UNIVERSITÀ DEGLI STUDI DI SIENA

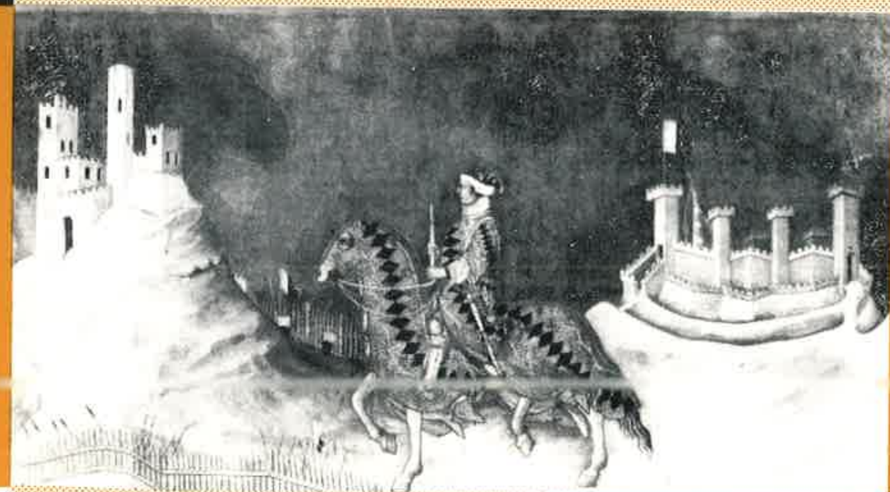
140

QUADERNI DEL DIPARTIMENTO
DI ECONOMIA POLITICA

BERNHARD BÖHM

AN INTRODUCTION INTO ENVIRONMENTAL ECONOMICS

(LECTURE NOTES)



QUADERNI DEL DIPARTIMENTO DI ECONOMIA POLITICA

Redazione: Dipartimento di Economia Politica, Piazza S. Francesco, 17 - 53100 Siena - tel.0577/298620

La Redazione ottempera agli obblighi previsti dall'Art.1 del D.L.L. 31.8.45 n.660

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Bernhard Böhm

AN INTRODUCTION INTO ENVIRONMENTAL ECONOMICS
(LECTURE NOTES)

Siena, Maggio 1992

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AN INTRODUCTION INTO ENVIRONMENTAL ECONOMICS

1. Studying the relations between the economy and the environment

1.1 Introduction

Environmental problems are considered to be the most serious problems for our future. Starting from regional burdens like deterioration of water quality due to overfertilization of soil or pollution of running waters by industrial waste water up to global environmental burdens like the increase of CO_2 in the atmosphere there is a wide range of nowadays well known problems. In many areas the resilience (i.e. the capability of absorbing changes or disturbances) of ecosystems has reached its limits.

Main factors for this development are
- overpopulation
- a unique technological potential in history
- the way we run our economy.

The last item does not only concern the western industrial society but also centrally administered economies and developing countries. The fact that the specific way of running our economy is an elementary factor for our environmental problems poses also a challenge for economic analysis. First, we face the question to what extent economic analysis of the present day, particularly economic theory, is able to describe relations between the economy and the environment in an adequate manner. It can be shown that this is not possible straightforwardly. In particular the frame for the description of the economic activities must be enlarged by essential aspects of the environment. As a consequence also the traditional economic database like national income accounting must be extended as well as the instruments of theoretical analysis.

> It should be recalled that national income accounting itself is a rather young achievement which has gained popularity with the assumptions of a particular economic theory (i.e. the Keynesian). From its beginnings up to date there are discussions about conceptual issues, conventions and prescriptions designed to shed some light on issues disputed in theory. So, as theory develops and emphasis is shifted different objects are attempted to be measured with changing degree of reliability and accurateness.

There are important people who plead for a basic change in the economic paradigm in this context (cf. Schumacher(1973) Georgescu-Roegen (1971), Boulding (1966)).

Accordingly the environmental problems also ask for a change of the orientation of economic policy. In this field nowadays we discuss indirect instruments for guiding economic activity like energy taxes, emission taxes, or direct measures, like orders (commands) or prohibitions to change economic conditions. One of the fundamental questions is whether we can adapt the currently existing system to a new one, or whether a fundamentally new construction is asked for. In certain respects we find parallels to the "social question" about a hundred years ago.

1.2 Functions of the environment for the economic system

The environment renders the life support system for the economy. This is the entire set of natural conditions that defines the human living space.

Main functions are:

1. Environment renders resources which are used in production. One distinguishes renewable resources (like wood, fish) and nonrenewable or exhaustible resources (like coal, natural oil). By sustainable use of a renewable resource one understands a use of the resource which does not reduce the stock. The extent of sustainable use is limited by the growth rate of the stock.
2. environment acts also as a receptacle for waste (or emissions) which are products that cannot be used anymore and which are originating jointly with production or consumption of other goods (i.e.. they are joint products). Waste or emissions can be solid, liquid, or gaseous. They are deposited in environmental media (air, soil, water) are partially accumulated, decumulated or transformed. This can be modelled or depicted by a transformation function. In analogy to resources one distinguishes naturally recyclable waste (e.g. straw) and such which cannot be naturally recycled (e.g. heavy metals) but need to enter a technological process. Different degrees of degradation and damaging effects are the reason for this distinction. Products or pollutants contained in an environmental medium (emissions) influence the quality and partially also the quantity of (possibly public) consumer goods which are rendered by the environment. A damage function describes the relationship between the emissions and the costs or benefits from the use of resources and public environmental goods.
3. The environment renders direct private and public consumer goods to the economy (air, water, amenity of landscape, possibilities for recreation which is often called environmental quality. The use of the environment as a public good can partly be measured in certain units but partly is not quantifiable at all (like amenity of landscape).
4. The environment renders the space which is used as a location for building, as agricultural land and which is essential for many other uses (like infrastructure).

These relationships can be visualized in a diagram (1).

1.3 Open and closed models

In traditional economic analysis production and consumption are modelled as an open system (cf. diagram (2)). Here resources are inputs, the waste is output and the economic activities to be analyzed are production and consumption. Waste originates in the production or the consumer sphere. "Open" means that the essential interaction with the environment is not considered, i.e. that the life support functions for the economy are not included in the analysis. These are, as mentioned above, mainly the rendering of resources, the acceptance of waste by the environment, as well as

the direct utility or the benefit from the environment, e.g. in the form of aesthetical satisfaction. On the other hand, in a closed system these functions of environment are also modelled. An example to make the system partly closed by considering recycling can be seen in diagram (3). The process of natural or industrial recycling recovers a part of the resources used in the economy. Only a part of the total waste is recycled, the rest is emitted into the environment from which also a part of the resources is taken directly. In this graph the system is not closed because of the flows of parts of the resources and waste directly from respectively into the environment.

In a completely closed system matter and energy are conserved. This is the content of the first law of thermodynamics. The entire earth as a system can be regarded as a closed system concerning matter. With respect to the energy balance this does not hold because of the energy derived from the sun.

1.4 Material- and energy balances

In the traditional economic analyses material and energy flows which are evaluated with prices are considered between and within the sectors of production and consumption. Once goods have been consumed they leave the economic system. This form of analysis is in contrast to the physical laws concerning the conservation of matter and energy. Matter and energy quantities which are moved by economic activities have a series of direct economic consequences. These flows can be visualized in diagram (4).

In equilibrium for each system the equation of balancing matter must hold. Inflowing matter is equal to outflowing matter. Also the energy balance equation must hold. Inflowing energy is equal to outflowing energy.

A system is closed if it exchanges no matter and no energy with its "environment". Closed systems are therefore specific equilibrium systems where the inflows and the outflows are zero. For the economy it follows that in equilibrium all resources taken out of the environment calculated in mass units equal all wastes which are delivered to the environment. Matter and energy balances yield information to judge economic processes especially if the information contained in prices is questionable. E.g. in the context of energy production one would have to relegate techniques with a negative energy balance even if such a technique would be economically viable as a result of distorted prices.

1.5 Entropy in economic processes

Natural systems which are not subject to external influences have a tendency to transform towards states of greater disorder. In physics this is meant to be described by the concept of entropy. One of the many equivalent definitions of entropy state: Entropy is the index of the amount of unavailable (or bound) energy in a given thermodynamic system at a given moment of its evolution. The second law of thermodynamics (the entropy law) states that the entropy of a closed system continuously and irrevocably increases towards a maximum, i.e. available (free) energy is continuously transformed into unavailable energy until free energy disappears completely.

Energy transforms into lower forms (less available) completely while the transformation from lower forms to higher valued (useful) energy is only possible with losses. The entropy concept can also be applied to the physical aspect of production and consumption. Even if matter which is taken out of the environment is again disposed of in the environment in such a way that the substance is maintained the form of matter has changed. Matter with lower entropy which is of potential use for the human being because it contains many other possibilities for use, will be transformed into such of high entropy, i.e. it will be devoted to a special use. E.g. burning a ton of natural oil to produce heat precludes the alternative use of this ton of oil to produce pharmaceuticals. These processes are irreversible. Each useful activity leads to an increase of entropy of the system and thus, to a decrease of the potential which could be useful for further activities.

The entropic evaluation of economic processes has been especially propagated in the book by Georgescu-Roegen (1971).

1.6 Extended circular flow relationships

The circular flow between the economy and the environment can be described by a matrix:

	economic processes	ecological processes
economic processes	economic inter-sectorial flows	flows from economic to ecosystem
ecological processes	flows from eco- to economic system	flows within the ecosystem

The first quadrant describes the relationships within the economic system as e.g. contained in the Input-Output table. The second one contains the flow of services of the economy to the environment. These are emissions originating in production and consumption. The third quadrant contains deliveries of the environment to the economy which partly enter production or enter final demand directly. The forth quadrant depicts processes within the environmental sector. They do not influence economic activity directly. Indirectly they have effects on the stocks of environmental media which are used by the economy e.g. by transformation processes.

Each model of an interaction between the economy and the environment must use informations of these four quadrants of the table. Different types of models can be developed differing according to the problem posed and the availability of data. Modelling the origination of pollutants involves e.g. the quadrants of the first row. To model the use of resources you need information from the quadrants of the first column. Modelling recycling processes requires consideration of quadrants 1, 2 and 3. In order to model and analyze policy measures for environmental

protection the quadrants of the first row have to be used as well as the feedback mechanism which involves both subsystems.

1.7 The concept of economic sustainability

From the insight that the way we run our economy is one of the essential factors for the deterioration of the state of the environment, we have to face the question about the principles of constructing an economy which will not entail deterioration of the environmental state and therefore is sustainable in the sense that it can be continued arbitrarily. Obviously the concept of an environmental state is relatively vague. One way would be to measure this state by the potential to offer resources and to assimilate waste. The capability to assimilate waste can be regarded also as a renewable resource. Consequently one of the main rules for environmental management would be not to depreciate the stock of resources. Obviously this demands too much. E. g. this would imply no use at all of exhaustible resources. But it also follows that one of the main tasks for environmental management would have to be to secure balanced rates of return and the waste-assimilation capability of the environment.

The keyword "sustainability" thus refers to a program for policy to seek or maintain an acceptable rate of growth in per capita real incomes without depleting the national capital asset stock or the natural environmental asset stock. This is, more accurately, the goal of sustainable growth.

The goal not to decrease natural resources can certainly be questioned. Two basic arguments for the existence of a sustainable economy despite decreasing stocks of resources can be given:

1. Technical progress will increase the efficiency of resource utilization
2. Natural capital could be substituted by man made capital.

These arguments, however, need careful examination. To create man made capital one would obviously need natural resources. Also, natural capital like forests fulfill life support functions which cannot always be supplied by man made capital. Technical progress has certainly a crucial function related to the saving of resources. Just think e.g. of the many possibilities of substitution of energy and materials by the new information technology. On the other hand, new technologies could also pose new risks (e.g. nuclear power). In addition, one cannot be sure that technical progress will continue steadily and there is no guarantee that it will be ready just when it is needed.

The main arguments for careful dealing with natural capital are the following:

- There is a substantial amount of ignorance and uncertainty about the functioning of the natural life support systems. E.g. we do not know how large exactly is the effect of deforestation to regional and global climate. Also the effects of CO2 emissions on the climate are not completely well known.

- Consumption of natural capital often constitutes an irreversible process. Mistakes can not be corrected: deserts are difficult to convert into fertile land and species which have died out are lost forever.

In addition to these reasons, the idea of sustainability and maintenance of the stock of natural resources is closely related to the idea of giving a fair chance to future generations. These are basic ethical considerations on which a sustainable development policy centers attention. This policy argues for a change in paradigm to take efficiently account of environmental constraints on the economic growth process. Conservation of resources and the need to develop an environmental ethic are central issues. It is entirely unclear what the intrinsic values of non-human nature are and what rights nature has, e.g. rights of animals beyond the rights of human beings.

What does it mean to maintain the stock of natural resources. Three concepts can be thought of:

1. physical quantities shall not change
2. the capital stock at current prices should not change
3. the capital stock evaluated at constant prices should not change.

So, which stock should be kept constant? Actually, the one which just happens to exist or is there an optimal one?. The latter could theoretically be found out only by cost-benefit calculations. The cost for an increase of the capital stock corresponds to the forgone use for other purposes. The utility has an economic dimension but also contains many elements which are outside the scope of economics proper. Practically, the evaluation of costs and benefits is very difficult in most cases if not impossible.

A "circular economy" designates an ideal economy which should comply with the following requirements for the production technology:

1. No use of non-renewable resources. Renewable resources should only be used in a sustainable manner.
2. All waste must be recycled either by industrial or natural ways.
3. Energy is to be supplied by solar sources (in the wide sense), e.g. water power, biomass, solar cells.

Such a circular economy constitutes a sustainable economy. The economic potential of such an economy at the current state of technological knowledge is not known yet but is currently investigated.

2. The importance of environmental data.

2.1 Problems with the current practice of National Accounting

For a proper assessment of the relationship between the economy and the environment one needs "good" data. One source commonly available is the set of economic data obtained from National Accounting. However, there are many problems related to the use of data generated in that framework.

National Income Accounting (NIA) should be able to:
- describe the development of economic activities and the productive power of a country;
- yield quantitative information about the welfare of the inhabitants of a country.

In earlier days growth was approximately set equal to increasing welfare. Today we notice many negative consequences associated with growth. This is felt seriously when e.g. the national product is used as a measure of well-being of a country. Because the national product is only one item provided by NIA it is worth examining the basic three types of difficulties the NIA suffers from:

a. inclusion problems:
   - Many items are included in the calculations of e.g. GDP which should not be, e.g. expenditures for repairing damages, government services are treated as final products not intermediary ones, all expenditures of private households are assumed to be for final products.
   - Items are not included but should be, e.g. work of housewives, social costs and benefits, certain qualitative aspects should be considered, value of leisure etc..

b. valuation problems:
   - Market transactions are valuated at market prices, imputed transactions are valuated at costs or opportunity costs.
   - Depreciation is usually estimated (at current buyers prices)
   - state services valuated at producers costs
   - quality changes are not considered, relevant for assessment of technical change (index number problems)
   - partition into price and quantity component not always possible.
   - change of values of stocks (inventory): which price to use.
   - systematic biases develop over time (e.g. indices).

c. dimensionality problems:
   By using only one number like GDP one cannot make a differentiated statement. Composition or distribution information is often more appropriate. Life style and -quality, employment situation and structure need to be taken into account. Social indicators can be used to cover these aspects. Should be amended by environmental indicators.

2.2 Environmental data

In addition to information about causes for environmental problems one also needs actual data to support environmentally relevant decisions. Mainly of interest are:

- Reports on the state of the environment (especially physical magnitudes)
- Reports on the cost which follow from the way we run the economy. Focus on monetary valuation of damages.
- Construction of a set of indicators on the state of environment to be integrated in general welfare indicators.

Follow-up costs of the economy:

Ecological and social costs from running the economy can be classified into
- defensive (compensatory) costs for repairing damages. Expenditures to fight effects from inflicted damages to the environment.
- Losses in production, income or wealth due to environmental damages, e.g. destroyed forests due to acid rain. This also contains additional transfer payments for social security systems like increased sick payments due to environmentally caused sickness. These do not separately enter NIA.
- Losses of health and welfare and losses in the nature, e.g. environmentally caused deseases, extinction of species. These costs cover all ecological costs which cannot be avoided or recovered by compensatory economic activity. They ultimately reduce the environmental capital.

The first two can in principle be valuated in money terms which is hardly possible for the third group. Defensive costs are relatively easy to compile. Most of them are included in NIA entering, however, positively.

2.3 Including the environment in National Accounting

The state of and the change in the environment is not covered in NIA. This puts the importance of GDP as (one-dimensional) welfare indicator into question.

In particular GDP does
- not contain or consider sufficiently environmental conservation activities (natural protection by farmers etc.)
- not consider sufficiently negative environmental effects of economic activity (like damages of health, of animals and plants, pollution of land, water, air, damages to materials like monuments and buildings, effects on climate).
- consider consequences of environmental damages positively if costs for repair or prevention arise.
- not or not sufficiently cover all problems associated with the extraction or use of exhaustible resources.

Some attempts to correct the common national accounting systems have been undertaken. Examples are Nordhaus and Tobin's "measure of economic welfare (MEW)" and the present movement towards an integration of economically relevant environmental aspects (as the new SNA by the UN). Extended national accounting will contain also an ecological system where emissions and immissions of pollutants as well as the stocks and their changes of environmental media will be considered.

2.4 Valuation techniques to measure environmental damage

Essentially what one wants to know when planning a particular development project is the cost, the benefit of the project and the total economic value which takes into consideration whatever is lost when the project is carried out. It is clear that several value concepts exist and play a role in answering this question.

A decision rule may be given as follows:

Let denote
B the benefits of the project,
C the costs of the project, and
Bp the benefits of preserving the environment by not doing the project.

Then
(1) Proceed with the project if (B - C - Bp) > 0.
(2) Reject the project if (B - C - Bp) < 0.

Bp may be measured by the total economic value which covers the actual use value, the option value (i.e. the value of the environment as a potential benefit as opposed to actual present use value), and the existence (or intrinsic) value. This value concept covers irreversibilities, the inherent uncertainty and incorporates somtimes unique values (like lost species).

Direct and indirect valuation

Direct valuation methods consider the environmental gains and seek to measure the money value of these gains directly. This can be done by:
- looking for surrogate markets: observing environmental benefits or costs that are frequently attributes of traded goods in actual markets.
- expeerimental techniques: simulating a market by placing respondents in a position in which they can express their hypothetical valuation of real improvements in specific environments. One tries to make this hypothetical valuation as close to reality as possible.

Indirect valuation methods calculate "dose-response" relationships and apply some measure of preference for the calculated effect.

Hedonic price approach

With the appropriate statistical technique this approach tries to
- identify how much of a property differential is due to a particular environmental difference between properties,
- infer how much people are willing to pay for an improvement in the environmental quality they face and what the social value of the improvement is.

Identification of a property price effect is done by multiple regression using data on similar residential properties over years or many diverse properties at the same time (cross section) or both. To find possible effects on the observed differences in price all relevant sets of variables must be included: property, neighborhood, accessibility, and environment variables. From the estimates elasticities of the changes in environmental variables on the price are calculated.

Contingent valuation method

Uses a direct approach to ask people directly what they are willing to pay for a benefit or to receive as a compensation for tolerating a cost. This is done by
- direct questionnaires
- by experimental technique.

One obtains personal valuation of the respondents for the increase or decrease in the quantity of some good, contingent upon a hypothetical market, i.e. to find out the willingness to pay or to accept if a market existed for the good in question.

This method also includes the institutional context in which the good would be provided and the way in which it would be financed. It is attractive because it should be applicable to all circumstances. It often is the only technique of benefit estimation. Its aim is to elicit bids (valuations) which are close to those that would be revealed if an actual market existed. Practically it is conducted by successively bidding and offering. The accuracy of the method could be checked by comparing with other valuation methods based on surrogate markets. However, there are a number of possible biases.

Travel cost approaches

They are based on the theory of demand extended to incorporate the value of time. Direct travel costs and forgone earnings (opportunity costs) are calculated. This is mainly used to assess recreational value of certain environmental goods.

3. Modelling environmental - economic relations

3.1 Extended Input-Output Tables

Based on the extended circular flow scheme current national accounting attempts to integrate environmental data in the national macroeconomic data base. Extended Input-Output tables which contain relations of the economic sectors with the environment serve as basis for developing first empirical models in environmental economics.

A simple possibility to extend the Input-Output table introduces environmental goods as additional inputs and outputs. The table would look as follows

	interindustrial transactions 1 2 . . . n	final demand	gross - production	production of envir. goods
sect. 1 2 ... n	Z	Y	X	N
input of envir. goods	M			

$Z = (z_{ij})$ designates the matrix of input flows of goods from sector i to sector j $(i,j=1,\dots,n)$,
Y is the matrix of final demand,
X is the matrix of gross-production,
$N = (n_{kj})$ the matrix of emissions of type k, which originate together with production of sector j $(k=1,\dots,n_1)$ and
$M = (m_{kj})$ the matrix of environmental inputs of type k $(k=1,\dots,n_2)$ for the production of sector j. n_1 and n_2 need not be equal.

In analogy to the traditional input coefficients $(A = (z_{ij}/x_j))$ of the Input-Output model one defines new sets of coefficients:

the matrix of environmental-input-coefficients

$$R = (r_{kj}) = (m_{kj} / x_j) \qquad k = 1,\dots,n_2 ,j = 1,\dots,n,$$

the matrix of environmental-output-coefficients

$$Q = (q_{kj}) = (n_{jk} / x_j) \qquad k = 1,\dots,n_1 ,j = 1,\dots,n,$$

where n_{jk} (with two indices) is an element of matrix N, n the number of economic sectors and n_1, n_2 the corresponding number of environmental goods.

Coefficients which yield total effects can be derived:

The elements of the matrixproduct $R(I-A)^{-1}$ show the quantity of environmental input k, which is required directly and indirectly for delivery of one unit of the product of sector j for final demand. Similarly elements of $Q(I-A)^{-1}$ yield the quantity of emissions of type k, which originate together with delivery of one unit of value of product j to final demand.

Example 1 (after BLAIR, MILLER 1985):

The following table Is given:

	interindustrial transactions 1	2	3	final demand	gross - production	production of envir. goods SO_2	HC
sek. 1	1	3	5	3	12	0	1
2	0	2	10	0	12	0	2
3	0	2	6	16	24	4	3
envir. goods:							
water	5	4	8				
land	10	10	1				

Calculate technical coefficients (A), ecological input- (R) and ecological outputcoefficients (Q). Find the input of ecological goods which are required for the production of one unit of value of final demand of each sector (R^*). Also find the quantities of pollutants (Q^*) which originate with this production.

Solution:

$$A = \begin{matrix} 0.08333333 & 0.25000000 & 0.20833333 \\ 0.00000000 & 0.16666667 & 0.41666667 \\ 0.00000000 & 0.16666667 & 0.25000000 \end{matrix}$$

$$R = \begin{matrix} 0.41666667 & 0.33333333 & 0.33333333 \\ 0.83333333 & 0.83333333 & 0.04166667 \end{matrix}$$

$$Q = \begin{matrix} 0.00000000 & 0.00000000 & 0.16666667 \\ 0.08333333 & 0.16666667 & 0.12500000 \end{matrix}$$

$$(I-A)^{-1} = \begin{matrix} 1.0909091 & 0.43636364 & 0.5454545 \\ 0.0000000 & 1.35000000 & 0.7500000 \\ 0.0000000 & 0.30000000 & 1.5000000 \end{matrix}$$

$$R^* = R(I-A)^{-1} = \begin{matrix} 0.45454545 & 0.7318182 & 0.9772727 \\ 0.90909091 & 1.5011364 & 1.1420455 \end{matrix}$$

$$Q^* = Q(I-A)^{-1} = \begin{matrix} 0.00000000 & 0.05000000 & 0.2500000 \\ 0.09090909 & 0.29886364 & 0.3579545 \end{matrix}$$

3.2 Applications of Input-Output analysis for pollution generation and abatement (Extended Leontief-models)

Generation of pollution in production can be modelled in the following way:

Let z_{pj} be pollution of type $p=1,\dots,n_1$ which is generated by production of sector j.

Measuring these quantities per monetary unit of output, i.e.
$a_{pj} = z_{pj}/x_j$,

then the total emission of pollutants $p=1,\dots,n_1$ for given production x_j $(j=1,\dots,n)$ is

$$x_p = \Sigma_j a_{pj} x_j \ .$$

Adding this line to the standard model of Input-Output analysis is equivalent to the addition of a further good for which there is no final demand.

The last line of the Leontief-inverse contains the quantities of pollutants, which are generated directly and indirectly for satisfying one unit of value of final demand for the commodity of a particular sector (pollution multiplier). These multipliers give an indication about the effects of measures which intend to reduce final demand. Because the totally generated pollution x_p can be allocated proportionally among the various goods of final demand where the pollution multipliers are used as factors of proportion.

Example 2: There are two sectors which produce two goods. Pollution is generated with this production. Final demand (Y) for good 1 is 600, and for good 2 it is 1500. The input-coefficients for goods production are

$$a_{11} = 0.15 \quad a_{12} = 0.25$$
$$a_{21} = 0.20 \quad a_{22} = 0.05$$

The pollution generation coefficients are

$$a_{p1} = 0.05 \quad a_{p2} = 0.04$$

Solve for the production quantity of goods 1 (x_1) and 2 (x_2) as well as for the total pollution generated (x_p) with this production.

Solution:

$$(I-A) = \begin{matrix} 0.850 & -0.250 & 0.000 \\ -0.200 & 0.950 & 0.000 \\ -0.050 & -0.040 & 1.000 \end{matrix} \qquad Y = \begin{matrix} 600.000 \\ 1500.000 \\ 0.000 \end{matrix}$$

$$(I-A)^{-1} = \begin{matrix} 1.254 & 0.330 & 0.000 \\ 0.264 & 1.122 & 0.000 \\ 0.073 & 0.061 & 1.000 \end{matrix}$$

$x_1 =$ 1247.5248 $\qquad x_p =$ 136.0396
$x_2 =$ 1841.5842

Question: By which amount decreases pollution if final demand for good 1 decreases by 100?

Solution: Decreasing y_1 by 100 yields
$x_1 =$ 1122.1122
$x_2 =$ 1815.1815
$x_p =$ 128.71287
Pollution is reduced by 7.317 units.

The model can be extended to incorporate pollution abatement or waste disposal activities in an added sector. Let x_u denote the quantity of pollutant eliminated by the abatement activity. Let Y_p denote the amount of pollutant tolerated (or else remaining). The model can then be written:

$$\begin{vmatrix} x \\ \text{--} \\ x_u \end{vmatrix} - \begin{vmatrix} A & : a_u \\ \text{------} & :\text{---} \\ a_p & : a_{uu} \end{vmatrix} \begin{vmatrix} x \\ - \\ x_u \end{vmatrix} = \begin{vmatrix} Y \\ \text{---} \\ -Y_p \end{vmatrix}$$

Columnvector a_u denotes the input-coefficients for deliveries of other sectors to the abatement sector.

Vector a_p denotes pollution generation coefficients as above.

a_{uu} is the intrasectoral pollution generation coefficient of the abatememt sector, since it cannot generally excluded that the abatement sector itself does not emitt pollutants.

As the total quantity of pollutant is

$$\Sigma_j\ a_{pj}\ x_j + a_{uu}\ x_u$$

the tolerated value (Y_p) must be deducted to yield the amount which is eliminated by the abatement activity (x_u). The last line of the matrix equation above becomes therefore:

$$\Sigma_j\ a_{pj}\ x_j + a_{uu}\ x_u - Y_p \ = \ x_u \qquad \text{or}$$

$$x_u - (\Sigma_j\ a_{pj}\ x_j + a_{uu}\ x_u) \ = -Y_p$$

<u>Example 3</u> (Blair/Miller 1985):

Transactions are given in the following matrix:

	goods-prod.	services	abate-ment	inter-mediary.	final-demand	gross prod.
goods	15.0	25.0	0.6	40.6	59.4	100.0
service	20.0	5.0	1.2	26.2	73.8	100.0
poll.	5.0	4.0	0.0	9.0	-3.0	6.0

How does gross-production of bothsectors change if tolerated pollution is reduced by one unit (i.e. from -3 units to -2)?

Solution:

$A =$

$$\begin{matrix} 0.150 & 0.250 & 0.100 \\ 0.200 & 0.050 & 0.200 \\ 0.050 & 0.040 & 0.000 \end{matrix}$$

$(I-A) =$

$$\begin{matrix} 0.850 & -0.250 & -0.100 \\ -0.200 & 0.950 & -0.200 \\ -0.050 & -0.040 & 1.000 \end{matrix}$$

$(I-A)^{-1} =$

$$\begin{matrix} 1.268 & 0.342 & 0.195 \\ 0.283 & 1.138 & 0.256 \\ 0.075 & 0.063 & 1.020 \end{matrix}$$

changed final demand:

59.400
73.800
-2.000

changed gross production:

$x_1 =$ 100.195
$x_2 =$ 100.256
$x_u =$ 7.020

changed intermediary demand:

40.795
26.456
9.020

Thus the change in gross production is:

0.195
0.256
1.020

3.3 Critical aspects of environmental Input-Output analysis

Although Input-Output analysis sofar seems to contribute well to a macroeconomic perspective of the environmental problem it has met with considerable critism.

Linearity of the model constitutes a problem. Particularly for the ecological system linearity is rather doubtful.
A constant technology assumption cannot be maintained in the long run. Consideration of the environment evidently implies to consider changes in technology i.e. adjustment processes will be triggered like substitution of inputs, production of different outputs and recycling. It is possible to consider models of activity analysis or a combination of input-output models with substitutional production models more appropriate in the longer run..

- Quantities of pollutants or wastes do themselves say little about how much remains in the environment and the damage done to the environment. The analysis must be amended by a consideration of relevant diffusion processes.

- Consideration of waste and pollutants as joint products neglects the fact that they bring about undesired inputs affecting production.

- Classification of economic sectors is problematic because coefficients may not tell much due to heterogeneity of products produced in one sector as well as the processes used. Although this also holds for the simple Input-Output model, demands for a high quality of data are crucial for environmental aspects.

- The regional character of the environmental problem is not captured by the above presentation. This, however, can be amended by integrating regional tables into the environmental framework.

4. External Effects

Technological external effects are direct nonmarket interdependencies among economic activities. They can arise in consumption or production activities and also between consumption and production. They can be negative or positive depending on the effect of the actions of an economic agent on the welfare of others.

Externalities violate a condition for optimality of a market equilibrium. Conditions for a Pareto-efficient equilibrium are violated. The question then arises whether the set of autonomous decisions of individual agents constitutes an optimal allocation.

Example:

Firm A produces quantity x of a commodity (e.g. paper) using labour Input (LA) according to the production function

$$x = f(LA).$$

Depending on the produced quantity pollutants are generated (h(x)) which are emitted into a river which is used by another firm B to produce commodity y (e.g. fish). Firm B produces according to the production function

$$y = g(LB, h(x)),$$

dependent on labour input (LB) but also the pollution content. Higher emissions of the pollutant by firm A influence production y of firm B negatively.

For given prices, p of good x, and q of good y, and the wage rate w (the same for both firms) optimality conditions for profit maximization are:

$$p.df(LA)/dLA = w \text{ for firm A, and}$$
$$q.dg(LB,h(x^*))/dLB = w \text{ for firm B.}$$

The influence of A on production of B is ignored by Firm A which in turn produces "too much" for a social optimum. This can be seen by internalising the external effect e.g. by merging the two firms and inspecting the joint optimum.

Now maximize aggregated profit

$$p.f(LA) + q.g(LB, h(f(LA))) - w.LA - w.LB.$$

The necessary conditions now differ from above:

$$p.df(LA)/dLA + q.(dg/dh)(dh/df)(df/dLA) = w$$
$$q.dg/dLB = w.$$

Since $dg/dh < 0$, the optimal labour input for firm A (and thus its produced quantity) will be lower than before when the externality is present.

Thus, with externalities the firms behaviour does not lead to an efficient allocation. How can the allocation be corrected?

Usually three possibilities are considered:

1. Introduction of taxes or subsidies to correct prices which are taken as the fundamental signal for the decisions of agents.

   As can be seen from the example, firm A uses the "wrong" price (p). The "social price" which also contains the detrimental effect which is caused by firm A is lower
   (p + q.(dg/dh)(dh/df))
   and would bring about an efficient allocation. By introducing a tax amounting to the difference between the private (p) and the social price (q.(dg/dh)(dh/df)) firm A could be forced to

base its decision on the lower price.

This proposal leads to practical problems of determining the exact tax rate because the size of the marginal effects of the externalities at the optimal production level need to be known. Mutual dependencies must be known well, but are usually different in each case.

2. One could attempt to create a market for the externality. This will also yield a price for it which could be considered in decisions.

What would be an equilibrium price for the externality? The largest amount which the affected firm would be willing to pay would be the marginal increase of its profits brought about by a reduction of the external influence. In the example above profits of B are G = q.g(LB, h(x)) - w.LB. The marginal profit is dG/dh = q.(dg/dh) which will be called the "price of the externality and denoted by r. With such a price the optimization problem of A would be
max (p.f(LA) + r.h(f(LA)) -w.LA).
The necessary condition is
(p + r(dh/df))(df/dLA) = w
and is the same as the one above for the joint (socially efficient) firm.

Note, that the introduction of a market can be costly. When there are only few participants transfer payments could achieve the proper level of the externality (e.g. pollution). This is more difficult when there are many participants or when the good in question is a public one.

3. One can define property rights, which lead to bargaining solutions via the market mechanism such that externalities can be avoided.

If externalities of a firm have detrimental effects on another one, it will always be profitable to transfer the property of one firm to the other. The purchasing price could be set at level which corresponds to the value under externalities as it value will increase after internalisation. The market mechanism could work to adjust property rights in such a way as to avoid externalities. This could be all right for private goods. For public goods this and the previous solution approaches are rather problematic.

5. Public goods

5.1 Definition

A public good is characterized by two features:
1. it can be used by several individuals at the same time without competing with one another (i.e. no rivalry in use),
2. it does not permit exclusion of other users (i.e. nonexcludability)

Therefore, public goods are such with a specific externality, because other consumers must consume the same amount of it. Examples: Streetlights, police, defense, lighthouse, environmental quality.

Whether a good is considered as public or not could depend on the state of techniques to exclude individuals from its consumption. Exclusion may be technically possible (e.g. cable TV, fees for university) but not desirable (e.g. university education). This is called a "merit good". The public character may relate to location, to a specific circle of people, or to particular time periods. The important distinction is the nonexistence of exclusive property rights for such goods. Goods for which this holds but rivalry in use exists are called "common property resources". For these goods problems of congestion may occur (e.g traffic on roads, free parking in streets). Historical reasons are sesponsible for the treatment of many common property resources as public goods. However, due to congestion and dangers associated with it there is a tendency to turn common property resources into goods subject to private property rights.

In this context and particularly related to environmental problems the question arises whether some functions of the environment could be better provided if they were privatised. E.g. private property could be established for certain areas so that the decentralized allocation mechanism of the market could offer appropriate solutions.

Total demand for a private good can be obtained by summing individual demands. For a public good this cannot be done because it is not divisible but is available only as a whole. One characterises a public good, therefore, by the summation of the individual valuations of this good.

5.2 Efficient allocation of public goods

We study a simple model with two goods, one is a public good (x) and the other one is private (y). The economy consists of two people. Thus, the total quantity of the private good is y=y1+y2. The public good is consumed by both. The transformation function T(x, y1+y2) describes the technical possibilities of this economy. Maximizing the social welfare function W(u1(x,y1),u2(x,y2)) under the constraint T(x, y1+y2)=0, yields the necessary conditions (t is the Lagrange multiplier):

$$\frac{dW}{du1}\frac{du1}{dx} + \frac{dW}{du2}\frac{du2}{dx} - t\frac{dT}{dx} = 0$$

$$\frac{dW}{du1}\frac{du1}{dy1} - t\frac{dT}{dy1} = 0$$

$$\frac{dW}{du2}\frac{du2}{dy2} - t\frac{dT}{dy2} = 0$$

From this system the following condition results:

$$\boxed{\frac{du1/dx}{du1/dy1} + \frac{du2/dx}{du2/dy2} = \frac{dT/dx}{dT/dy} \quad \text{or} \quad MRS1 + MRS2 = MRT}$$

which is expressed in terms of marginal rates of substitution (MRS) and of transformation (MRT) between the public and the private good. MRT indicates the opportunity costs of one unit of the public good in terms of the private good. The MRS's indicate which marginal utility from the private good the individual can give up for a marginal utility derived from the public good, given a constant utility level.

This optimality condition differs from the one in competitive equilibrium. In the present case the sum of the individual marginal utilities must be equal to the marginal rate of transformation. In competitive equilibrium the condition is that each individual MRS must be equal to the MRT. As the latter is equal to the relative price and all individuals are assumed to face the same prices, it is suggested to interprete the individual MRS's between the public and the private good as individualized prices. In other words, the MRS denotes the "willingness to pay" according to the individual subjective preferences. Thus, individuals demand different quantities of private goods at a price which is the same for all, whereas they consume the same quantity of a public good at a differing willingness to pay.

The condition above also determines the supply of the public good. Theoretically each consumer pays for it according to the individual willingness to pay. If all people are taxed according to this principle each would be paying a subjective contribution determined by the individual MRS. Such an efficient allocation is called a "Lindahl equilibrium".

The conditions are very difficult to realise. To determine the optimal quantity of the public good one would need to know all individual MRS's. But these are not revealed by prices as with private goods nor can demand for the public good be individually adjusted. Thus, there is no way to establish a market for the public good.

Can the individual willingness to pay for a public good be found out by questionnaires?

If the answer is known to be used for deciding the level of taxes most people will cheat. If the answer does not influence taxation there will be a tendency to overstate. The problem to find out the true willingness to pay is known by the name the "free rider" problem.

6. Fundamental concepts of the economic theory of exhaustible and renewable resources

6.1 Discounting

Discounting of values which are to be consumed or produced in future periods indicates a specific view on preferences about future goods as compared to present ones i.e. present ones are considered more important than future ones. This is called time preference and shows the impatience of economic agents.

Discounting is a fundamental concept of intertemporal analysis. The existence of interest rates explain discounting. From it derives the question how much worth at the present is a particular sum of (e.g.) money, which is due in a future period (i.e. its present value).

Another reason for existence of positive rates of discounting is the productivity of capital. If, instead of consuming some resource now, one invests it, one may yield a higher level of consumption later than at present. Waiting for the future benefit will be worth it if the cost of impatience does not exceed the future benefit.

The relationship between consumption possibilities in period t and t+1 can be described by a transformation function $T(c_t, c_{t+1}) = 0$. The marginal rate of transformation of c_t into c_{t+1} (i.e. $(dT/dc_{t+1})/(dT/dc_t)<0$) expresses how much more can be consumed in the future period if consumption in period t is reduced in favour of productive investment. This is the gross productivity of the invested capital (foregone consumption). It is equal to 1+r with r the net productivity of invested capital (or the internal rate of return, or marginal efficiency of capital). r also measures the social opportunity cost.

On the other hand we can characterize time preference by an intertemporal utility function $U(c_t, c_{t+1})$. The marginal rate of intertemporal substitution $dc_{t+1}/dc_t = -(dU/dc_t)/(dU/dc_{t+1})$ therefore equals 1+s with s the rate of time preference.

At the point of tangency between the transformation and the utility function the rate of time preference and the internal rate of discount are equal. This point yields the best intertemporal allocation which can be achieved under the given technological conditions which in turn is compatible with the impatience of agents. Interpreting the utility function as a social welfare function would permit to obtain equality between the social rate of time preference and marginal efficiency of investment when capital markets are perfect. In practice this is often not the case.

Therefore, we have usually two sources for determining a discount rate: the social opportunity costs in terms of the marginal efficiency of investment, and the social rate of time preference or impatience. Both convey how society values present goods via future ones. A difference between the two rates indicates a discrepancy between views of the society and technical possibilities. High social discount rates imply neglecting of problems of future generations. High technical marginal rates of return imply faster depletion of existing resources.

Thus, discounting reflects the level of discrimination against future generations. It influences rates of exploitation of exhaustible resources and leads to inconsistency with the concept of sustainability, because the higher the discount rate the less is our consideration for maintaining the environment intact.

The following aspects should be considered when choosing a rate of discount:

1. Determination of an aggregate welfare function from individual preferences is - to say the least - an open question (in view of existing impossibility theorems). This obviously effects aggregation of individual time preference and thus, a social discount rate.
2. To determine a social discount rate by means of a bargaining solution with the parties interested would require the presence of future generations.
3. The planning horizon of a society is usually much longer than that of individuals.
4. Assuming a growing economy would imply an improved level of welfare for future generations. However, this depends on the way welfare is measured.

6.2 Some basic problems in natural resource economics

It is common knowledge that most resources on earth are scarce and therefore only available for a limited period. But it is not clear what scarcity exactly means . One needs concepts for measuring scarcity:
- duration of resource availability
- stating required quantities given a pattern of demand
- computation of long run requirements under consideration of temporary changes

Assumptions about price changes and other adjustment processes have to be laid open when making statements about resource scarcity:
- price levels
- techniques of depletion
- existence of competing resources (substitutes) and/or production techniques
- search costs

From the finiteness of the earth and the relative closedness of our system it follows that natural resources are limited and, insofar as they are not renewable, their exploitation takes place at the cost of future generations: Thus, the problem of intertemporal allocation of the natural resource exists. For renewable resources this problem also covers the process of regeneration.

The character of the resource (public, nationalize, private good) has influence on properties and consequences of optimal solutions of the dynamic allocation problem.

Intertemporal efficiency of resource utilization can be measured according to different criteria:

1. (Koopmanns efficiency): Output in one period cannot be increased without decreasing it in another period.
2. (Pareto efficiency): A person (or generation) cannot be made better off in one period by intertemporal use of a resource without making another person (generation) worse off in another period.

Both criteria do not require discounting in principle. They provide partial rules in the sense that by comparison certain outcomes can be excluded which do not meet the criteria. But more than one allocation can satisfy the criteria.

A specific allocation can be found by optimization of a dynamic social welfare function (for which one has to find a suitable functional form and a social discount rate, however). In most cases the following function for an infinite horizon is chosen:

$$W(t) = \int_{t0}^{\infty} e^{-\delta t} w_t(C_t)\, dt.$$

To solve dynamic allocation problems this function is optimized subject to specific constraints.

7. Exhaustible resources

7.1 The problem under perfect competition

Optimal depletion of an exhaustible resource poses a purely economic problem. One tries to find the path of the resource stock which simultaneously determines the optimal flow of resource utilization.

Example:

(1) A given resource stock S_0 shall be depleted over a finite horizon T. The amount of depletion (x_t) is therefore dependent on the choice of the time horizon and the intertemporal utility function. Suppose it is the same over all periods $U(x_t)$, the total utility is:

$$W = \int_0^T U(x_t)\, dt,$$

which should be maximized. The flow of extraction corresponds to the reduction of the stock:

$$-x_t = dS/dt.$$

The total stock S_0 is to be entirely exhausted:

$$S_0 = \int_0^T x_t\, dt.$$

A solution of this optimization problem yields the results which can easily be checked: The stock is divided into equal parts to be extracted:

$$x_t = S_0/T$$

(2) Now change the assumption such as to discount utility over time:

$$W = \int_0^T e^{-\delta t}\, U(x_t)\, dt,$$

The optimal solution shows a distribution over the finite horizon in favour of the earlier periods. It just corresponds to the idea of discounting.
Choose e.g.

$$U(x_t) = (1/1-\alpha)\, x_t^{(1-\alpha)},$$

one obtains

$$x_t = x_0\, e^{-(\delta/\alpha)t} = S_0(\delta/\alpha)[1/(1-e^{-(\delta T/\alpha)})]e^{-(\delta/\alpha)t}$$

(3) Now change the problem again by considering an infinite horizon. In our first problem (the equal distribution) it is not possible to find a positive value for the flow to be extracted per period because the resource is finite. There is only one theoretical solution with equal extraction per period: $x(t)=0$. But this solution is not efficient in the sense of Pareto: One can extract more in one period and not be made worse of in another one.

In the case of discounting we can find an optimal solution:

$$x_t = x_0\, e^{-(\delta/\alpha)t} = S_0(\delta/\alpha)e^{-(\delta/\alpha)t}.$$

Extraction of the resource proceeds with a constant growth rate (δ/α).

In the example extraction costs have been neglected. Also the

price does not play any role. By analyzing the necessary conditions for a maximum one gains better insight into the problem. There the role of the price is revealed.

In the infinite horizon problem with discounting the necessary conditions are:

(a) $dU/dx_t = \mu(t)$
(b) $dS/dt = -x_t$
(c) $d(\mu(t)e^{-\delta t})/dt = 0.$
μ is the shadow price (or the Lagrange-multiplier) of the resource.

From (c) follows $d\mu(t)/dt = \delta\mu(t)$ and therefore $\mu(t) = \mu_0 e^{\delta t}$. Considering (a) it also follows that the growth rate of the marginal utility is equal to the discount rate (δ). From the theory of demand it is known that there exists a proportionality between marginal utility and commodity prices. Intuitively, it follows that the growth rate of the marginal utility is equal to the growth rate of the price and equal to the discount rate (δ) if one assumes the price path given. With perfect competition one obtains the condition

$$\boxed{(dP/dt)(1/P) = \delta}$$

which is also called "Hotellings rule".
It implies that $P(t) = P_0 e^{\delta t}$.

This rule can also be intuitively derived from the principle of discounting. Denote the current market price of the resource below the ground (in situ) as $P(t)$. A corresponding amount invested on the capital market at interest rate δ yields after one period: $(1+\delta)P(t) = P(t+1)$. Thus we obtain $(P(t+1)-P(t))/P(t) = \delta$ which is the condition that the resource owner is indifferent between extracting the resource or investing its value on the capital market. I.e. a resource in the ground is earning interest like any other asset.

The analysis of necessary conditions also shows that there does not exist an equilibrium solution (except if extraction is zero). With positive extraction the resource stock must decrease. Since $\delta>0$ the shadow price of the resource $\mu(t)$ grows with rate δ. From $(d\mu/dt)/(dS/dt) = -\delta\mu/x_t < 0$ we see that there is a negative relationship between price increase and resource extraction. The higher the price grows the slower the extraction, or the other way round, the fewer of the resource is left under ground the higher the price (equal to the marginal utility of the resource).

According to Hotellings rule different price paths can be chosen dependent on an initial price P_0. Setting the optimal initial price must be done under consideration of demand and supply conditions. The given stock of resources S_0 and the demand function (in the example $x_t^{-\alpha} = \mu(t) = P(t)$) determines the initial price ($\mu_0 = (S_0\delta/\alpha)^{-\alpha}$ in the example). The larger the initial stock the lower the initial price and vice versa. A higher initial price means that optimal extraction proceeds slower. The path of optimal extraction always lies below a path with a lower initial price.

What makes the setting of the initial price so relevant is the existence of a backstop-technology, i.e. a substitute for the resource which takes its place if the price reaches a certain level. If P_0 is set too high, the resource may not be fully exhausted when the backstop-technology is introduced. In the opposite case the resource may already be exhausted before a backstop technology may be substituted. This can happen either because it has not yet been fully developed or it is only available at a higher price.

So far we have ignored costs of extraction. If there are no extraction costs the price of a resource under ground (or royalty) is the same as the market price for the consumer. If costs are considered the market price (p_t) differs from the royalty (P_t) by the amount of the costs (K_t). Cost may depend on the quantity extracted. For simplicity we shall consider only constant costs. The path for the market price now becomes $p_t = P_0 e^{\delta t} + K$. Hotelling's rule still holds for the royalty, i.e.

$$\boxed{(dP/dt)(1/P) = \delta = (dp/dt)/(p-K).}$$

Therefore, $P_0 = P_T e^{-\delta T}$ and since $P_T = p_T - K$ we have $P_0 = (p_T - K)e^{-\delta T}$. If the backstop price p_B will be reached in time T. i.e. $p_T = p_B$, then the relationship between the initial price P_0 and p_B can be used to derive the equation for the price path:

$$P_t = (p_{B,T} - K)e^{-\delta(T-t)}.$$

This relationship can be used to analyze the effect of changes in some basic variables like costs, discount rate, and the backstop price.

A decrease in costs would lead to an increase of the initial royalty (P_0) if p_0 is kept unchanged. But the royalty grows with the discount rate, so that the price of the backstop technology will be reached while resources are still available. If an optimal result must be obtained the market price p_0 needs to decrease less than the decrease in costs. For a given $p_{B,T}$ we have

$$p_0 = (p_{B,T} - K)e^{-\delta T} + K.$$

$$\text{Thus } dp_0/dK = 1 - e^{-\delta T}.$$

Effects of a change in $p_{B,T}$ and the discount rate δ are given by

$$dp_0/d\delta = -\delta(p_{B,T} - K)e^{-\delta T} < 0$$

$$dp_0/dp_{B,T} = e^{-\delta T} > 0.$$

7.2 Monopolistic extraction

As known from basic microeconomics a monopolist sets prices at a higher level as compared to perfect competition. If we assume the monopolist to maximize the present value of his profits taking the perceived demand function ($p(x_t)$) as given, i.e.

$$\int_0^\infty e^{-\delta t}\, x_t \cdot p(x_t)\, dt$$

subject to the constraints as given above, we obtain the modified necessary conditions:

$$(dp/dx)_t\, x_t + p_t = p_t(1 + 1/\epsilon) = \mu_t$$

equal to the marginal revenue of the monopolist according to the Amoroso-Robinson relation ($\epsilon < -1$ is the price elasticity of demand. Therefore we have $p_t > \mu_t$. Also $\mu_t = \mu_0 e^{\delta t}$ holds. This shows that in this case the marginal revenue grows with rate δ, not the price. Whether the price grows by more or by less than δ depends on the price elasticity of demand. Is the demand function isoelastic we obtain Hotelling's rule as above.

In any case the initial price p_0 is higher than the one resulting with perfect competition. Thus, tendentiously, a monopolistic structure seems to favour slower extraction of exhaustible resources.

8. Renewable resources

8.1 The problem under perfect competition

The stock of renewable resources S(t) regenerates according to natural processes governing growth and decay. So, making use of these resources does not only depend on economic but on biological principles too. A main problem is the preservation of the resource in view of the danger of extinction. The change in the stock of the resource depends on a great number of factors (like age structure, regional circumstances). A simplified presentation of the essential problem can be given by assuming that growth only depends on the level of the stock.

$$dS/dt = R(S).$$

R(S) is the regeneration function.

In reality it can be observed that the typical shape of this regeneration function implies that stock increases up to a limit of satiation and decreases thereafter. Frequently one uses a logistic function to describe this feature

$$R(S) = \alpha S(1-S/\beta), \quad (\alpha,\beta \text{ constant}).$$

Let x_t denote the level of exploitation (harvest, or yield) of the resource in period t. The development of the resource follows

$$dS_t/dt = R(S_t) - x_t.$$

The maximum sustainable yield x_{MSY} occurs at a level of the resource stock S_{MSY} which corresponds to the maximum value of the growth function. The yield can only be maintained at a level which is at or above S_{MSY}. Is the level below this critical value we have a biologically overexploited population.

Harvesting effort (catch or harvesting intensity) E is the ratio of the actual harvest x to the stock S. The higher the effort the higher is the harvest. We have x = ES. If one wants to harvest just as much as the stock naturally regenerates then the choice of effort determines the harvest and the stock because

$$x = ES = R(S) \text{ as } dS/dt = 0.$$

This is the sustainable yield. Every larger harvest will diminish the stock and every smaller harvest will increase it. From this relation one can derive the yield-effort-curve: For the logistic case we have

$$x(E) = \beta E(1 - E/\alpha).$$

Now, costs and returns determine the desired level of exploitation. If we assume for simplicity that the effort is the sole production factor with unit costs of c then total costs are

$$K= cE$$

Given the price of the harvested resource as P we have total

revenue as G = Px. Maximizing profit $\Phi = Px(E) - cE$ leads to the necessary condition that price must equal marginal costs. This holds for a single firm (or a group which decides jointly, i.e. single or joint ownership) facing a perfectly competitive market for the harvested product. But this does not concern the access to the resource.

If there is open access to resource exploitation the possibility for making profits will be the more limited the more competitors join in the exploitation. A positive profit will induce competitors to enter and to increase effort in turn. To large an effort will lead to losses and a reduction of competitors. The optimal exploitation effort E^* will therefore be such that no profit will be made: $\Phi(E^*) = 0$. The equilibrium stock (S^*) in such a situation is called a "bionomic equilibrium" as it is determined by biological and economic parameters.

Properties of the single or joint ownership solution (individual optimal solution):

- The optimal harvest is lower than the maximum sustainable yield.
- The higher the costs the lower the yield. There is a limit below which there will not be harvested. If costs are zero (c=0), profit maximization coincides with the MSY.
- Profit maximization does not necessarily (e.g. in this example) lead to extinction.

Properties of the open access solution:

- The stock will be less than that associated with individual profit maximization.
- A maximum sustainable yield will not occur except if by chance the total cost curve cuts the total revenue curve at its maximum.
- Extinction is not a necessary consequence of open access either. It only occurs if
  - a) exploitation is costless or
  - b) harvesting exceeds the natural regeneration rate persistently

Open access and common property are institutions to be clearly distinguished. But one can have common property with open access. However, it is more likely that rules will be introduced for a common property resource which limits access somewhat. A high risk of extinction will prevail if regeneration requires certain minimal levels of stock (i.e. the case of "depensation").

8.2 Intertemporal allocation of renewable resources

Now we need to investigate the optimal intertemporal allocation which should obtain under the goal of maximization of the present value of profits.

Assume the yield (harvest) can be described by a production function such that it is depending on effort and the level of the stock: $x_t = E_t f(S_t)$. Profit Φ is then given by

$\Phi = p_t x_t - cE_t = p_t x_t - c(x_t/f(S_t))$.

We simplify using $c/f(S_t) = K(S_t)$, the unit cost function depending on the stock with $dK/dS < 0$.

Given the path of the price p_t the present value of profits is

$$\int_0^\infty e^{-\delta t}(p_t - K(S_t))x_t \, dt,$$

which is to be maximized subject to the constraint

$x_t = R(S_t) - dS/dt$.

For the stationary case that yield rate equals reproduction rate ($x_t=R(S_t)$) the necessary conditions are

$$\delta = dR/dS - [R(S).dK/dS - dp/dt]/(p - K(S)).$$

This can also be written as

$$\delta(p - K(S)) - dp/dt = d/dS(R(S)(p - K(S))) = d/dS(x_t(p - K(S))), \text{ da } x_t=R(S_t).$$

$\Phi(S_t) = x_t(p - K(S))$ is the level of profits which can be achieved sustainably at a stock level S_t. $(p - K(S)$ is the marginal profit of an increase in the current harvest. This marginal profit must be equal to the discounted value of future marginal profits which follow from a change in stock (including price). I.e.

$$(p - K(S)) = (d\Phi/dS + dp/dt)/\delta.$$

$-dK/dS.R(S) > 0$ can be interpreted as marginal stock effect w.r.t costs and, thus, also as a welfare effect (which may be negative if one considers pollution as a renewable resource). If one relates this effect to the current marginal profit $(p-K(S))$, which corresponds to the present welfare gain, adds the reproduction rate of the resource dR/dS, one obtains a net rate of return of the resource stock. At constant prices this rate is equal to the discount rate.

If costs are zero $K(S)=0$ we have the necessary condition

$$dR/dS + (dp/dt)(1/p) = \delta.$$

The advantage taken from the marginal reproduction rate plus the increase in prices must equal the discount rate. If the sum exceeds δ it is advantageous to harvest the resource later to realize a higher return. Otherwise, an immediate harvest is better.

The solution of the necessary conditions for a profit maximum yields the value of the optimal stock. The decision whether to let the resource grow or whether to harvest is made according to the initial situation S_0. If $S_0 < S_{opt}$ it should be let to grow, if $S_0 > S_{opt}$ it should be harvested, in order to attain the optimal stock.

How does the discount rate influence the result?

1) If $\delta=0$ the sustainable profit is maximized because each immediate reduction of the harvest leads to an everlasting increase in future profits. This is the case of indifference between present and future.
2) If δ goes towards infinity profit ceases.
3) For $0<\delta<\infty$ the sustainable marginal profit decreases if the stock increases.

If costs are independent from the stock the marginal reproduction rate dR/dS corresponds to the discount rate. Obviously the maximum sustainable yield will be reached at a discount rate of zero, i.e. when $dR/dS = 0$.

It remains to note that from the necessary condition Hotelling's rule derives for the case where $R(S) = 0$, i.e. resources are not renewable.

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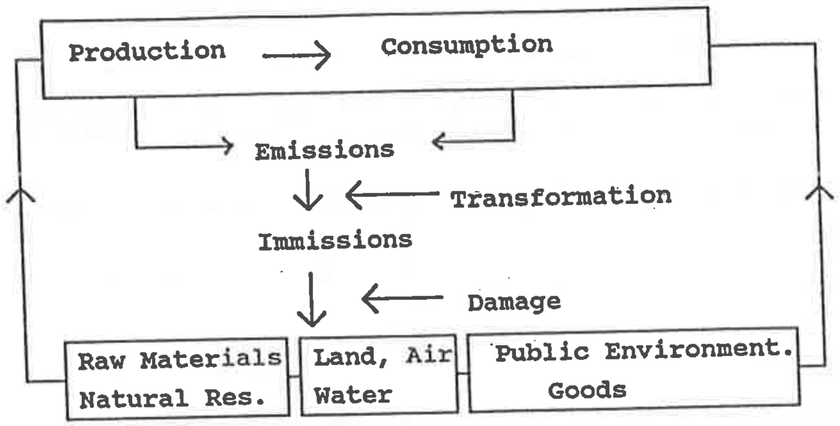

Diagram 1

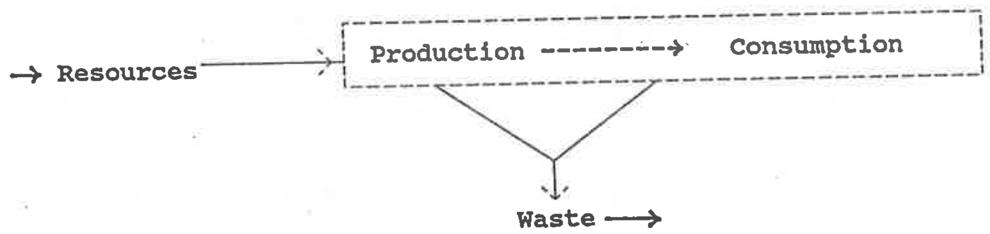

Diagram 2: The open economic system

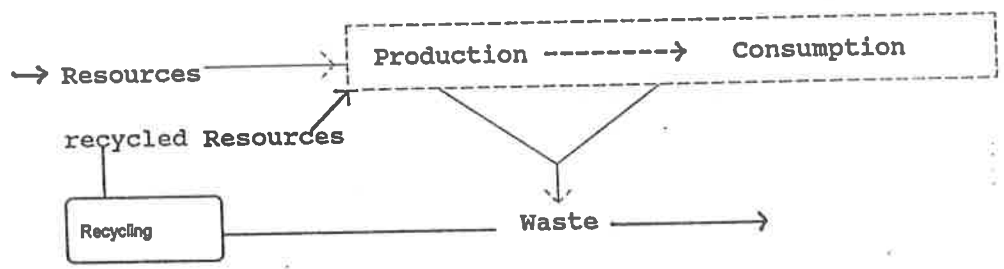

Diagram 3: partially open system

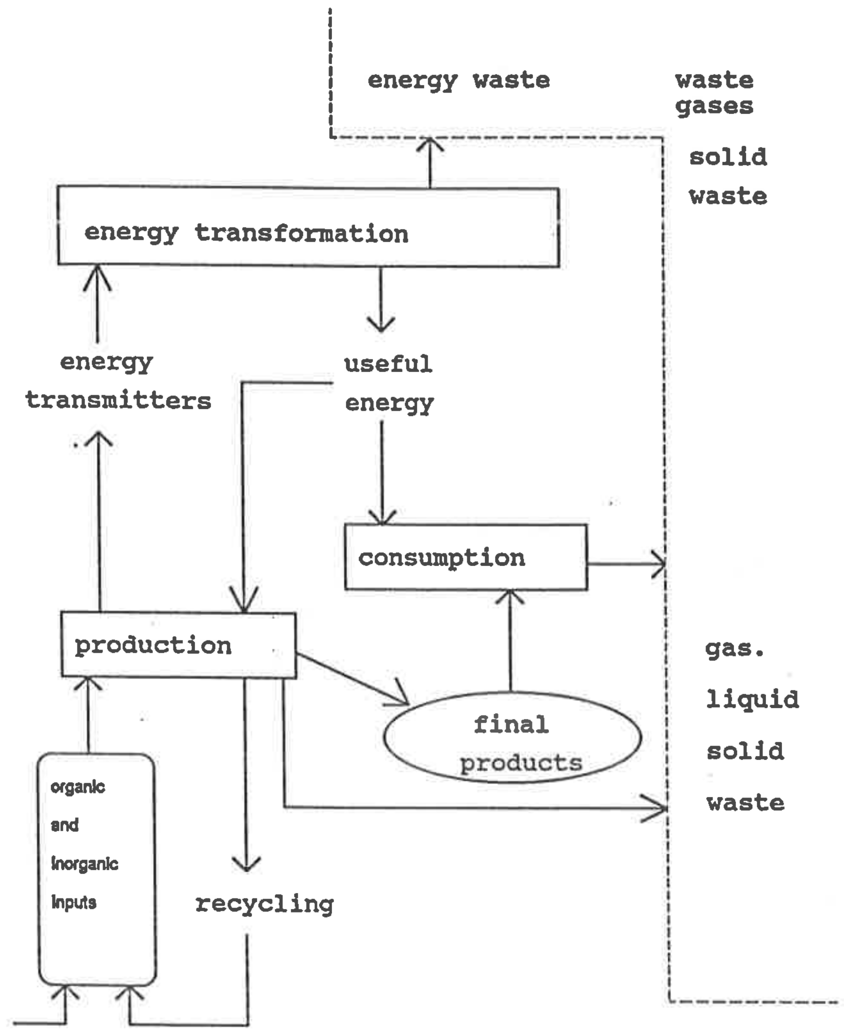

Diagram 4

Mass and energy flows in an economy

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