Chapter 2: Economic Efficiency

I  Human Environment Relationship

1. Our discussion will center around the relationship between human actions and the environmental consequences of those actions.

2. The role of the environment in economic thinking has changed substantially over the past 30 or 40 years.

(1) The simplest economic system virtually ignores the environment.

Traditionally, adding the environment focused on its role in "extraction" - another input.
More recently, this view has been expanded to consider the other important interaction with the environment - "residuals"

In economics, however, the emphasis in terms of resource and the environment is their role as an asset, providing services. The definition of services is very broad. For example, recently the "existence value" of resources have been recognized, but this can also be considered as serving people in terms of the satisfaction of knowing the existence of these resources.

(2) Direct consumption

(i) air

(ii) recreation

(3) Inputs to production

(i) oil, natural gas

(ii) minerals

(iii) timber

(iv) water
4 In what way should we utilize these services? The optimal use depends on the efficiency criteria that we follow. It is important to distinguish between what should be done and what is being done:

(4) DEFINITION: Positive economics is a systematized body of knowledge concerning what is (Keynes). – both a description and an understanding of what is.

(i) Tietenberg alternatively defines it as an attempt to describe what is, what was or what will be.

(ii) Here is where models come into play.

- What will happen if the price of corn increases by 10%?
- What are the consequences of implementing a tradable permit system on SO₂ for utility companies?

(5) DEFINITION: Normative economics is a body of systematized knowledge discussing criteria of what ought to be. Many times the criteria are the major decisions. Human health? National Income? Sustainability (and which version of it)?

(i) Normative economics often involve value judgment.

(ii) Should we use a tradable permit system to control SO₂ pollution? What is the best way of doing it?

(6) Example: Raising minimum wage to $6/hr.

(i) Positive economics would predict how many jobs would be lost, versus increase in income for those keeping their jobs with the higher wage.

(ii) Normative economics would be required to judge the outcome, appealing to various criteria.

(iii) Many times the two methods should be combined to provide policy recommendations: If the minimum wage is raised to $6/hr, what will happen (positive economics). Are these consequences what we prefer? If not, what should instead be done (normative).

II Static Efficiency

1 One criterion in allocating resource and environment use is static efficiency.

(1) An allocation is said to satisfy the static efficiency criterion if the allocation maximizes the net benefit from the use of those resources.
(2) **DEFINITION:** net benefit = total benefit - total cost.

(3) We first discuss ways of measuring benefits and costs of env/res use.

2. Benefits, i.e. the value of environmental services
   (1) Just like how people value a regular good, the valuation of res/env is based on how people value their services.
   (2) For res/env services that are consumed directly, their value is based on people’s utility functions
       (i) Utility schedule:

       | Number of 60 sunshine days in a year | utility | marginal utility |
       |-------------------------------------|---------|-----------------|
       | 0                                  | 0       |                 |
       | 1                                  | 100     | 100             |
       | 2                                  | 180     | 80              |
       | 3                                  | 240     | 60              |
       | 4                                  | 280     | 40              |
       | 5                                  | 300     | 20              |

   (ii) Decreasing marginal utility -> demand curve. Marginal utility is the benefit derived from the last unit of service.

   **Total utility function**

   ![Total utility function graph]

   **Marginal utility**

   ![Marginal utility graph]

   (iii) Area under the demand curve measures total utility. It is the total *willingness to pay* (*WTP*) of the consumer for the sunshine days. The benefit of the sunshine days equals to WTP.

   (2) For res/env services that are inputs to production processes, their value is based on the demand of the production process (which is maximizing its profit) for these services.
       (i) Production function: total products and diminishing marginal productivity.
Production function

(ii) Value of marginal product (VMP) = (price) (MP) is the derived demand function for the services -> another type of demand function.
(iii) Again: the area under the demand function is the net revenue generated by the service, thus the total willingness to pay for the services.

(3) In summary, one way of representing people’s valuation is through the demand curve:
(i) Demand curve measures how much a person (or a group) is willing to pay for an additional amount of the service. (marginal value of the service)
(ii) The area under the demand curve is the total willingness to pay (WTP) for a certain amount of the service.
(iii) WTP is the total benefit of utilizing this amount of the service, while demand curve (or price) measures the marginal benefit of utilizing the last unit of the service.
(iv) When we use demand curve to measure WTP, always keep in mind what the value measures: utility (from regular demand function) or revenue (from the derived demand function)

3. Costs:
(1) Many times, the costs of using a res/env service include both direct costs and opportunity costs. For example: cutting trees for housing and furniture
   (i) **direct cost**: the cost of machinery and labor used in cutting and processing trees
   (ii) **opportunity cost**: is the net benefit forgone because the trees cannot provide such services as reducing CO₂, species protection, etc.
(2) Direct cost:
(i) Production theory: increasing marginal cost (the cost of producing the last unit of the good).
(ii) The upward sloping MC curve is the supply curve for a competitive firm.
(iii) Total cost of producing certain quantity is the area under the MC curve.
(3) Opportunity cost:
   (i) Since it measures the forgone benefit, and demand curve measures the benefit of the services, we can derive the marginal opportunity cost curve from the demand curve.

   ![Demand Curve and Marginal Opportunity Cost](image)

   (ii) It is similar to MC, and total opportunity cost is the area under the MC curve.

4. Static efficiency; maximize net benefits
   (1) Net benefit (NB):

   ![Net Benefit Diagram](image)

   (2) **RULE:** *benefit is maximized when MB=MC*. Look at $Q_1$, $Q^*$, and $Q_2$. 
5. Example:

(1) Demand (Marginal Benefits): \( P_d = MB = 90 - q \)
(2) Supply (Marginal Cost): \( P_s = MC = 50 + q \)
(3) Static Efficiency \( \Rightarrow MB = MC \)

(i) Total Benefits = OCBD
\[ = OPBD + PCB \]
\[ = 20 \times 70 + \frac{1}{2} \times (20 \times 20) \]
\[ = 1400 + 200 \]
\[ = 1600 \]

(ii) Total Cost = OABD
\[ = OAED + ABE \]
\[ = 20 \times 50 + \frac{1}{2} \times (20 \times 20) \]
\[ = 1000 + 200 \]
\[ = 1200 \]

(iii) Total Net Benefits = Total Benefits - Total Costs
\[ = 1600 - 1200 \]
\[ = 400 \]
6. Pareto Optimality
   (1) The static efficiency criterion is approximation to some stricter efficiency
criteria. These criteria are theoretically justified, but may be difficult to use.
(2) There are several such criteria. Each has its pros and cons. One of them is
Pareto efficiency (optimality).
   (3) **Definition:** An allocation is **Pareto Optimal** if there exists no other allocation
such that some people are made strictly better off without harming others in
the system.
(4) An allocation that is efficient (maximizing net benefits) is P-optimal. It is not
true the other way. Example:
   (i) starting situation: a paper firm pollutes a river, and residents
downstream complain.
   (ii) now impose a tax on emission to restrict pollution. The tax raises the
total benefit (=firm’s profit + residents surplus), but the firm is hurt.
   (iii) The pollution tax is not a Pareto improvement
(5) Starting condition matters.

III. Dynamic Efficiency

1. Static efficiency is inadequate when time is important in affecting the payoff
   (1) Resource and environmental problems are not static issues. Current use of
env/res services affect future stocks
(2) Example:
   (i) oil: extraction now reduces future stock
   (ii) nuclear waste generated now affect future generations
2. Need to extend the static efficiency criterion to include other time periods
   (1) Need to compare net benefits in one period with that in other periods. A dollar
this year is not equal to a dollar next year
   (2) To compare these, we rely on the method of discounting, or the notion of
present value
   (i) time value of money: given interest rate per year $r$,
      $X$ today = $X (1+r)$ next year = $X (1+r)^2$ two years later.
   (ii) the present value of receiving $X$ n periods from now, with interest
rate $r$, is
      \[ \text{PV}_n(X) = X / (1+r)^n \]

<table>
<thead>
<tr>
<th>Time Period</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>…</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present Value</td>
<td>X</td>
<td>X/(1+r)</td>
<td>X/(1+r)^2</td>
<td>…</td>
<td>X/(1+r)^n</td>
</tr>
</tbody>
</table>

(iii) a stream of benefits, $B_0, B_1, \ldots, B_n$, is equivalent to
      \[ \sum_{i=0}^{n} \frac{B_i}{(1+r)^i} \]
Example: The present value of receiving $3,000, $5,000, $6,000, $10,000, and $12,000 at the end of the next five years is $29,200 if interest rates are 6%. This is the case, because you could invest $29,200 today and at the end of each year withdraw exactly the stream of benefits above.

(3) Discount rate is crucial in evaluating resource problems because they typically involve long time periods. Example: (without inflation) the present value of $1 million

<table>
<thead>
<tr>
<th>years from now</th>
<th>at 7% discount rate</th>
<th>at 10% discount rate</th>
<th>at 15% discount rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>$33,948</td>
<td>$8,519</td>
<td>$923</td>
</tr>
<tr>
<td>100</td>
<td>$1,152</td>
<td>$73</td>
<td>$0.85</td>
</tr>
</tbody>
</table>

(4) Then what is an appropriate discount rate for res/env projects?

(i) for regular investment, \( r \) measures the opportunity cost of capital and is determined in capital markets

(ii) res/env related investments are special because

• a high discount rate is unfair for future generations
• their future benefits and costs are uncertain

(iii) traditionally environmentalists argue for low discount rate. Reason:

• the benefits of res/env preservation happens in the future: e.g. preserving a piece of wetland helps biodiversity that may yield benefits way in the future
• the benefit of destroying these resources provides more immediate gains
• a low discount rate helps preservation

(iv) Now another argument: should use high \( r \). Reason:

• Many benefits of preservation cannot be measured, and thus are not included in project evaluation. Destroying a piece of wetland for a supermarket typically does not consider value of biodiversity.
• A typical investment involves capital expenses now and monetary gains later on. For the supermarket, the gains would be the revenue generated by the supermarket.
• Then a high discount rate may make the project less profitable, driving out the project.
(5) Compounding

(iv) It is the opposite of discounting. How much is $X today worth at time period \( t \), given discount rate \( r \)? It is worth $X(1+r)^t$.

(v) Denote it as \( FV_t(X,r) = X(1+r)^t \).

3. Dynamic Efficiency

(1) DEFINITION: An allocation of resources across \( n \) time periods is **dynamically efficient** if it maximizes the present value of net benefits that could be received from all possible allocations of those resources over \( n \) periods.

(2) Example: Two period depletable resource (oil)

(i) 2 time periods labeled periods 0 and 1

(ii) Oil reserves = 100 barrels

(iii) Interest rates are at 10%

<table>
<thead>
<tr>
<th>Period 1</th>
<th>Period 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( MB_1 = 50 - \frac{1}{2}Q_1 )</td>
<td>( MB_2 = 50 - \frac{1}{2}Q_2 )</td>
</tr>
<tr>
<td>( MC_1 = 10 )</td>
<td>( MC_2 = 10 )</td>
</tr>
<tr>
<td>( MNB_1 = 40 - \frac{1}{2}Q_1 )</td>
<td>( MNB_2 = 40 - \frac{1}{2}Q_2 )</td>
</tr>
<tr>
<td>( TNB_1 = 40Q_1 - \frac{1}{4}Q_1^2 )</td>
<td>( TNB_2 = 40Q_2 - \frac{1}{4}Q_2^2 )</td>
</tr>
</tbody>
</table>

(iv) The problem is to allocate the oil between the two time periods.

(3) Question: What is the statically efficient allocation?

- \( MB_1 = MC_1 \Rightarrow MNB_1 = 0 \)
- \( MNB_1 = MB_1 - MC_1 = 50 - \frac{1}{2}Q_1 - 10 = 40 - \frac{1}{2}Q_1 \).
- \( MNB_1 = 0 \Rightarrow Q_1 = 80 \).

(i) The same statically efficient solution would also apply to period 2. But there is not enough oil to go around.

(ii) Note: if the stock > 160 barrels, static efficiency is adequate regardless of \( r \). why?

(4) Question: Any suggestions regarding how this allocation should occur?
(5) Question: What if we allocate 50 barrels to each period? Would this be dynamically efficient?
   - No, it would assume the two periods are of equal value. Given the discount rate at 10%, this is not the case.

(6) We will use three methods for solving this problem, but first we need to define some terms

<table>
<thead>
<tr>
<th>Present Value Marginal Benefits</th>
<th>Period 1</th>
<th>Period 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV[MB(_1)] = 50 - (\frac{1}{2}Q_1)</td>
<td>PV[MB(_2)] = (50 - (\frac{1}{2}Q_2))/1.1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Present Value Marginal Costs</th>
<th>Period 1</th>
<th>Period 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV[MC(_1)] = 10</td>
<td>PV[MC(_2)] = 10/1.1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Present Value Marginal Net Benefits</th>
<th>Period 1</th>
<th>Period 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV[MNB(_1)] = 40 - (\frac{1}{2}Q_1)</td>
<td>PV[MNB(_2)] = (40 - (\frac{1}{2}Q_2))/1.1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Present Value Total Net Benefits</th>
<th>Period 1</th>
<th>Period 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV[TNB(_1)] = 40Q_1 - (\frac{1}{4}Q_1^2)</td>
<td>PV[TNB(_2)] = (40Q_2 - (\frac{1}{4}Q_2^2))/1.1</td>
<td></td>
</tr>
</tbody>
</table>

(i) Numerically

<table>
<thead>
<tr>
<th>(Q_1)</th>
<th>PV[TNB(_1)]</th>
<th>PV[TNB(_2)]</th>
<th>PV[TNB(_1)]</th>
<th>PV[MNB(_1)]</th>
<th>PV[MNB(_2)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>1344</td>
<td>1276.912</td>
<td>2620.912</td>
<td>16</td>
<td>12.7</td>
</tr>
<tr>
<td>49</td>
<td>1359.75</td>
<td>1263.933</td>
<td>2623.683</td>
<td>15.5</td>
<td>13.16</td>
</tr>
<tr>
<td>50</td>
<td>1375</td>
<td>1250.5</td>
<td>2625.5</td>
<td>15</td>
<td>13.61</td>
</tr>
<tr>
<td>51</td>
<td>1389.75</td>
<td>1236.613</td>
<td>2626.363</td>
<td>14.5</td>
<td>14.07</td>
</tr>
<tr>
<td>51.46</td>
<td>1396.37</td>
<td>1230.07</td>
<td>2626.44</td>
<td>14.27</td>
<td>14.27</td>
</tr>
<tr>
<td>52</td>
<td>1404</td>
<td>1222.272</td>
<td>2626.272</td>
<td>14</td>
<td>14.52</td>
</tr>
<tr>
<td>53</td>
<td>1417.75</td>
<td>1207.477</td>
<td>2625.227</td>
<td>13.5</td>
<td>14.98</td>
</tr>
<tr>
<td>54</td>
<td>1431</td>
<td>1192.228</td>
<td>2623.228</td>
<td>13</td>
<td>15.43</td>
</tr>
<tr>
<td>55</td>
<td>1443.75</td>
<td>1176.525</td>
<td>2620.275</td>
<td>12.5</td>
<td>15.89</td>
</tr>
</tbody>
</table>

(ii) Graphically

- Optimality rule: PV[MNB\(_1\)] = PV[MNB\(_2\)]
- **Question:** What happens as the interest rate increases?
  
  Rotate PV[MNB\(_1\)] downward and shift consumption to the present.
(iii) Mathematically
- Two pieces of information
  \[ \text{PV}[\text{MNB}_1] = \text{PV}[\text{MNB}_2] \]
  \[ \Rightarrow 40 - \frac{1}{2}Q_1 = 36.4 - 0.45Q_2 \]
  \[ Q_1 + Q_2 \leq 100 \]
  \[ \Rightarrow Q_2 \leq 100 - Q_1 \]
- Assume equality in (ii) [Note: this is obviously the case since it would be a waste to use less than 100 barrels when the two time periods want 100 barrels.]
- Plugging into the first piece of information yields
  \[ 40 - \frac{1}{2}Q_1 = \frac{40}{1.1} - \left( \frac{0.5}{1.1} \right) (100 - Q_1) \]
  \[ \Rightarrow 40 - \frac{1}{2}Q_1 = -10/1.1 + (0.5/1.1)Q_1 \]
  \[ \Rightarrow 0.95Q_1 = 49.09 \]
  \[ \Rightarrow Q_1 = 51.43 \]

4. Marginal User's Cost
   (1) At the dynamically efficient allocation, MB>MC in both periods
   (i) This is due to the scarcity of the resource stock
   (ii) As \( Q_1 \) increases, two costs are incurred:
     - cost in period one increases, along MC (=10)
     - \( Q_2 \) decreases, reducing \( \text{PV}[\text{TNB}_2] \)
   (iii) Similarly, as \( Q_2 \) increases, two costs are incurred
     - cost in period two increases, along MC (=10)
     - \( Q_1 \) decreases, reducing \( \text{FV}[\text{TNB}_1] = \text{TNB}_1 (1+r) \)
   (iv) The gap is caused by resource scarcity. If stock is high, then higher \( Q_1 \) may not affect optimal \( Q_2 \). Then MB=MC for period 1.

(2) We define the gap as marginal user cost (MUC).
   (i) MUC is the marginal net benefit forgone in a period due to resource scarcity.
(ii) In essence, it is an opportunity cost of extracting the resource at any point in time. Therefore, it depends on the net benefit of extraction in other time periods.

(iii) In a period, an efficient allocation requires: \( MB_t = MC_t + MUC_t \), or \( MNB_t = MUC_t \).

(iv) In two period problems:
- \( MUC_1(Q_1) = PV[MNB_2(100-Q_1)] = PV[MNB_2(Q_2)] \)
- \( MUC_2(Q_2) = FV[MNB_1(100-Q_2)] = FV[MNB_1(Q_1)] \)

(v) In our example, \( MUC_1 = 14.27 \) and \( MUC_2 = 15.7 \), while \( PV[MUC_1] = PV[MUC_2] = 14.27 \)

(vi) How does the interest rate affect the MUC?
- It reduces \( MUC_1 \). Why?
- It raises \( MUC_2 \). Why?

(3) When MC is independent of resource stock (or constant MC, as Tietenberg calls it), MUC rises a the rate of interest

(i) Constant MC ⇒ \( MUC_1 = PV[MNB_2] \)

(ii) Not true if MC depends on \( Q_t \).

(iii) Similarly, constant MC ⇒ \( MUC_2 = FV[MNB_1] \), or \( PV[MUC_2]=MNB_1. \)

(iv) Remember dynamic efficiency requires: \( MNB_1 = PV[MNB_2] \).

(v) Thus \( MUC_1 = PV[MUC_2] \). *Generally*, \( PV[MUC_1]=PV[MUC_2] \).

(vi) \( MUC_1 = MUC_2/(1+r) \Rightarrow MUC_2 = (1+r)MUC_1 \).

(4) Summary of dynamic efficiency in the two period, constant MC case

(i) With a positive discount rate, less is used in period 2 than in period 1.

(ii) The higher the discount rate, the greater the difference between periods.

(iii) With constant marginal costs, the marginal user’s cost rises are the rate of interest.

5. N period, constant marginal extraction cost

(1) *Question:* What would expect to happen with three or more periods?

(i) Amount of extraction, \( Q \), declines over time.

(ii) MUC increases over time at the rate of interest. Figure 7.2
Example:

(i) Uses oil reserves of 40 barrels and an interest rate of 10%
(ii) MC = 2
(iii) MB = 8 - .4Q

Result: Figure 7.2.

(i) Notice that there is no sudden collapse of resources. Instead, they run out slowly.
(ii) Intuition:

• Treat oil in the ground as an asset
• Price line must be continuous - arbitrage argument.
• MUC rises at the rate of interest
• All of the resource must be used up. Reason: at the last unit, MC=2<MB=8 (because Q small). Thus, the last unit will be extracted.
• At the last unit, TMC line hits choke price (the price at which the demand = 0).
• These conditions jointly determine the extraction path.
6. Transition to a Substitute

(1) Up until now, we have treated individual resources as unique, with no substitute possibilities.

(2) Suppose we now allow substitutes. Examples:
   (i) oil, natural gas, nuclear, wind power and solar power

(3) Example #1: Infinitely Available Substitute - Oil to Solar Power
   (i) The only difference is a different choke price
   (ii) The rules in (5.3.ii) still apply

(iii) Conclusions:
   - Initially, prices are lower and quantities consumed are higher for the depletable resource.
   - The depletable resource is used up sooner - in essence because the substitute product means its less scarce.
   - Prior to the switch, only the depletable resource is used. After the switch point, only the renewable resource is used.
• The transition is smooth.
(4) Example #2: Depletable to Depletable (oil to nuclear)

<table>
<thead>
<tr>
<th>Price</th>
<th>Demand, MB</th>
<th>Choke Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3</td>
<td>MEC_1</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>MEC_2</td>
</tr>
</tbody>
</table>

(i) The conclusions are similar to those in Example #1.
(ii) This same approach can be used to look at varying ore qualities

7. Increasing Marginal Extraction Costs
   (1) Example: Mining moving from high to lower grade ores
   (2) Marginal User's cost no longer rises at the rate of interest
   (3) Depletable Resource may not be entirely exhausted. It may become more expensive to extract the ore (at the marginal) than the marginal benefits justify.

8. Exploration and Technological Progress
   (1) Historically, consumption of depletable resources has increased over time.
   **Question:** Does that imply that resources have been used inefficiently, since we have found, so far, that quantity should decline over time?
   (2) Not necessarily:
   (i) Exploration retards the rise in marginal costs.
   (ii) Technological change can actually reduce the marginal extraction costs.
   (iii) Example: Iron Ore Industry - Pelletization
   • 1947: prediction that Mesabi range would be used up by 1954 (the source of 60% of world iron ore)
   • 1955: U.S. New and World Report concluded there was no problem
   • Shift from standard ores (>50% iron) to pelletization process using ores with 30-50% iron.
   • Savings occurred due to a reduction in net energy (blast furnaces more efficient using pellets) and reduced labor requirements.
   • Eg. a blast furnace rated at 1500 tons/day was able to produce up to 2800 tons/day due to pelletization.
   (iv) Demand changes can occur over time (i.e., exogenously determined demand changes).

9. Market Allocations
   (1) Will the markets lead to dynamically efficient allocations of depletable resources?
   (2) Yes, under certain conditions:
(i) The property rights must exist in order to insure efficient transactions.
(ii) Reliable information on future prices and costs are needed
(iii) Reliable information or forecasts on technological change and exploratory payoffs are needed.
(iv) Equal social and private discount rates are required.
(v) Environmental costs are fully accounted for
(3) Question: What impact will the inclusion of environmental costs have on the depletion of depletable resources?
   (i) It depends upon the nature of the environmental costs. Are they cumulative or one-time costs?
   (ii) With one-time costs, and constant marginal extraction costs, we simply are raising the marginal extraction costs.

\[\begin{array}{c|c|c}
\text{Price} & \text{Demand, MB} & \text{Choke Price} \\
\hline
10 & 8 & \text{MEC} + \text{MC}_{\text{pollution}} \\
6 & 4 & \text{MEC} \\
2 & 2 & \text{Choke Price} \\
\end{array}\]

- This will lead to higher prices, less demand and the resource lasting longer.
- May switch sooner to a renewable alternative that is not polluting.
(iii) If the costs are cumulative, as with most toxic substances, and/or marginal extraction costs are increasing over time, one may never extract all of the resource. (marginal cost becomes non-constant)

IV. Sustainability

Efficiency criterion is concerned with current generation only. What about future generation? They are affected by our actions.

1. John Rawls’ principle of justice:
   (1) Place everyone behind a "veil of ignorance"
   (2) No one knows which generation they belong to
   (3) Make decisions regarding rules to govern society and then force everyone to live by them once the veil is removed.
2. Rule from this principle: sustainability
(1) Many definitions. The most popular one: at a minimum, future generations should be left no worse off than current generations.

(2) Efficiency cannot guarantee sustainability. Key element: sharing between generations.

3. Several versions of interpretation of the sustainability rule:

   (1) Hartwick rule
       (i) Invest a certain portion of the proceeds of using physical resources in man-made capital so that the total value of capital (sum of man-made and natural capital) remains unchanged.
       (ii) Requires a sufficient degree of substitutability between man-made and natural capital. May be difficult to satisfy.
       (iii) Example: land and machinery/new seed for agricultural production

   (2) Nondeclining value of natural capital
       (i) Implies that natural capital is homogeneous.
       (ii) Counter example: water/air vs. gold

   (3) Nondeclining physical service flows from selected resources. Most economists do not agree with this approach.