
# Lecture 5

# Dynamic Efficiency & Sustainable Development

# Dynamic Efficiency & Sustainability

- Introduction
- A Two-Period Model
- Defining Intertemporal Fairness
- Are Efficient Allocations Fair?
- Applying the Sustainability Criterion
- Implications for Environmental Policy

# Introduction

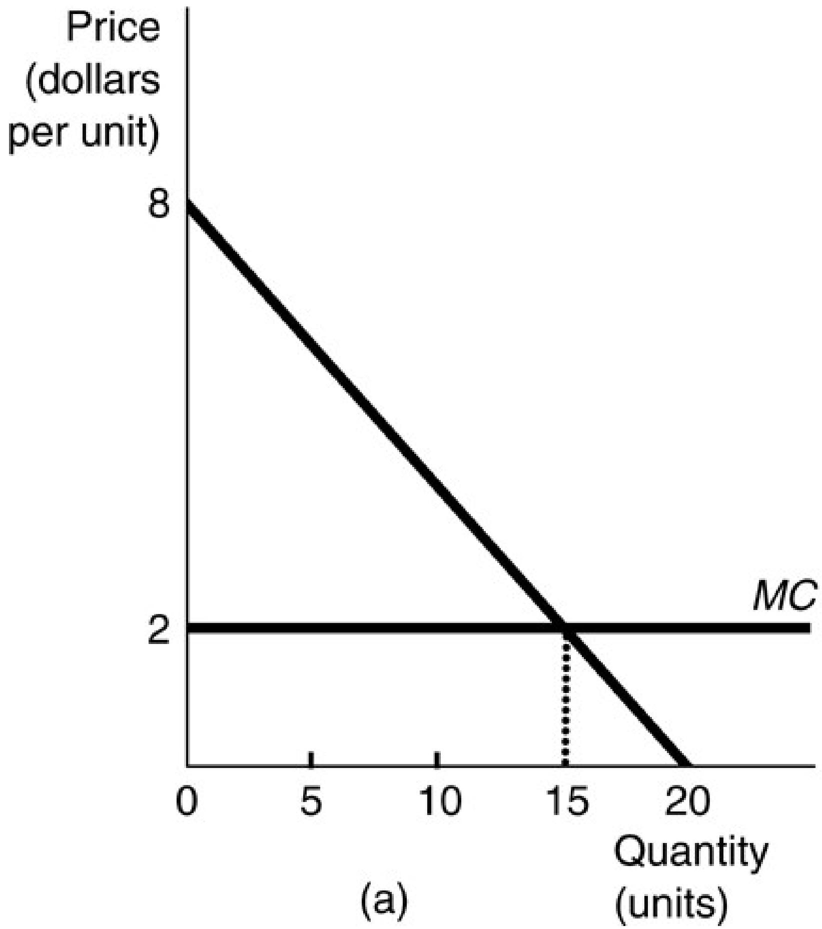
- We deal with the treatment of future generations.
- Topics covered include
  - the concern of fairness in the allocation of a resource over time;
  - the compatibility of equity and efficiency;
  - sustainable development.

# A Two-Period Model

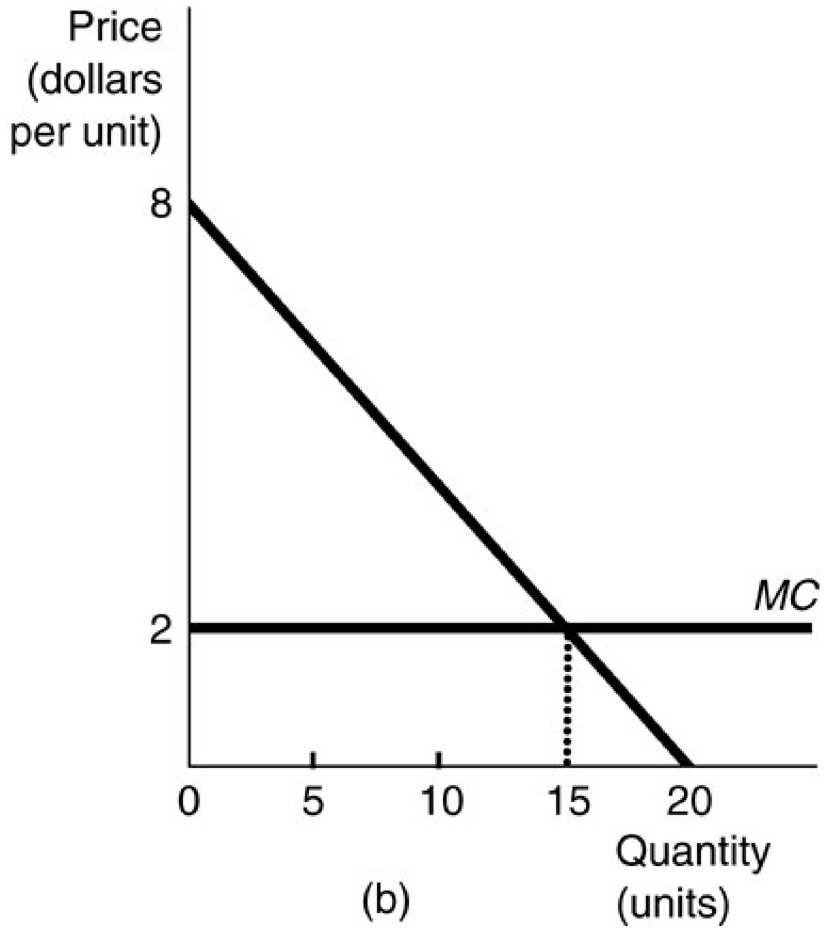
- Numerical Example:
- Assumptions
  - Fixed supply of certain depletable resource
  - Consider two time periods only
  - Total supply is 20 units
  - Demand (marginal WTP) is constant:

$$P = 8 - 0.4q$$
$$MC = \$2$$

# A Two-Period Model




**(a) Period 1**



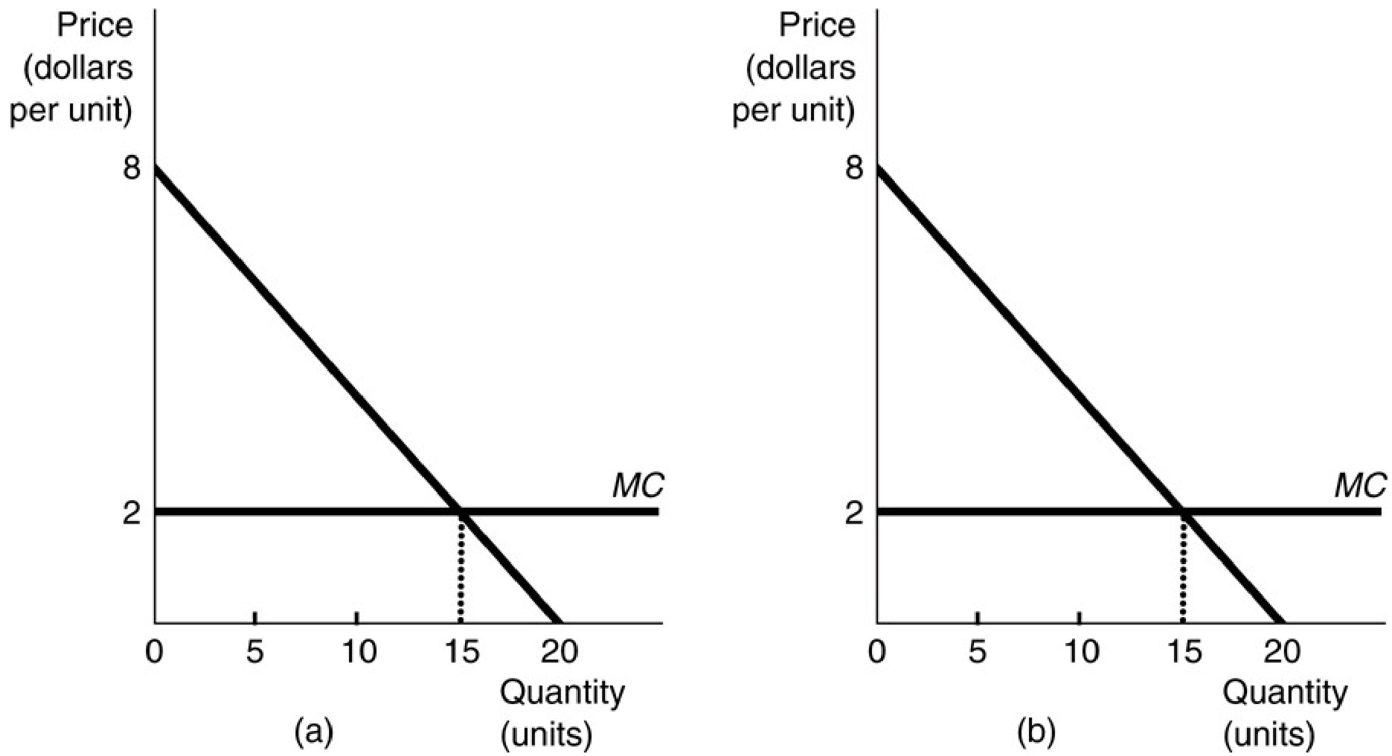

**(b) Period 2**

# A Two-Period Model

- If supply is sufficient to meet demand, then a static efficient solution will provide the optimal allocations over time, regardless of the discount rate.

- For example, if the total supply of a depletable resource were 30 or more, what will the efficient quantities for each period?

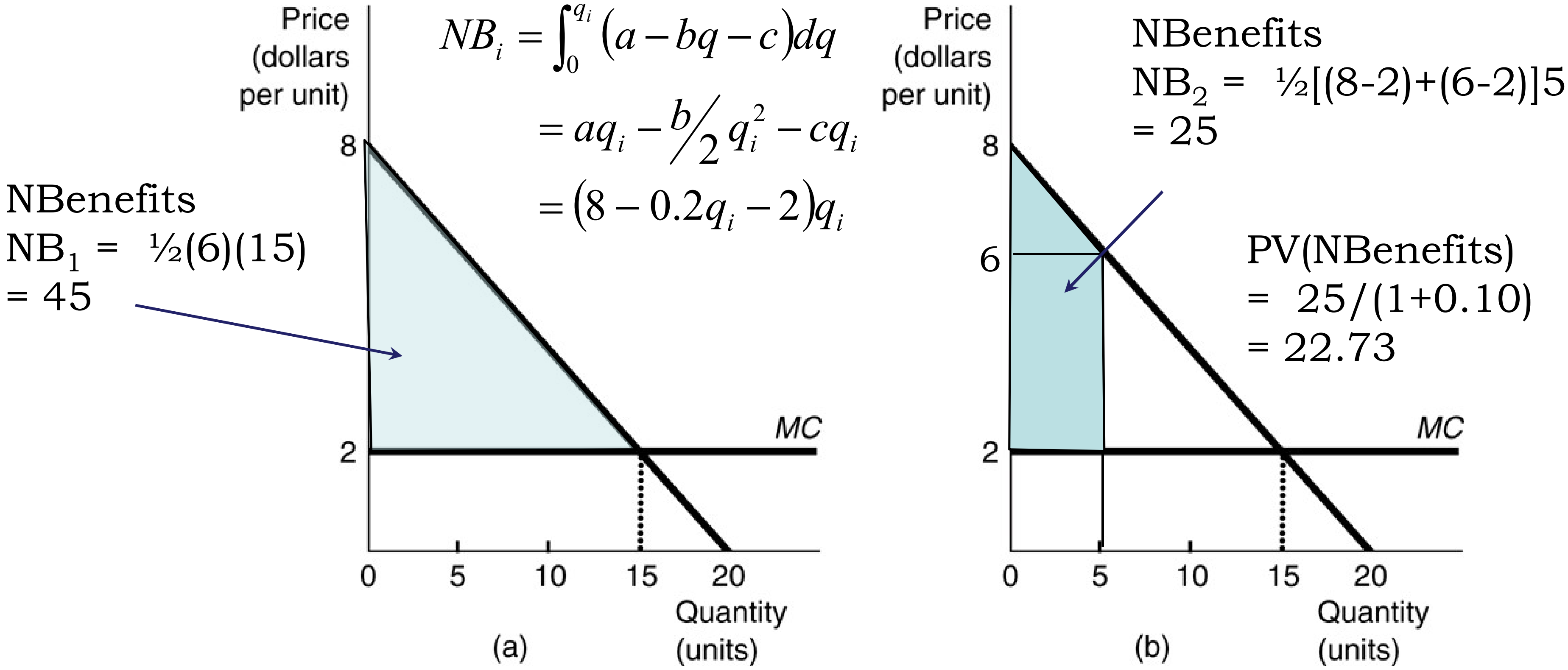
# A Two-Period Model




If total supply amount is >30, regardless of discount rate, what efficiency criterion can we use?

# The Allocation of a Depletable Resource

- If we had only 20 units to allocate and we used 15 in the 1st period, then we will have only 5 in the 2nd period.




PV(NBenefits in 2 periods) = 45+22.73 = 67.73

Does this allocation maximize total benefits?

# Dynamic Efficient Allocation

- If supply is not sufficient we must determine the optimal allocation using the dynamic efficiency criterion: maximize the present value of net benefits.

- The present value for a two-period model is the sum of the present values in each of the two years.

$$\left.\begin{aligned} &\max_{q_1,q_2} TNB = NB_1(q_1) + \frac{NB_2(q_2)}{(1+r)} \\ &s.t. \quad q_1 + q_2 \le \overline{Q} \end{aligned}\right\rangle \Rightarrow \max_{q_1,q_2} L = TNB + \lambda\left(\overline{Q} - q_1 - q_2\right)$$

$$\left.\begin{aligned} &\frac{\partial NB_1}{\partial q_1} = 0 \Rightarrow NB_1' = \lambda \\ &\frac{\partial NB_2}{\partial q_2} = 0 \Rightarrow \frac{NB_2'}{(1+r)} = \lambda \end{aligned}\right\rangle \Rightarrow \left| \begin{aligned} &NB_1' = \frac{NB_2'}{(1+r)} \\ &\Rightarrow \frac{NB_1'}{NB_2'} = \frac{1}{(1+r)} \end{aligned}\right.$$

# A Two-Period Model

- If supply is not sufficient we must determine the optimal allocation using the dynamic efficiency criterion: maximize the present value of net benefits.

- The present value for a two-period model is the sum of the present values in each of the two years.

- The present value in each period is the portion of the area under the demand curve and above the supply curve or the area under the marginal net benefit curve (which is the demand curve minus the marginal cost). The vertical intercept is the marginal net benefit at zero divided by (1 + r).

# Dynamic Efficient Allocation

- The dynamically efficient allocation will satisfy the condition that the present value of the marginal benefit from the last unit in period 1 equals the present value of the marginal net benefit in period 2.

- This leads to the condition that the percentage change between the two periods Marginal Benefits should be equal to the discount rate

$$\frac{NB_2' - NB_1'}{NB_1'} = r \quad \text{Hotelling's rule}$$

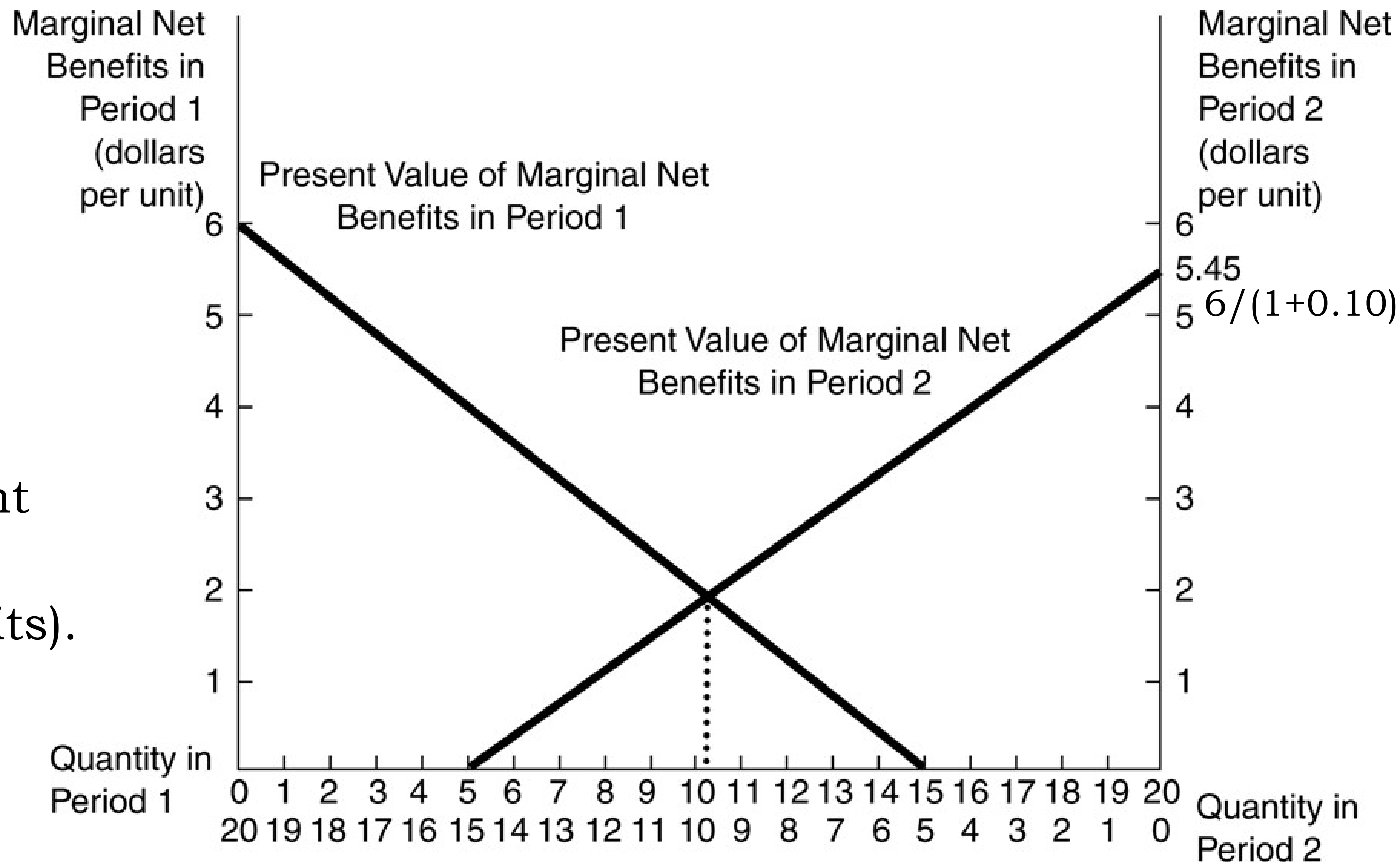
- Or put it differently the rate of increase in marginal benefits over time should equal the discount rate

# Dynamic Efficient Allocation

- A two period model can be illustrated graphically by flipping the graph of period 2 such that the zero axis for the period 2 net benefits is on the right side, rather than the left.

The size of the box represents the resource constraint.

Any point on the horizontal axis sums to the amount of the resource constraint (=20 units).



# Dynamic Efficient Allocation

- In the example we can calculate optimal quantities to be extracted in each period

$$MNB_i = 6 - 0{,}4q_i \qquad \left.\begin{array}{l} \dfrac{6-0{,}4q_1}{6-0{,}4q_2} = \dfrac{1}{1{,}1} \\ q_1 + q_2 = 20 \end{array}\right\} \Rightarrow \left| \begin{array}{l} q_1 = 10{,}238 \\ q_2 = 9{,}762 \end{array}\right.$$

- Prices are calculated by inserting the efficient quantities into the willingness to pay (demand) function and solving for price.

$P_1$ = 3.905 and $P_2$ = 4.095

# Dynamic Efficient Allocation

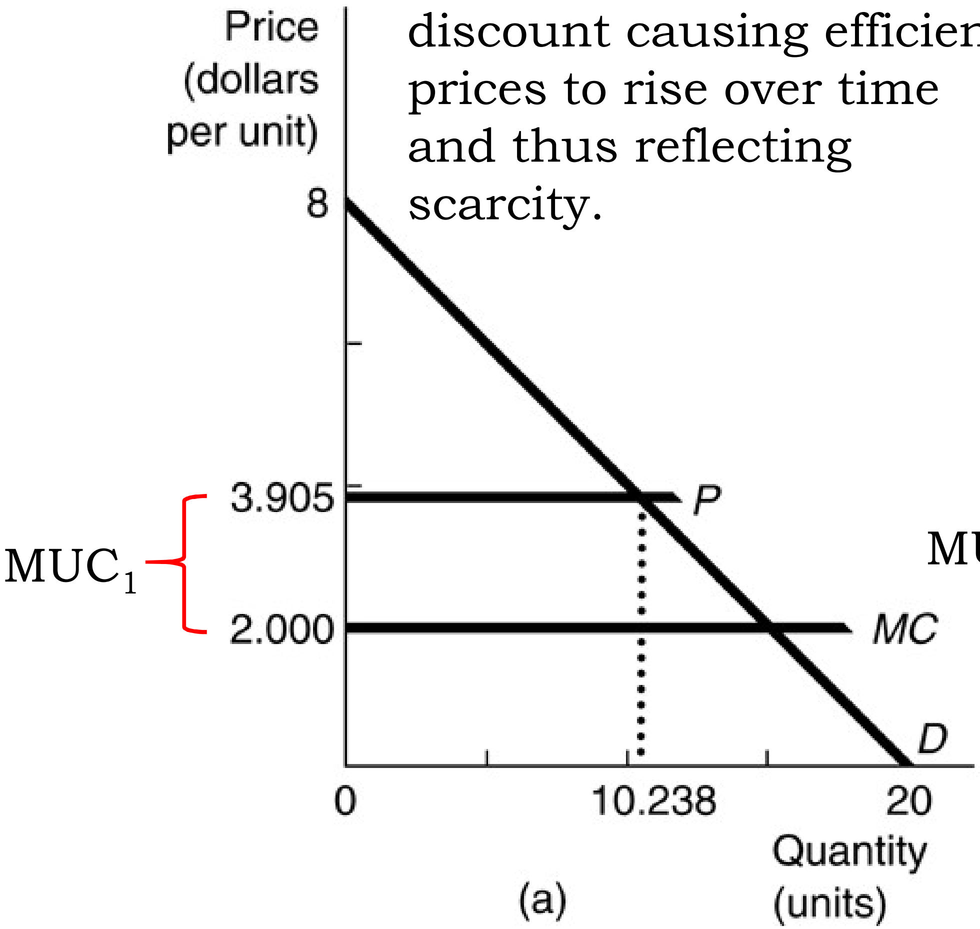
- It is clear that in the absence of scarcity, price will equal marginal extraction cost, and since this is the same in both periods, prices will be the same in both periods.

- Scarce (finite) resources have a value over and above their cost of production, which is due to their scarcity. This extra value is considered as (Hotelling's) scarcity rent or marginal user cost (MUC).

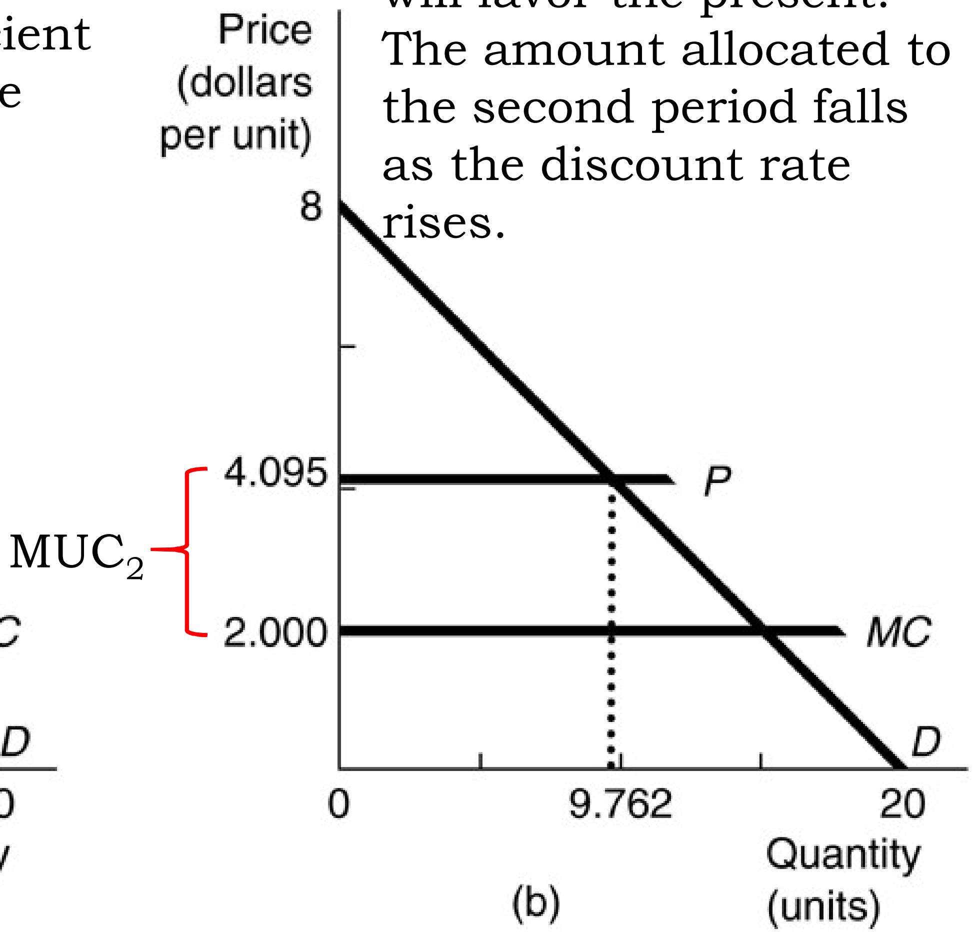
- The marginal user cost for each period in an efficient market is the difference between the price and the marginal extraction cost.
  - $MUC_1 = 1.905$ and $MUC_2 = 1.905(1+r) = 2.095$

# Dynamic Efficient Allocation

Marginal user cost rises over time at the rate of discount causing efficient prices to rise over time and thus reflecting scarcity.




A higher discount rate will favor the present. The amount allocated to the second period falls as the discount rate rises.



# Dynamic Efficient Allocation

- Marginal user cost rises over time at the rate of discount causing efficient prices to rise over time and thus reflecting scarcity.

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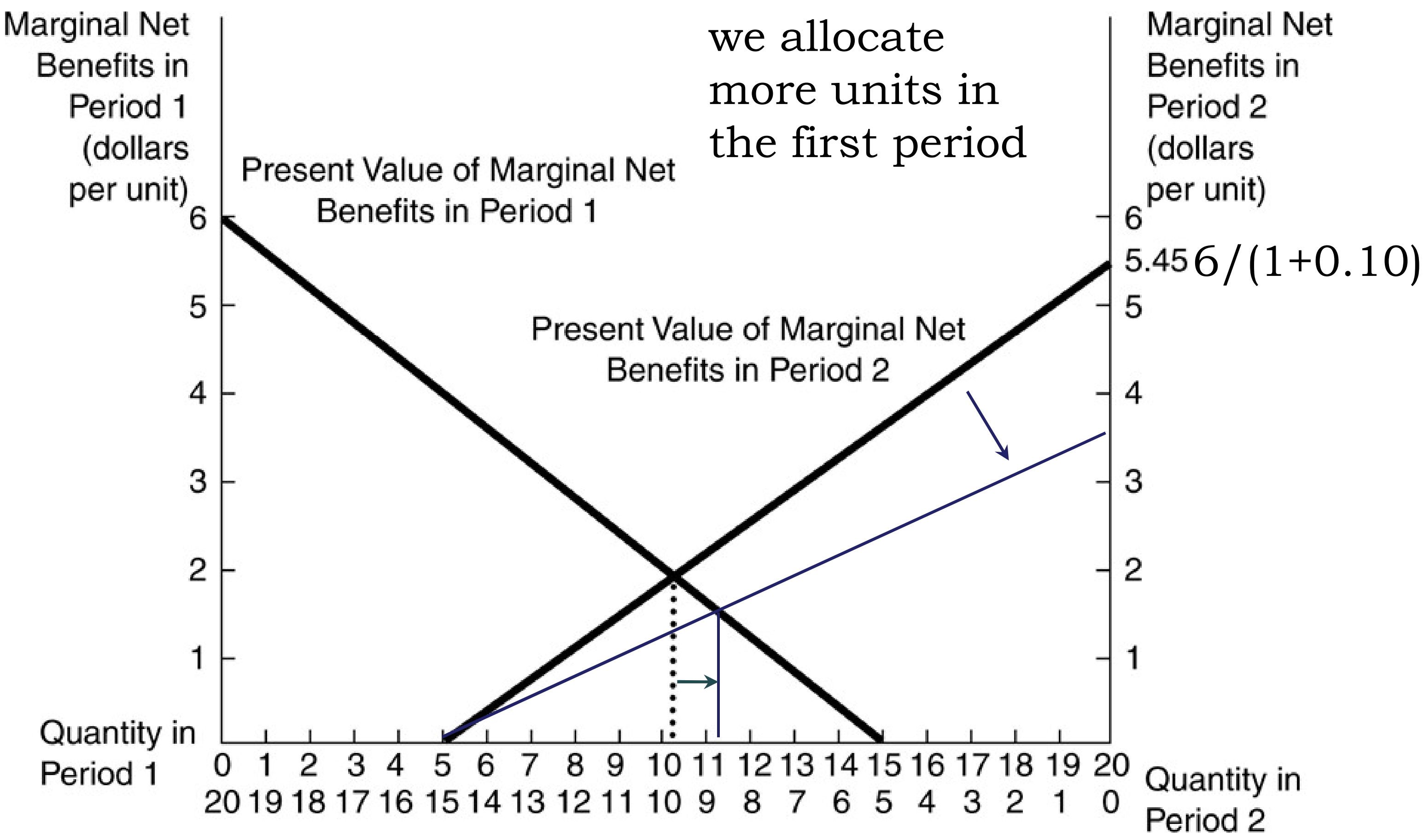
# Dynamic Efficient Allocation

As the interest rate increases we allocate more units in the first period



# A Two-Period Model

Exercise

Assume that we have a finite stock of a non-renewable resource that will be extracted over the course of two periods. Demand in each period is given by:

$$P_t = 11 - q_t$$

where $P_t$ is the per-unit price and $q_t$ is the quantity extracted and consumed in period $t$, with $t = 1,2$. We further assume that each unit of the resource is extracted at a constant marginal cost of $MC$=€$1$. The market for the resource is perfectly competitive. Finally, we assume that the real interest / discount rate is r = 20%.

1. Calculate the quantities of the resource extracted in each period if the finite stock of the nonrenewable resource is $Q = 25$ units.
2. What will be the price of the resource in the first and second period?
3. Calculate the quantities of the resource extracted in each period if the finite stock of the nonrenewable resource is $Q = 10$ units.
4. Calculate the price at each period.
5. Calculate the Marginal User Cost (*MUC*) in each period.
6. Is there any relationship between the *MUC*s in the two periods? Explain.
7. Illustrate diagrammatically the market equilibrium in each period separately. Show the Marginal User Cost in each period in your graphs.
8. Is the resource exhausted in the two periods? Explain your answer.

# A Two-Period Model

Exercise

1. Calculate the quantities of the resource extracted in each period if the finite stock of the nonrenewable resource is *Q = 40* units. κόστος:

$$P_t = MC_t \Rightarrow 11 - q_t = 1 \Longrightarrow q_t = 10$$

   Therefore, in each period there is a demand for 10 units, with aggregate demand in both periods being 20, which is less than the available 25 units. Therefore there is no shortage.

2. What will be the price of the resource in the first and second period?

   Since there is no shortage, the resource should be priced at MC, that is at 1 euro.

# A Two-Period Model

Exercise

3. Calculate the quantities of the resource extracted in each period if the finite stock of the nonrenewable resource is $Q = 10$ units.

   At this level of resource availability there is shortage of supply and thus we have to price the resource above MC. To calculate the optimal allocation and pricing, we set PVNB equal in both periods.

$$PVNB_1 = PVNB_2 \Rightarrow 10 - q_1 = \frac{10 - q_2}{1 + 0{,}2} \Longrightarrow 1{,}2(10 - q_1) = 10 - q_2$$

   We also have to respect the resource constraint:

$$q_1 + q_2 = 10 \Longrightarrow q_2 = 10 - q_1$$

   substituting one into the other, we get:

$$1{,}2(10 - q_1) = 10 - (10 - q_1) \Longrightarrow 12 - 1{,}2q_1 = q_1 \Longrightarrow q_1 = 5{,}45$$

   That is, $q_1=5{,}45$ and from the constraint, $q_2=4{,}55$.

4. Calculate the price at each period.

   Substituting the optimal quantities into the demand in each period we get:

$$P_1 = 11 - q_1 = 11 - 5{,}45 = 5{,}55$$

$$P_2 = 11 - q_2 = 11 - 4{,}55 = 6{,}45$$

# A Two-Period Model

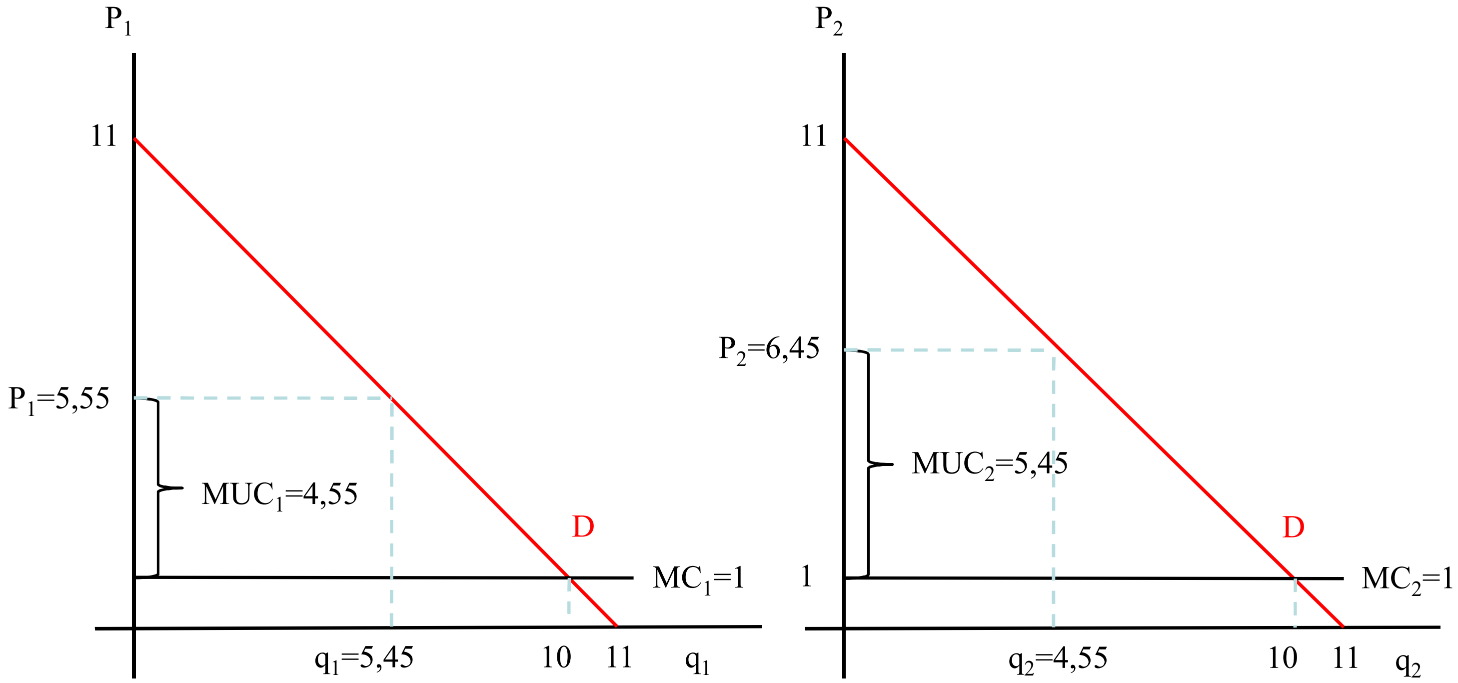
Exercise

5. Calculate the Marginal User Cost (*MUC*) in each period.
   The MUC (or scarcity rent) in each period is calculated as the difference between the price and MC:

$$MUC_1 = P_1 - MC = 5{,}55 - 1 = 4{,}55$$

$$MUC_2 = P_2 - MC = 6{,}45 - 1 = 5{,}45$$

5. Illustrate diagrammatically the market equilibrium in each period separately. Show the Marginal User Cost in each period in your graphs.



# Defining Intertemporal Fairness

- How much should we leave for future generations? What is the appropriate rate of discount?
  - A Theory of Justice by John Rawls—everyone with unknown generations , standing behind a “veil of ignorance”, decide the rules.
  - Sustainability criterion—future generations should be left no worse off than current generations and should perhaps be left better off.

# Are Efficient Allocations Fair?

- A dynamic efficient allocation will not automatically satisfy the sustainability criterion, but can be consistent with sustainability.
  - With a discount rate greater than zero, an economically efficient allocation will allocate more of a resource to the first period than the second. This requires that price increases over time. Net benefits will be greater in the first period than the second.
  - The sustainability criterion can still be met if the first period sets aside sufficient net benefits for the second period.

# Applying the Sustainability Criterion

- The sustainability criterion is very difficult to implement since it requires knowledge of future generation's preferences

- A more operational criterion is Hartwick's Rule.
  - Total capital is defined as physical capital plus natural capital.
  - If all scarcity rent is invested in capital, the value of the total capital stock will not decline.
  - If the principal or the value of total capital is declining, the allocation is not sustainable.

- But complete substitutability between physical and natural capital is an extremely strong assumption.

# Applying the Sustainability Criterion

- Weak sustainability—the maintenance of total capital
- Strong sustainability—the maintenance of the value of the stock of natural capital
- Environmental sustainability—to maintain certain physical flows of certain individual resources

# Example

## The Alaska Permanent Fund

One interesting example of an intergenerational sharing mechanism currently exists in the State of Alaska. Extraction from Alaska's oil fields generates significant income, but it also depreciates one of the state's main environmental assets. To protect the interests of future generations as the Alaskan pipeline construction neared completion in 1976, Alaska voters approved a constitutional amendment that authorized the establishment of a dedicated fund: the Alaska Permanent Fund. This fund was designed to capture a portion of the rents received from the sale of the state's oil to share with future generations. The amendment requires:

> *At least 25 percent of all mineral lease rentals, royalties, royalty sales proceeds, federal mineral revenue-sharing payments and bonuses received by the state be placed in a permanent fund, the principal of which may only be used for income-producing investments.*

The principal of this fund cannot be used to cover current expenses without a majority vote of Alaskans.

The fund is fully invested in capital markets and diversified among various asset classes. It generates income from interest on bonds, stock dividends, real estate rents, and capital gains from the sale of assets.[7] To date, the legislature has used some of these annual earnings to provide dividends to every eligible Alaska resident, while using the rest to increase the size of the principal, thereby assuring that it is not eroded by inflation. The 2010 dividend was $1,281.

Although this fund does preserve some of the revenue for future generations, two characteristics are worth noting. First, the principal could be used for current expenditures if a majority of current voters agreed. To date, that has not happened, but it has been discussed. Second, only 25 percent of the oil revenue is placed in the fund; assuming that revenue reflects scarcity rent, full sustainability would require dedicating 100 percent of it to the fund. Because the current generation not only gets its share of the income from the permanent fund, but also receives 75 percent of the proceeds from current oil sales, this sharing arrangement falls short of that prescribed by the Hartwick Rule.

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*Source*: The Alaska Permanent Fund Web site: http://www.apfc.org/home/Content/home/index.cfm

# Example

“Most Alaska residents will soon be getting a check for $1,174 simply for living
Each person’s share of the state’s vast oil wealth was announced with much fan

APFC VISION STATEMENT

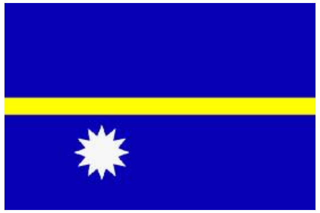
OUR VISION IS TO DELIVER SUSTAINED, COMPELLING INVESTMENT RETURNS AS THE UNITED STATES’ LEADING SOVEREIGN ENDOWMENT MANAGER, BENEFITTING ALL CURRENT AND FUTURE GENERATIONS OF ALASKANS.

| FY18 TOTAL FUND ASSETS UNDER MANAGEMENT (AS OF JUNE 30, 2018) | FY18 TOTAL FUND RETURN | ANNUALIZED FUND RETURN SINCE INCEPTION |
|---|---|---|
| $64,894,345,000 | 10.74% | 8.86% |

PRINCIPAL

$46,029,992,000

# Example



## Nauru: Weak Sustainability in the Extreme

The weak sustainability criterion is used to judge whether the depletion of natural capital is offset by sufficiently large increases in physical or financial capital so as to prevent total capital from declining. It seems quite natural to suppose that a violation of that criterion does demonstrate *unsustainable* behavior. But does fulfillment of the weak sustainability criterion provide an adequate test of *sustainable* behavior? Consider the case of Nauru.

Nauru is a small Pacific island that lies some 3,000 kilometers northeast of Australia. It contains one of the highest grades of phosphate rock ever discovered. Phosphate is a prime ingredient in fertilizers.

Over the course of a century, first colonizers and then, after independence, the Nauruans decided to extract massive amounts of this rock. This decision has simultaneously enriched the remaining inhabitants (including the creation of a trust fund believed to contain over $1 billion) and destroyed most of the local ecosystems. Local needs are now mainly met by imports financed from the financial capital created by the sales of the phosphate.

However wise or unwise the choices made by the people of Nauru were, they could not be replicated globally. Everyone cannot subsist solely on imports financed with trust funds; every import must be exported by someone! The story of Nauru demonstrates the value of complementing the weak sustainability criterion with other, more demanding criteria. Satisfying the weak sustainability criterion may be a necessary condition for sustainability, but it is not always sufficient.

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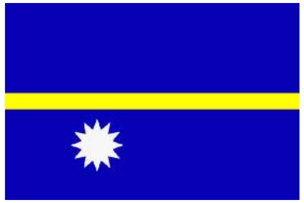
*Source*: J. W. Gowdy and C. N. McDaniel, "The Physical Destruction of Nauru: An Example of Weak Sustainability." LAND ECONOMICS, Vol. 75, No. 2 (1999), pp. 333–338.

# Example



The **Nauru Phosphate Royalties Trust** (NPRT) was a sovereign wealth fund developed by the government of the Republic of Nauru in which the government invested money from the state owned mining company, Nauru Phosphate Corporation. This money was then re-invested in a real estate portfolio, among other things, to provide the government with a reliable national income following the depletion of minable phosphates on the island. Although at one time successful, mismanagement and corruption later essentially bankrupted the fund, thus virtually bankrupting the entire Republic.

At the peak of the trust's wealth, the NPRT had investments totaling A$1 billion. These investments included properties in Australia, the Philippines, Guam, and the USA.
This great wealth led to high external representation and excessive official overseas travel (that included golf in the Bahamas) which blew out budgets year after year so that the government began to borrow money  to supplement its huge spending. The public service had over 1,500 employees (in a country with a population less than 10,000) and the government  ran deficits of A$10 mill. in the 1990s. Eventually, more than A$200 million was borrowed. In order to consolidate this debt and pay interest, the government took out an A$240 million loan from General Electrics Capital Division, which was levied against the nation's international real estate portfolio. The virtual end of mining on Nauru and the budget deficits made it very difficult for Nauru to pay its debts. International creditors didn’t receiving payments, then seizing rights to Nauru's entire real estate portfolio, and even seizing the sole aircraft of Air Nauru.

# Implications for Environmental Policy

- Not all efficient allocations are sustainable and not all sustainable allocations are efficient.

- Market allocations may be either efficient or inefficient and either sustainable or unsustainable.

- Policy changes that can produce win-win situations because by correcting an inefficiency, net benefits are increased.