Lecture 6

Depletable Resource Allocation

Depletable Resource Allocation: The Role of Longer Time Horizons, Substitutes, and Extraction Cost

- Introduction
- A Resource Taxonomy
- Efficient Intertemporal Allocations
- Market Allocations of Depletable Resource

Introduction

- This chapter presents the topic of resource scarcity within the general taxonomy of resources.
- This chapter studies the implications of both efficient and profit-maximizing decision-making.

A Resource Taxonomy

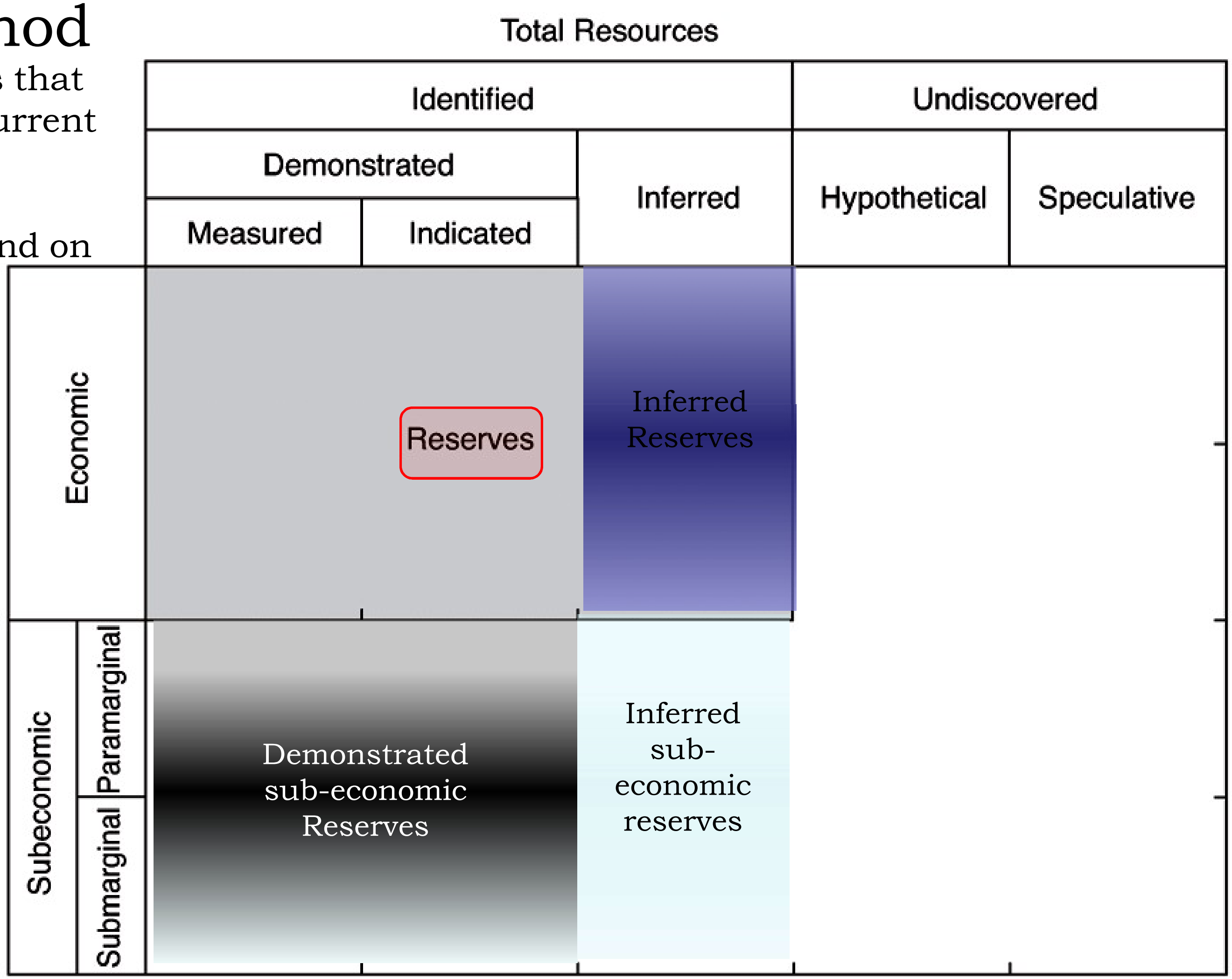
- A **resource taxonomy** is a classification system used to distinguish various categories of resource availability.
  - Current reserves are resources that can be extracted profitably at current prices.
  - Potential reserves resources potentially available. They depend on people's willingness to pay and technology.
  - Resource endowment represents the natural occurrence of resources in the earth.

A Resource Taxonomy

Deterministic method

Current reserves are resources that can be extracted profitably at current prices.
Potential reserves resources potentially available. They depend on people's willingness to pay and technology.
Resource endowment represents the natural occurrence of resources in the earth.

- Horizontal axis
(geological certainty)
- already identified
- undiscovered
- Vertical axis
(economic feasibility)
- economically recovered with the existing technology at the current market prices
- not recoverable.



A Resource Taxonomy

Terms

Identified resources: specific bodies of mineral-bearing material whose location, quality, and quantity are known from geological evidence, supported by engineering measurements.

Measured resources: material for which quantity and quality estimates are within a margin of error of less than 20 percent, from geologically well-known sample sites.

Indicated resources: material for which quantity and quality have been estimated partly from sample analyses and partly from reasonable geological projections.

Inferred resources: material in unexplored extensions of demonstrated resources based on geological projections.

Undiscovered resources: unspecified bodies of mineral-bearing material surmised to exist on the basis of broad geological knowledge and theory.

Hypothetical resources: undiscovered materials reasonably expected to exist in a known mining district under known geological conditions.

Speculative resources: undiscovered materials that may occur in either known types of deposits in favorable geological settings where no discoveries have been made, or in yet unknown types of deposits that remain to be recognized.

Source: U.S. Bureau of Mines and the U.S. Geological Survey. "Principle of the Mineral Resource Classification System of the U.S. Bureau of Mines and the U.S. Geological Survey," *Geological Survey Bulletin* (1976): 1450-A.

A Resource Taxonomy

- A depletable resource is not naturally replenished or is replenished at such a low rate that it can be exhausted.
  - The depletion rate is affected by demand, and thus by the price elasticity of demand, durability and reusability.
- A recyclable resource has some mass that can be recovered after use.
  - Copper is an example of a depletable, recyclable resource.
- A renewable resource is one that is naturally replenished.
  - Examples are water, fish, forests and solar energy.

A Resource Taxonomy

- The management problem for depletable resources is how to allocate dwindling stocks among generations while transitioning to a renewable alternative.
- The management problem for renewable resources is in maintaining an efficient and sustainable flow.

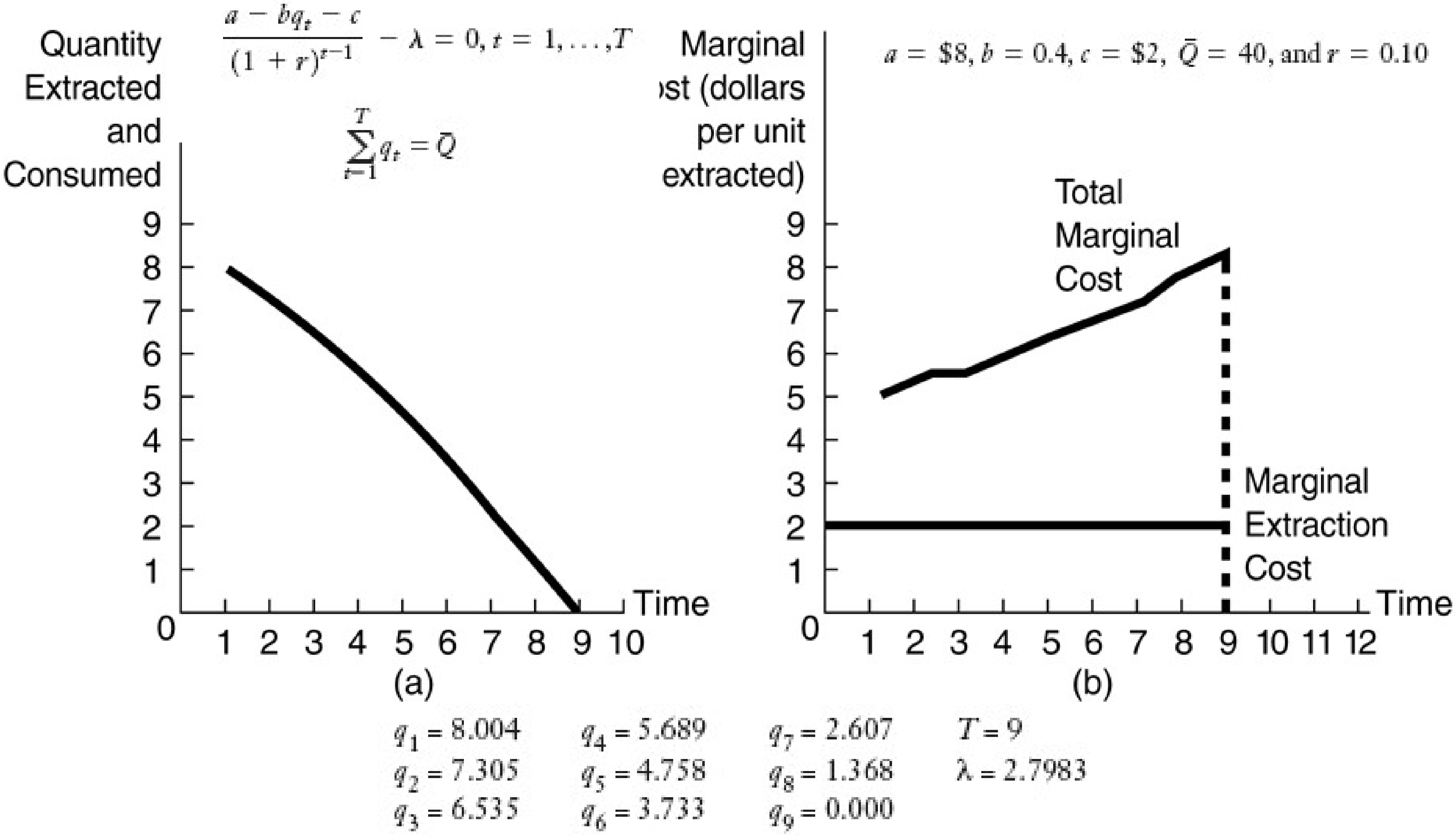
Efficient Intertemporal Allocations

- The Two-Period Model Revisited
  - Dynamic efficiency is the primary criterion when allocating resources over time.
  - Recall the two-period model from the previous lecture. This model can be generalized to longer time periods.
  - An n-period model presented in what follows, uses the same numerical example from the previous lecture, but extends the time horizon and increases the recoverable supply from 20 to 40 units.

Efficient Intertemporal Allocations

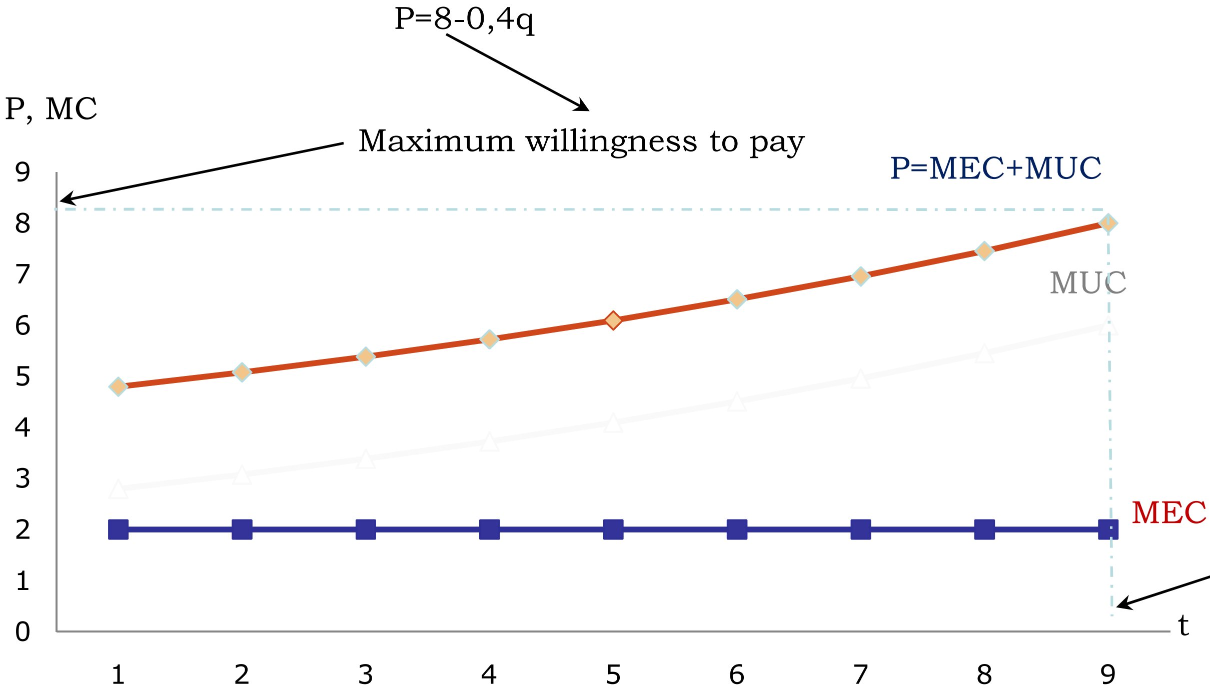
- The N-Period Constant-Cost Case
  - With constant marginal extraction cost, total marginal cost (or the sum of marginal extraction costs and marginal user cost) will rise over time.
  - The graph in the following slide shows total marginal cost and marginal extraction cost.
  - The vertical distance between the two, equals the marginal user cost. The horizontal axis measure time.
  - Rising marginal user cost reflects increasing scarcity and the intertemporal opportunity cost of current consumption on future consumption.

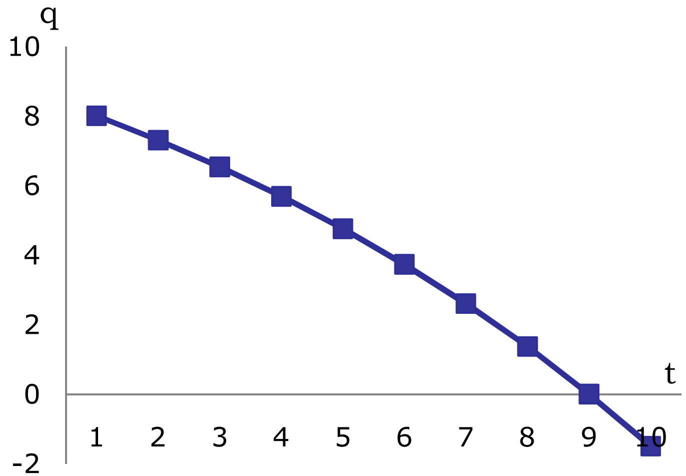
Efficient Intertemporal Allocations



Constant Marginal Extraction Cost with No Substitute Resource:
(a) Quantity Profile. (b) Marginal Cost Profile

Efficient Intertemporal Allocations





$q_1 = 8.004$	$q_4 = 5.689$	$q_7 = 2.607$	$T = 9$
$q_2 = 7.305$	$q_5 = 4.758$	$q_8 = 1.368$	$\lambda = 2.7983$
$q_3 = 6.535$	$q_6 = 3.733$	$q_9 = 0.000$	

Efficient Intertemporal Allocations

- Main results:
- As costs rise, quantity extracted falls over time.
- Quantity extracted falls to zero at the point where total marginal cost reaches the maximum willingness to pay (or choke price) for the resource such that demand and supply simultaneously equal zero.

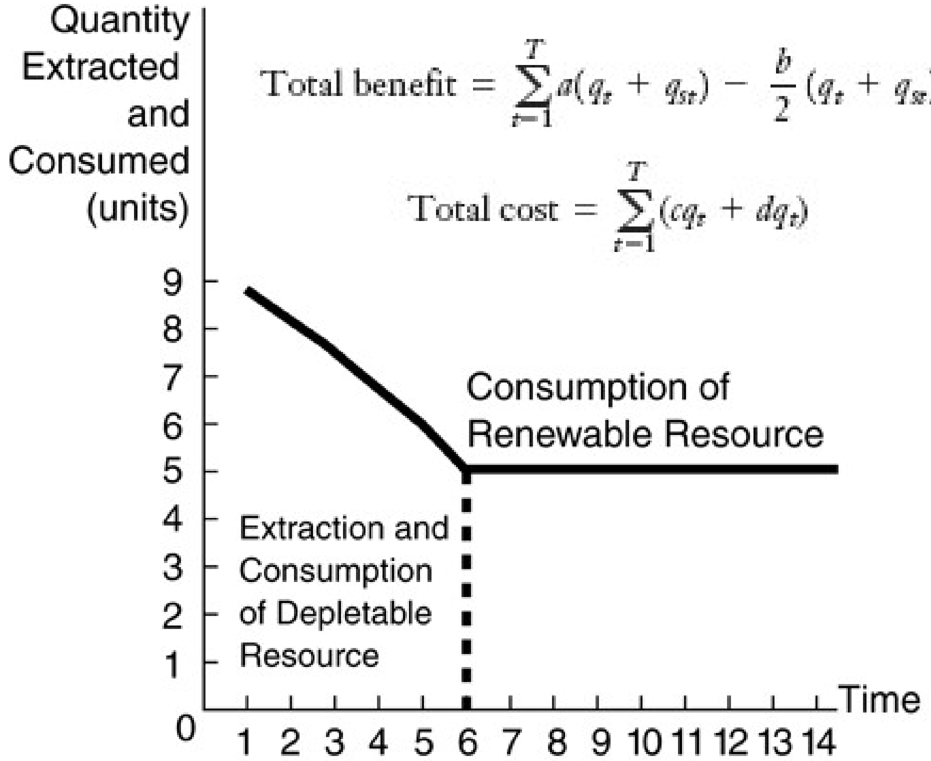
Presence of renewable alternative

- Transition to a Renewable Substitute
  - An efficient allocation thus implies a smooth transition to exhaustion and/or to a renewable substitute.
  - The transition point to the renewable substitute is called the switch point.
  - At the switch point the total marginal cost of the depletable resource equals the marginal cost of the substitute.

Presence of renewable alternative

$$\text{Total benefit} = \sum_{t=1}^{T} a(q_t + q_{st}) - \frac{b}{2}(q_t + q_{st})^2$$

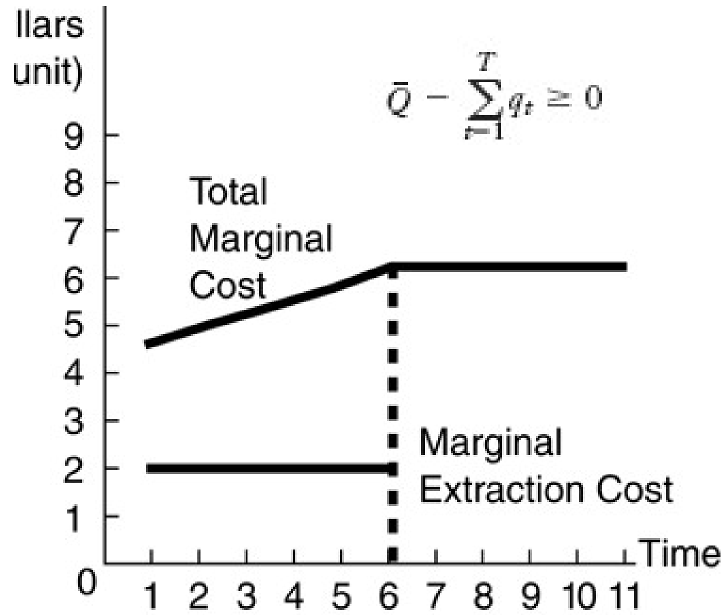
$$\text{Total cost} = \sum_{t=1}^{T} (cq_t + dq_t)$$



(a)

$$PVNB = \sum_{t=1}^{T} \frac{a(q_t + q_{st}) - \frac{b}{2}(q_t^2 + q_{st}^2 + 2q_t q_{st}) - cq_t - dq_{st}}{(1+r)^{t-1}}$$

$$\bar{Q} - \sum_{t=1}^{T} q_t \geq 0$$



(b)

$$\frac{a - b(q_t + q_{st}) - c}{(1+r)^{t-1}} - \lambda \leq 0, t = 1, \ldots, T$$

$q_1 = 8.798$ $q_3 = 7.495$ $q_5 = 5.919$

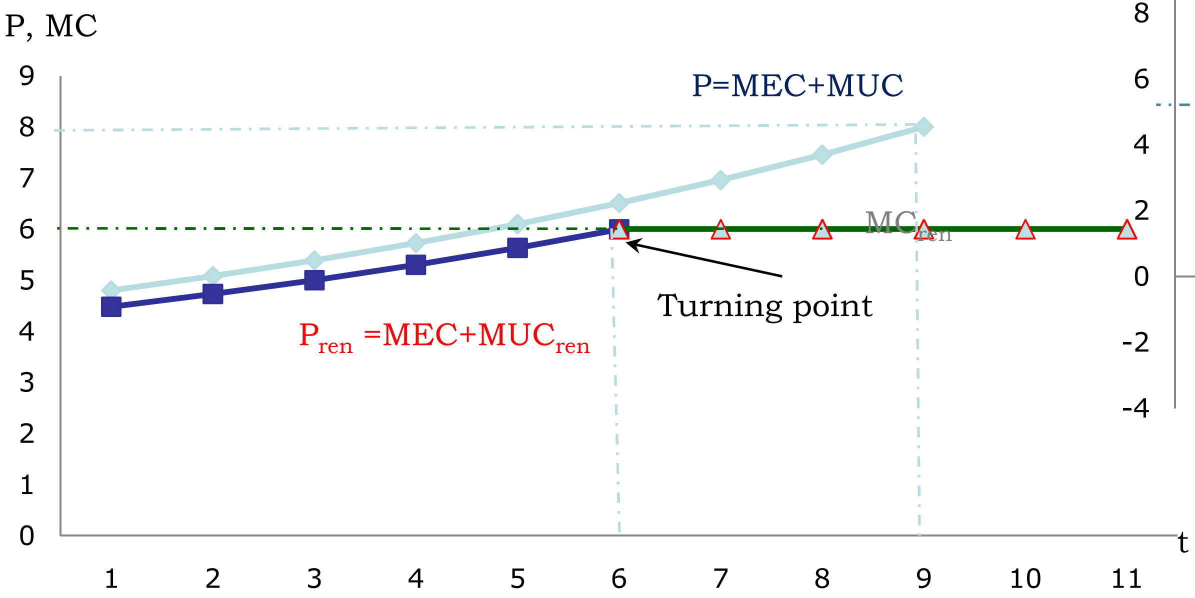
$q_2 = 8.177$ $q_4 = 6.744$

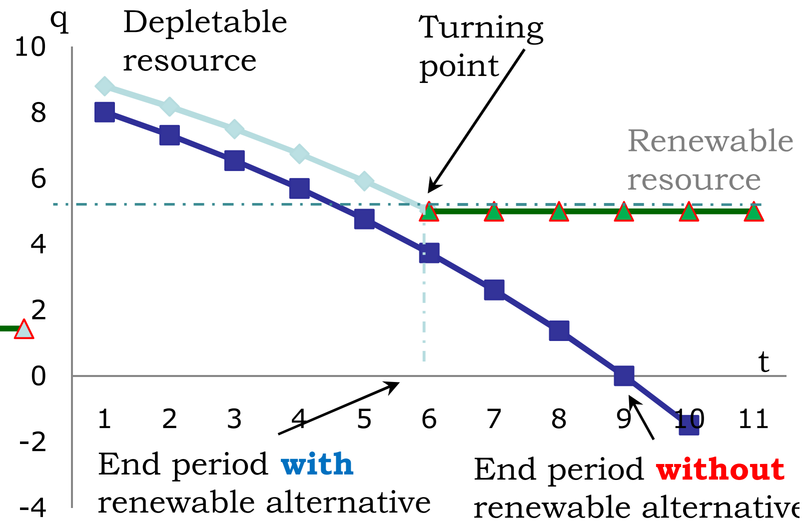
$q_{s6} = 2.137$ $q_{st} = \begin{cases} 5.000 \text{ for } t>6 \\ 0 \text{ for } t<6 \end{cases}$

$q_6 = 2.863$ $\lambda = 2.481$

Constant Marginal Extraction Cost with Substitute Resource:
(a) Quantity Profile. (b) Marginal Cost Profile

Presence of renewable alternative





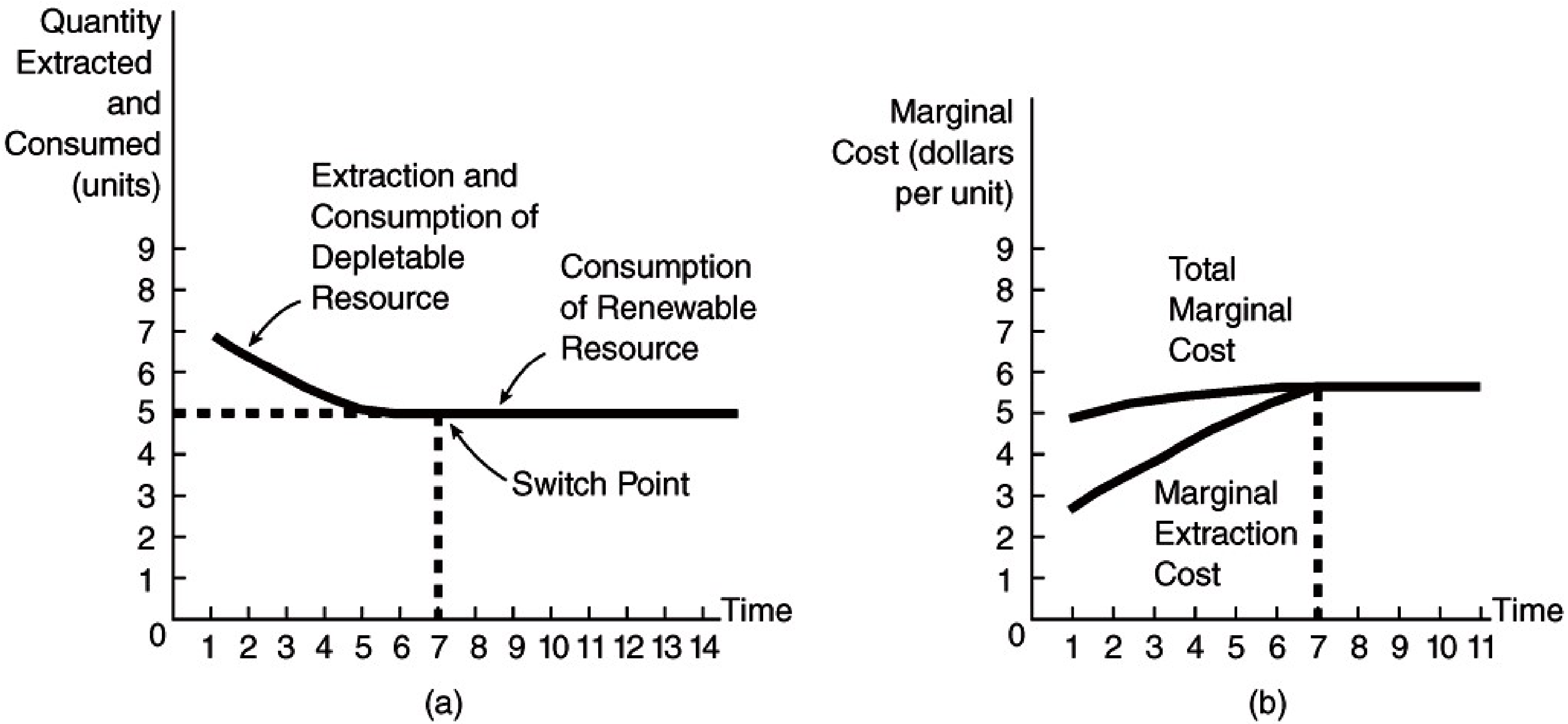
$$\frac{a - b(q_t + q_{st}) - c}{(1+r)^{t-1}} - \lambda \le 0, t = 1, \dots, T$$

$$q_1 = 8.798 \quad q_3 = 7.495 \quad q_5 = 5.919$$
$$q_2 = 8.177 \quad q_4 = 6.744$$
$$q_{s6} = 2.137 \quad q_{st} = \begin{cases} 5.000 \text{ for } t>6 \\ 0 \text{ for } t<6 \end{cases}$$
$$q_6 = 2.863 \quad \lambda = 2.481$$

Increasing MC of extraction

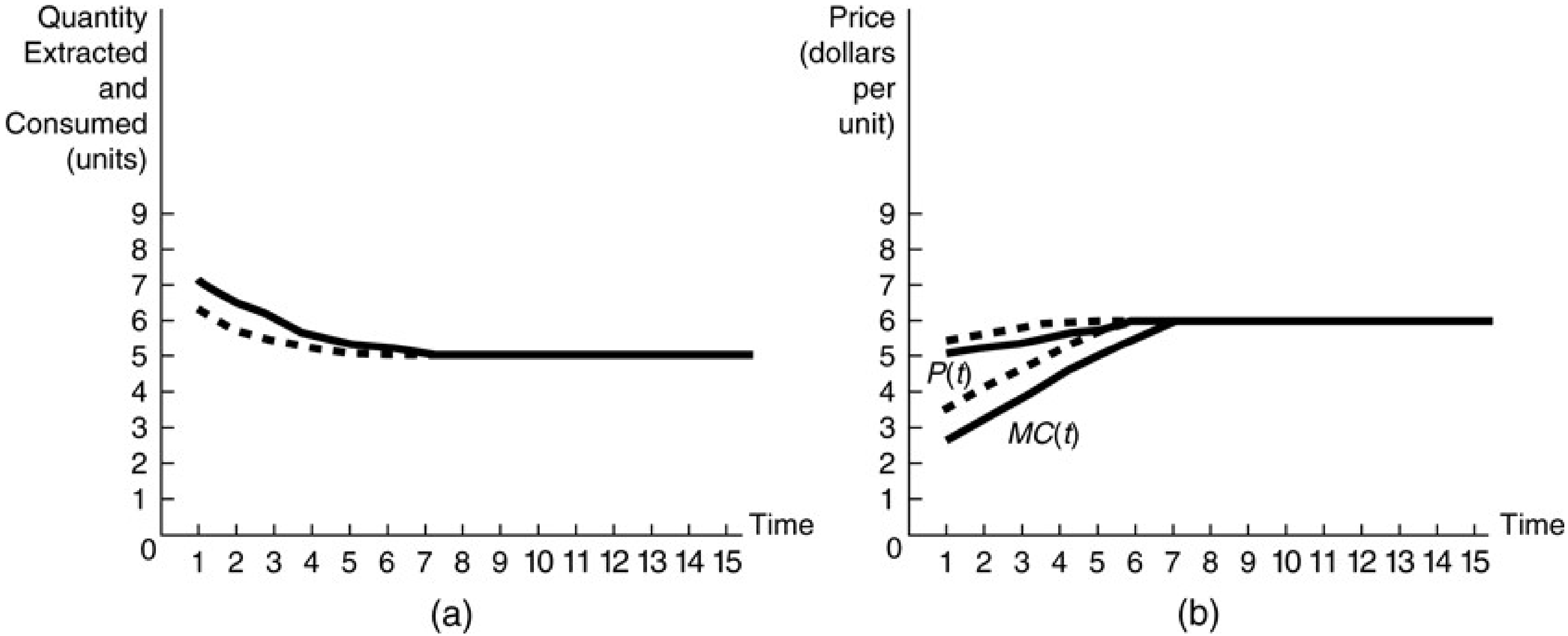
- Increasing Marginal Extraction Cost
  - For this case, the marginal user cost declines over time and reaches zero at the transition point.
  - The resource reserve is not exhausted.
  - The marginal cost of exploration can be expected to rise over time as well.
  - Successful exploration would cause a smaller and slower decline in consumption while dampening the rise in total marginal cost.

Increasing MC of extraction



Increasing Marginal Extraction Cost with Substitute Resource:
(a) Quantity Profile. (b) Marginal Cost Profile

Increasing MC of extraction



Increasing Marginal Extraction Cost with Substitute Resource in the Presence of Environmental Costs: (a) Quantity Profile. (b) Price Profile
(Solid Line—without Environmental Costs;
Dashed Line—with Environmental Costs)

Technological progress

- Exploration and Technological Progress
  - Technological progress would also reduce the cost of extraction.
    - Lowering the future marginal cost of extraction would move the transition time further into the future.
    - Total marginal cost could actually fall with large advances in technology.

Example

Historical Example of Technological Progress in the Iron Ore Industry

The term *technological progress* plays an important role in the economic analysis of mineral resources. Yet, at times, it can appear abstract, even mystical. It shouldn't! Far from being a blind faith detached from reality, technological progress refers to a host of ingenious ways in which people have reacted to impending shortages with sufficient imagination that the available supply of resources has been expanded by an order of magnitude and at reasonable cost. To illustrate how concrete a notion technological progress is, consider one example of how it has worked in the past.

In 1947 the president of Republic Steel, C. M. White, calculated the expected life of the Mesabi Range of northern Minnesota (the source of some 60 percent of iron ore consumed during World War II) as being in the range from five to seven years. By 1955, only eight years later, *U.S. News and World Report* concluded that worry over the scarcity of iron ore could be forgotten. The source of this remarkable transformation of a problem of scarcity into one of abundance was the discovery of a new technique of preparing iron ore, called *pelletization*.

Prior to pelletization, the standard ores from which iron was derived contained from 50 to more than 65 percent iron in crude form. There was a significant

Example

percentage of taconite ore available containing less than 30 percent iron in crude form, but no one knew how to produce it at reasonable cost. Pelletization is a process by which these ores are processed and concentrated at the mine site prior to shipment to the blast furnaces. The advent of pelletization allowed the profitable use of the taconite ores.

While expanding the supply of iron ore, pelletization reduced its cost in spite of the inferior grade being used. There were several sources of the cost reduction. First, substantially less energy was used; the shift in ore technology toward pelletization produced net energy savings of 17 percent in spite of the fact that the pelletization process itself required more energy. The reduction came from the discovery that the blast furnaces could be operated much more efficiently using pelletization inputs. The process also reduced labor requirements per ton by some 8.2 percent while increasing the output of the blast furnaces. A blast furnace owned by Armco Steel in Middletown, Ohio, which had a rated capacity of approximately 1,500 tons of molten iron per day, was able, by 1960, to achieve production levels of 2,700–2,800 tons per day when fired with 90 percent pellets. Pellets nearly doubled the blast furnace productivity!

Sources: Peter J. Kakela, "Iron Ore: Energy Labor and Capital Changes with Technology." SCIENCE, Vol. 202, December 15, 1978, pp. 1151–1157; and Peter J. Kakela, "Iron Ore: From Depletion to Abundance." SCIENCE, Vol. 212, April 10, 1981, pp. 132–136.

Market allocations of depletable resources

- Appropriate Property Right Structures
  - Markets will behave well as long as the property-rights structures governing the resources are **exclusive, universal, transferable** and **enforceable**.
  - A resource governed by a well-defined property rights structure will then have both a use value and an asset value to its owner.

- Environmental Costs
  - The inclusion of environmental costs would result in higher prices
    - which will dampen demand;
    - from supply side effect, which causes the transition point to be sooner;
    - Which effect dominates depends on the shape of the marginal extraction cost curve.
  - The concept of external environmental costs ties together the fields of environmental and natural resource economics.