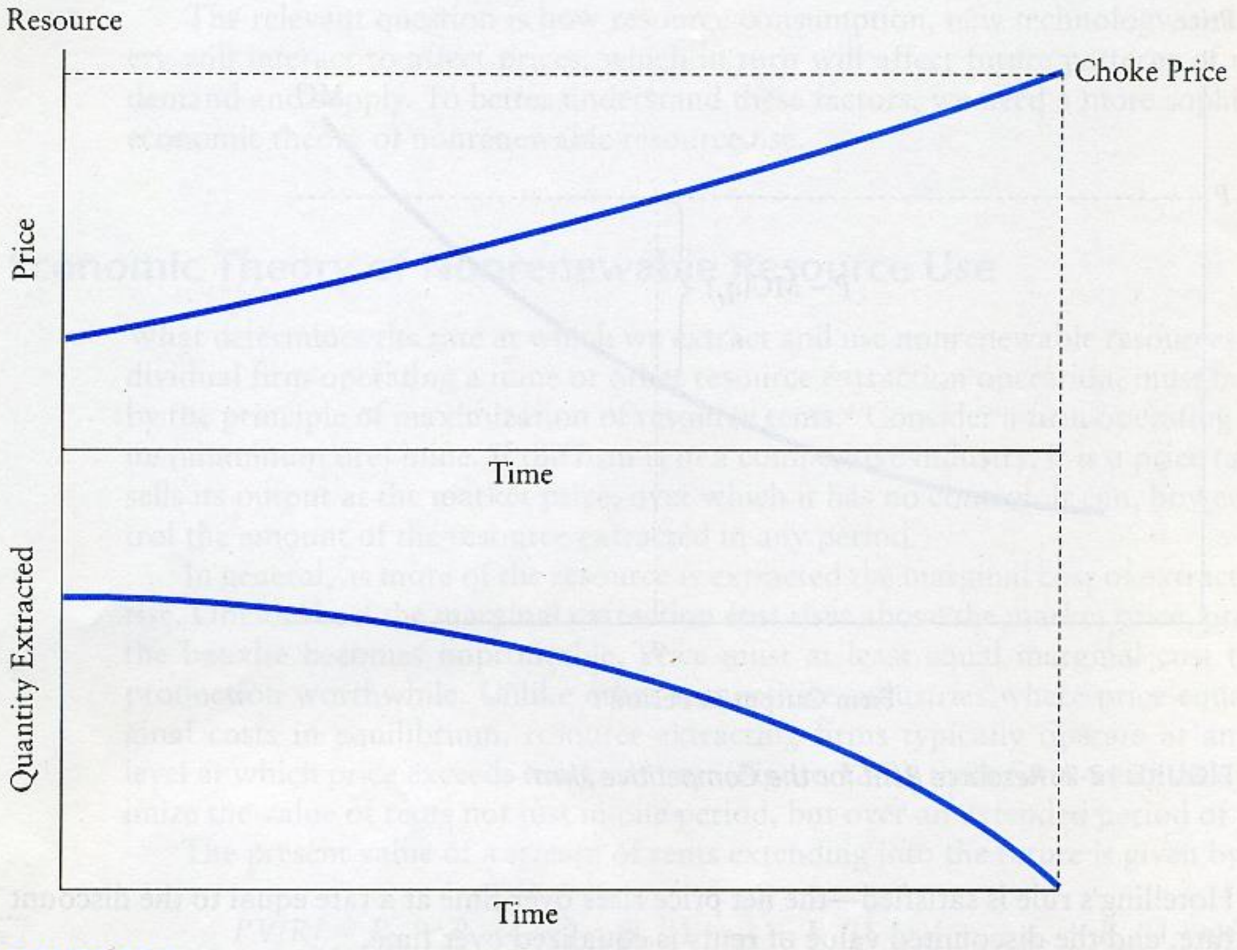


FIGURE 12-3 *Exhaustion of a Mineral Stock*

Economic theory of non-renewable resource use

- **Long-term Trends in Non-renewable Resource use:**

How well does this theory of resource depletion fit into real world?

According to Barnett and Morse (1963), the most mineral resource prices fell from the Industrial Revolution through the mid-twentieth century. At the same time, global non-renewable resource consumption steadily expanded. Three major factors were possible:

1. **continual resource discovery**
2. **improved resource extraction technology**
3. **resource substitution, such as use of plastics in place of metals.**

Economic theory of non-renewable resource use

- **Despite the unreliability of reserve estimates and indices of depletion, new discoveries and improved extraction technologies can not extend non-renewable resource lifetimes forever.**
- **In addition, the economic incentive to deplete high-quality reserves first means that over time the remaining reserves will be of lower quality, more difficult and expensive to extract. Thus we can predict a long term resource use profile similar to that shown in Figure 12-4.**

Economic theory of non-renewable resource use

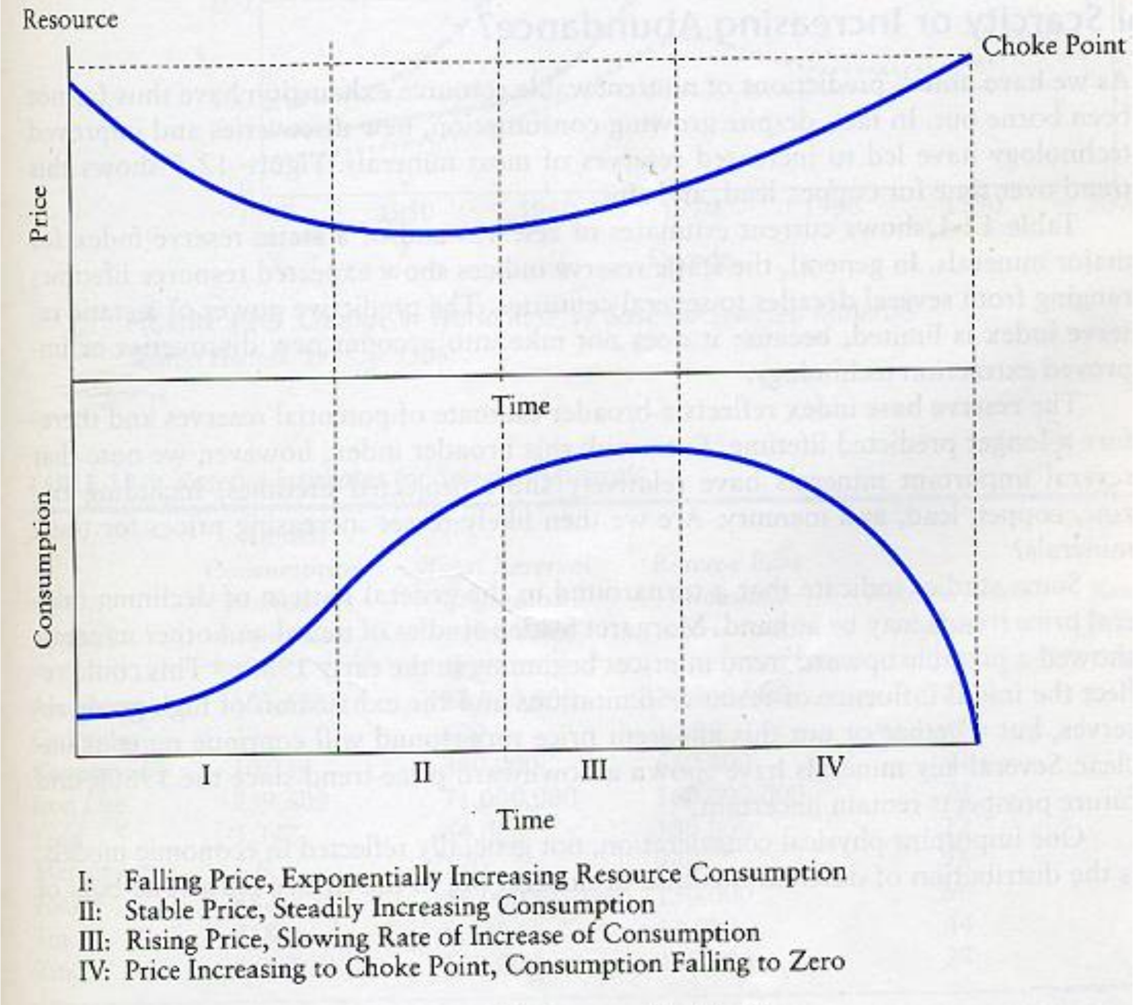


FIGURE 12-4 *Hypothetical Nonrenewable Resource Use Profile*

Economic theory of non-renewable resource use

- **Global scarcity or increasing abundance?**

  Table 12-1 shows current estimates of reserves and of a static reserve index for major minerals. In general static reserve indices show expected resource lifetimes ranging from several decades to several countries. The predictive power of static reserve is limited, because it does not take into account new discoveries or improved extraction technology.

- **The reserve base index reflects a broader estimate of potential reserves and therefore a longer predicted lifetime. However, even with this index, several important minerals have relatively short projected lifetimes.**

Economic theory of non-renewable resource use

- **Are we then likely to see increasing prices for these minerals?**

TABLE 12-1 *Reserve Estimates for Selected Minerals*

Mineral	*Annual Consumption (thousand metric tons)*	*Total Reserves (thousand metric tons)*	*Reserve Base (thousand metric tons)*	*Reserve Index (years)*	*Reserve Base Index (years)*
Aluminum	103,625*	23,000,000	28,000,000	222	270
Cadmium	20	600	1,200	30	60
Copper	10,714	340,000	650,000	32	61
Iron Ore	959,609	71,000,000	160,000,000	74	167
Lead	5,342	64,000	130,000	12	24
Mercury	6.6	120	240	18	36
Nickel	882	49,000	150,000	56	170
Tin	218	9,600	12,000	44	55
Zinc	6,993	190,000	430,000	27	62

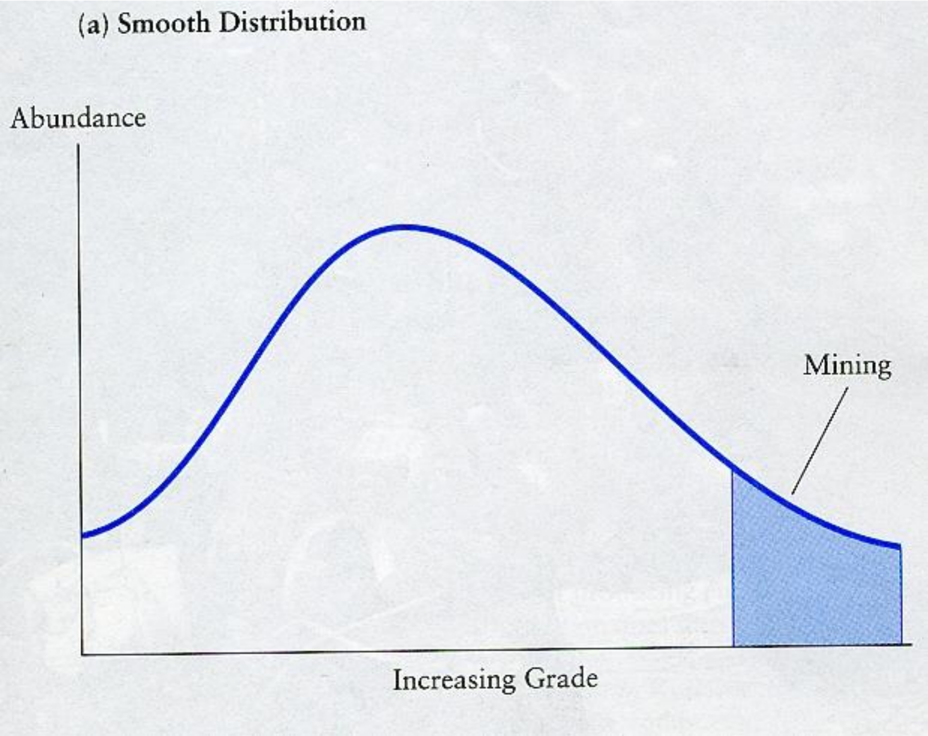
Source: Derived from World Resources Institute, 1994; and U.S. Geological Survey, 2001.

*Annual consumption of bauxite ore.

Economic theory of non-renewable resource use

- One important physical consideration, not generally reflected in economic models, is the distribution of different qualities of mineral ore in the earth's crust.
- The bulk of available reserves are of considerably lower grade than those exploited commercially.
- Studies of mineral abundance have often assumed a relatively smooth distribution pattern similar to that shown in Figure 12-6a. If this is accurate, the market should indicate mineral resource depletion with gradually rising prices from higher extraction costs.

Economic theory of non-renewable resource use



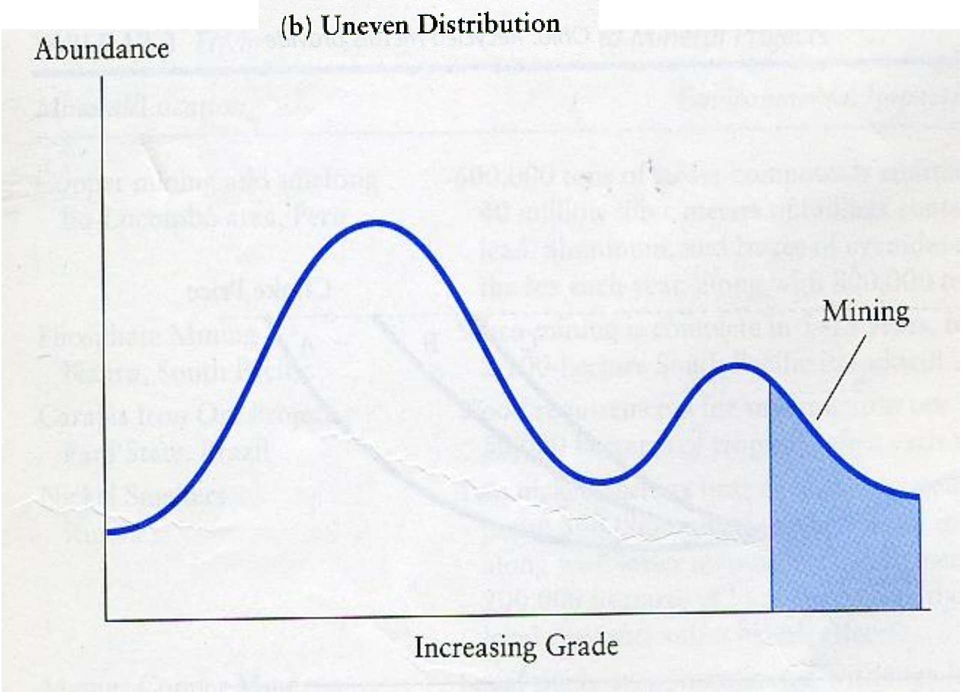


FIGURE 12-6 *Distribution of Mineral Ores in the Earth's Crust*

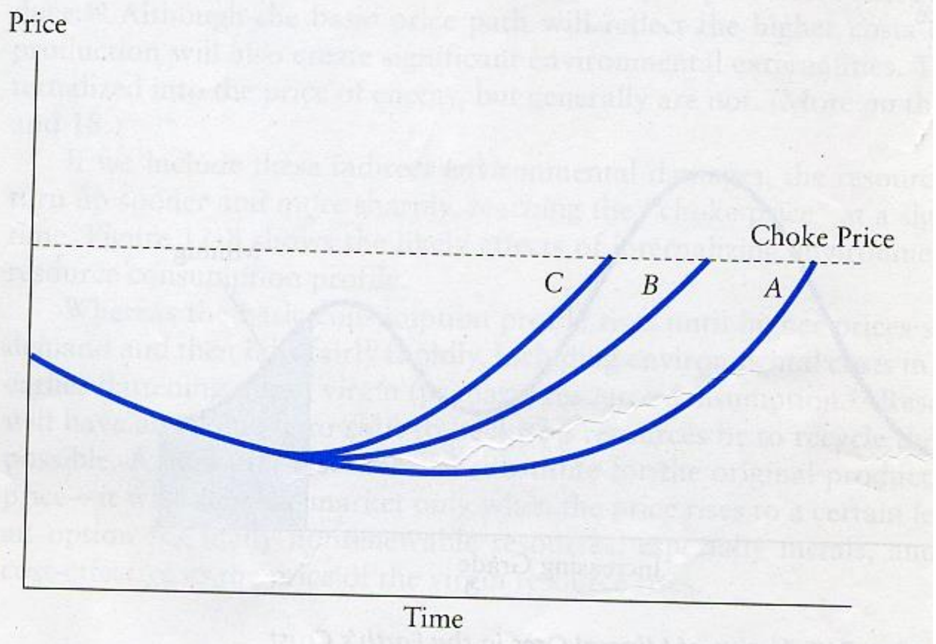
Source: Adapted from Skinner, 1976.

Economic theory of non-renewable resource use

- However, the relative abundance of high and low-grade ore may also be uneven, showing a pattern similar to Figure 12-6b. If this is the case, when the high-grade reserves are exhausted, recovering lower-grade ores will be significantly, more difficult and expensive as well as more environmentally damaging.
- The lower the ore grade, the greater the volume of wastes and generated in producing minerals of marketable quality.

Internalizing environmental costs of resource recovery

- **The exhaustion of high-grade deposits results in higher private and environmental costs of resource recovery. Figure 12-7 shows the implications of this for resource price profiles.**



A: Basic Price Path
B: Price Path with Direct Environmental Costs
C: Price Path with Direct and Indirect Environmental Costs

FIGURE 12-7 *Resource Price Profile with Environmental Costs*

Internalizing environmental costs of resource recovery

- We should consider both direct and indirect environmental costs associated with resource recovery.
- Mining, for example, produces vast quantities of wastes, some of them extremely toxic, as well as other damage to land and water (Table 12-2 and Table 12-3)

Internalizing environmental costs of resource recovery

TABLE 12-2 *The Environmental Costs of Mining*

Activity	*Potential Impact*
Excavation and Ore Removal	Destruction of plant and animal habitat, human settlements, and other features (surface mining) Land subsidence (underground mining) Increased erosion; silting of lakes and streams Waste generation Acid drainage and metal contamination of lakes, streams, and groundwater
Ore Concentration	Waste generation (tailings) Organic chemical contamination Acid drainage and metal contamination
Smelting/Refining	Air pollution (including sulfur dioxide, arsenic, lead, cadmium, and other toxics) Waste generation (slag) Impact of producing energy (most energy used for mineral production goes into smelting and refining).

Source: Excerpted from John E. Young, *Mining the Earth*, Worldwatch Paper 109, pp. 17, 19. ©1992. Reprinted by permission of Worldwatch Institute. www.worldwatch.org.

Internalizing environmental costs of resource recovery

TABLE 12-3 *Environmental Impacts of Selected Mineral Projects*

Mineral/Location	*Environmental Impacts*
Copper mining and smelting Ilo-Locombo area, Peru	600,000 tons of sulfur compounds emitted per year; nearly 40 million cubic meters of tailings containing copper, zinc, lead, aluminum, and traces of cyanides are dumped into the sea each year, along with 800,000 tons of slag.
Phosphate Mining Nauru, South Pacific	When mining is complete in 5–15 years, four-fifths of the 2,100-hectare South Pacific island will be uninhabitable.
Carajás Iron Ore Project Pará State, Brazil	Wood requirements for smelting iron ore will deforest 50,000 hectares of tropical forest each year.
Nickel Smelters Russia	Two nickel smelters near the Norwegian and Finnish borders pump 300,000 tons of sulfur dioxide into the atmosphere, along with lesser amounts of heavy metals. More than 200,000 hectares of local forests are dying as a result, and local residents suffer health effects.
Mamut Copper Mine Sabah Province, Malaysia	Local rivers are contaminated with high levels of chromium, copper, iron, lead, manganese, and nickel.
Gold Mining Amazon Basin, Brazil	Rivers are clogged with sediment and 100 tons of mercury are released into the ecosystem each year.

Source: Excerpted from John E. Young, *Mining the Earth*, Worldwatch Paper 109, pp. 17, 19. ©1992. Reprinted by permission of Worldwatch Institute. www.worldwatch.org.

Internalizing environmental costs of resource recovery

- **In addition, lower-grade resources typically require more energy per unit to produce. Although the basic price path will reflect the higher costs of energy, energy production will also create significant environmental externalities. These could be internalized into the price of energy but generally are not!**
- **If we include these indirect environmental damages, the resource price path will turn up sooner and more sharply, reaching the "choke price" at a significantly earlier time. Figure 12-8 shows the likely effects of internalizing environmental costs on the resource consumption profile.**

Internalizing environmental costs of resource recovery

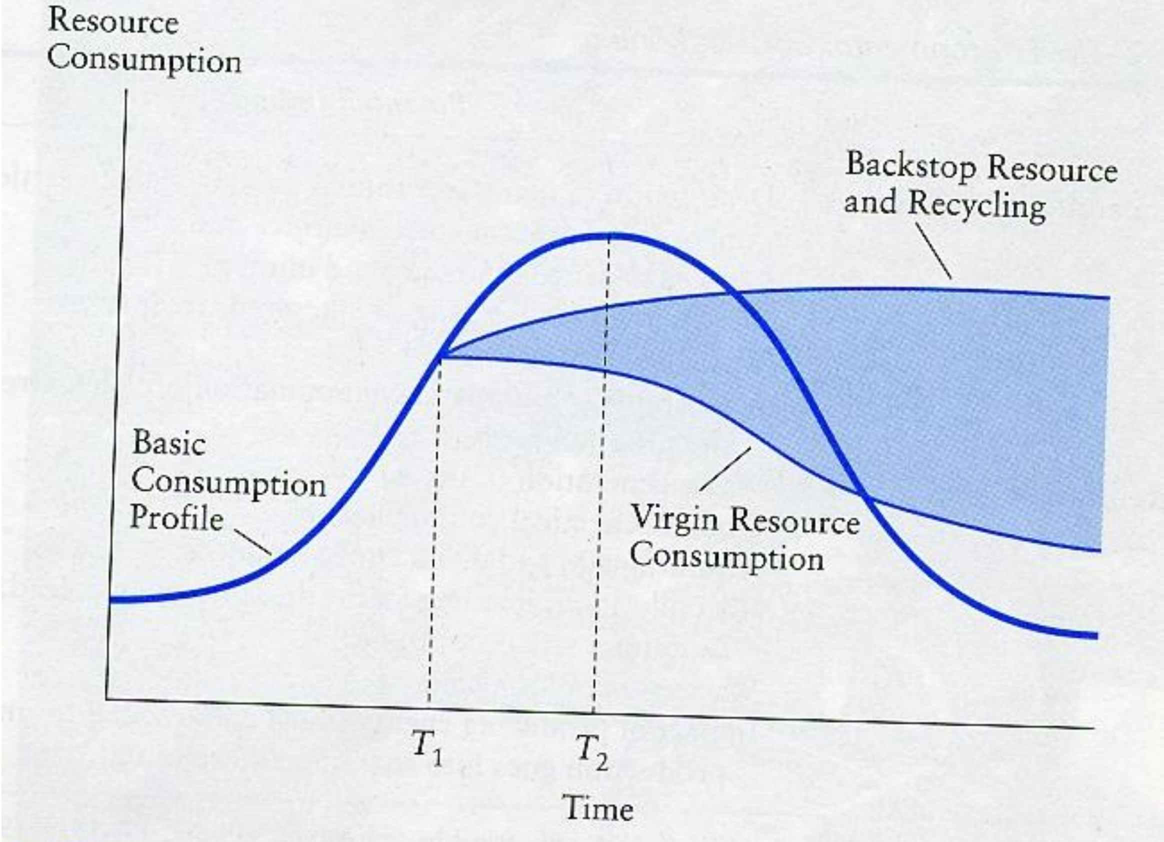


FIGURE 12-8 *Resource Consumption Profile with Backstop Resource or Recycling.* Internalization of environmental costs causes virgin resource consumption to peak at T_1 instead of T_2.

Internalizing environmental costs of resource recovery

- **Whereas the basic consumption profile rises until higher prices start to constrain demand and then falls rapidly, including environmental costs in price leads to an earlier flattening out of virgin (primary) resource consumption.**
- **Resource consumers will have an incentive to shift to backstop resources or to recycle the resource where possible. A backstop resource can substitute for the original product, but at a higher price: it will enter the market only when the price rises to a certain level.**
- **Recycling is an option for many non-renewable resources, especially metals, and becomes more cost-effective as the price of the virgin resource rises.**