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PANTEION UNIVERSITY OF POLITICAL AND SOCIAL SCIENCES

ENVIRONMENTAL ECONOMICS. POLICY TOWARDS ECOLOGICALLY SUSTAINABLE ECONOMIC DEVELOPMENT

THEORY
MODELLING

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ATHENS 1994

PANTEION UNIVERSITY ATHENS

ENVIRONMENTAL ECONOMICS. POLICY TOWARDS ECOLOGICALLY SUSTAINABLE ECONOMIC DEVELOPMENT. THEORY - MODELING

PHD DISSERTATION THESIS

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18 OCTOBER 1994

to my mother who is proud
to my father who would be
proud

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PART B: MODELING

PREFACE

In 1988 I was following the lesson of Environmental Management in Institute of Regional Development, given by Prof. D. Papaioannou. Then, I had my first contact with the discipline of Environmental Economics. I was impressed since Environmental Economics are related to the early concept of Economic Development together with some of the contemporary problems of our society. So, I decided to continue further my post graduate studies on the field of Environmental Economics. Initially, I did my dissertation for the Institute of Regional Development on this discipline. The title was "Environmental Economics, Theory - Application". After this first meeting with the subject, I received a scholarship from Institute of State Scholarships for a PhD degree on Environmental Economics.

Besides, I was lucky for meeting Prof. Peter Nijkamp, who has performed large scale research on Environmental Economics. I found myself at Free University Amsterdam, studding under the advises of Prof. Nijkamp. However, I had already started my PhD research in the Pantion University, Athens under the supervision of Prof. N. Konsolas and Prof. T. Tassopoulos.

For certain administration's reasons the two projects come together. The outcome is the present study.

After some considerable research for a PhD. thesis I have reached a conclusion I like to give here. A PhD thesis is not one man work. It is rather a project. For my PhD thesis there is a number of people who helped considerably me; each one performed a particular task. First, Prof. Nijkamp who led me in the deep water of the very essence of environmental economics, both theoretical and applied. He was/is inspiring for me.

Second, Prof. N. Konsolas who offered me a friend environment of administration which helped a lot my research.

Third, Prof. T. Tassopoulos who borrowed to me his great mathematical and computer science capacities. He was working with me for a successful accomplishment of the second part of my study.

Next I would like to thank all those who helped me for finishing my study in the present form: Perikles Lefkas, Kaiti Lefka, Marina Koutsouri, Maria Koka, Maria Brina, Nikos Papaioannou, Tasos Karaganis.

Financial support to perform this Ph.D research was given by the National Foundation of Grands of Greek State.

INTRODUCTION

The present study refers to the discipline of Environmental Economics. Specifically, it aims at introducing the current concept of the Ecologically Sustainable Economic Development in the framework of traditional Environmental Economics.
Ecologically Sustainable Economic Development (ESED) emerged as a rather political principle that focuses on the confrontation of the current environmental problems. Indeed, ESED was initially deprived from any scientific basis. However, it gradually attracted a significant scientific interest. Several disciplines are tracing the scientific implication of ESED within their domain. In a similar way, the present study examines the scientific implications of ESED within the economic science. In other words, ESED is examined in the light of the science of Environmental Economics.
Indeed, the concept of ESED raises several interesting research issues within the spectrum of Environmental Economics. Some of these issues were well investigated by the traditional theories of Environmental Economics. However, even these issues obtain new dimensions after the emergence of ESED. The distinguished characteristic of ESED implications in the framework of Environmental Economics is that they form a completely comprehensive proposition for a scientifically based policy towards ESED. Therefore, the environmental problems solutions, emerging within Environmental Economics domain, are now classified according to their importance. Moreover, their ability to confront efficiently the current environmental problems is reexamined.

Let us trace briefly the research issues raised by ESED in the framework of Environmental Economics.

First, the conditions that lead towards ESED are investigated on a scientific basis; moreover, they are classified according to their importance. Indeed, ESED stems down to certain tenets of its achievements. These tenets pertain to Normative Economics since they refer to "what should be done by our societies so that Economic Development is to be Ecologically Sustainable".
This first research issue is handed by the first chapter of the present study under the title "Scientific Ecologically Sustainable Economic Development".

Second, the long tradition of Environmental Economics, both normative and positive, gives some tenets which underlines a policy towards Environmental problems.
Usually, these tenants take the form of explicit solutions of the environmental problems. In

the light of ESED it should be investigated whether these solutions-tenets accomplish the achievement's conditions of ESED. In other words, our question is: could a Policy, designed in the framework of traditional Environmental Economics lead towards ESED?
This problem is examined by chapters 2-6. Specifically, each chapter deals with a particular direction of traditional Environmental Economics as well as with its tenets-solutions to environmental decay. The basis of the analysis in chapters 2-6 is microeconomic theory since the research issue concerns the use of the environment in a individualistic level. That is to say the analysis examines the utilization of a particular environmental element by the relevant users.
The structure of chapters 2-6 is the following: Chapter 2 examines these solutions which emerge by the functioning of the pure competitive market in the absence of any institutional intervention. Chapter 3 investigates the change of the ownership of the common property natural elements; is the environmental protection of the private elements sufficient to fulfill the achievements' condition of ESED?
Chapter 4 regards the intervention of the government aiming at eliminating the external environmental cost of the polluting activities to its optimum level. So, the environmental decay is limited to its optimum level. Chapter 5 presents and examines in the light of ESED the renewable resources economics and the relevant policy's implications. Finally, chapter 6 examines some well known principles of ESED's achievement against the conditions of ESED that were exposed in chapter 2.

The third research issue implied by ESED is the problem of the scarcity of the natural resources as inputs of the economic production. This issue has a long tradition in economic science Ricardo initially examines the implications of land's scarcity on agricultural production and on the social evolution. Since then a great debate is established among economists about the implications of natural resources' scarcity on the economic process. The emergence of ESED offers a new interest on the issue, under the pressure of the current environmental problem. Evidently the natural resource's scarcity is examined in an aggregate level, which on one hand regards the aggregate level of natural resources and on the other hand the aggregate level of economic production's requirements for natural inputs. In effect the relevant research issue pertains to microeconomic theory. This issue is examined by chapter 7.

Another research issue raised by ESED is the process of modeling that is required for the design of ESED. Environmental Economic models are, beyond any doubt, of great help for exploring ESED. Models provide us with some scientific tools which are indispensable for any planning process. However, the issue of modeling today becomes essentially complex in spite of the existence of many technical tools. For these technical tools tend to change into a game the process of modeling. Indeed, the scientific requirements of falsifiability, intersubjectivity, repeatability no longer form the basis of any modeling process. The second part of the present study deals with the modeling of environmental economic systems. Specifically, we examine a particular difficulty which is present in a considerable number of case studies. The difficulty consists in the absence of sufficient statistical data. A methodology is then proposed for these cases (chapter 9). Moreover, this methodology may be used in the "Environmental Impact Assessment". Chapter 10 applies the proposed methodology in a case study. Finally, the epilogue presents a summary, some concluding remarks and some prospects concerning the scientific implication of ESED.

PART A

THEORY

CHAPTER 1

SCIENTIFING ECOLOGICALLY SUSTAINABLE ECONOMIC DEVELOPMENT

1.1 Introduction

The aim of he first chapter is to present the concept of Ecologically Sustainable Economic Development in a scientific framework. The concept of Ecologically Sustainable Economic Development, abbreviated as ESED from now on, emerged as a Political concept or Policy target (WCED 1987).
ESED, then, attracted a lot of scientific interest.
It however, has been perceived in numerous ways and therefore there is no common ground yet. The present chapter aims at tracing the scientific implications of ESED.

Initially, the state of the art for ESED definitions and scientific implications are presented. It is evident, then the diverse perceptions of ESED.
Next we try to trace literally the concept of ESED.
Several interesting conclusions stem from this examination.
In the next step we utilize system's theory and specifically prof. Passet's approach about economics and environmental systems in order to investigate the scientific implications of ESED.
From Passet's approach several new concepts emerge (biological sustainability, crucial biological level etc.). They are of great help for the scientification of ESED. Specifically, Passet's approach lead to the establishment of the conditions of ESED's achievement.
The conditions of ESED's achievement are analyzed further in the light of the conventional economic theory. Finally these conditions are proposed to form the scientific of ESED. This ground differs from the corresponding Political one that stems from the origins of ESED.

1.2 Sustainability definitions

THE BRUNLAND REPORT
The concept of sustainable economic development or ecologically sustainable economic development emerged from the publications of the World Conservation Strategy (IUCN 1980) as a policy framework against the environmental decay of our planet because of increased pollution and intensified extraction of natural resources.
However the concept has grown in popularity since the publication of the "Brundtland report" (WCED 1987), where sustainable development is defined as the development that meets the needs of present generations without compromising the ability of future generations to meet their own needs" (WCED 1987), or as: "a pattern of social and structural economic transformations which increases the benefits available in the present without jeopardizing the likely potential for similar benefits in the future" (WCED 1987).

These are two general definitions of a patterns of evolution for the world which may face a great variety of sustainability threats. Those include, severe economic recessions, large scale wars, severe climate changes, environmental decay etc. Obviously, most of these threats are far remote from the common context of sustainability threats, mainly due to the fact that they are scientifically too vague for any further analysis.
A more scientifically oriented definition of sustainability can be found a few pages later in the Brundtland report, that states: "in essence sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations" (WCED p.46).

All three definitions have at least one common ground. The needs of present and future generations should be potentially satisfied, without the existence of trade offs between present and future needs' satisfaction. This point needs some further clarification. Sustainability, according to the above definitions, does not ensure the satisfaction of the needs but rather, leaves open the possibilities for such a satisfaction. That means that sustainability emphasizes necessary but not sufficient conditions for "needs satisfaction", to use the mathematical term.
Thus, sustainability is not finding a way of evolution which meets the needs of future generations -probably unknown today- but it is rather finding a way that does not destroy the potentials for those needs satisfaction. As a result, we have to trace and to prevent. Whatever threats may destroy the potential of the contentment of basic needs today and tomorrow.
Some examples of such threats are:
- a planet falls and destroys the earth
- human species extinction due to a virus
- climate changes
- serious natural disasters
- large scale wars
- serious economic recession

If we are to examine sustainability as a policy target we are forced, first and foremost, tc limit analysis to anthropogenic threats and to check the corresponding activities and onl' next, to extend analysis towards non anthropogenic threats whenever it is possible from th nature of each particular threat. Evidently, there are two main origins of anthropogenic threats: firstly, economic activities of human beings and secondly, political cultural induce activities such as war, environmental behavior etc.

Concluding this section we may say that the origins of the sustainability concept, as expressed in the Brundtland report,offer, although political in nature, a promising direction of a scientifically traceable and manageable concept.

1.2.2 Other sustainability definitions

After the Brundland report a large number of definitions for sustainability have been given, as the concept increased in popularity and became a subject of scientific inquiry. Let us mention some popular definitions here in order to examine some further dimensions of the concept concerned.

Allen defines "sustainable utilization is a simple idea: we should utilize species and ecosystems at levels and in ways that allow them to go on renewing themselves" (Allen 1980).

Goodland and Ladec state that "sustainable development implies using renewable resources in a manner which does not eliminate or degrade them , or otherwise diminish their usefulness for future generations..."(Goodland and Ledec 1987). Sustainable development further implies using non-renewable mineral resources in a manner which does not unnecessarily preclude easy access to them by future generations. "Sustainable development also implies depleting non-renewable energy resources at a slow enough rate so as to ensure the high probability of an orderly societal transition to renewable energy resources" (Goodland and Ledec 1987).

Christensen outlines sustainable development as the development permitting the existence of the natural environment which acts as a basis for human welfare since it provides living conditions and acts as a productive basis (Christensen 1989).

These latter definitions refer, obviously, to the natural environment and its maintenance. These authors, starting from the concept of sustainable development, emphasize the fact that sustainable development mainly means maintaining the natural environment.

This is not an coincidental phenomenon. It seems that these authors regard the existence of the natural environment as a prime condition of sustainable development, no matter what other conditions might follow it.

As James, Nijkamp and Ophoor say natural environment is the "living room" for Homo Sapiens (James 1989). Therefore its maintenance emerges as a chief precondition for sustainable development.

In a shell nut, we may say that these authors state that in order to sustain development we have to sustain, at least as a pre-condition, the natural environment.

On the other hand, there are some definitions stemming from other directions. Let us mention a few of them.

Pearce, Barbier and Markandya denote that "we take development to be a vector of desirable social objectives and elements that might include:

- increases in real income per capita
- improvements in health and nutritional status
- educational achievements
- access to resources
- a more fair distribution of income
- increases in basic freedoms

Sustainable development is then a situation in which "the development vector increases monotonically over time" (Pearce et al 1989).

Pezzey denotes that "our standard definition on sustainable development will be the criterion of a non-declining per capita utility, because of its self evident appeal as a criterion for intergenerational equity". Somewhere else Pezzey says that a non- declining per capita production may be an alternative sustainability criterion.(Pezzey 1989)

These definitions regard sustainability as a somewhat different course. They emphasize the sustainability of welfare, utility or production (economic output) over time. Thus, at first glance, one may say that the natural environment should be sustained as far as it contributes directly or indirectly to welfare or utility of present and future generations.

There is a problem arising: measuring in the present the welfare of future generations. It seems that there is not a strict way of doing so. Specifically, how can we say which development is sustainable, when development is defined as a non-declining utility and there is not a measure of future generations utility ?

It seems that this problem comes about since the second category of sustainability definitions goes further than the first one and tries to examine "what should be done" now and in future, while the first category regards generally the question "what should be avoided" now for development to be ecologically sustainable.

Indeed, since the answer to "what should be done" refers to some economic performance indicators of each generation it can only be given by each one generation for its own development. For instance, the present generation cannot know with any precision the desirable level of economic development of the fifth future generation.

As a result, the second category of definitions leads to some impasses for any attempt to determine at present a strategy towards sustainability. Actually, the only way which is available to each generation for grounding a policy towards sustainable development is to leave open the possibilities -potentials- for economic development in future. This practice consists in avoiding each activity that decreases the potentials for economic development in future. That is to say, to ensure the prime conditions of sustainable development. However, as we have seen, the prime condition of sustainable development refers to the maintenance of the natural environment. This is tantamount with the policy conclusion derived by the first category of sustainability definitions.

There is an intermediate approach, falling in between of the above two classes of definitions, which examines both sides of the problem: natural environment maintenance and economic development by each generation.

Von den Bergh and Nijkamp define "ecologically sustainable development" as "the dynamics in economic activities, human attitudes and human population, such that an acceptable standard of living for every human being is fulfilled by the availability of natural resources, ecosystems and life support systems" (Van den Bergh 1991). Evidently, this definition follows both the first class of definitions, since it refers to "availability of natural resources", and the second class, since it refers to an "acceptable standard of living" for each one generation.

From the above analysis is derived that sustainable development is a rather general concept, allowing several interpretations and policy implications. As we will see in some subsequent paragraphs, these interpretations usually lead towards contradictory policy targets or sustainability criteria.

As a result, we are forced to examine further the concept of sustainable development in order to arrive at a concept allowing to formulate.

1.3 Exploring the concept of Ecologically Sustainable Economic Development (ESED)

1.3.1 The literal meaning of Ecologically Sustainable Economic Development (ESED)

In the preceding paragraphs we have reached the conclusion that sustainable development has to do with the natural environment, with economic growth or economic development and with economic welfare. However, we did not draw the clear implications of ecologically sustainable economic development for regarding concepts.

The goal of this section is to explore these implications wherever this is possible.

We first try to scrutinize the words which form the concept of ESED. In almost every definition we find the words "sustainable" and "development" whatever the rest context of the definition.

The word "sustainable" means something which is preserved, maintained, retained and even intensified as long as it is possible.

The word development, has for economists a specific meaning.

It refers to an economy which increases the welfare, a utility of the members of the society. Pezzey defines development as increase in social utility or in per capita consumption (Pezzey 1989).

Daly denotes that development implies "qualitative improvements" in an economy, as opposed to growth that refers to the quantitative scale of the outcome of the economy" (Daly 1990).

Although, there are some contradictions in the above definitions, we may conclude that development of an economy means something good for the respective members of society, since their welfare increases.

Connecting now the words "sustainable" and "development" we get the term "sustainable development". Literally interpreting the concept, it means a way of development which could be first maintained and even intensified as long as it is possible. "As long as it is possible" implies that there is no time border in the future at which development stops.

Having indicated what sustainable development means, we have to examine the conditions leading towards sustainable development.

For the purposes of our study, we assume a closed society, whose sustainable development we will examine.

Firstly, in order to sustain development it is prerequisite that the relevant society should be sustained. Sustaining society means:

-sustaining the society's "living room", that is the natural environment of the society.

-sustaining the human beings of the society hence, i.e. the natural reproduction of human species should not be in perished.

Secondly, besides the above conditions which ensures the survival-sustainability of the society we have to introduce those conditions that preserve the sustainability of economic development. That means sustaining the potentials for economic development for the future generations.

Let us examine closer the above conditions. The first one implies that a society, in order to survive, needs at least its natural environment. One cannot imagine a society without some land, water, atmosphere and some other natural elements. However, the new problem that arises now is determining how much and exactly which elements of the natural environment may be regarded as the indispensable living room of a society? We keep this question for further examination in some following sections and for the moment we draw the conclusion that the natural environment plays a crucial role in the society's survival and hence in sustainability.

The second condition emerges as an extension of the first one. It denotes that we cannot consider a sustainable society without having secured the survival and hence the reproduction of human beings. The first condition does not always ensure the second one. There are cases where the maintenance of the natural environment may not ensure the survival and reproduction of human beings. This survival requires some specific characteristics of the natural environment. For example, the natural environment may survive despite the presence of high radioactivity, but human beings cannot. The reproduction of human beings besides any other prerequisite requires the provision of food for the present and for the future. Let us assume that food provision is performed via the function of the economy and therefore its sustainability is examined by the third condition examined below.

Specifically, the third condition denotes that the sources of economic welfare should remain open in the future. The natural environment provides two distinct factors of welfare. The direct contribution is the amenity welfare arising from aesthetic uses, while the indirect contribution is the use of environmental elements as inputs of economic production. A first conclusion may be drawn here: sustainable development, besides the first two conditions, means leaving open the potential uses of the natural environment as an aesthetic factor and as an economic production input. Obviously, there are millions of particular uses or potential uses of the environment. How many of them should one generation sustain for potential use for future generations? This question becomes more difficult if one considers that there are uses of the environment which exclude future use of it; these uses eliminate the respective potential uses of coming generations. What is the sustainability criterion in this case, since there is no intergenerational welfare criterion. This issue forms the subject of a closer analysis in the next sections.

Concluding this section we may say that the natural environment is involved in all three conditions for sustainable development. How the natural environment contributes to each one condition and how each contribution is related with one another is the subject of the next paragraph, where the concept of sustainable development is further scrutinized.

1.4 Ecologically Sustainable Economic Development; A System Approach

1.4.1 The roles of the natural environment

The aim of this section is to examine the way in which thenatural environment is involved in sustainability conditions mentioned in paragraph 1.3.

The first condition refers to the "living room" of society, meaning the characteristics of the environment that form the natural basis of society. This basis comprises exclusively of natural elements and natural functions that are indispensable to maintaining the "life space of society". As a result, the first condition refers to the natural system of our planet, that is the biosphere system.

The second condition refers to the natural characteristics of human beings and to those characteristics of the biosphere system which are indispensable for human beings existence. Specifically, it refers to those natural characteristics that are essential for the survival of human species in the long run. These characteristics may not be included in the natural characteristics ensured by the first condition, since the first condition refers to the reproduction of the natural "living room", while the second one refers to the reproduction of the human species. Evidently, some additional natural characteristics may be needed to permit the survival of human species in the natural "living room" because the distinct physiology of man. At this point we exclude food provision from those natural characteristics that are indispensable for man's reproduction, because food provision is performed via some social processes that are examined traditionally in political economy (Malthus, Ricardo) and thus, food provision is considered as an operation performed by the economic system. In effect we will examine food provision in the framework of the third condition that deals with the sustainability of economic development. As a result, the second condition refers to a certain number of natural characteristics which are indispensable for the reproduction of human species, so that, like the first one, it refers to the natural or biosphere system of our planet.

The third condition mentions the contribution of the natural environment to economic welfare. Economic welfare is the ultimate target of economic production and thus the utmost target of the function of economic system. The natural environment plays a significant role in that function, as it provides significant inputs to all phases of economic production. However, we have distinguished two kinds of natural environmental contributions to economic welfare, as the direct welfare of aesthetics and economic production inputs. For the moment and for analytical purposes we will keep them together.

Having in a preliminary stage outlined the contribution of the natural system to the maintenance of the "natural living room" of society, to the maintenance of human species (human system) and to the economic system's function, we will now examine the relationship among these three systems -natural, human, economic-, since from this research we may come to understand the exact contribution of the natural environment to sustainable economic development. Exploring these interrelationships, we may arrive at rigid conclusions on what sustainable economic development implies and on the exact conditions for its achievement, if there are any.

1.4.2 Passet's approach

According to professor Passet (1979) the natural system, the human system and the economic system are interrelated and the relationship is described by a hypersystem including its subsystems. Specifically, natural systems include both the human system and the economic system as they are subsystems of the natural-biosphere system. In turn, the human system includes the economic system as its subsystem. Figure 1 represents the above interrelationship.

In order to connect Passet's approach with our interpretation of sustainable economic development given in the preceding paragraphs, we may say that the first condition of sustainability, the maintenance of the natural living room of society, refers to the natural-biosphere system of Passet's approach; the second condition, that of maintaining the natural characteristics permitting human beings reproduction, refers to the human system; and finally, the third condition refers to the economic system.

In Passet's systems approach, each system includes all its indigenous elements and functions. So we can say that the natural biosphere system includes all natural elements and all biosphere functions of our planet; the human system contains all functions of human beings: natural, intellectual, cultural, ethical etc.; and the economic system can be identified with what we have defined as economic functions: production and consumption of economic goods.

Then the question concerning the validity of the relationship between the three systems, as it is given by Passet's approach, remains open. We will examine this validity since the exact conditions, on which sustainable economic development depends, are strongly

influenced by it.
The exact question is then the following: is the economic system really a subsystem of the human system? is the human system a subsystem of the biosphere? and hence, in the economic system a subsystem of the biosphere system?

It is better to start our examination from the economic system, examining whether this system is a subsystem of the human one. From the system's theory, by definition we know that all functions of a subsystem belong to its hypersystem too, but not all functions of the hypersystem are included in each of its subsystems. The same property applies also to system's rules (Von Bertalanffy 1972 and Passet 1979).
In our case, what we need to prove is that all elements and functions of the economic system are also included in the human system.From the very definitions of economics as a science of scarcity, we know that the economic system performs the following task: it allocates the limited (scarce) means to the best satisfaction of unlimited and competing human needs (Samuelson 1969 and Daly 1977).

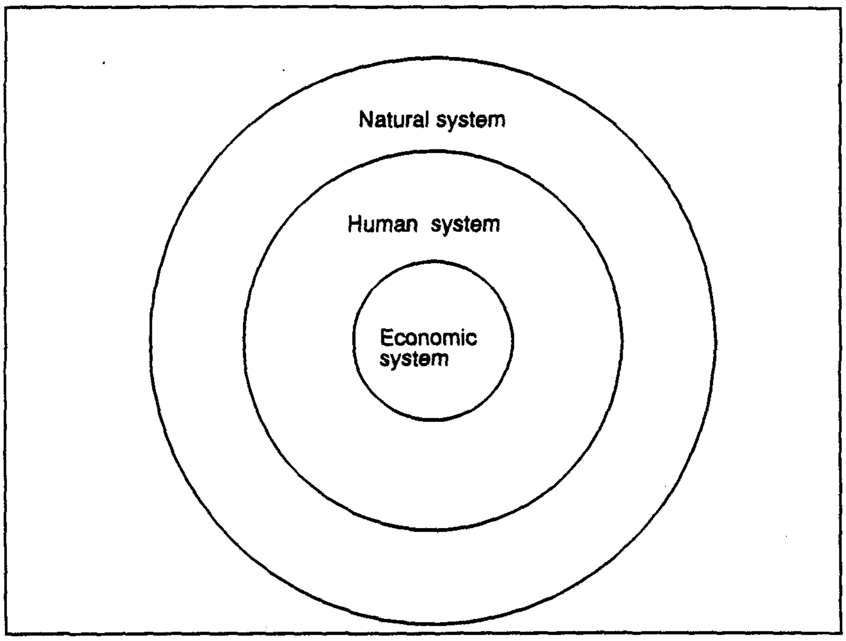

Figure 1 Natural, human and economic systems

Obviously from the above definitions follows that the function of the economic system has to do with human beings; moreover, its function finds its justisfaction only in reference to human beings and specifically to the satisfaction of their needs. In absence of human beings there is no economic function due to two main reasons: who will perform these functions and for whom?

On the other hand, human beings are far from simple performers of economic functions. They develop culture, ethics, affection, parallel to their economic activities. Besides, they perform their own biological function as a mammal species. That means that there are social spheres and natural processes of human beings which have nothing to do with their economic sphere. All the more, some of them may have much more importance than economic activities and so they confine the economic process. For example, normally no human being is able to produce for thirty hours continuously, since the biological (natural) process of human body resists to it.
As a result, it follows that the economic system constitutes a subsystem of the human one. Therefore, all economic functions are included in the human system, but there are human functions that are not contained in the economic system. In effect, the rules governing the economic system do not apply to the whole human system which is governed by some other rules. On the other hand, the rules applying to the human system govern also the economic system, together with economic system's rules.

Next, our analysis will examine the relationship between the human system and natural-biosphere system. Human beings, obviously,
belong to the class of vertebrates and to the subclass of mammal species and to the genus of Homo. So, the human species is a part of the biosphere (Limme 1737). Passet says that the human cell contains elements of the ocean where life emerged, and that the human brain contains elements from several stages that human the species has passed through up to now.
As a result, the human species is a subsystem of the nature-biosphere.
The question arising now is: is the human species the entire biosphere system? The answer is evidently no; this does not need more elaboration. Note that there are millions of organic and non-organic species in the biosphere related to the human species in a intricate way, although they do not belong to the human species. Indeed, biologists ensure that the presence of these biotic and non-biotic species is an indispensable factor for the survival of human beings (Odum 1971).

Next, the relationship between the economic system and the natural-biosphere system, remains to be examined. Inductively from the above discussion, it follows that since the economic system forms a subsystem of the human system and the human system is a subsystem of the biosphere, the economic system forms also a subsystem of the biosphere. However, it is desirable to spend a little bit attention to this relationship. Obviously, the economic system is based on the earth's surface and it uses biosphere conditions for its function. One cannot imagine an economy without at least some crucial natural elements such as land, water, or air. This indicates but does not prove that the economic system is a subsystem of the biosphere, since one may insist that economic and biosphere systems are related via an overlapping relationship like the one presented in Figure 2. That is an illusion which can easily be proved considering the laws governing these two systems. Obviously, each law of the biosphere system applies also to the economic one, while the laws of economic system do not hold for the whole natural system. For example, let us examine an economic law, that of "diminishing marginal productivity" of some input of a production process as it has been indicated by Ricardo for the agricultural sector (Ricardo 1817). Evidently, this economic law has its origins in the natural properties of the elements which participate to the production process; thus, these properties strongly influence the social and economic process. However, we find that this law is not generally valid -it does not underlie every production process-; thus, in the economic spectrum the same phenomenon may be expressed by different laws.

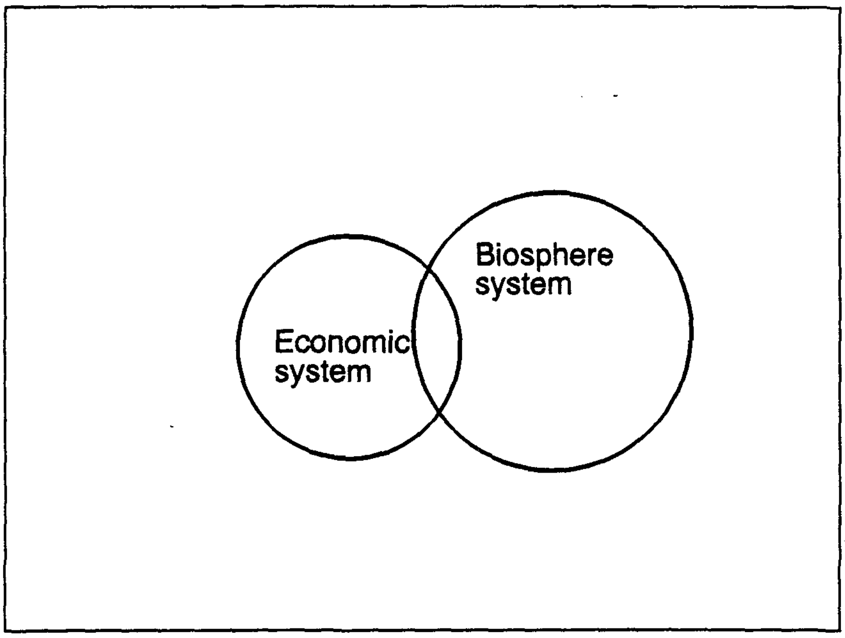

Figure 2 Natural and economic systems

For example, in the well-known Cobb-Douglas production function $Q = K^a.L^b.R^c$. where $a+b+c=1$ and Q, K, L and R stand respectively for production, capital, labor, resources; the marginal productivity of each production factor is constant. Sometimes however we may even find increasing marginal productivity of a production input during a production process. As a result, the production outcome of a random production factor may be described by either diminishing or constant or even increased marginal productivity. We question now whether these laws also govern the natural process implied by input-output transformation of the relevant production process.

We can easily prove that the natural low governing each production process is the law of matter conservation (material balance principle) which governs this process regardless of the economic law that describes the productivity of the relevant production factors. The natural law is valid, regardless of the economic law governing the particular economic phenomenon. The total matter of a particular production factor is equal before and after the production process.

The difference between the economic output of a production process and the natural output exists in the fact that economic output brings the concepts of economic usefulness and economic efficiency. What is described as an economic output is a part of the total natural output; the rest may be described as the economic waste of the process; the economic output is the useful economic good. Technical efficiency may change the proportion between economic output and economic waste, but it cannot change their sum determined by the material balance principle. This principle is a law of the biosphere system which governs also the economic system.

Changing technical efficiency of a specific factor of a particular production process, we may possibly alter the law of diminishing marginal productivity to constant productivity; however, this alteration dose not violate the physical law underlying the process. We should mention at this point Georgescou-Roegen's interpretation of the production function and its implication for the increasing efficiency of a production process. Georgescou-Roegen says that the new state in the increased efficiency is another process and thus we cannot speak of transforming a "diminishing marginal productivity" of a factor to "constant marginal productivity" (Georgescou-Roegen 1971, 1979).

The conclusion of the above analysis is that the natural law of matter conservation is valid in any transformation of the economic system. On the contrary, the economic laws which may describe this transformation have no relevance in the biosphere system; in other words, these laws do not govern the respective natural precesses, although they originate from some natural properties, eg. capacity of land for production. The same conclusion is reached if we examine every economic law in comparison with the natural laws describing the same phenomenon. As a result, we may say that biosphere laws are always valid to the economic system. Probably, we do not know the exact economic and social implications of these laws, though they are present and underlie any economic phenomenon. For example, we may not know the exact implications of the second law of thermodynamics on economic system's evolution, as is witnessed by the current debate about it (Georgescou-Roegen 1971, Solow 1974, Daly 1981, Young 1991). However, since this law is valid in the human and economic system's evolution, some distinguished scientists devote much work to researching its implications.

It appears, from the above discussion, that the economic system is a subsystem of the biosphere system and in this way all economic system elements also belong to the biosphere system, and all economic functions are subject to biosphere laws.

Finishing this long section, we may conclude that Passet's interpretation of the biosphere, human and economic systems' relationships is a well-established approach. Thus, we will use it in the following paragraphs in order to examine the exact meaning of sustainable economic development, the sufficient and necessary conditions for its achievement, and for further elaboration of the current environmental and natural resources problems.

1.5 An alternative inquiry into ESED

1.5.1 Introductory remarks

The target of the present section is to embrace the concept of sustainable economic development, as it is presented in the preceding parts of this chapter, in the alternative framework arising from the system's approach. By doing so, we aim to resolve some confusions or contradictions we face, while we are examining the concept as it comes up from several definitions up to now.

The alternative framework may be a useful tool for exploring the sufficient and necessary conditions of sustainable economic development and thus establishing this concept on a scientific ground as a clear policy target.

We have examined, in the preceding sections, the relationships between the three systems involved in the sustainable economic development issue. Specifically, we conclude that the economic system is a subsystem of the human system, the human system is a subsystem of the biosphere-natural system and hence, the economic system forms a subsystem of the biosphere system. The representation of these relationships is shown in Figure 1.

The concept of sustainable economic development refers to the inner, economic system. This concept means the maintenance of economic system and its evolution and development.

From the system theory we know that it is not feasible to maintain a subsystem while destroying any other system that includes it. The opposite, in general, holds, as it is possible to destroy a subsystem of a hypersystem while maintaining and growing that hypersystem. The implications of these principles in our examinations are obvious. It is not feasible to sustain an economic system while disturbing and destroying the human and/or the natural system. The natural system will be mentioned, from now on, also a biosphere system or an environmental system. On the contrary, theoretically it is possible to sustain the biosphere system and the human system in absence of the economic system. It is historically proved that there were periods in the earth's history without the presence of Homo species and hence without the presence of an economic system, as well as periods with the presence of

Homo species but without the economic system as it is underlaid by the transaction-market economy. We consider that the exchange activity and its evolution, the market exchange, mark the emergence of a distinguished subsystem of the human system, as the economy system, because the emergence of the market exchange mechanism started to form a separate activity of human beings with its own rules.

As a result, the sustainability of the economic development presupposes the existence of the economic system which in turn, presupposes the existence of the biosphere and human systems.

1.5.2 Biosphere system maintenance

The biosphere system is formed by all biotic and abiotic elements of the earth's environment and all atmospheric levels that surround the earth. Each element of the biosphere system participates in several natural functions and all natural functions in turn determine the intricate evolution of the biosphere system. Observing now the biosphere evolution, we may conclude that not all natural elements (species) survive during its process, and that the extinction of some of them does not affect the evolution of the system. In the past, we know that there were extinctions of several biotic and/or abiotic species, induced by human activities or not, without violating the maintenance and the evolution of biosphere system. However, we also know that certain activities of human beings in the present era have put the natural system in peril.

It follows that there are certain natural elements and certain levels of quantity and quality of these natural elements determining the unproblematic evolution of the biosphere. These levels were secured in the past, but are no longer taken care of the present; and hence the current environmental problems emerge.

Here we have to admit that our knowledge concerning the biosphere system and its evolution is really limited. Ecology as a science examining the environment is relatively a new one and the biology knowledge is not enough to describe and predict the evolution of the biosphere (Nargaad 1989). Despite the existence of a considerable lack of knowledge, it seems that we are able to assert that certain species with some particular properties play an indispensable role in the function and evolution of the biosphere. The preservation of these species and of their natural properties leads towards sustaining the biosphere system's function and its evolution. Maintenance of the biosphere system's function and its evolution will be from now on be mentioned as "biological sustainability" or "biosphere sustainability". Therefore, in order to ensure "biological sustainability", in spite of our limited knowledge, we have to preserve certain quantities (stock) and certain qualities of some natural species or elements, biotic and abiotic. The levels will be mentioned "biologically critical levels". Thus,"biologically critical levels "are those levels of certain important natural species which, when preserved, ensure the "biological sustainability", as the sustainability of the biosphere has been defined.

1.5.3 Human system sustainability

At first glance,one may conclude that ensuring "biological sustainability" results in sustaining human system as well. That is not true however since the history of earth includes long periods before the emergence of the human species; that is to say, the sustainability of the biosphere system does not directly imply the maintenance and the sustainability of the human system. Indeed, human species require some particular natural conditions for their survival.
We may distinguish hence between two classes of these conditions. The first are refer to the provision of food and the second to particular environmental conditions permitting the survival of human beings. The food provision is assumed to be the main target of the economic system, and therefore we will examine it later on an analysis of the economic system. Thus, the issue of the maintenance of those natural conditions which, besides food provision, ensure the sustainability of human system, remains to be examined here.

We are almost able to distinguish those natural conditions that are indispensable for the sustainability of human beings. These conditions are supported by some environmental functions and elements. The preservation of these environmental functions may be referred to as "human biological sustainability" and those levels of natural species-elements which ensure this sustainability may be referred to as "human's biology critical levels".
However, in order to avoid so many new terms we will comprise the natural conditions which are indispensable for sustaining the human system to those conditions which are required for sustaining the biosphere system; so the term "human biological sustainability" will be contained in the term "biological sustainability", and the term "human's biology critical level" in the term "biologically critical levels".
As a result, the term "biological sustainability" implies the sustainability of those natural functions which ensure the maintenance and evolution of the biosphere system as well as of the human system.
The term "biologically critical levels" implies those levels of the crucial natural elements which secures, the above defined "biological sustainability".

At this point,we have to distinguish between two categories of biological functions that are necessary for the sustainability of the human system. The first ones are those functions taking place in the natural environment, the second are taking place within the human body. We may refer to the former as exosomatic functions and to the latter as endosomatic functions. Of course, there are close interactions between them and specifically the exosomatic functions influence the endosomatic ones.
Obviously, the sustainability of the human system depends on the proper operation of both categories of natural functions. However,there is a specific property of endosomatic functions which should be mentioned here. The human species has the characteristic of self-

reproduction. By this process the endosomatic functions of one generation may operate properly in spite of the fact that the respective function in the previous generation was taken in a deficit state. This explains the sustainability of the human system in historical periods or in the present time, when the human beings suffer from serious problems in their endosomatic function due to health conditions (virus, diseases) or overexploitation of human power etc. (Passet 1979).
However, even this self-sustainability process of the human endosomatic functions has a certain limit, which when violated implies that the relevant problems are inherited by the future generations via the biological heredity.
For the sake of simplicity, we include the biological limit of this self-sustainability process in the above mentioned "biologically critical levels".

We have confined our examination of human system sustainability to the natural processes indispensable for human beings survival in the long run. However, there are several other spheres of the human system, such as culture, ethics (anthropogenic elements) etc. One may assert that the sustainability of the human system means, besides the sustainability of the above examined natural process, the sustainability of certain anthropogenic elements like culture as well. Probably that question is right, but we, well exclude these factors from our work for two main reasons.
First, we consider that the natural processes necessary for human beings are the prime conditions for their sustainability. Provided these conditions are fulfilled, any other dimension of the human system might be free to develop. Secondly, these additional dimensions require an examination by other disciplines as anthropologists, sociologists etc. and thus they are out of our economic science background.

Concluding this paragraph, we may say that the natural conditions, which ensure the natural maintenance and reproduction of human species and hence the natural sustainability of the human system, will be referred to as a part of "biological sustainability"; and those levels of natural elements or functions which secure this sustainability will be referred to as "biologically critical levels". Besides, we restrict our inquiry for human system sustainability only to the relevant natural conditions and thus we exclude cultural and ethical requirements.

1.5.4 Economic system sustainability and performance

While the biosphere and the human system seem to perform their functions without a scale measurement since these functions are related with some qualitative targets (the good operation and reproduction of these systems), economic systems perform a task to which we can attribute a scale.

The target of an economic system is the transformation of several means (production factors) to several outputs (economic goods) which in turn, contribute to human utility or enjoyment of life (Georgescou-Roegen 1971). This activity carries the seed of its density of its performance, since obviously, this transformation may take place at several levels with different outputs.

The concept of economic development refers exactly to the performance level of the economic system.

Economic development usually means increasing the output of the function of an economic system, that is to increase the utility or the enjoyment of life. Here there is an ambiguity since economists also use another concept, that of economic growth which implies to increase the quantitative output of the economic system which in turn, increases the utility. However, some economists assert that increasing utility may come about also via quantitative changes of the economic system output, such as an increase of the leisure time; these qualitative improvements are mentioned as economic development, while economic development includes economic growth as well (Daly 1978).

Formally, we can say that economic development refers to any increase of utility which derives from all those utility factors that have a price on the market; while economic growth refers to a subclass of economic development, including only increases in the production outputs. Thus, for example, utility derived from a forest, whose use we have to pay a price for, belongs to economic development as far the forest is left alone; whereas when that forest requires a production process for it maintenance, the relevant utility belongs to economic growth; note that the utility we derive by playing with our friends is neither economic growth nor development, since there is no market price we have to pay for it.

The sustainability of the biosphere and the human systems results in the existence of the economic system. However, they do not imply anything for economic system's performance (economic development).

The concept of "sustainable economic development" obviously concerns the performance of the economic system and specifically the increasing of that performance. Evidently, that performance and its evolution pre-suppose the existence of the economic system as it is ensured by the sustainability of the biosphere and human systems, but they also require some additional conditions. We are interested in these additional conditions that are provided by the biosphere and human systems.

Let us first examine the contribution of the biosphere and the human systems to economic development.

The human system contains the subjects and one of the principal means of economic

development. Economic development takes place due to the relevant human desire moreover ,economic development requires human labor as a production factor. The sustainability of the human system seems to provide directly the economic system with those human factors which are necessary for economic development.
On the other hand, the natural system provides economic development with the natural inputs of the production processes.
However, there is an asymmetry between the contribution of these two systems. It seems that the sustainability of the human system is able to provide constantly economic development with the necessary human factors due to the reproduction process of man. On the contrary, the sustainability of the biosphere system does not imply that, besides the existence of an economic system, it can provide constantly the necessary natural inputs for economic development.

Indeed, the issue of economic development provision with natural inputs raises several critical problems due to the scarcity of natural resources. Thus we have the well-known issues of substitutability between natural inputs and man-made capital, technical progress, future discoveries of natural resources etc. (Solow 1986, 1974 a, b, Georgescou-Roegen 1976, Hotelling 1991, Daly 1980, Pearce and Turner 1990).
It seem to us that due to the validity of the flows-funds production model we can conclude, at least for the moment, that the economic production requires, to some extent, natural inputs (Georgescou-Roegen 1971, 1975). Thus economic development cannot come about without some natural inputs. Sustainable economic development implies the maintenance or even the increase of economic development (economic system performance) at all times. In effect, sustainable economic development requires the use of some natural inputs.
However, due to the necessary depletion of natural resources, economic development in one period may diminish the potentials for economic development in future periods.
This subject is also related strongly to the population number of each generation (Daly 1979). Economic development is a magnitude measuring, in some way, the sum of the utility of the members of a society; so economic development is a per capital magnitude.
Thus, the population number is a critical factor for sustainable development, since the same economic output implies different development levels for different populations.
As a result, the sustainability of economic development depends on the magnitude of economic output and on the population level. The magnitude of economic output depends on the presence of natural inputs of which the existence at a certain level is not simply ensured by the sustainability of the biosphere system.

Therefore, the critical problem arising here is that of determining the level of economic output (economic system performance) and of the respective natural inputs required for this development in relation to a population number, by the criterion that the resulting development may be characterized as sustainable, for the present and for each future generation. In other words, we have to define a sustainability criterion in terms of a somewhat arithmomorphic concept. We will mention some of the often used criteria:

1. ensuring today's development level for all generations. In other words, according to the current technical knowledge, it implies ensuring equal natural inputs for each future generation, provided there is an equal population in each generation. It follows that if a generation increases its technical knowledge, it will potentially enjoy a higher economic output and hence a higher development. But are natural resources enough to support today's development for all future generations? If not, what is the development level that could be potentially sustained by the current known natural inputs for all future generations, if any?

2. ensuring the existence of some natural inputs securing, at least, a survival level for each future generation; but then the question is: the survival of which population in each generation?

3. ensuring the long run existence of natural resources and hence of the natural inputs, since we face uncertainty concerning future technical knowledge and future available natural resources.

4. non-declining economic utility for all future generations

5. non-declining economic utility for each generation, with the minimum per capita consumption increasing (Pezzey 1989)

6. ensuring sufficient natural inputs for all generations, which are able to provide them with an "acceptable standard of living", under the current technical knowledge.

7. being inactive, since each generation bequests the next one with sufficient capital and technical knowledge, so that the required natural inputs for economic production in the long run will tend to be very small quantities (Solow 1974).

Evidently, the above criteria do not offer a precise rule in the form of a quantitative clear-cut proposition. The reason is obvious: the goal of a sufficient provision of natural inputs for economic development is burdened by some crucial uncertainties. First, we do not know the future availability of natural resources; second, we cannot foresee the future needs for natural inputs; third, we cannot foresee the level of economic production that will be desirable by future generations; and finally, we cannot predict the population level of future generations, neither can we identify it based on solid scientific grounds so that the development is to be sustainable in the long run. At this point we quote Georgescou-Roegen who states "whenever we try to prescribe a quantitative policy for the economy of natural resources we can only play the tune by ear. Instead of basing our recommendations on the ultrafamiliar principle of maximizing utility we should try to minimize future regrets" (Georgescou-Roegen 1979).

Consequently, we may safely assert the following: economic development needs natural inputs. Therefore, sustainable development requires a sufficient provision of natural inputs; in other words, the availability of a sufficient magnitude of natural inputs which can support the economic development in each future period is required. However, this requirement cannot lead to some clear-cut criteria for its achievement, as it is burdened by various kinds of insurmountable uncertainties.
As a result, the condition of the availability of natural inputs for economic development is not analogous to the prime condition of sustainable development (the biological sustainability) since the prime condition is clearly fulfilled via the existence and the good function of the biosphere and the human system while there is no a clear-cut operational criterion for the availability of natural inputs.

According to the hierarchical importance of these two conditions for the achievement of sustainable economic development, we classify them as follows: the "biological sustainability" is the first-order or the prime condition, while the availability of natural resources is the second-order condition. It goes without saying that the violation of the first-order condition leads to the extinction of human beings, while the non-endurance of the second-order condition has some unclear implications for mankind's evolution (see chapter 8).

1.6 Concluding remarks

The conditions for ecologically sustainable economic development will be discussed. The analysis of this chapter indicates that sustainable economic development, although an ambitious term, implies two distinct conditions for its achievement.

The first condition regards the existence of the economic system. We have seen that the economic system's existence requires the existence of the biosphere and human systems. Indeed, "biological sustainability" presumes the existence of the biosphere and the human systems, thus "biological sustainability" secures also the existence of the economic system. Evidently, we cannot speak of economic development without ensuring the economic system's existence. Therefore, we regard this first condition as the "prime condition" or as

the first-order condition of sustainable economic development.
As a result, "biological sustainability" is a prerequisite for sustainable economic development. "Mankind's survival ......is neither only biological or only economic. It is bioeconomic" (Georgescou-Roegen 1976). According to what we have concluded in the preceding sections the economic conditions of mankind's survival presupposes the biological one which is mentioned as "biological sustainability".
It seems that this prime condition is well defined and does not involve much ethical changes for its achievement.
Probably, there is limited knowledge concerning biosphere functions but that knowledge is drastically increasing in the past years. So, we mainly know the principal biosphere functions and the contribution of the natural elements to them. In addition, we are able to develop strategies for dealing with such technical uncertainties. Thus, we know what we have to do in order to protect "biological sustainability".
On the other hand, we have said that the "prime condition" does not involve many ethical alterations which means that there is no need for new ethics. Indeed, the effects of disturbing "biological sustainability" affect each generation creating them, as well. These effects are the gradual disturbance of human life and eventually the extinction of the human species. Thus, besides the future generations, the disturbance of biological sustainability concerns the present generation and their immediate descendants (Georgescou-Roegen 1976, Nijkamp 1990). As a result, it is expected that the present generation would confront these effects without the need of ethical concern for the future generations.

Let us now come to the second-order condition which concerns to the availability of natural resources in the time. In the preceding sections, we saw that this condition leads to some inaccurate criteria, since it bears some fundamental uncertainties and involves ethical considerations since the concept brings the seed of the conflict between present development and the potential of future development.

There is an asymmetry between the "prime condition" and the second-order condition. The former concerns equally the well-being of the present generation as well as of its immediate descendance and of any future generation, while the latter may imply sacrifices of the present generation on behalf of the future human beings.
Besides, the second-order condition dose not lead to some clear-cut criteria for its achievement, while the prime condition certainly does.

Generally, in order to design sustainable economic development, we have to distinguish these two conditions since each one requires different strategies and measures. However, the majority of the authors who are interested in sustainable economic development examine only one of these conditions or both, but then in a confused way. This results in the examination of the one side of the issue that establishes some criteria which do not lead towards sustainable economic development since they concern only one of the two conditions.

Finishing this chapter, we will re-interpret here some well-known definitions of economic sustainable development and we will classify them according to the sustainability criterion each definition refers to. When Pearce, Barbier and Markandya speak of maintaining the services and quality of the stock of natural resources over time they mainly regard "biological sustainability" (Pearce 1988, Barbier Markandya 1990).

When Pearce and Markandya define that "sustainability might be refined in terms of a requirement that the use of resources today should not reduce real income in the future" they examine the availability of natural resources, the second-order condition (Pearce and Markandya 1988).

Nijkamp et al. when speaking of society's "livingroom" it seems that they regard "biological sustainability" (Nijkamp et al. 1990)

The debate between Georgescou-Roegen, Solow, Stiglitz et al. concerns the second-order condition, that is the availability of natural inputs for economic production.

Passet's examination mainly concerns the "biological sustainability" that is the prime condition of a sustainable economic development.

CHAPTER 2

ECOLOGICALLY SUSTAINABLE ECONOMIC DEVELOPMENT VIA THE ENVIRONMENTAL PROTECTION IN A PURE COMPETITIVE MARKET

2.1 Introduction

2.1.1 Environmental Economics and "Biological sustainability".
Introductory remarks

Sustainable economic development, a concept developed in the eighties which encompasses all of the dimensions of current environmental problems. The question arising is whether a theory dealing with Environmental Problems was existed before the emergence of the concept of sustainable economic development. The answer is obviously "yes".The theory of environmental policy had a long theoretical and practical tradition before the emergence of the new term. That theory dealt with the same problems as the concept of sustainable economic development. One of the bases of Environmental Policy Theory was Environmental Economics. In the field of environmental economics many great endeavors have contributed to the study of environmental concerns and as a consequence to the design of environmental policy.

Few distinguished examples of books and papers on the topic include: The Theory of Environmental Policy by W. Baumol and W. Oates, The Problem of Social Cost by C. Coase 1960, The Steady-State Economy by Daly 1971, the Energy and Economic Myth by Georgescou-Roegen 1977, the Cost of Growth by Mishan 1967, the Theory and Application of Environmental Policy by Nijkamp 1974 are a small number of inquiries in the framework of the traditional Environmental Economics (Baumol and Oatees 1988, Georgescou-Roegen 1971, Coase 1960, Daly 1977, Mishan 1967, Nijkamp 1974).

In fact, the term sustainable economic development is scientifically based on the theory of the traditional Environmental Policy, accompanied with current contributions to the subject. Indeed, the new term is a review of traditional Environmental Policy Theory seen under the light of current environmental problems such as holes in the ozone-layer, global climate changes, pertinent pollutants etc.

As we saw in the previous chapter the concept of sustainable economic development contains two distinct, although maybe connected, issues. The first is that of a "biological sustainability" which describes the conditions that ensure the maintenance of the natural and human systems in the long run and therefore the existence of economic system. The second is that of sufficient "availability of natural inputs" for economic production (economic system performance), in the long run.

Both issues are well covered, though not always clearly separated, in the framework of traditional Environmental Policy Theory. Indeed, biological sustainability is the basic concept behind the well-examined subject of environmental pollution which has received significant attention in Environmental Policy. On the other hand, the availability of natural inputs for economic production concerned economists while examining the relevance of entropy law in economic processes as well as the optimal extraction of the exhaustible resources as it is examined initially by Hotelling in his well-known article and by many other authors later on (Hotelling 1931).

Evidently, economic theory has played a significant role in developing traditional environmental Policy. Hotelling, Georgescou-Roegen, Coase, Baumol have used mainly economic theory in establishing their inquiry in environmental Policy. As Boumol and Oates (1975) state "man's influence on the quality of the environment depends on two things: the damage he does and the effort devoted to undoing that damage". This phrase underlines the relevance of economic theory in dealing with environmental policy. Because the damage to the environment represents a cost and on the other hand, the effort devoted to undoing that damage also implies a cost, the equity of the marginal expressions of these two costs indicates the optimal damage on the environment -and the optimal size of environmental quality- and thus it determines the equilibrium, the social optimal position. As a result, economic theory forms the corner stone of traditional environmental Policy, at least in theory.

Chapters 2 up to 7 of the present study examine the relationship between economic theory on environmental issues and ecologically sustainable economic development.
Actually, the aim of these chapters is to examine the ability of the economic theory and its derogative traditional environmental Policy, to prescribe and to ensure "biological sustainability" which is the prime condition of sustainable economic development. In other words, we will examine whether traditional environmental Policy is a sufficient tool which can determine the "biological crucial levels" and ensure their maintenance. "Biological crucial level" of the quantity or/and of the quality of natural element ensure the "biological sustainability" of the respective natural element and functions. If so, then the strategy designed according to traditional environment policy may be able to ensure "biological sustainability"; otherwise, we are forced to find some other tools for securing the prime condition of Ecologically Sustainable Economic Development (ESED).

The possible question here, is why we examine only the relation between "biological sustainability" and traditional environmental Policy theory and not the relation between this theory and the "sufficient availability of natural inputs" for economic production. This occurs because the two conditions of ESED have some significant differences. First, the issue of "biological sustainability" does not involve ethical criteria related with a concern for future

generations, since the survival of human species is included in the moral spectrum of each rational individual of each generation. Note that "biological sustainability" concerns the survival of human beings sustained by a natural environment which is well functioning. On the other hand, the issue of "sufficient availability of natural inputs" for economic production provokes strong ethical considerations since the level of economic production today may affect the potential for economic production in future generations.
Second, the notion of "biological sustainability" leads to some certain criteria for its own achievement. The principal criterion is the preservation of the "biological crucial levels" that are clearly intensified. On the other hand, the uncertainties embodied in the issue of the "sufficient availability of natural inputs" prohibit the establishment of some clear-cut criteria. In other words, while the planing of a strategy towards "biological sustainability" may involve some kinds of technical uncertainties that can be removed by a suitable scientific endeavor, the "sufficient availability of natural inputs" requires some kind of speculation about the future of mankind.

In effect we will devote the following chapters on the subject of "biological sustainability" leaving the examination of sufficient "availability of natural inputs" for a specific chapter (chapter 8). Specifically, in chapters 2-7 we will present the solutions of environmental problems as they have been proposed in the framework of environmental economics and then we will test the ability of those solutions to ensure "biological sustainability".
We classify the solutions to the environmental problems arising in the environmental economic theory according to their main characteristics. Specifically, in the present chapter we will examine the solutions of environmental problems which emerge by the operation of the perfectly competitive market without any additional regulation.
The relevant proposed solutions are presented and then we proceed by examining whether these solutions are able to determine and to ensure "biological sustainability", by preserving the "biological crucial levels" of the relevant natural elements and functions.

2.1.2 Structure of chapter 2

In section 2.2 the Coase's theory is briefly presented since this theory investigates the function of the competitive market in cases of environmental disturbances, whatever these disturbances may be.
In section 2.3 the solutions-outcomes of the competitive market in cases of environmental disturbances are further examined. Specifically, we use the relevant literature in order to

describe the exact resolutions of the environmental problems.
In section 2.4 the solutions-outcomes, presented in the previous section, are imposed to critical review. Specifically, we examine whether these solutions-outcomes suffice to preserve the "biological sustainability", the first-order condition of Ecologically Sustainable Economic Development. In fact the same is the target of section 2.5. Actually, section 2.5 investigates those factors which influence the solution-outcomes of the competitive market as far as environmental disturbances are concerned.
Finally Chapter 2 closes with the relevant concluding remarks.

2.2 Coase's theory

2.2.1 The Nature of the Problem

The main principle of Coase theory is that the competitive and cost free market leads towards the optimal solution of environmental problems without any additional governmental action (Pearce and Turner 1990).

Let us outline the theory: The negative effects of environmental decay are due to the fact that individuals ignore the costs imposed on society by these effects. However, as these costs become gradually significant the affected members want to avoid them by avoiding the relevant negative effects.
For example, an old time upstream tannery created unnoticed problems on the function of a downstream fishery since its functions created as much waste as is absorbed by the river's self-cleaning capacity. Gradually, the work of the tannery increased to a level at which the produced waste was above the river's self-cleaning capacity. In effect, the operation of the fishery gradually was affected so much that its owner wanted to avoid the relevant negative effects.
The willingness of the fishery owner is the new essential factor which would lead to the avoidance of the effects arising from the pollution by preventing the pollution. So that the protection of the relevant environmental function-element would emerge. Moreover, the level of protection will be the social optimum one.

How will the solution come about according to the examined theory ? If the competitive market works cost free, the solution will emerge without any kind of intervention, legal or economic.

Specifically, no matter who, the polluter or sufferer, would be legally responsible for bearing the pollution cost, the market function would lead to the optimal solution -optimum protection-.

How does this happen? We will try to examine that with the example used by Prof. Coase and by adding several components which elaborate and simplify further the problem (Coase 1959).

In the same street there are two enterprises, a confectionery and a private hospital. The confectionery's operation produces smells which affect the good operation of the hospital in several ways for example by creating aesthetics problems and therefore diminishing its customers, by disturbing the doctors, by affecting patients with respiratory diseases. These effects are the outcome of the air pollution caused by the confectionery's operation.

We initially assume that the confectioner is legally responsible for the negative effects of pollution. Thus, the hospital owner can claim from the confectioner to diminish his activity up to a level at which the hospital does not bear any negative effects and hence any cost induced by these negative effects.

In fact both parts will enter a negotiation procedure. The outcome of the negotiation depends on whether the exercised level of the polluting activity contributes more to the confectioner's income than it subtracts from the doctor's income, the subtracted income of the doctor being the cost he bears due to the effects of pollution. The confectioner then is able to compensate the doctor for the lost income, and still appropriate a profit. As far as this happens the confectioner will continue his activity, since the profit he earns is able to compensate the lost income of the doctor and to leave a profit to the confectioner. The equilibrium level of polluting activity is that at which marginal increase of polluting activity offers so much additional profit to confectioner as the lost additional income of doctor it causes. For if the additional profit earned by confectioner is less than the additional lost income of doctor, then the confectioner will stop that level of his activity which cannot compensate the doctor and still leave a small profit to confectioner. Therefore, he would continue the level of the polluting activity which offers that marginal profit to him which is just equal to the marginal lost income of doctor.

Let us assume now that the confectioner is not legally responsible for bearing the cost of air pollution. This simply means that the doctor has no legal claim from the confectioner to stop his activity.

We can easily prove that the outcome under the new legal conditions is exactly the same as under the previous one.

As long as the additional profit the confectioner earns is larger than the additional lost income of the doctor, the confectioner will continue his activity level, since he is not going to accept any proposed deal by the doctor to diminish his activity. For the doctor is able to offer as compensation a sum less or just equal to his lost income and this sum is less than the additional profit the confectioner earns by not accepting the deal and continuing the relevant level of his activity. Therefore, the confectioner will continue operating at this.
On the contrary, if the confectioner earns less additional profit than the doctor's losses, he will accept the deal to decrease his activity by that level which brings such an additional profit to him which just equals the compensation the doctor offers. For the proposed compensation can be larger than what he earns by additional operation.
As a result, the equilibrium level of confectioner's polluting activity is that level which creates so much cost (lost income) o doctor as the earned profit of the confectioner. The lost income of the doctor is equal to the maximum compensation he would offer each time.

Consequently, independently of who carries the legal liability, the victim or the sacrificer, the factor that determines which activity -the polluting activity or the affected activity- will continue is the value of the production output, the profit, attributed by each activity.
The activity leading to higher profit will prevail until that level continues to yield higher additional profit, since it can compensate the competitive activity. The exercise of the dominant activity would stop at that level, at which the additional profit a small increase of this activity offers is exactly the same with the lost profit this increase causes to the opposite activity via the respective decrease of it. -This lost profit it which would be attributed by the opposite activity if the relevant decrease did not occur-. Beyond this level the opposite activity can attribute more additional profit (Coase 1961, Pearce and Turner 1990).

2.2.2 Two opposite production factors

Advocates of this approach believe that there are two exactly opposite production factors involved in the negotiation process. Furthermore it can be said that these two opposite factors originate from two opposite property rights.
The first right is the right of an entity (enterprise, individual) not to be affected by other entities.
The second right is exactly the opposite, it is the right of an entity to affect the other entities.
In the case of environmental pollution and deterioration, we can describe the two rights as

follows: first is the right of a unit to pollute and therefore to impose costs on other units. Second is the right of a unit not to be polluted and therefore not to be affected by the activities of any other unit.

The exercise of each right creates a utility to the respective entity. However, since these rights are opposite they cannot be exercised simultaneously; increasing the exercise of one right implies equally diminishing the exercise of the opposite right.
Which right prevails and at what level depends on the income produced by the exercise of each one of the two opposite production factors that arise from of the two opposite rights. Specifically, when the market works perfectly and costlessly then the allocation between the exercise of the two opposite production factors will be that in which the value of total production is maximized. In other words, the exercise of each one factor is that which maximizes the sum of the profits arising from the two relevant opposite activities. The factor that creates more production value dominates and this will continue up to the level at which the opposite factor starts producing more production value, that is, it will continue as long as the level at which the marginal production value of both factors is equal.
This point is the socially optimal allocation of the two factors since at this allocation the relevant total production is maximized. That socially optimal allocation/solution will be reached regardless of which right, "to affect" or "not to be affected", holds in the legal institutional framework of the relevant market. That is to say the optimal allocation will be achieved no matter who holds the rights, the victim or the sacrificer, on the relevant polluting activity (Pearce and Turner 1990). The market rearranges the initial legal arrangement of the relevant rights so that the social optimal solution results since the exercise of the factor creating more production value can compensate for the opposite factor not being exercised. This will continue until the opposite factor starts producing more value in other words, until the marginal production value of both factors equals.
Thus, no government action is required in order to induce the originator of the polluting activity to compensate the sufferer.

The advocates of this theory are opposed to Pigou approach on the economic externality issue (Pigou 1920). Pigou accepts that the polluting activity has to bear "the external cost" which it causes to the sufferer's activity. Therefore, a tax is needed to be imposed on the polluter's activity; this tax is equal to the external cost imposed on the sufferer's activity.
Actually, Coase disagrees with this approach and he asserts that no tax is required because of the reciprocal nature of the problem
-the existence of two opposite production factors accounts for this reciprocal nature-. He adds that if a government imposed a tax on the polluting activity then another tax should be

imposed on the sufferer's activity, since the exercise of the sufferer's right automatically creates an "external cost" to the polluting activity because it directly diminishes the operating level or even probably the existence of the polluting activity.
Instead the two way tax system described above, a similar two direction subsidies system may work. This system consists of compensating each unit for not exercising its right or for diminishing its activity level; the subsidy each unit receives is equal to the additional profit the unit looses by not exercising its right and so by not developing its activity. Coase says that both systems, taxes and subsidies, could also work together (Coase 1961).
As a result, what is needed is not a Pigovian-tax imposed on the polluter but either a two directions taxes system or a similar subsidies system, because there are two opposite rights (and hence two opposite production factors) and the exercise of one of them automatically imposes an "external cost" to the other.
Imposing one or both of these systems has the same result as not-imposing any system and therefore any intervention is redundant.

Consequently, at this paragraph we reach the same conclusions as the preceding section. That is, no matter who has the property right to exercise its own production factor, the polluter or the sufferer -or even if there is no legal establishment of these rights- the market will arrange these rights in such a way that the relevant total production, arising from the exercise of these factors, is maximized and therefore the social optimum allocation comes about. Clearly, these factors are opposite which means that an increase in the exercise of one of them implies an equal decrease in the exercise of the other one. What accounts for the opposite nature of these factors is the very fact that they originate from two opposite (property) rights; the first is the right of a unit\entity "not to be affected" by the activities of other units\entities while the second is the right of a unit\entity "to affect" other units.

2.2.3 Transaction cost - government intervention

The preceding analysis assumes that the market is costless, that means that a transaction takes place without sacrificing any existing production factor and therefore, without a cost. However, the real market involves costs in almost any transaction activity. The present paragraph gives the Coase' s school approach for the case of the existence of a transaction cost.

We saw that if the market is costless, a re-allocation of the opposite production factors will

take place as long as there is a benefit (B), in the form of an increase in the total production arising from this rearrangement of the relevant opposite property rights.
Under the presence of a transaction cost (T), the net benefit arising now from any re-arrangement equals (B - T) and therefore the outcome, that is the net profit arising from this reallocation, differs significantly from that when there is no transaction cost. Obviously, the net profit\benefit of this reallocation in the absence of a transaction cost is B.

Let us examine further the outcome (B - T).
Firstly, if T-B > 0, then the transaction cost is bigger than the increase of the production resulting from the reallocation and therefore no re-allocation will take place; hence, the initial delineation of the relevant rights remains.
Secondly, if T-B < 0, then the reallocation and the respective rearrangement occur since there is a net benefit equal to B - T.

Evidently, in the presence of transaction cost the initial delineation of the property rights matters. Under one specific initial allocation, B-T may be greater than zero and thus the relevant reallocation will occur while, under the opposite initial allocation B-T may be less than zero and so no reallocation will occur. In other words, in the presence of a transaction/reallocation cost, two different initial allocations of the production factors may lead to different final allocations and hence, to two different optimum outcomes of the market (Mishan 1974 p. 465 - 470). We have assumed that the transaction cost T is the same for both initial legal regimes.
The outcome arising from each initial allocation (legal regime) is the social optimum under the specific conditions this initial allocation implies. Because for any reallocation to occur, we should take into account the cost of its performance and if that cost is less than the increase of the total production, the rearrangement is undertaken, otherwise it is not (Coase 1960).
Nevertheless, and that is of significant importance, if society as a whole compares the two different outcomes which it may derive from the two opposite initial delineations, one outcome is certainly better in an overall alocative perspective, since it leads to higher total production value minus the transaction cost. However, this better outcome is the social optimum (preferable) only if the initial delineation of property rights leads to it otherwise; this better outcome is not the social optimum because its achievement creates more reallocation cost than the increase of the production value (Mishan 1974 p. 469-471). To quote, on this point Coase "in these conditions the initial assignment of legal right does have an effect on the efficiency with which the economic system operates. One arrangement of rights may bring about a greater value of production than any other. But unless this is the

arrangement of rights established by the legal system, the cost of reaching the same result by altering and combining rights through the market may be so great that this optimal arrangement of rights, and the greater value of production which it would bring may never be achieved" (Coase 1960).

What is the role of government intervention in the presence of a transaction cost? Government intervention has a cost, so any rearrangement or arrangement of the relevant rights caused by a governmental action has an opportunity cost. This cost could be perceived as another form of transaction cost; let us denote it by G.
If that cost G is less than the market transaction cost T, then governmental intervention is desirable since by it the same result as that of the market rearrangement could be achieved at lesser cost (T-G). Moreover, it is possible that a rearrangement not to take place via the market because T > B while this rearrangement to occur via the governmental intervention because G < B, since G could be less than T. Evidently, the realization of this rearrangement induced by the government results in an social better outcome since the total production increases.

2.2.4 Diagrammatic exposure

This paragraph aims at giving a brief diagrammatic exposure of Coase's approach. Figure 1 gives the main points of Goase's theory.

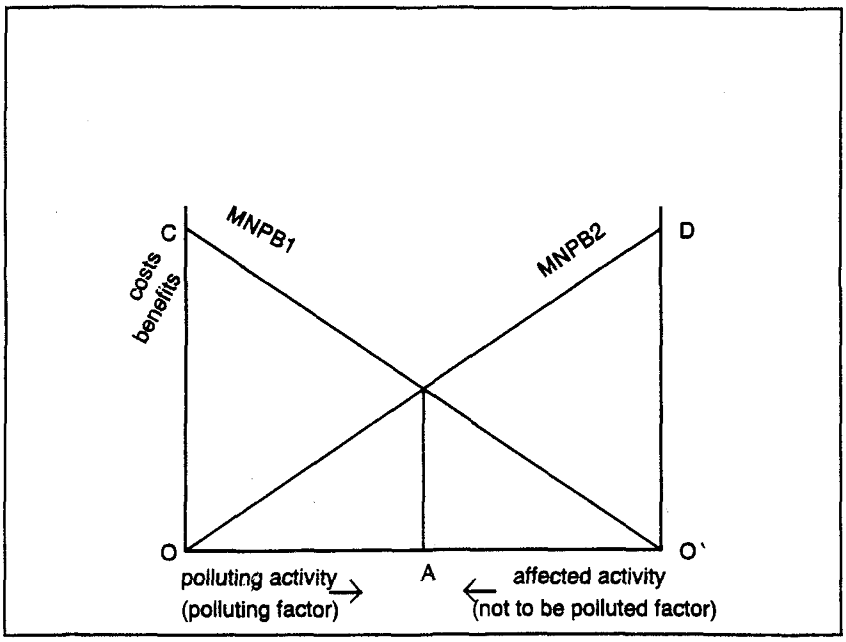

Figure 1 Diagrammatic exposure of Coase's approach

On the horizontal axis the magnitude of two activities which arise from the exercise of the two opposite production factors (and from the two opposite rights) are presented.
The magnitude of each activity increases by enhancing the exercise of the respective production factors. Obviously, increasing one activity means equally diminishing the other one.
On the vertical axis the cost and benefit coming from these activities are presented.
Curve MNPB1 (marginal net private benefit) denotes the marginal benefits of the polluting activity; curve MNPB2 presents the marginal benefits of the affected by the pollution activity.
Coase's theory denotes that the optimum outcome is at that level of the two activities which is determined by the intersection of the marginal benefits curves. That level would be achieved whatever the initial delimitation of the relevant rights. For if the polluter has the right "to pollute" he will choose to exercise his production factor at the level OO' and thus he will work at the point O', where his marginal benefits curve intersects the horizontal axis (at point O' the marginal benefit becomes zero).
However, at this level the opposite activity (the hospital of the example) has a profit to compensate the polluter and the polluter has a profit to accept that compensation, since the sufferer earns more than the polluter; the sufferer's marginal curve is above the polluter's curve. This will continue as far as the level A because only at the range (AO') the polluter will accept the proposed deal. For at range OA the polluter earns more than what the sufferer is willing to offer and thus the polluter will increase his activity as far as A.
Consider now that the relevant property rights are held by the sufferer (he has the legal right "not to be polluted"). He would exercise O'O level of his activity and so he will work at the point O, excluding the operation of the polluting activity.
However, at the point O the polluter will offer compensation which can be larger than the marginal profits of sufferer, since the polluter has more marginal benefits than the sufferer at the OA range of the polluting activity.
As a result, the sufferer will agree to decrease his activity as far as it reaches level O'A. However, he will not accept any decrease of his activity beyond A because at the range O'A he marginally earns more than what sufferer could marginally offer (Pearce and Turner 1990).

Still, the social optimum level of polluting activity and so of pollution would be reached regardless of the initial assignment of the two opposite rights and regardless of the initial allocation of the two opposite production factors.

2.3 Environmental protection in Coase's approach

In this section we will deal with analyzing how environmental protection will emerge according Coase's school.
We saw that the market allocates the two opposite rights/ production factors "to protect" and "to pollute" environment, in such a way that lead to the maximization of the relevant production value. The arising question is: does this allocation lead towards the sufficient protection of the natural system, and how?

The maximization of production is social optimum because it leads to the maximization of the relevant utility.
Since the protection of the environment is a utility, the relevant market function will lead to environment protection as long as that protection is socially desirable. This implies that environmental protection will take place as long as this protection gives higher utility than the non-protective utilization of the environment.

Environmental elements, such as clean water and air contribute to individuals welfare and thus to social welfare. In the past, the part of the welfare arising from environmental elements was free welfare and thus it was out of economic spectrum, since environmental goods were "free goods".
Gradually, however, environmental welfare became non-free welfare as natural elements became scarce and the use of these elements for one purpose excludes their use for other purposes. So, environmental elements became "economic goods". That means if one wishes to enjoy the utility they offer in their natural form (clean form), he has to compete with others who want every alternative use of these elements since these alternative uses degrade the natural form of the environmental elements.
Specifically, if one wants to enjoy the environmental utility one deprives society from another production factor since such a use of the "clean" environment has an opportunity cost which is the "lost production" -lost utility- arising by any possible activity that degrades the environment. Therefore, one has to be willing to pay for enjoying the environmental utility; however, whether he will actually pay for this utility depends on the legal delineation of the relevant property rights. But regardless of the legal delineation the market allocates the utilization of the environmental elements between "clean environment" and "polluting activities" in such a way that maximizes the relevant total production. As a result, environmental utility has a price that is its opportunity cost. This price will be paid either by those who desire "clean environment" or by those who perform the polluting activities; this depends on the legal framework.

Consequently, we see that environment has two competitive and alternative uses: the protection and the degradation of the natural environment. They constitute two production factors, two welfare factors. Each one of these factors opposes each other: the exercise of one excludes equally the exercise of the other. The market allocates them in such a way that the maximum production is achieved. That is fulfilled at the equilibrium position of the relevant market. The level of the environmental protection determined at this equilibrium is the social optimum protection level since any departure of this level diminishes the relevant total utility and hence the total welfare.

2.4 Some common objections to Coase's approach

This section aims at outlining briefly the well known antithesis to Coase's theory.

First, the state of competition may not be that assumed by Coase. In the real world, the market may work in oligopolistic or monopolistic conditions. That simply signifies that we cannot identify the marginal benefit curve of one entity working under imperfect competition with the respective curve under competition. Thus if the polluter is a monopoly, his MNBC will be above the competitive MNBC. So a higher, than that under perfect competition, level of his activity is determined by the market function. This higher level of the polluting activity transgresses the so-called as social optimum level of environmental pollution which is determined by the competitive market (Pearce and Turner 1990).
On the contrary, when the sufferer holds a monopolistic activity, the environmental protection transgresses the relevant level arising under competition.
However, significant modifications of Coase's theory to fix the imperfect competition conditions have been tried by Buchanan (Buchanan 1969).

Second, there are huge difficulties in the bargaining between the holders of the two opposite production factors.
Besides the existence of a transaction cost prohibiting a rearrangement of the initial allocation of the two production factors, there may be several other non-economic obstacles so as this rearrangement is never achieved. In effect, the social optimum environmental protection level is not ensured.
Such obstacles may be the large number of the units involved in the bargaining process so as they cannot communicate. Moreover, one part may use threat in order to exercise his own right. Furthermore, there may be a limited knowledge about the effects of pollution so as

the sufferer's underestimates the benefits arising by the protection of the environment.

Third, there is the non-convexity issue. This subject is well examined by several distinguished authors, so we will give here only the main point of the problem in the framework of our interpretation of Coase's theory (Baumol and Brandford 1972, Pearce and Turner 1990).

The non-convexity issue, if strictly confined to Coase's approach, leaves open the possibility that either polluters' or sufferers' marginal net benefit curve is not declining as the respective activity increases. That may lead to a case, in which there is no unique and stable equilibrium solution. For example, let us assume that only the polluters' marginal net benefit curve (MNPB1) is not diminishing as his activity increases, and specifically that this MNPB1 curve slopes upwards. This situation is presented on Figure 2, where there are two possibilities.

First, Figure 2, MNPB1 curve cuts the MNPB2 (sufferers' marginal benefit curve) from above. Then the intersection point determines a stable equilibrium solution and thus the social optimum environmental protection level is the unique equilibrium level defined by the marginal rule. Therefore, Coase's approach holds also in this case.

Second, figure 3, MNPB1 curve cuts the MNPB2 curve from below. The intersection point determines an allocation of the two opposite production factors which is neither optimum nor stable equilibrium. For any departure of E leads far from that point.

Specifically, it can be seen that the initial assignment of the rights, that is the initial allocation of the respective production factors, remains unchanged. Thus if the polluter holds initially the right to "pollute", the outcome is the O' point and the sufferer will not exercise any level of his activity and no environmental protection will occur-. On the contrary, if the sufferer holds the right "not to be polluted" then the outcome is the point O and thus the polluting activity will not take place at all.

As a result, if there is no convexity either to the sufferer's or to the polluter's marginal benefits curves, then it is very possible that the initial allocation of the two opposite rights remains.

Finally, we mention the "welfare effect". This consists in the fact that a different delineation of the two opposite rights may lead to different welfare levels for polluter and for sufferer. In fact it implies a sensitivity of the location of the marginal benefits curves. This sensitivity is caused by the different welfare effect which is caused by each of the two opposite initial delineations of the relevant rights. That is based on the very fact that the "maximum sum a person is willing to pay for something of great value to him is obviously related to, and limited by, his income or welfare. In contrast, the minimum sum he will accept to go without it may be related to his income or wealth also, but it is not limited by them" (Mishan 1974 p. 560). Specifically, the second sum is bigger than the first (normal welfare effect). That happens because when a person has initially the right to use a "good" his welfare is bigger, than when he has to pay in order to enjoy the same "good".

In our case, the initial allocation of the two opposite factors determines "who is willing to pay" , the polluter or the sufferer. Thus, a different initial allocation changes the welfare levels of the two parts.

Specifically, when the polluter has the right to pollute, his welfare level -wp1- is bigger than his welfare level when he does not hold this right -wp2-. For he will require a bigger sum of compensation for reducing his activity if he has the right to exercise this activity, than the sum he will offer for an equal increase of his activity when he does not have the relevant right. These conditions imply that the marginal benefits curve of the polluter is at higher level when initially he has the property right to pollute than when the sufferer has the right "not to be polluted"; the effects on the marginal curve of sufferer are reserve. Figure 4 presents these effects MPBC1 -w1- is the polluter's curve when he has the legal right "to pollute", then the sufferer has the MPBC2 -w1- curve; on the other hand, when the sufferer has the right "not to be polluted" his curve is the MPBC2 -w2- and the polluter's curve is MPBC1 -w2-. If the polluter has the legal right "to pollute" the equilibrium allocation of the two opposite factors is at the point O_1 (the polluter uses OO_1 level of the production factor "to pollute" while the sufferer uses $O'O_1$ level of the factor "not to be polluted"). On the other hand, if the sufferer holds the relevant legal right the equilibrium allocation is at the point O_2.

Evidently, we assume for simplicity that all bargaining profits are appreciated each time by the holder of the relevant legal right and thus we exclude further welfare effects, on both parts, arising by bargaining (Dolbear 1967). This means, in figure 4, when the polluter holds the relevant right all bargaining profits are gained by him, while when sufferer has the initial legal right "not to be polluted" all bargaining profits, are transmitted to him. This assumption does not alter the nature of the relevant conclusions.

What is important in the case of the presence of welfare effects is that, even without transaction costs, the rearrangement outcome depends on the initial arrangement of property rights and therefore, on the initial allocation of the two opposite production factors. Specifically, it can be said that if we assume the presence of positive-normal welfare effects, the exercise of the polluting production factor is bigger when the polluter holds initially the legal rights (Mishan 1974). This implies a lower environmental protection level when the polluter has the initial rights.

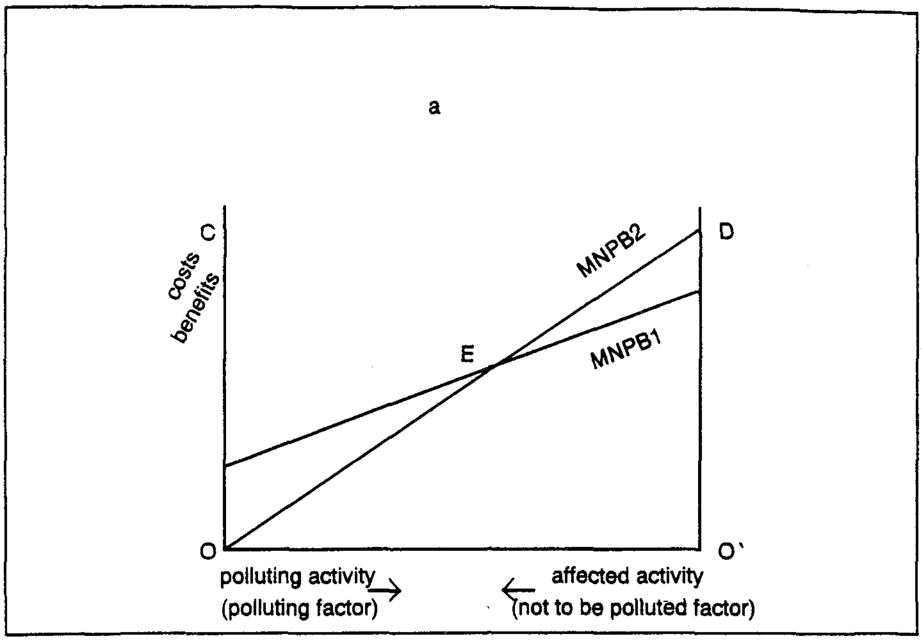

Figure 2 Non-convexity issue (a)

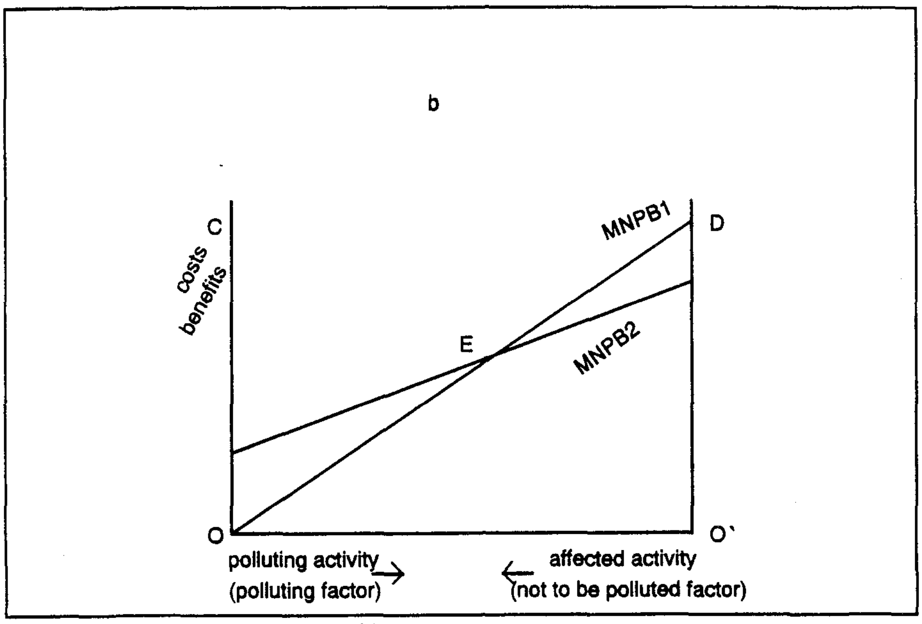

Figure 3 Non-convexity issue (b)

Another significant point of the analysis is that if there is no legal initial delimitation of the relevant property rights then the outcome of bargaining, whether in the presence of welfare effects or transaction costs, is exactly the same as with the case in which the rights are initially owned by the polluter. For polluter starts his activity without any obstacle and he would stop his activity at the level maximizing his profit, unless he would be compensated to reduce or to stop his activity before reaching that level. The initiative for bargaining and for compensating belongs, in both cases, to the sufferer since the polluter has no motive for starting negotiations over the level of the polluting activity.
As a result, non established legal rights, either to the polluted or to the polluting activities, simply means in economic ground that the relevant rights belong implicitly to the polluting activity and hence to the polluter.

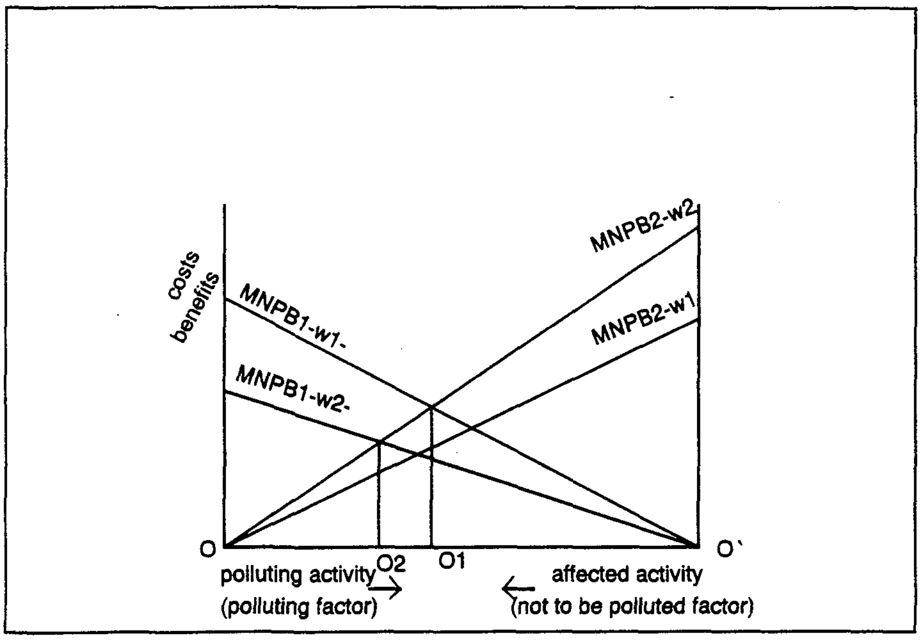

Figure 4 The welfare effect on the marginal benefits curves

2.5 Determining the benefits of Environmental protection

2.5.1 "Biological sustainability" and optimum level of environmental protection

The aim of the remaining sections of this chapter is to examine whether the optimum environmental protection level as defined by Coase's approach, is able to ensure the "biological sustainability". The maintenance of the "biological sustainability" requires the

preservation of the "biological crucial level(s)" of the relevant natural element(s) and function(s).
Is the "biological crucial levels" protected by the market function as presented in Coase's approach? This is the subject of the present sections.

We saw in the previous chapter, that the "biological crucial level" of an environmental element or function is uniquely determined by the processes and the operations of the biosphere system. Specifically, the "biological crucial level" is the lower level of the relevant natural element or function, which ensures the maintenance and evolution of the relevant biosphere operation to which this element or function participates.
On the other hand, the optimum environmental protection level is determined by the intersection of the polluter's and the sufferer's marginal benefits curves, and so it depends on the position and slope of these two curves. So if we wish to examine whether that optimum protection level is larger, smaller or equal to the relevant "biological crucial level" we have to examine all those factors influencing the position, the slope and the movements of these curves.

In order to simplify the examined issue we assume that there exist the polluting activity and the exactly opposite activity aiming at protecting the relevant environment from the polluting activity. The benefits of the polluting activity are depicted in the polluter's marginal benefits curve, while the benefits of the protecting activity in the sufferer's marginal benefit curve. The sufferer's benefits, obviously, refer to those benefits that arise by the use of the environment in its natural form, a use that does not affect the respective environmental element or function. Thus, usually sufferer's benefits will be mentioned as environmental utility benefits implying those benefits which emerge arising from the protecting activity.
Some further characteristics of the sufferer's benefits arise from the nature of the polluter's activity depicted in polluter's marginal benefits curve (Mishan 1981). If polluter does not initiate pollution there is no competition for environmental uses and so, the part named sufferer does not compete for his environmental utility because that utility exists free. So, there is no marginal benefits curve of the sufferer -Mishan following a similar reasoning develops an ethical analysis for this issue (Mishan 1981)-.
We have to emphasize here that the competition for the use of the environment in its natural form and without affecting this form, caused by the large number of entities which desire that use, creates a market for the relevant environmental element. Thus, each entity operates on a (marginal) benefits' curve. However, this form of competition differs from the one presented in Coase's approach. For all decision making units desire the use of environment in its natural form and moreover that use not to destroy (pollute) the

environment. Therefore the outcome of this kind of competition is the allocation of the environment among all entities that desire it. So, the "biological crucial level" is not in peril in that case.

Note that some authors identify the "external costs" which are caused by the polluting activity with the benefits of the sufferer arising from the use of environment in its natural form (non-polluted form), because these benefits emerge in their economic form due to the existence of the polluting activity. Thus, the marginal benefits curve of the sufferer, if read from left to right in any of our figures, presents what some authors call "marginal external costs of pollution" as the polluting activity increases.

2.5.2 The effect of the reaction time. The human gauge of environmental utility

As we saw in the previous paragraph, the introduction of environmental utility that is the benefits of environmental protection into economic spectrum is caused by the reaction against the decaying activities. Specifically, as the decaying activities increase by producing some economic goods, environmental utility stops being a free utility since it has an opportunity cost.
This simply means that environmental utility has a price which is equal to its opportunity cost; its opportunity cost is equal to the value of the economic goods produced by the decaying activity. That price will be paid either by polluter or sufferer depending on who holds the initial legal rights, and it will have the form of compensation to the bargainer who holds the initial legal right. However, the outcome will be the same no matter who holds the relevant legal rights. The outcome is the optimum level of environmental utility arising from the optimum level of environmental protection.
The price of environmental utility comes into existence at the time when sufferer's marginal benefits curve emerges and takes the form presented in all figures of this chapter; this curve indicates the highest price that sufferer will pay or the lowest compensation that he will accept in order to buy or to sell respectively each level of his environmental utility (if he actually buys or sells depends on the legal arrangement of the relevant rights).

Consequently, regardless of the initial assignment of the legal rights, the time of emergence of the sufferer's marginal benefits curve is related to the emergence of the sufferer's feeling that the environment has became a scarce good.
Then, if the sufferer has the right "not to be polluted", it is obvious that he will ask for

compensation for selling levels of his right to the polluter since the sufferer realizes that environment is a scarce good and so, the sufferer and the polluter cannot exercise their rights simultaneously. Otherwise, the polluter would not accept paying any compensation since he can use the environment without affecting the sufferer's use since environment would not be scarce.

Symmetrically, if the polluter has the right to "pollute", the sufferer will offer compensation only when he feels that he looses his environmental utility previously considered as free utility.

The crucial question now is, when the environment starts to be perceived as a scarce good, the "biological crucial level" been already violated? In other words, the question is whether at the point that the sufferer starts reacting against pollution, which is the point at which he perceives that the environment has become scarce, the "biological crucial level" has been already transgressed and therefore the "biological sustainability" of the relevant environmental element or function is not ensured.

This question may become more crucial when the polluter has the legal right "to pollute" since in this case sufferer's reaction may be delayed due to the very fact that sufferer bears the cost of compensation -see welfare effects above-; on the contrary, when the sufferer has the right "not to be polluted" it is expected that he reacts earlier since he asks for a compensation for permitting the polluting activity to take place.

The answer to the above question cannot be general since it is possible that there are cases where the reaction comes after the violation of "biological crucial level" for example, the ozone depletion problem, while of course there are cases where the reaction comes well before the "biological crucial level" is violated.

The problem examined above becomes more evident if we regard the properties of the human perception of environmental utility. Evidently, this perception refers to the sufferer's feeling of a scare environment since the sufferer is the entity that pursues environmental protection.

This perception cannot grasp all characteristics of a specific natural element or function but only those which contribute directly to human utility. However, a specific natural element or function embodies some characteristics and operations which do not contribute directly to the individual's utility. In effect, individuals may ignore their usefulness or even their existence.

On the other hand, these natural characteristics may contribute significantly to the maintenance of the "biological sustainability" of the relevant part of biosphere system. As a result, these unperceived natural functions, elements or characteristics become scarce while the benefits emerging from their protection are not included directly in individual's (sufferer's) relevant benefits. So, the violation of their crucial biological level is a very possible outcome since their decay may continue without any reaction.

The above conclusion holds even if we assume that individuals desire "biological sustainability" and therefore they want to secure it or even if we assume that individuals want to restore the "biological sustainability" when it is violated. Note that the problem examined in the previous paragraph is a quite different than the present one. Specifically the previous paragraph examines whether "biological sustainability" is preserved via the preservation of the environment as a factor that contributes utility while the present paragraph assumes that "biological sustainability" is an explicit target. Indeed, individuals' perception, as it operates via the senses of individuals, cannot take into account all the potential threats to the environment due to the human physiology. Therefore, in an individualistic level, the threats to "biological sustainability" may not be perceived before its violation. However, the reversal of this deterioration is not always possible since irreversible disturbance may have been imposed on the biosphere system.
Note that we examine the preservation of "biological sustainability" in the level of the individual where an ordinary individual perceives and reacts against the decay of the environment. Obviously, an ordinary individual acts on the basis of the information he gets through his senses. The development of additional specific instruments and information agencies imply an additional cost that could be undertaken in a few limited cases where environmental decay is perceived as serious. This additional cost creates a negative welfare effect for the sufferer in the case that the polluter holds the right "to pollute". These welfare effect results in a relative underestimation of the benefits arising by environmental protection by the sufferer (which is equal to the cost of environmental decay). This, in turn, brings a delay in the reaction of the sufferer.

2.5.3 The Subjectivity issue

In order to analyze this issue we assume that human perception of environmental utility is a gauge measuring all threats of environment and so all benefits arising from its protection. Thus, we exclude the effect of a limited human perception examined in the second part of the above paragraph.

The decision rule is that environmental protection will take place as long as it contributes a higher utility (value of production) to individuals, than that the utility created by the opposite activity which destroys the environment.

The environmental utility, as any other utility, has a subjective nature depending on the idiosyncrasy of each entity (Paulopoulos 1982). As a result, the environmental utility of each individual and thus each sufferer's marginal benefits curve depends on his priorities and his preferences. That, in turn, results in a different optimum level of environmental protection for each individual against the same environmental threat.

In addition, if we assume that the supply of environmental goods is almost given by nature and thus it can not be significantly augmented by human activities, then we conclude that the value-price of the environmental utility could differ notably for each individual. Note that the marginal benefits curve of sufferer may be interpreted as his demand curve for the environment while the marginal benefits curve of polluter may be seen as his demand curve for the same good.

On the other hand, we have concluded that the "biological crucial level" of a natural element is uniquely determined by biosphere laws and operations. Therefore, there are only two ways which lead to identifying the "biological crucial level" with the relevant optimum level of environmental protection determined by the market.

In other words the "biological crucial level" is safely preserved via the optimum environmental protection of the market only in two ways. Firstly, it is preserved by chance; indeed, the optimum environmental protection level is defined in market via the bargaining between all relevant sufferers and polluters could be above or equal to the relevant "biological crucial level".

We remind here that the market optimum level is defined to take into account all individuals' (sufferers) benefits arising from the protection of the environment.

The second way is the existence of an almost total consensus among all the concerned individuals of a society. Particularly, all individuals want to secure the relevant "biological crucial level" regardless of the other preferences of each individual.

This simply means that the optimum level of environmental protection -environmental utility- of each individual and thus, the corresponding market level for the whole society cannot be lower than the relevant "biological crucial level". In other words, all the concerned individuals have confined the decision space which is subjected to bargaining at those levels of environmental protection which ensure the maintenance of the "crucial biological level". Diagrammatically this is presented on Figure 5, where the "biological crucial level" corresponds to O'A level of the environmental protection -O'A exercise of the environmental protection right which starts from O'-. At level O'A the marginal benefits curve of the sufferer (MNBC2) takes the vertical direction tending to infinity; MNBC1 curve presents the marginal benefit of polluting activity.

Actually, the analysis of figure 5 implies two alternative things. First, sufferers constrain their decision space at the AO range of the protection activity -the protection level is higher than O'A level- and thus, the marginal benefits curve of environmental utility ends at point E. Secondly, the marginal benefits for increasing environmental protection -the marginal benefits of environmental utility- tend to infinity for all O'A range of environmental protection and so, environmental protection will take place for at least O'A level.

The question arising now is whether the above modified scheme of environmental utility -environmental protection activity- marginal benefits curve is possible to exist in the real world. In other words, can real individuals have such a perception of environmental utility which ensures "biological crucial level" as happens with those individuals of Figure 5? That is the subject of the two following paragraphs. Note that if the answer to the above question is negative, then only by chance the optimum protection level brought about through individuals behavior, would correspond to the "biological crucial level" securing "biological sustainability".

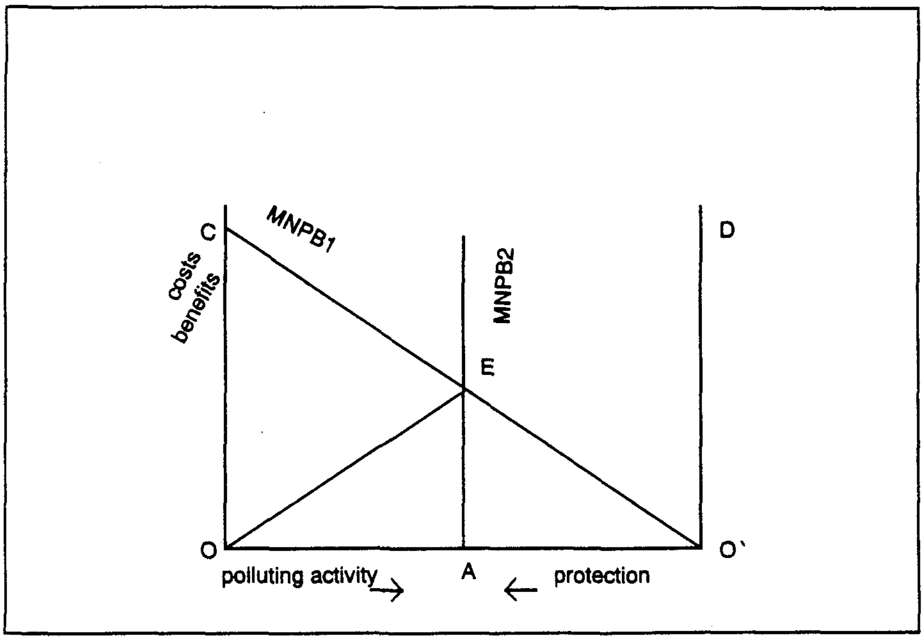

Figure 5 Optimum protection level that preserves the "biological crucial level"

2.5.4 "Time span effect"

The magnitude of environmental utility is equal to the economic value of environmental protection (sufferer's right) and it determines the level of the marginal benefits of the environmental protection. This level in turn influences the determination of the optimum protection level.

Actually, the economic value of environmental protection is influenced by the life span of the relevant entity, that is it is influenced by the life span of each individual.

Why?

Each individual reacts and wants to protect the environment when he fells that he looses his environmental utility due to a polluter's activity. Evidently, he reacts against those actions of other individuals (polluters) which affect his own environmental utility by a decaying environment within his own life span.

In other words, individuals perceive that environmental utility which arises in their own life time. So, they protect environment as long as it contributes utility in their own life time. Finally, they protect it as long as that protection offers higher utility than any alternative use of environment. The alternative use is any polluting activity. As a result, the value of environmental protection depends on the magnitude of the environmental utility perceived by the relevant entities in their own life time.

There are, however, decaying-polluting activities which influence the environment after the present generation's life time, although they are performed during the present generation's life time span (Opchoor and van Straeken 1991). The reaction against this kind of activities could be modest or non-existing since present individuals do not perceive the loss of their own environmental utility. Thus, the relevant "biological crucial level" may be violated in the future due to present decisions, although that level may be preserved during the present generation's life time.

What does this mean in a formal economic analysis?

Because of the very fact that present individuals do not perceive all costs associated with polluting activities, they also perceive a limited magnitude of the benefits arising from the protection of the related environmental elements. Specifically, the present individuals perceive those benefits of the environmental protection that are equal to the cost of pollution which is imposed or perceived to be imposed on the present time.

So, the marginal benefits curve of the environmental protection (protecting activity) moves towards horizontal axis, OB curve in figure 6, compared to that curve which takes into account the overall environmental protection benefits (the protection benefits of all generations), OA curve in figure 6; Moreover, that curve probably is non-existing if the pollution effects on present individuals are unnoticeable.

The rationale behind the above conclusion is the following. If the polluter has the legal rights "to pollute" then the bargaining starts at the OO' level of the polluting activity (figure 6). In that case, the sufferer (the consumer of the environmental utility) will compensate the polluter to reduce his activity. That compensation represents a cost for the sufferer and thus he will not offer more than the magnitude of the environmental utility he wants to enjoy and which is lost due to the polluting activity. As a result, the sufferer will compensate aiming at a suitable reduction of the present effects of the pollution and therefore he will not deal with the relevant future effects that will emerge after his own life time. In effect, the benefits of the environmental protection that are noticeable by the sufferer do not include the overall protection benefits since the benefits that would emerge due to the protection of the environment for the future times are not considered by the present sufferer. So, the marginal benefits curve of the present sufferer is moved towards OO' axis, compared to an unlimited production benefits curve.

Similarly, if the sufferer has the legal right "not to be polluted", then the bargaining starts at O'O level of the environmental protection axis. The sufferer probably asks for a higher compensation at each polluting activity level compared with that compensation he would offer if polluter had the respective legal right. So, probably the marginal benefit curve of the sufferer is initially above OB curve. Let us assume that this curve is OEZ (see figure 6). There are, however, two reasons which will tend to move OEZ curve towards OB curve. Firstly, the sufferer would probably have to prove legally that he really loses utility in order to ask for compensation from the polluter. That automatically leads OEZ curve towards ONB curve.

Secondly, the competition among sufferers to receive a compensation for something they do not really lose would lead them to ask for a lower level of compensation until that compensation reaches the real cost imposed on sufferers. The real cost imposed on sufferers of the present generation is depicted by curve OB.

We remind here that the cost imposed on the sufferer is equal to his lost environmental utility which in turn, is equal to the benefits of the protecting activity (environmental protection).

Let us call the above described effect of the underestimation of the all time benefits of the environmental protection as "time span effect".

Note that this underestimation occurs when the decision about the level of the pollution activity, which affects environment both in the present and in the future, is taken at the present time.

In the following text we give some examples of real world conditions that may lead to the "time span effect".

First, some pollution forms lead irrevocably to the "time span effect" because of the cumulative characteristic of some kinds of pollution. As such kind of pollution we may mention the persistent pollutants and those pollutants which have very slow degradations process. Indeed, all the decisions of today, concerning these pollution forms, also affect future individuals. In fact, they affect future individuals harder since new quantities of pollution will be added to the existing pollutants This leads to extremely harder effects in future.

The second is the very fact that individuals' life time is limited. Considering the benefits of environmental protection, individuals perceive these benefits for their foreseeable future only, ignoring all those benefits arising when they will have expired (Mishan 1981).

So, they probably accept the violation of the "biological crucial level" if this violation arises after their life time. For, as we saw above, the polluting activity gives to sufferers significant income in the form of compensation for the lost environmental utility if sufferers have the relevant legal rights. However, present sufferers sell also the environmental utility of the future individuals and therefore they could sell this utility in a lower price than it really is worth. Symmetrically, if polluters have the relevant legal rights, present sufferers may not want to lose part of their income for compensation aiming at ensuring the "biological crucial level" for future generations.

Even if we assume that maybe there are some individuals that are willing to preserve the relevant "biological crucial level" for all future generations -as far as it depends on their own decisions- and therefore they take into account all, present and future, benefits of the environmental protection it is very difficult to derive an almost a consensus among all of those involved. However, such a near consensus is a prerequisite for obtaining the slope and the level of the (marginal) benefits curve of the environmental protection that can preserve the "biological crucial level". Otherwise, the (marginal) benefits curve, which is determined by the mean of the respective curves of all involved individual, can have such a scheme and level that lead to the violation of the "biological crucial level" in the future.

For example, an old man in his 70's, rationally acting would offer very small part of his income to protect himself from the effects of ozone layer depletion since he would not believe that he would be seriously affected in his own life time. His marginal benefits curve of ozone protection would move towards the horizontal axis, in contrast to the respective curve of an individual in his 30's. Let us assume now that the relevant society consists of two members, the old man and one man in his 30's. The marginal benefits curve of the whole society only by chance could be at such a level that ensures the maintenance of

"biological crucial level" of the ozone layer in the next 50 years although this maintenance is irrevocably determined from the decisions of the two present men.
We can assume that an immortal individual or a society of such individuals would have a market curve of marginal benefits of ozone protection which secures the relevant "biological crucial level". That kind of individuals realize all present and future benefits arising from the protection of the ozone layer since they are aware of the present and future effects caused by the ozone depletion on them.

Consequently, we may say that because of their limited life time span individuals perceive only a limited loss of the overall loss of the environmental utility caused by some polluting activities, and hence a limited benefit of the respective environmental protection. This is very possible for those polluting activities that continue to affect the environment, and sometimes effect it more in the future (Ophcoor and Van Straaten 1991).
However, the biosphere system does not have a limited time span, as a matter of fact its life span tends to infinity. On the other hand, the decisions concerning the protection and the pollution of biosphere system are made by economic units, in an individualistic level, which have a very narrow future. Indeed, an economic prediction for 60 years is a very long prediction (Parset 1979). So it is very possible the overall cost of an environmental decay, which equals the benefits of the relevant environmental protection to be higher than the costs perceived by the generation that takes the relevant decision because this generation takes in to account only the part of the costs which emerge within its life time while ignores the costs which will occur in the future.
This means that while the all time benefits of environmental protection, if taken into account, may lead to preserving the "biological crucial level" as the optimum protection level -in figure 6 the "biological crucial level" corresponds to OM protection level determined by the overall benefits curve OA-, the benefits considered by the present generation are lower so that the optimum protection level is less than that level which corresponds to "biological crucial level" -the present generation's marginal benefits curve is OB defining O'S protection level-.
That is attributed to the very fact that the decisions that concern natural system and are made at the present may affect environment also in a future time while the individuals that are involved in the procedure of making these decisions regard only the effects that emerge in the present.
This effect will be called, from now on, "time span effect" implying the inequality between individuals' (economic units') life time and the biosphere system's life time which leads to the underestimation of the environmental impacts of the present economic decisions.

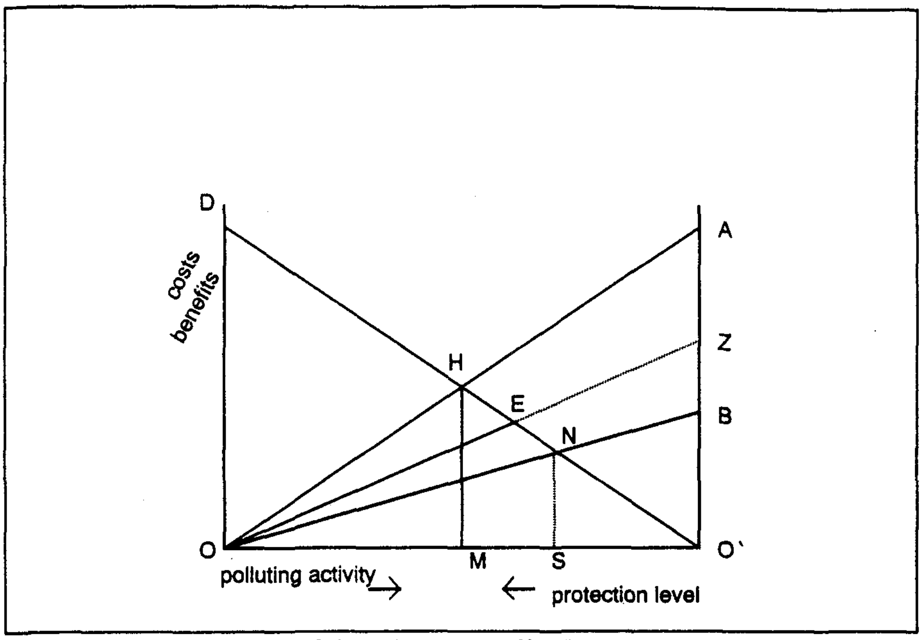

Figure 6 Representation of the "time span effect"

2.5.5 Space span effect

Space span effect implies the underestimation of the benefits of environmental protection when the decisions concerning the level of environmental protection are taken by individuals who perceive only a limited magnitude of these benefits since part of the effects of the relevant environmental decay are imposed outside of their life space. Thus, the optimum level of environmental protection arising from market functions, as presented by Coase, would be at a level lower than that which takes into account the overall space benefits of environmental protection.

If we assume now that the optimum level of environmental protection arising when the overall space benefits are taken into account corresponds to the respective "biological crucial level", then, the determined by the market level in the presence of the "space span effect" is lower than the "biological crucial level".

This analysis holds if either the polluter or the sufferer holds the relevant legal right.

However, is this effect possible in the real world?

There are several kinds of decaying activities the effect of which occur far away from the site of the polluting activity and from the site in which the individuals that are involved in the procedure that determines the level of the polluting activity live.

That implies that the sufferer who decides on the level of environmental protection benefits, perceive only a limited part of benefits arising from the environmental protection.

Specifically, he perceives only those benefits that arise from the protection of the environment against the polluting activity within his life space. That becomes evident if we consider that the market on the pollution-protection of an environmental element takes place within the boarders of an institutional market that only by chance includes all the space in which the impacts of the relevant polluting activity occur. Thus, as the decision concerning the level of the polluting activities is taken inside the boarders of an institutional market, "the official sufferers" would bargain according to a modest level of benefits arising from the protection.
As examples of these kinds of decaying activities we may mention the acid rain in Scandinavian countries caused by industries in G.Britain. Also we mention the effect of radioactive residuals in third world countries although they do not contribute anything to these residuals and they do not decide on them.

Consequently, we see that whenever the overall cost of environmental decay and so the overall benefits of the relevant protection are not perceived by the individuals influencing the relevant decision process (as it is described by Coase's approach) since part of the environmental effects are imposed out of the relevant institutional market where the individuals participate, then, the level of the environmental protection benefits is underestimated. In effect, the determined optimum level of environmental protection may be frequently lower than that level that corresponds to "biological crucial level". Specifically, if we assume that the optimum level of environmental protection determined by the market when all the benefits of the environmental protection are taken into account corresponds to the "biological crucial level" and so the "biological sustainability" is preserved then, certainly the optimum protection level which is determined in the presence of the "space span effect" will be lower than the "biological crucial level" and therefore "biological sustainability" is violated.
This phenomenon of the space discrepancy between the institutional market's space where the polluting activities take place and the space where the their effects are spread out will be called "space span effect".

2.5.6 Conclusions concerning the "time span effect" and the "space span effect"

Assume that rational individuals desire "biological sustainability" for their own natural environment. This implies that they have either an environmental protection marginal benefits curve of such as that of figure 5 (vertical at the "biological crucial level") or a curve

with a normal scheme which lies at a level high enough to ensure "biological crucial level". However, because of the "time span effect" and the "space span effect" individuals may secure "biological sustainability" for them while they affect "biological sustainability" for future generations or/and for other individuals living out of their space.
As a result, sufferers' marginal benefits curve may neither take the horizontal direction at the environmental protection level corresponding to "biological crucial level" nor be at a so high level that preserves this crucial level since that curve may not include the overall benefits of environmental protection and so the benefits arising from protecting "biological crucial level" in all time and space.

Now, one may assume that individuals, acting out of affection for future individuals and for individuals in other spaces, would desire sustainability for all time and space. Thus, they determine their decisions in such a way that they do not affect the overall sustainability.
But, that affection cannot be included in the economic framework of Coase's approach since it implies some economically irrational individuals. For they sacrifice their economic interests for other individuals' interests.
If one assumes now that such an incentive can be included in the spectrum of economic utility by considering that it is a factor adding utility to individuals then, another problem arises. This is the following one: it is required a near consensus among individuals about the affection level (specifically, about the utility they obtain from this affection). That level should be high enough to ensure the existence of "biological crucial level" for all time and space. Otherwise, the determined by the market optimum protection level may be lower than the level securing "biological crucial level" since the protection level is determined by the market is as a mean of all the individuals' protection levels.

2.6 Determining the benefits of the polluting activity

2.6.1 Changes in market conditions

In the analysis of the preceding section we assumed that the position of the marginal benefits curve of the polluter is given and so we examined the influences of the sufferer's marginal benefits curve in the determination of the optimum level of environmental protection. The terms are reversed in this section as we assume that the level of environmental utility (protection) is given and we examine the effects of changing the level of the polluting activity benefits.

There are changes in market conditions which lead to the marginal benefits of the polluting activities to a higher level and so the marginal benefits curve of the polluter moves upwards-right determining a higher optimum level of the polluting activity (see figure 7).

An example of such changes could be mentioned the following.
Changes of the attractiveness of the product of the polluting activity by advertising so that consumers would be willing to offer a higher price in order to enjoy the consumption of the relevant good. In effect, the relative prices of this product increases. These new conditions may move the marginal benefits curve of the polluting activity upwards-right even if we assume that free entry is permitted in the relevant industry since this movement is caused by changes of the level and of the elasticity of relevant demand curve (Paulopoulos 1982). That movement might be smaller when free entry occurs.
Another reason for such a movement is the emergence of an additional demand for the relevant product caused by the emergence of new consumers. If, now, free entry is assumed in the relevant activity, then, the marginal benefits curve of the polluting activity would remain almost in the same level since the polluters would compete for a predetermined total magnitude of the production factor that is used by the polluting activity (OO' quantity in Figure 7). However free entry in reality is not as feasible as in theory. When free entry does not occur, the polluter acts as oligopolistic or monopolistic in the market of the good produced by the polluting activity. Therefore, the marginal benefits curve moves upward-right. Then, if the influence of the sufferers does not exist and therefore the bargaining between polluters and sufferers does not take place, the optimum level of the polluting activity could be lower than that which is determined under perfect competition (in figure 7 the optimum level for a monopolistic polluter is OP while the optimum level under competition is OO'; both determined in the absence of bargaining). -Note that the monopolistic polluter appropriates usually a higher marginal benefit for each production level-. However, if bargaining between polluters and sufferers takes place the optimum level of the polluting activity may be larger (OA in figure 7) when the polluters act as monopolists than when they act in a competitive market (OB in figure 7). This simply means that in the presence of an additional demand for the product of the polluting activity the slope and the location of the marginal benefits curve of the polluting activity may be such as to determine a higher optimum level of this activity, if free entry to this activity is not permitted. We emphasize here that before the emergence of the additional demand the polluting activity product was sold in a competitive market and only the emergence of the additional demand transforms the form of the market.

Are these evolutions possible in the real world?

The very fact that huge sums are spent for advertising is explained by two reasons (Daly 1979). Firstly, it aims at changing consumers preferences, an effect which has been examined above as the first event that leads to the change of relevant market conditions. Secondly, it aims at attracting new consumers into the relevant market an effect that was just examined. Evidently, firms spend money on advertising since they believe that the new consumers would be their clients. For the entry of new producers could be difficult, at least for some significant time span. Therefore, the relevant firms could be transformed to monopolists or oligopolist, for some time.

The existence of oligopolist or monopolist polluters in the market where their products are sold do not influence the form of the market where the bargaining between polluters and sufferers. That market is still assumed to be competitive.

Closing this section we may conclude that, in the real world the marginal benefits and hence the relevant curve of the polluting activity can move to higher levels for several reasons. The effect of this movement is the determination of a higher optimum level of the polluting activity (see figure 7). As a result, the determination of optimum level of the polluting activity is sensitive to changes of the conditions of the market where the product of this activity is sold.

On the other hand, the "biological crucial level" of a natural element or function is uniquely determined in physical terms and it corresponds only to a certain level of the polluting activity and so, to a certain level of the protection activity. In other words, the relevant "biological crucial level" is preserved only when the polluting activity does not overcome a certain level.

In this way, the insurance of "biological crucial level" is sensitive to changes in the market condition determining the benefits of the polluting activity. So, the market mechanism only by chance could secure the "biological crucial level".

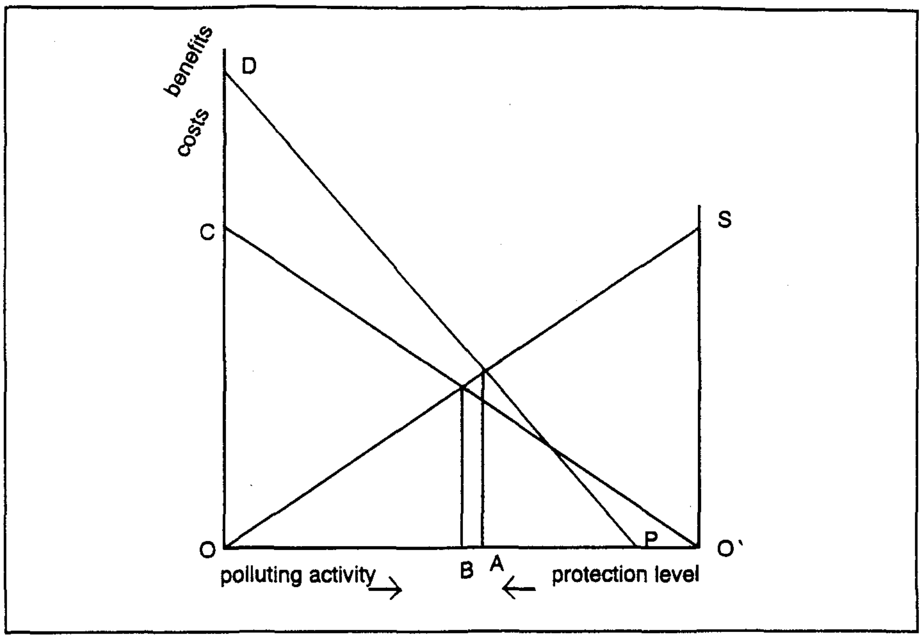

Figure 7 Changing the levels of the polluters' benefits

2.7 Concluding remarks

We examined whether the optimum level of a polluting activity and the optimum level of the respective protecting activity, as they are brought about by the market, could preserve the "biological crucial level" so as to ensure the "biological sustainability".
We found several reasons prescribing that the "biological crucial level" may not preserve the optimum protection level determined by the relevant market. These reasons are:

a. The limited ability of individuals' senses to perceive all of the negative results of environmental decay. Therefore, individuals underestimate the benefits of environmental protection which, in turn, results in determining an optimum level of environmental protection which is lower than that corresponding to "biological crucial level"; in other words, the optimum level of the environmental protection does not suffice to preserve the respective "biological crucial level".

b. The "time span effect" implies that individuals' life time differs significantly from the biosphere system life time. This results in an underestimation of the costs of environmental degradation by individuals -or similarly in an underestimation of the benefits of the environmental protection- since they consider only that part of environmental degradation which emerges in their own life span, or in a just few years longer span acting on behalf of their own descendants.

On the other hand, their decisions determine the environmental decay in future periods, too. Specifically, this is evident when the effects of the polluting activities are persistent.

c. The "space span effect", similar to the above effect, implies that there are cases where the sufferers perceive only a limited range of the environmental decay effects so they consider only a limited spectrum of the environmental protection benefits. The cause is that a part of the environmental deterioration effects is imposed outside the life space of the sufferers who participate in the institutional market in which the bargaining between polluters and sufferers takes place. So the optimum level of environmental protection is lower than the protection level which is determined by taking in to account all of the benefits of environmental protection. Therefore it is more difficult for this protection level to ensure the "biological sustainability".

d. The subjective nature of the perception of the environmental utility leads to a different optimum level of the environment protection level for each different individual (decision entity). However, the "biological crucial level" is determined according to the processes of biosphere functions.. Therefore the identification between the optimum level of environmental protection and "biological crucial level" could only happen by chance.
Even if we assume that there are individuals whose the optimum protection level ensures "biological crucial level", we can not envisage an almost consensus among all concerned individuals so that the determined by the whole market protection level could preserve the "biological crucial level".

e. There are two specific types of welfare-income effects influencing significantly the level of environmental protection benefits. The first kind is analyzed by Mishan (1981). This regards the influence of welfare effects on the polluters and sufferers marginal benefits curves. Specifically, this kind of welfare effect is caused by the initial legal delimitation of the relevant property rights.
The second welfare-income effect refers to the welfare effect arising from the income constrain of sufferers. This income constrain might lead to a different marginal benefits curve for each income level. Indeed, the income of an individual influences the payment (the compensation) the individual could offer (ask) so as it influences the location of the relevant individual's bargaining curve. Therefore, it seems very difficult to get an almost consensus, among all individuals, concerning the location of the bargaining curve so as the respective of the whole market curve preserves the "biological crucial level".
The possible result of such an income effect is that zones of different levels of environmental protection would emerge. For different income levels would protect their own environment

at different levels. However, this situation could hardly correspond to the maintenance of the relevant "biological crucial level".

f. The existence of transaction costs influences strongly the outcome of the market functioning on the levels of the polluting and protecting activities. Specifically, we want to emphasize the very fact that different levels of transaction costs, all other conditions the same, lead to different outcome of market functioning and thus, to different optimum levels of the polluting and protecting activities.

On the other hand, only a certain range of polluting and protecting activity preserves safely the "biological crucial level". In other words, the "biological crucial level" is preserved only if either the protection activity is larger than a certain level or the polluting activity is smaller than a certain level. Thus, the influence of the transaction cost indicates that the market function could only by chance result in maintaining the "biological sustainability" of the natural element on hand, because "biological sustainability is uniquely determined while market outcome is influenced by several social, technical and other conditions.

The arising question now is what is the relevance of Coase's approach in the environmental protection.

Excluding the presence of welfare effects, assuming that they are negligible, we may realize that Coase's approach applies those cases that concern the "amenity utility". By "amenity utility" we mean a very limited aspect of environmental utility, which concerns only some limited dimensions of natural system. Usually, "sight utility", "hearing utility" and "aesthetics utility" are the main categories of the "amenity utility". Moreover, Coase's approach refers to the cases in which the effects on the "amenity utility" are reversible.

The distinct characteristic of "amenity utility", in our analysis, is that if involves only those environmental disturbances which can not violate the "biological sustainability".

In the presence of welfare effects, Coase's analysis may concern cases in which the polluter and sufferer are the same unit which aiming at allocating better the two opposite production factors it owns (Mishan 1981).

Note that Coase's approach is not suitable for deciding about "biological sustainability", in this case too.

If we assume here some additional conditions, then Coase's the analysis may apply also to "biological sustainability" issues. These conditions are: first, the decision unit is quasi-immortal so that all future effects of a today decision are taken into account; second, the relevant entities stretch to all that space where the impacts of the relevant decisions occur; and third, the entities are able to perceive all dimensions of environmental decay.

CHAPTER 3

ECOLOGICALLY SUSTAINABLE ECONOMIC DEVELOPMENT VIA THE PRIVATIZATION OF COMMONS

3.1 Introduction

3.1.1 Introductory remarks

The target of this chapter is to present the theoretical approaches which assert that the change of the ownership of the common propertied natural resources would lead to their protection. Specifically, the privatization of the common resources would transform the "tragedy of commons" to the protection of "privates".

Furthermore, the present chapter aims at investigating the efficiency of the proposed transformation of the common ownership of resources to ensure their biological sustainability.

We proceed with this analysis after the examination of the "Coase school" because the proposed alteration of resources ownership seems to accept an institutional modification of the market institutions. Such a modification is not acceptable by the "Coase approach" which regards as superfluous any institutional alteration since the market alone regardless of the institutions ruling the natural resources would solve optimally any environmental problems.

Actually, the "approach" examined in this chapter is established in the literature of environmental and natural resources economics as a distinct "approach". Therefore, it deserves a separate investigation of its relevance against the new issue of "sustainability".

3.1.2 Structure of the chapter

Chapter 3 initially, presents the literature about the drawbacks of the common ownership of natural resources (paragraph 3.2).

Next, paragraph 3.3 elaborates some new element of natural resources economics which are of great help for the analysis that follows. Specifically, paragraph 3.4 examines the existence of two different patterns of harvesting. Each pattern has some specific properties which characterizes its economic analysis.

Then, paragraph 3.4 presents a realistic approach of natural resources economics for both private and open access ownership regimes. This approach utilizes the conclusions reached in paragraph 3.3. Finally, paragraph 3.4 reexamines some well known approaches of natural resources policy in the light of the new elements of the relevant analysis.

In fact, paragraph 3.4 examines the ability of private ownership to preserve the biological sustainability of natural resources.

Paragraph 3.5 introduces the effects of demand for natural resources in the analysis. The market equilibrium of the utilization of a resource is investigated.
Paragraph 3.6 examines the sustainability of a resource against the market equilibrium of its utilization for both private and open access regimes.
Finally, chapter 3 closes with the respective conclusions presented as concluded remarks.

3.2 Review of the theory

3.2.1 The non-existent ownership of some natural resources

A large part of the current environmental problems and their tremendous dimensions is attributed to the ownership regime of the commonly owned natural resources or, more generally, natural elements. Common ownership leads to their unlimited use which results in their over-exploitation and decay (Hardin 1968).
The current societies and institutions of the West have left out of the system of private ownership several natural resources or elements such as forests, wildlife, rivers, air e.t.c. Without elaboration on the particular reasons which have led to such a practice, one can distinguish two main reasons behind it. First, the enormous magnitude of some natural resources prevented their privatization since it was politically unacceptable by the relevant societies. Second, the traditional use of some common natural elements did not induce any particular scarcity of them since they had large volume compared to human needs. (Dales 1972, Gordon 1959, Kottis 1971)

Yet these resources were usually under the national-governmental command so they might be regarded as national property. National property does not alter essentially the practical side of their common use although usually then there are some rules governing their use. In that case we speak of "common restricted" resources, while if no rule or agency oversees their use it may be called "unrestricted" (Dales 1972).

3.2.2 Economic behavior to "commons"

As we have seen in the previous chapter the standard economic thought regards two subjects involved in economic life. The consumer, who aims at maximizing his own utility under his income restriction and the producer, who intents to maximize his benefits by selling his production at the market. Authors dealing with the subject of common property natural resources assert that the rational self interested consumer and producer would use as much as they could of the services of the common resources since they are "free services".

Specifically, the relevant consumer aims at maximizing the sum of his utility. We may distinguish this sum in two classes. The first class includes all utility arising from the consumption of the goods sold in the market, these goods have a price. The second class includes the utility coming from the use of the "free goods" like the common property resources. Actually, economic theory examines the endeavor of obtaining the utility of the first class. However, the relevant authors assert that the consumer would try to obtain as much utility as he can from the common goods since he acts under the income restriction which implies a limited utility from the market goods.
This behavior lead to the "overuse" of the common resources. Worse, as the population increases the decay or the extinction of several common resources may arise (Dales 1972, Mishan 1972).

On the other hand, the producer acts in a similar way leading to analogous results. Indeed, the intention of the producer is to maximize his benefits which, in turn, implies he should minimize his production cost. The production cost refers to the cost of obtaining the production factors. There are two kinds of production factors: those which should be bought at the market and those which are free such as air, rivers, sea water etc.
The rational producer would maximize the use of the second class of production factors since by doing so he economizes on his production cost. As Mishan mentions characteristically the same would have happened with human power (labor cost) when the slavery had been acceptable by societies; While now the usual practice against labor cost is its minimization since human power has a price(Mishan 1972).

3.2.3 The privatization of common resources

The privatization of common resources results in certain advantages as far as their protection is concerned.
First, privatization would induce the existence of a market for the use of the resources. So there would be a price for their use which would partly reflect the cost of the recourse maintenance in a good condition and the general concern of the owner for the recourse. As

a direct result of this price existence a different inclination to their use would be developed by the relevant consumers and producers compared with the common ownership of these resources. Specifically, the consumer perceives that the consumption of these resources comes under his income restriction. On the other hand, the producer perceives a cost for their use as production factors; this cost he attempts to minimize.
So the "demand" of the "privatized" natural resources has been drastically modified under the new ownership regime because of the rational behavior of the relevant economic units.

On the other hand, the supply side emerges differently under the new ownership regime. The owner would protect the resources, the natural elements since they contribute income, or more general utility, to him. Acting rationally he would undertake those protection measures which prevent the degradation of the resources. A certain level of degradation would be permitted for a considerably high price (cost) which would function as a counterincentive against this.

3.2.4 Rent, natural resources protection and the optimum population

Private ownership of natural elements creates conditions leading towards the existence of a "rent" appropriated by the owner and hence inducing their protection.
"Imagine a society where all land is being used and even the poorest of it commands a positive rate.....and suppose that an initial state of equilibrium exists and in particular that at existing land values and rents there is neither investment nor disinvestment in the quality of the soil. Population growth when superimposed on this initial state will lead to increases in land values and rents; these increases in turn, will lead to economies in the use of soil by means of the substitution of manufactured fertilizers and other intensive forming practices against inputs of natural soil fertility. The process may described as one of investing in soil fertility, and the equilibrium stock of soil fertility will accordingly rise (or it rate of decline will fall). In a general form, the conclusion is that the level of rent determines the quality of the soil that it is economic to maintain. It is also clear, that when man -made inputs are substitute for natural inputs in the food- producing industry the real cost of food increases and the standard of living in terms of food falls. Rising rent, therefore tend to slow down population growth and lessen the population pressure that produces them" (Dales 1972). So the owner of the recourse undertakes the activities which protect the recourse due to the rent it brings, that rent by turn, is determined by the market on the recourse.

The result of the whole process is that the recourse is protected better under private than under common ownership.

A second interesting point of the analysis is that the rent appropriated by the recourse owner keeps the population to its optimum level. On the contrary, under common ownership an increase of the relevant population may lead to the over-exploitation of the recourse for the maintenance of the population. Indeed, the rent mechanism acts towards eliminating the "redundant" population. So, the recourse is used by a "normal" pattern. That is why, Dales says, there has been no problem concerning land exploitation in the USA in the last 350 years despite the drastical increase of the relevant population since the land is privately owned. On the other hand, the same society faces serious problems as far as the biological conditions of some common resources, such as air, waters etc. are concerned. Since these resources are "common" their use is not connected economically with population increases. Therefore population develops without any concern of their limits but the marginal restriction of their extinction (Dale 1972).
Gordon also explains why those who work on harvesting common natural resources always stay at merely a survival level, except for some "lucky cases". The rent appropriated by the owner of the recourse for a common recourse is dispersed among all users (Gordon 1954).

3.3 The existence of two kinds of harvesting patterns

Before we proceed elaborating on some crucial points of the economics of natural recourse exploitation and its differences under common and private ownership, we present here a significant diversification between two production-harvesting patterns which are usually followed in that exploitation. This diversification may clarify significantly the real physiology of natural resources harvesting and thus it may lead to useful policy conclusions.

There are two kinds of harvesting patterns of natural resources (or production patterns of any other good). We will try to describe the main distinct characteristics of these patterns. For the sake of simplicity we will assume a production-harvesting process which is performed by one "changeable" production factor.

The first pattern, the usual in economic thought, is that in which the production process start, by exercising a desired quantity of the "changeable" production factor, at one point of time or period. Then we know the production resulting from this quantity of the production factor. Changing the used quantity of the production factor we produce different levels of product. That process is usually presented in economics by the production function curve.

The usual scheme of this curve is that of figure 1. Figure 1 presents on the horizontal axis the "changeable " production factor and on the vertical axis the total production.

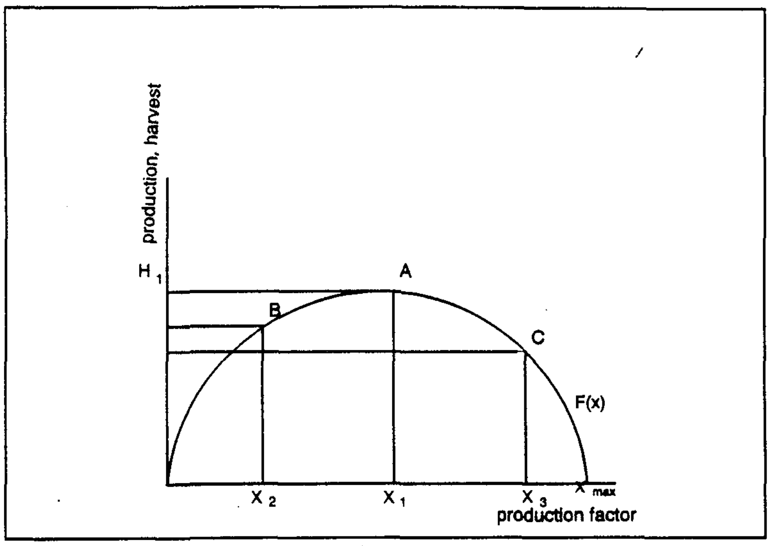

Figure 1 The "normal" production pattern

The total production increases initially. At a certain level of the production function curve it starts increasing by a diminishing rate and then it reaches a maximum level (H_1). Beyond that level the total production decreases down to zero at X_{max} level of the production factor. The diminishing rate of increase up to X_1 and the negative rate of increase beyond X_1 level of the production factor are the effects of the well-known law of diminishing returns.

We emphasize that F(x) function presents the total production produced when the corresponding level of X factor has been used at once. This means that each point of F(x) presents the production of a production process which uses the corresponding level of the production factor X. Any other point of F(x) represents another production process which uses a different level of X factor and of course, produces a different quantity of the product. The used level of the production factor X in a specific process is independent of the used quantity of that factor in any other process presented on F (x). In other words, the producer is able to choose the desired level of X and to produce the relevant production level. He may start producing with X_1 or X_2 or X_3 or X_{max} level of X, depending only on his own decisions.

In order to come now to our point, we may consider that the production factor X is the effort of harvesting a natural resource and that the outcome, the harvest, is represented by H. In this production pattern, the harvester could decide and implement the level of harvesting effort obtaining a given harvest level. According to the law of diminishing returns, at a higher than X_1 level of effort the total harvest is diminishing and finally at Xmax level the harvest becomes zero due to the "congestion" of the exercised effort. However, any point beyond X_1 is a realistic level and harvester could choose this level to harvest.

Each choice of the level of effort is made independently any effort level exercised in other harvesting processes. The applied effort initiates a certain harvest process. Generally, in this kind of harvest, an effort level is exercised all at once and is not increased gradually. Therefore, a harvesting process starts at once and is not reached gradually in a sequence of processes each of them being caused by an effort level that increases gradually up to the desired level.

Another important characteristic of this kind of harvesting pattern is that the production function F(x) of figure 1, representing the total harvest (product) at each effort level applied at once, cannot represent the depletion of the stock of the relevant recourse. Indeed, any point of F(x) represents a process starting from the same initial stock with any other precess depicted on F(x) a specific process describes the harvest captured by exercising, all at once, the corresponding effort level on the initial stock. So, for example, point A indicates the harvest captured by exercising X_1 effort level on the initial stock of the recourse called I. B indicates the harvest captured by exercising X_2 effort level on the same initial stock I. Any process described by any point of F(x) production function starts from the same initial stock I with all other processes described by the other points of F(x).

As a result, the "stock effect" is not examined in the first kind of production-harvesting processes. The diminishing rate of harvest is the pure result of the law of diminishing returns.

Note that this kind of production processes the one which is examined mainly by economic theory.

Let us examine now the second kind of production/harvesting pattern. This production pattern requires only gradual increase of the "changeable" production factor. This occurs by adding new quantities to the already used levels. So, if the producer wishes to exercise a certain level of the production factor he should use gradually all smaller levels of the factor until the desired level is reached.

In this pattern the total production at a certain level of the production factor includes all those quantities produced by a sequence of production processes. These processes have been initiated by a respective sequence of levels of the production factor up to the desired level -each level of the factor cause a production precess that creates a quantity of production-. The desired level of the factor is not exercised at once and the production at that desired level of factor would be reached step by step. The total production at the desired level of production factor is the cumulative production produced by increasing gradually the production factor until the desired level.

In order to clarify the above pattern of production we will demonstrate with an example. Let us consider the "reading effort" as the production factor and the pages studied as the production. If we desire five hours of reading we should start from one hour and gradually pass to two, three, four hours until we reach the desired five hours of reading effort. Obviously, we have to increase gradually the "reading effort". We cannot exercise at once five hours of reading, all other factors being constant (for example one person and one book).

The studied pages,(the total production), is estimated as follows: in the already existing quantity, the additional quantity produced by any additional reading effort is added up until the desired level of effort has been exercised. For example, let us assume that 1 hour of reading yields 10 pages, 2 hours 17 pages, 3 hours 22 pages, 4 hours 25 pages, 5 hours 26 pages and 6 hours 26 pages.

In this example, the production function F(x) presenting the relationship between the total production and the exercised production factor differs significantly from the production function of Figure 1 presenting a "normal production pattern".

Here the total production is a cumulative quantity containing the production that has been produced gradually as the factor increases up to the desired level. For example, the 4 hours of reading yield 25 pages which is the cumulative production of all reading effort until the 4th hour has been used.

That "cumulative pattern" of production is significantly different from that of the normal pattern. Let us use the above example in order to elaborate on this difference.

Note that the total production reaches a maximum level, 26 pages in our example and then remains constant for any additional exercised quantity of the production factor. That happens since the total cumulative product cannot disappear for any reason. In other words, since the production that corresponds at a specific level of the exercised factor includes all the production created by the sequence of all the smaller levels of the factor, that production cannot decrease. Note that the production resulting from a specific level of the production factor is analytically represented as a production process; this process differs from any other that uses a different quantity of the factor.

In our example, the total cumulative production remains constant at the level of 26 pages whatever the reading hours above 5 hours. The 26 studied pages remain in the mind of reader once they have been studied for ever. He cannot read more pages after 5 hours however, he maintains the studied volume no matter how many hours above 5 he attempts to read.

We will call this cumulative pattern of production process "reading pattern" in order to distinguish it from the normal production pattern presented in Figure 1. The scheme of the "reading pattern" of production function is presented in Figure 2. Note that a certain production process is represented analytically by a curve that starts from the origins of the axis and terminates at the point indicated by the exercised total level of the production factor. Indeed, the points of the F(x) function of Figure 2 represent different levels of the same production process as new quantities of the production factor are added up to the existing quantities up to the desired level. In effect, another precess is represented by another curve that starts also from the origins and terminates at a different point determined by the total-final exercised level of the factor, in this now precess. Note that all processes follow the same scheme and differ only at their ending point.

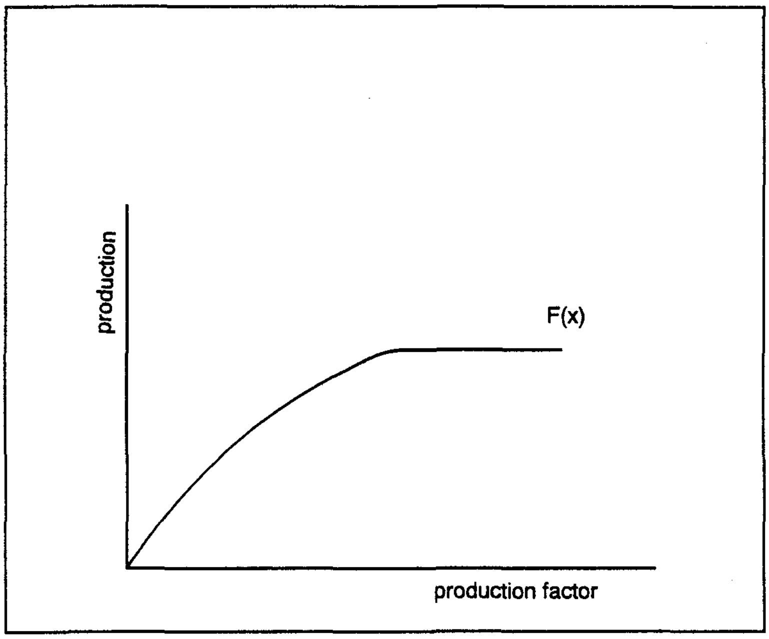

Figure 2 The "reading" production pattern

On the contrary, the points of the production function F(x) of figure 1 present different processes of the same phenomenon, each point describes one individual process.

Another significant difference of the "reading pattern" of production as compared to the "normal pattern" is that the "reading pattern" considers also "the stock effect". That is to say, the production is influenced by the stock depletion. Indeed, production is a process which starts from an initial stock of a recourse on which additional levels of effort are gradually exercised; new effort levels are continuously added to the existing ones.
Existing effort levels have resulted in, a stock depletion of the recourse. So the additional yield of each additional effort might increase at a declining rate or even by a rate tending to zero -so that the cumulative production increases by a declining rate or remains constant respectively-, since the additional effort harvests a reduced stock compared with the initial stock. The "stock effect" partly explains why the cumulative production does not increase for ever but remains constant after a level.
The second explanation of the behavior of the cumulative production pattern is the law of diminishing returns.
In our example of the reading effort, it is the law of diminishing returns which causes "congestion" in the reader mind and so he cannot increases for ever the number of pages studied. In this example there is no stock effect since it is evident that there are as many pages for reading as one wishes.
However, it is important to note that the cumulative production is not decreased as additional quantities of effort (a production factor) are exercised but remains constant after a certain level of effort. It remains constant when the additional production of each additional effort becomes zero, in other words, when the marginal production equals zero. Evidently, what matters is the cumulative production at each effort level since it is the total real production one obtains by exercising a certain effort level.

Concluding this section we emphasize the main difference between the two kinds of production patterns. The normal production pattern is presented in cases in which the producer is able to exercise all at once the desired level of the production factor obtaining the respective total production. Each point of the production function F(x) describes a distinct process of production which is performed by exercising the relevant level of production factor. That process is independent from any other process described by any other point of F(x).
The "reading pattern" of production has a successive characteristic since each process is achieved by establishing of all smaller levels of the production factor until the level that corresponds to the specific process is reached.
In the field of natural resources economics, we may assert that there are natural resources the harvest of which pertains to the normal production pattern while there are others pertaining to the "reading pattern".

3.4 Economics of exploiting a recourse under private and "open access" ownership

3.4.1 The general analysis and the marginal case of a costless harvesting effort

We consider two resources; one can be harvested by the normal production-harvesting pattern and one by the "reading pattern". Their production-harvesting functions are given by Figure 3 and Figure 4 respectively.

In the case of private ownership of the relevant recourse, we know from economic theory that the equilibria effort level applied is determined at the point where the owner maximizes his profits (profits = total revenues - total costs). So the exercised effort level at equilibria is determined at the level that the parallel to the total cost curve is adjacent to the total revenues curve. In our examples that are presented in figures 1 and 2, we assume that the total revenues curve (TR) coincides with the total production curve -the price of the harvest is assumed to be the unit so that the TR curve coincides with the total production curve-.

In the case of an "open access" recourse the exercised effort level is determined at the point where the total cost curve intersects the total revenues curve.

A general conclusion can be drawn from Figures 3 and 4. Whatever the harvesting pattern of a recourse the open access ownership always results in a larger exercised effort level than the exercised effort when the recourse is private. This happens because new harvesters may use the recourse, when it is an open access recourse, as long as TR>TC (Pearce and Turner 1990).

Let us consider now the marginal case of a costless effort. In this case the total cost curve coincides with the effort axis. Figure 3, which depicts a normal production-harvesting pattern, shows that if the recourse is "open access" the effort level tends to Xmax and the corresponding harvest level tends to zero. A harvest level that tends to zero simply means that the congestion of the effort, as it is expressed by the law of diminishing returns, leads to a negligible real harvest. The congestion of the effort is the result of the "open access" ownership of the resource. Figure 4 where a "reading harvesting pattern" is depicted shows that, if a recourse is "open access" the equilibrium is undefined since the total costs curve (effort axis) is parallel to the total revenues curve TR, for larger levels of x1 effort levels. This indicates, that the exercised effort level could be any level higher than x1. In the real world, the above outcome reveals a peculiar competition among harvesters to capture, and therefore, to appropriate the maximum possible harvest level H1. Actually, the harvesters compete for "who captures" first the larger possible proportion of H1, and towards this target each of them would devote an effort level. The total effort level of all harvesters would be higher than x1;, the exact magnitude would be determined by the particular condition of the harvesting and of the recourse characteristics. However, we should not expect that the effort level would tend to infinity since the harvesters would realize that by doing so they would not profit. Simply, the total effort level would be determined as each harvester tries to get the larger proportion of the maximum possible harvest H1 before the other harvesters. Once they realize that there no profit in increasing their effort they would stop it.

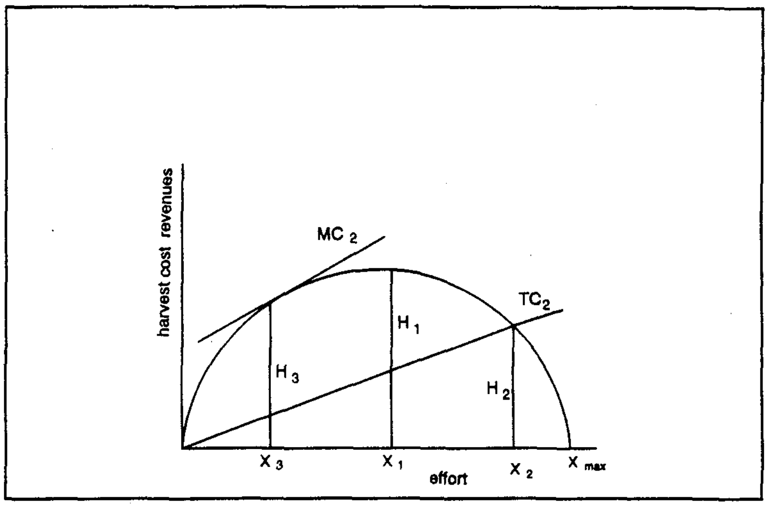

Figure 3 Equilibria under private and open access ownership for a "normal harvesting process"

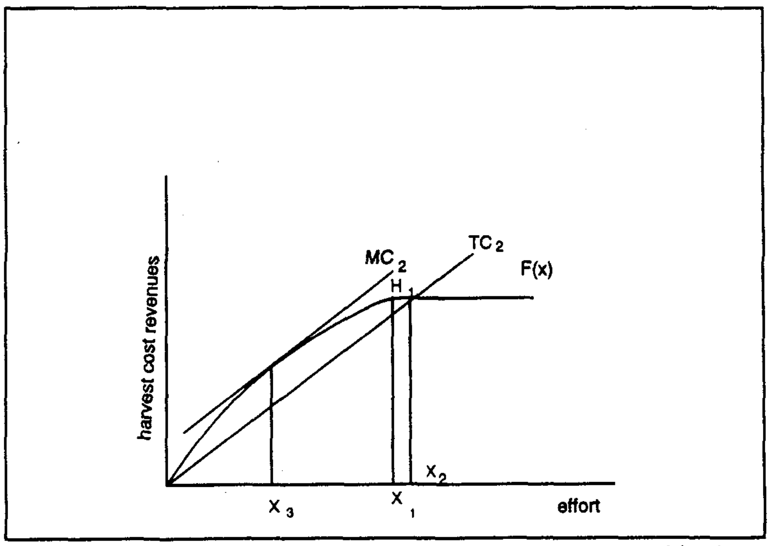

Figure 4 Equilibria under private and open access ownership for a "reading harvesting process"

3.4.2 Exhaustible and non-exhaustible renewable resources

Usually in the field of environmental economics we follow the classification of natural resources as renewable and non-renewable (Pearce and Turner 1991).
The first category, renewable resources, denotes those resources which might self-regenerate over time. As a result, their stock will reach the carrying capacity of the relevant ecosystem for these resources, provided they do not receive any external disturbance.
The second category, non-renewable resources, contains all those resources whose stock is fixed by nature. So they will maintain their stock, provided disturbances are imposed. However, once that stock has been reduced it will remain in the new reduced level.
Resources such as birds, water, forests, productive capacity f land, sun etc. belong to the first category. The second category consists of resources such as fossils, fuel, minerals etc. Obviously, the above classification denotes a natural property of the resources and nothing more; some resources can regenerate and so their stock changes while the stock of others remains intact if they are left alone. The above characteristics of natural resources are not influenced by human activities. In other words, a recourse is renewable or nonrenewable regardless of the human activities on it.

When the utilization of resources is introduced into analysis, then a new concept should be entered also. That is the concept of the "exhaustible" and "non-exhaustible" resources (Nijkamp 1979, Dasgupta and Heal 1979). The new classification reveals a characteristic of natural resources that is related only to mankind's use of them; Exhaustible resources are those which may be exhausted by constant usage and includes both categories of natural resources, renewable and non-renewable. Exhaustion of a natural recourse means that the resource could be extinct under certain some kinds of usage.
Let us examine first the non-renewable resources. They are exhaustible resources under any pattern of extraction. For they would be gradually led into extinction since any extraction pattern substacts from the fixed initial stock. As a result, all non-renewable resources belong to the class of exhaustible resources.
On the other hand, the renewable resources pertain to both, exhaustible and non-exhaustible categories. It depends on the pattern of their use.
Exhaustible renewable resources are the renewable resources that are exhausted under extensive usage. That particular pattern of use is any pattern in which the extraction rate is constantly above the recourse self-regeneration rate.
The non-exhaustible renewable resources refers to those whose natural characteristics impose certain limits on their extraction pattern, so that the extraction rate cannot constantly overcome their self-regeneration rate. As a result, these peculiar natural

characteristics of the non-exhaustible resources ensure their continuance since they cannot be led into extinction. The productive capacity of the land and the wind, pertain to the non-exhaustible renewable resources category. The wind cannot be exhausted by human use since its self-regeneration capacity is not influenced by this use. As far as the productive capacity of the land is concerned there is a lower boundary below which that capacity cannot be reduced, although certain production methods may decrease it.

Van den Bergh refers to the non-exhaustible renewable resources as "unconditionally renewable resources" while he mentions the exhaustible renewable resources as "conditionally renewable resources" implying that if used in a certain way they may be led into extinction (Van den Bergh 1991).

Usually in the field of environmental and natural recourse economics there is a confusion between the terms "non-renewable" and "exhaustible" resources. The term "exhaustible" is used instead of the term "non-renewable" resources and that is correct as long as the "non-renewable" resources are used by man since any non-renewable resource is exhaustible when it is used. However, this confusion obscures the fact that there are also renewable resources which are exhaustible (Van den Bergh 1991 28p.). That obscurity has significant implications on economic analysis; one implication we will examine below when the conclusions of Prof. Gordon will be reconsidered.

3.4.3 Economics of non-exhaustible and exhaustible resources exploitation. The sustainability issue

NON-EXHAUSTIBLE RESOURCES

The natural characteristics of the resource and the technical properties of the effort determine the pattern of harvesting (the harvest level, its growth rate and its maximum) of the recourse exploitation. However, the natural characteristics of the recourse impose certain limits which ensure its existence through its self-regeneration capacity. Note that for a non-exhaustible recourse the self-regeneration capacity is not drastically influenced by the harvesting pattern. Since the recourse is not exhaustible it maintains its self-regeneration capacity and therefore its productive properties.

In other words, the natural characteristics of the resource lead towards a sustainable (or a quasi sustainable) harvesting pattern which can be realized at any future time.

Literally, a sustainable harvesting pattern is that pattern which can be repeated at any future time. That is to say the initial productive properties of the recourse remain intact when the harvesting process has been accomplished. However, even in the case of a non-exhaustible recourse, a specific effort may diminish the initial productive properties of the recourse up to a certain extent so that the initial harvesting process can not repeated in the future since the initial productive capacity has been reduced. This reduction of the recourse productive capacity is limited by the inexhaustible nature of the recourse. When this limit has been reached the recourse maintains for ever its remaining productive capacity, as long as the same effort is applied. Once this limit has been reached, the next harvesting process can be characterized as sustainable.

As a result, it is possible for an effort type to cause a non-sustainable harvesting process when exercised on a non-exhaustible recourse. However, the non-sustainable process(es) would emerge initially for certain levels of the exercised effort. Sooner or later, a sustainable process would be reached since the productive capacity of the recourse cannot be eliminated for ever because the recourse is non-exhaustible.

Let us consider, for example, the harvesting effort leading to the F1(x) harvest curve of Figure 5. Our assumption is that this effort is costless. As we have concluded in the preceding sections the equilibria harvest level would be at H1max level where the parallel to the total cost curve is adjacent to the total revenues curve if the recourse is private. In this case H1max coincides with the maximum sustainable yield of the recourse for this specific effort.

If the effort has a cost and the ownership is still private, then the equilibria harvest level would be less than H1max. Obviously the new equilibria level is sustainable too.

We assume now that another type of effort is exercised and the new harvesting function is F2(x) of Figure 5. Of course, F2(x) presents a harvesting pattern different from F1(x) (therefore, different harvest growth rate and maximum harvest). F2(x) delineates a new sustainable pattern of the recourse use. For it is the nature of the recourse (non-exhaustible) which always determines a sustainability of the use, no matter what the technical characteristics of the effort. Note that we ignore the marginal case where an effort invokes initially an unsustainable process. Generally, the harvest function F(x) presents only sustainable harvest levels when it refers to an exhaustible recourse.

EXHAUSTIBLE RESOURCES

In the case of the harvesting of an exhaustible resource the natural characteristics of it do not impose any particular limits on the harvest level, on the rate of harvest variation when the effort increases and on the maximum yield except from the marginal limit imposed by the resource extinction. The specific pattern of harvest function f(x) depends on both resource characteristics and on the technical properties of the effort. The important difference compared with a non-exhaustible recourse harvesting, is that the harvest levels depicted on a harvesting function may be unsustainable levels. In other words, the harvesting process represented by each point on the harvesting function, for example of f1(x), may be a non-sustainable process; then the respective harvest is not sustainable since the same process cannot be repeated when it is accomplished. Specifically, the next process will be one that offers a lower level of harvest, all other conditions remaining constant (effort's cost, harvest's price etc.).

Indeed, since nature does not impose any particular limit on the harvest level a highly effective effort may capture an unsustainable high harvest even when a low level of this effort is exercised.

Note that in the case of an non-exhaustible resource nature imposes an absolute limit on the level of harvest. This limit is the self-generation capacity of the resource. In fact, only occasionally and for a limited number of harvesting processes the harvest may be larger than the rate of self-generation capacity hence, the resource is non-exhaustible.

Generally, we may conclude that whether or not the harvest level of an exhaustible natural resource is sustainable depends on both the technical effectiveness and the exercised quantity of the effort (see also chapter 5). In our example in figure 5, whether H1max harvest is or is not a sustainable level of exploitation depends on the effectiveness of each particular type of effort. If, for example, we assume that for a certain effort H1max is not a sustainable harvest, the maximum harvest level of a different effort with lower effectiveness could be sustainable; thus, for example, H2max could be a sustainable level. The same may be true also for other than Hmax harvest levels of the f1(x) curve.

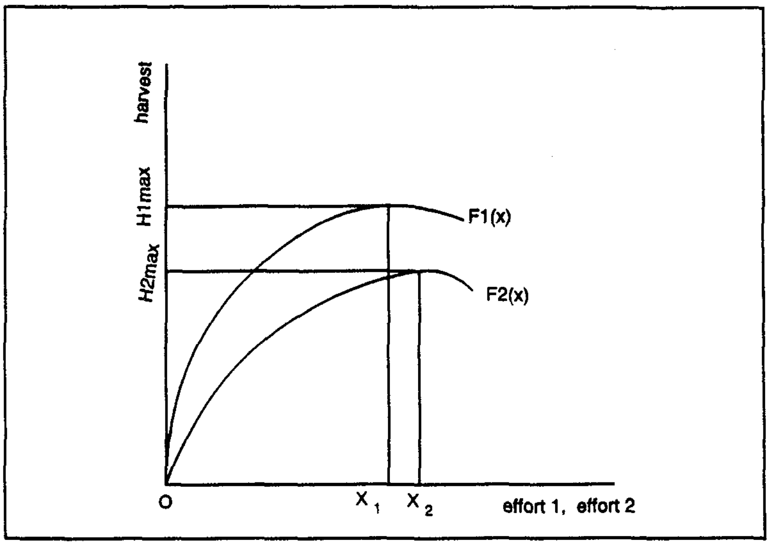

Figure 5 Harvesting functions for two different efforts

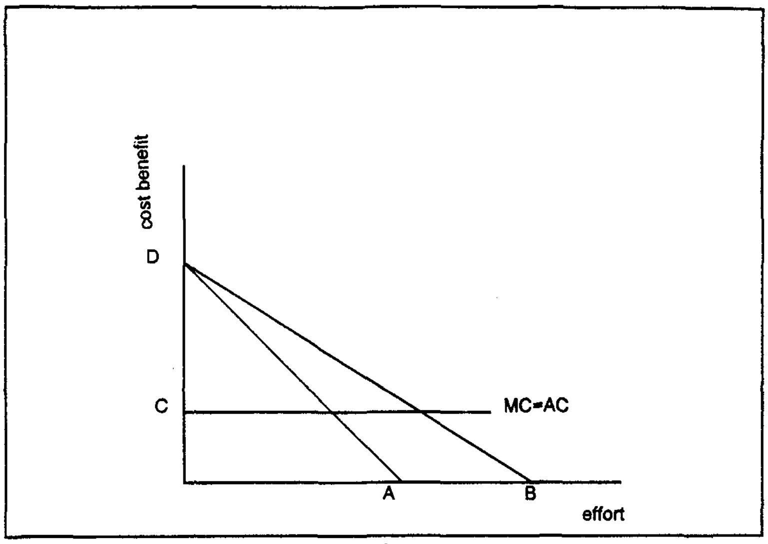

Figure 6 Determining the level of use for a private and open access natural element

3.4.4 Gordon in retrospect

Prof. Gordon examines the use pattern of a common property natural resource and compare that pattern with that under private ownership (Gordon 1954). He uses the curves presented in Figure 6: MP curve depicts the marginal productivity of the recourse use and AP the average productivity. Gordon examines how the effort level is determined under common and private ownerships. We will try to delineate the main points of Gordon's analysis.

He assumes, for simplicity, that the harvesting effort has a constant cost per unit so that the marginal cost (MC) and the average cost (AC) of effort coincide; they are straight lines parallel to the effort axis (see figure 6).

He indicates that the effort level is determined, when the recourse is under private ownership by the intersection of MP curve with MC curve. That is the socially optimum level of effort.

On the other hand, when the recourse is a common property the exercised effort level is determined by the intersection of AP curve with MC curve. What matters each one harvester now is for how much effort he continues to add to his income. Therefore, he will continue adding effort as far as by doing so he will increase his income.

Let us examine now a specific case of a renewable resource exploitation which has led Gordon to draw a not well-established conclusion which in turn has led to faulty Policy directions.

It is the case of a costless effort. In that case the marginal cost curve (MC) coincides with the harvesting effort axis. Gordon mentions that the exercised effort level, when private ownership is assumed, is OA and it corresponds to the maximum sustainable harvest.
The question arising now is this: why have there been negative impacts on natural resources and a great number of them have been led into extinction while the maximum harvesting effort (OA), which could be exercised even at an open access recourse, utilizes the resource of its maximum sustainable harvest?
Indeed, in any case the common ownership implies a larger utilization of the recourse compared with the private ownership. According to Gordon's position the only negative effect of common ownership is that it diffuses the rent otherwise appropriated by the owner of the recourse. So, the users of the recourse cannot become rich (Gordon 1954).
However this does not concern the natural conditions of the recourse which is the main issue of our analysis. As far as the natural condition of the recourse is concerned, in Gordon's analysis the recourse in the worse case of a costless effort would be utilized at its maximum sustainable yield. In any other case that the effort bears a cost the resource would be used at lower levels than its maximum sustainable capacity. Therefore according to Gordon, we may securely assert that under common ownership and for a costless effort the utilization of the relevant resource is the more profitable for the society since under these conditions the actual harvest is the maximum sustainable harvest.

This conclusion contradict reality and has its origins in the confusion between exhaustible renewable and non-exhaustible renewable resources.
Gordon had in mind a non-exhaustible renewable recourse when he drew his conclusion. For such a recourse the exercised effort level, when the effort is costless, is what renders the maximum sustainable yield; hence Gordon's conclusion is then correct. For example, if the exercised effort level is X_1 of figure 5, when the effort 1 holds, then the harvest is H1max which is the maximum sustainable yield under these particular exploitation conditions. A qualitatively different effort (the effort 2 of figure 5), if it is costless, is exercised at a level that attributes the maximum harvest under the new technical conditions (H2max).
Evidently, any effort which bears a cost implies utilization of the recourse at levels less than the maximum sustainable yield. That particular level will be determined at that point of the harvest curve where the parallel to the total cost curve is adjacent with the harvest curve. That level will be another sustainable harvest level since any point of the harvest curve presents a sustainable harvesting process.

The analysis is completely different in the case of an exhaustible resource. As we have seen in the preceding section the harvesting of an exhaustible resource is not always at a sustainable level. It depends on the characteristics of the harvesting effort; so it is possible for a harvesting effort to harvest the recourse well-above its regeneration capacity even at the lowest level of the effort. So, the recourse is not necessarily harvested by a sustainable pattern and therefore it might be gradually led into extinction or at least to a decrease of the initial stock. Of course, there are some kinds of effort permitting a sustainable use of an exhaustible recourse.

Generally, the harvesting function of an exhaustible recourse may present either a sustainable or an unsustainable pattern of the recourse use. Evidently, in that case the harvest level determined by a costless effort could be either sustainable or unsustainable; the same holds for any other harvest level determined by a cost bearing effort.

So, Gordon's conclusion is not generally valid in cases of exhaustible renewable resources. The effort level OA of figure 6 may correspond to an unsustainable pattern of the recourse use. The same may occur for any other effort level. What would happen actually depends on the particular properties of the harvesting effort.

The last conclusion explains the reality of the use of renewable resources. They may disappear or be reduced since they are harvested above their regeneration capacity. That is much more plausible as the harvesting effort increases, all other conditions remaining constant, or when the exercised effort increases in the case of a common property recourse compared with a private recourse. That is why so much attention has been paid in analyzing the common property effect on the well-being of natural resources.

Note that the above analysis holds for both the normal production and the "reading production" patterns.

Note also that non-exhaustible resources could have either the normal production pattern or the "reading pattern". In the case of a non-exhaustible renewable resource whose production pattern pertains to the "reading pattern" that pattern depicts only the law of diminishing returns since there is no stock depletion of a non-exhaustible resource. The harvester continues to exercise increased quantities of effort on the same, almost irreducible, stock.

3.4.5 Biological sustainability and economics of natural resources exploitation

In this section the implications of the economic analysis on biological sustainability of natural resources are examined. In fact, the main question penetrating this section is whether the "tragedy of commons" could be transformed to a sustainable "heaven of privates" by altering the ownership of the resources form common to private.

Non-exhaustible resources: Their sustainability is maintained due to their natural characteristics. Therefore, the ownership regime is non-differential to maintaining their "biological crucial level". To put it differently, since the natural characteristics of non-exhaustible resources confine their economic use within their biological limits they maintain their biological sustainability under any kind of usage.

Exhaustible resources: The exercised effort level is lower under private ownership than under the open access regime. The direct result of such a condition is that when the recourse is a private property, it is more plausible for the recourse to be harvested in a sustainable manner. In other words, exercising smaller quantities of effort it is more possible to use the resource below its "crucial biological level". And so the probability for the resource to maintain its "biological sustainability" is increased. However, the fact is that it is simply "more possible" and not "ensured".

For example, let us assume that the "biological crucial level" of a recourse corresponds to H_3 harvest level of Figure 3 which, in turn, corresponds to X_3 effort level.
The private ownership of the recourse may determine any effort level up to X_1 and thus it may determine effort levels above X_3. The exact effort level depends on the exact cost of the effort. As a result, for a certain range of cost of effort's private ownership defines effort levels which utilize the recourse in an unsustainable manner.
The only effect of privatization is that it decreases the possibilities for determining an effort level leading to unsustainable use of the recourse. In effect, privatization decreases the probability for the violation of the "biological crucial level" of the resource on hand. Hence, privatization increases the possibilities for preserving the "biological sustainability" of the resource.

3.5 Market equilibrium under private and common ownership

3.5.1 Introducing the demand

We proceed our analysis introducing the factor of demand in our analytical framework. The previous analysis considers demand for the harvest as given and examines the effects of harvesting a recourse. Specifically, we assumed that the whole harvest could be sold at the market or that it is desirable for self-consumption by the harvester.
Now we introduce the demand factor in order to examine the combined effect of demand and supply when a recourse is common and when it is private property.

There are two classes of natural resources: those which are almost given by nature and cannot be augmented by human actions and those that can be augmented by human activities.

The first class includes all those resources presenting an upper limit, given by nature, compared with their demand for human uses. The upper limit cannot be exceeded by human activities. Therefore, all the demand cannot be satisfied.
The reasons of the first class may be further classified in two groups.
The first group contains those resources whose "biological sustainability" cannot be violated when they are utilized. Usually they are non-exhaustible resources which present a "biological crucial level" that is always sustained by the self-regeneration capacity of the resources. If these resources are common property then the relevant supply curve is OS of figure 2, where OS is the upper quantity given by nature. On the other hand, if these resources are common their owners will not perceive any threat to the resources and so, they will take no action for the resources' protection. As a result, the supply curve under privatization will be OSS_2 curve. Note that the only difference between the common ownership and private is that the supply curve takes the vertical direction at the upper level of the resource. The explanation is very simple. In the case of private ownership the owner of a resource asks a price for offering the upper quantity of the resource. This price depends on the expressed demand for that quantity. Specifically, the higher the expressed demand the higher the price is; in the marginal case of an excess demand this price tend to infinity. Note that the upper quantity of the resource cannot be increased. Therefore, the price mechanism allocates the upper quantity of the resource among its potential users.
The second group of the first class contains those resources which face the danger of violation of their "biological sustainability" when they are utilized, so this group contains all exhaustible resources; however, there are some non-exhaustible resources which belong to

this group, specifically, they are those non-exhaustible resources whose "biological crucial level" lies above the non-exhaustible level that can be maintained by the self-regeneration capacity.

The owner of a resource of the second group perceives a potential threat for the resource. Therefore, he develops a policy for the recourse protection. Such a policy brings a cost, even in the form of forgone revenues of the owner as he eliminates the supplied quantity in order to protect his recourse.

That protection cost alters the supply conditions and moves the supply curve to OS_1S_2 curve while the supply curve for the some resource in the case of common ownership's curve.

The second class of resources is the one which does not present an upper limit in quantity compared to human demand since they can be augmented by human action, at least to a certain extent. The supply curve has the form of OSS_4 and OS_1S_3 when the resource is private and common respectively. -We may regard that OS is the quantity given by nature, while SS_4 is the outcome of human activities-. Actually, as any natural resource, the quantity of the second class resources is also given by nature however, certain of their productive capacities can be augmented by human actions regardless of the impact of these actions on the other characteristics of the resources.

Nevertheless, even for the above kind of resources there is an upper qualitative and quantitative limit. What distinguishes then, the second class resources from the first one is that in the second class the absolute natural limits are well above the human demand levels. That does not mean the relevant "biological crucial level" is above the demand level and therefore, BCL is not influenced by human use.

Evidently, since the privatization of these resources results in a cost of the resources' maintenance and the cost of their productive characteristics' augmentation, the supply curve under private ownership would be OS_1S_3 while under common ownership would lie on the quantity axis (OSS_4). Notice that in the case of a changeable recourse the quantity axis may depict a particular productive characteristic of the recourse. As the utilization of this characteristic increases it is likely that the natural condition of the recourse deteriorates and specifically at a certain level of its exploitation the "biological crucial level" is transgressed.

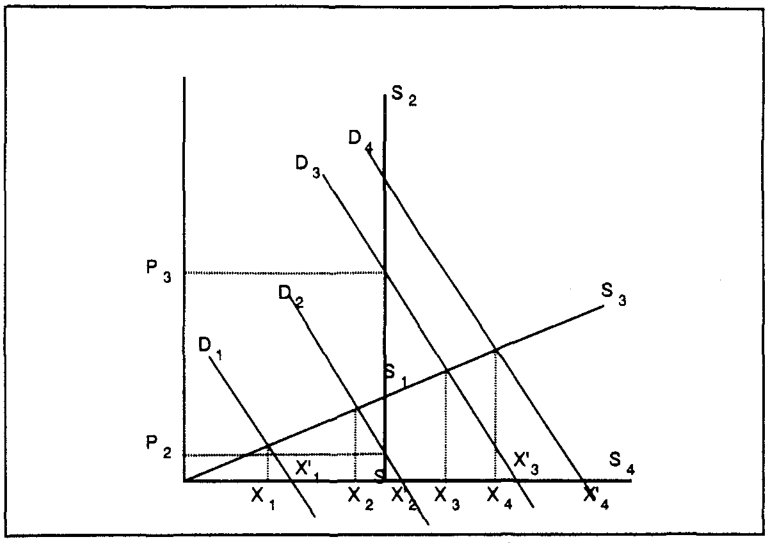

Figure 7 Market equilibrium for private and common resource

3.5.2 The demand factor and the market equilibrium

We introduce now the demand factor in order to examine the effect of the two ownership regimes for both of the above mentioned classes of resources on the market equilibrium of the resources use.

1a. Let us examine the first group of the first class of resources. It includes those resources which do not face threats for their "biological sustainability". Note also that all the resources of the first class present an upper limit which cannot be released by human activities. The supply curve is almost the same under common and private ownership, it is OS and OSS_2 curves respectively. The upper quantity given by nature is OS of figure 7.
We consider three demand levels $D_1<D_2<D_3$ (see figure 7). When the demand curve increases the supply curve at levels lower than the upper quantity OS,(for example the demand D_1 at the X'_1 level), the market equilibrium is the same under both ownership regimes.
The same happens also when the desired demand exceeds the upper level OS, for example D_2 and D_3 demand levels. Then the market equilibrium is at the level OS, for both ownership regimes. However, privatization has a significant effect in the last case. If the recourse is common the demand levels D_2 and D_3 would require X'_2 and X'_3 of the recourse's quantity respectively. Both levels are not feasible since they are above the OS level. There is the problem of confining the recourse's use on the feasible natural boundaries. In other words, a mechanism is required in order to distribute the resource's total quantity among its users. For a common resource such a distribution mechanism does

not exist. So, we may suspect the development of violent behavior among the potential users or the existence of an administrative mechanism of distribution.
On the contrary, when the recourse is private the supply curve is OSS_2 and the equilibrium use of the recourse would be at the quantity OS. Now, there is a market induced mechanism of peaceful distribution of the recourse quantity among its potential users.
This mechanism is implemented by the existence of a rent appropriated by the owner. Thus when the demand is D_2 the rent is P_2 while when the demand is D_3 the rent is P_3. This rent is offered by the most profitable activities in a competitive market and so the efficient distribution of the recourse use as a production factor or as a consumption good is ensured. Note that as the level of demand increases the rent also increases and it ensures the allocation of the resource to the most profitable uses that exist at each demand level.
The last conclusion adheres to the historical observation of the recourse' use. When the resources were open access, elements and their maximum natural supply was less than the desired quantities by the relevant populations, the distribution mechanism took a violent form of clashes or wars among nations, clans etc.
Frequently, that led to great movements of the relevant populations settlements (Georgescou-Roegen 1979). Through time, the organization of the societies and the cultural characteristics did not permit violence among the members of the societies. The institution of private property replaced the violent distribution mechanism, at least in the civilized societies of the west.

1b. The second group of the first class includes all resources which may face threats to their "biological sustainability" when they are utilized. The supply curve is OSS_2 and OS_1S when the resource is common and private respectively (the reasoning is given above).
Let us examine the demand curve D_1. We see that the equilibrium level, determined when D_1 is assumed, is smaller under private ownership (X_1) as opposed to that under common ownership (X'_1). However, when D_3 is the demand level the outcome is the same under both regimes; specifically, the equilibrium use of the resource is at its maximum OS level.
Generally, for a certain range of demand the use of a resource under private ownership is lower; on the other hand, there are demand levels determining the same outcome under private and common ownership.

2. Let us examine now a "changeable resource".
The supply curve under common or open access regimes lies on the quantity axis (OSS_4) while under private property the demand takes the form of OS_11S_3.
Under these conditions and as figure 7 depicts, the market equilibrium level of the recourse

use is always higher when the recourse is common than when the recourse is private. For example, when the demand is D_1 the equilibrium use of the recourse is X_1 under private ownership, smaller than X'_1 which is the respective level when the recourse is common. Similar results arise for D_2, D_3 and D_4 demand levels.

3.6 The market equilibrium level of a resource use and its "biological crucial level"

3.6.1 Introductory remarks

The conclusion of the preceding section is that the market equilibrium level of the use of a recourse is lower when the resource is private than the respective use when it is a common or open access.

The above general conclusion has a very interesting policy implication. Since the recourse use is lower for a private recourse it is more possible for a private recourse to preserve its "biological sustainability", that is to be used at a level lower than its "biological crucial level". For example, if we assume that a recourse has the OS_1S_3 supply curve in figure 7 and its "biological crucial level" corresponds at the OS level of its use and the demand curve is D_2, then the equilibrium level of use is (X_2), which is lower than the relevant "biological crucial level" ("BCL"). In this example we see that privatization ensures the preservation of "BCL". However, in the same example there are some changes in the market conditions which lead to violation of the "BCL".Just as an example consider a change of the demand level towards D_3, when even private ownership does not ensure the preservation of "BCL" (see figure 7).

As a result, despite the above general conclusion the exact outcome of the market and hence the preservation of the "BCL", depends on the relative location of the supply and demand curves in each particular case. In the following sections we examine the factors which determine the position of the two curves.

3.6.2 The factors that determine the demand

As we have already seen, a movement of the demand curve may lead to a market equilibrium level of utilization which is higher than the "BCL" of a recourse even in the case of a private resource.

Which are the factors determining the position of the demand curve?

The demand level is determined by the expressed willingness of the users to utilize the recourse. It is therefore determined by the preferences' spectrum of the users. The preferences are influenced by the necessity the users feel for the recourse, their income levels and the preferences-inducing system (advertisement). Any alteration of these factors alters the demand level for a particular good.
So, the particular factors determining the demand level of a natural recourse are independent from the factors determining the resource's biological condition. As a result, they may lead to a demand level in excess of the "BCL" (with a given supply of the resource). In effect, we cannot generally expect the demand level to be such as to ensure the "BCL" of the relevant recourse.

3.6.3 The factors determining the supply

We will emphasize the factors determine the supply because they are influenced by the ownership regime which is the subject of this chapter. Specifically, in the present section we will examine the factors which would determine a supply level that could violate the relevant "BCL".
In the analysis following we will always assume that the recourse is a private property. The factors examined in this section have been mentioned partly in the previous chapter when we studied the issue of negotiation among polluters and sufferers. Hence, this section will examine only that particular characteristic these factors take when a natural recourse is a private property.

"TIME SPAN EFFECT"
The supply curve depicts partly the concern of the owner for the maintenance of the recourse since it generates a profit for him. Let us assume that by protecting the productive characteristics of a resource he probably protects at the same time the whole system of its biological characteristics, or in other words, he act towards its biological sustainability.
The self-interested rational owner would protect the recourse so that he would obtain profits for all of his time span. The direct result of the above practice is that the biological condition of the resource does not deteriorate significantly as long as the decisions concerning its utilization have instantaneous and simultaneous impacts on its productive

characteristics. The owner would protect the resource against such deterioration arising during the period he possesses it.
However, there is in the real world another kind of decisions concerning the use of a recourse: those which affect the biological condition of the recourse after the life time of the present owner who is a mortal being (Nijkamp and Rowvendal 1988). Evidently, the profits caused from such a relevant use arise during the life time of the owner since the relevant use takes place within this time span. Therefore, the owner appropriates the relevant benefits while he avoids the effects of the resource deterioration.

Thus, there is no economic reason restraining the owner from not permitting such a utilization pattern since it brings profits without creating any specific cost of decay during the life time of the owner. -Note that we examine exclusively the changes in economic behavior when the ownership of a resource alters from common to private since any culturally induced behavior remains the same under both ownerships-.

On the other hand, the decision to use the resource without concern for it beyond ones life time may lead towards the violation of the biological sustainability of the recourse. Because it may cause the transgression of the recourse's "BCL". Specifically, this transgression comes to light at a time beyond the life time of the present owner.
This transgression is more possible when one contemplates two technical characteristics of natural deterioration. These are the cumulative nature of some deterioration process and the combined effects of some pollutants (Nargaad 1991).

As a result, we may conclude that the interest to protect, depicted on the supply curve of a resource owner, may be insufficient to ensure the "biological crucial level" of the recourse at all times. For the recourse is quasi-immortal by nature, while the economic units (owners) who use it face a limited time span and so their economic profits may be exchanged for the resource's deterioration; provided that this deterioration occurs beyond the time span of the owner.

"SPACE SPAN EFFECT"

This effect is a practical inability of private ownership to protect the "biological sustainability" rather than a theoretically proved inconvenience or inconsistency, therefore we will briefly mention it.
In the real world, the owner of a recourse may cause negative environmental impacts to a part of the same recourse or to another environmental element which sites on another place

and does not belong to him.

Actually, since the natural environment and the resources are not restricted within the institutional boundaries of the relevant markets they usually extend beyond one market and so they belong to more than one owner. It is then possible owner of a part of a recourse to undertake decisions which affect negatively another part of the recourse that is not possessed by him. He receives revenues for acting in this way, while his own part of the resource maintains its good-biological conditions. In economic terms that means that the supply curve of the owner perceives only that concern for the recourse ensuring biological sustainability on his own part of the recourse while it permits decisions affecting negatively the part of resource which does not belong to him.

As a result, the location of the supply curve does not ensure an overall biological sustainability for all parts of the relevant resource.

Theoretically this problem is removed if we assume an owner possessing all parts of a recourse or of the relevant environmental element.

"THE SUBJECTIVITY ISSUE"

In the pure competitive market the supply curve of a good (resource) presents, at each point, the marginal real cost of the production-maintenance of an additional quantity of the good-recourse. Usually, such a cost is estimated on the basis on some real factors that create this cost.

However, it seems that there are several subjective factors involved in the cost of a natural recourse's maintenance. This cost directly refers to what should be maintained. "What should be maintained" receives also some subjective interpretations in this case.

First, we mention the subjective respect for the resource; it is related to "how important" is the relevant recourse for its owner. Translated in pure economic terms (although they are not exclusively economic factors which determine this respect) it refers to the "income" or "wealth" effect. That is to say the importance of the resource is influenced by the income level of the owner. Hence the location of the supply curve is influenced by the "income" or the "wealth" level of the relevant owner.

The direction this effect takes is not uniquely determined. However, we may be able to delineate it.

The poor owners who possesses the relevant recourse, and maybe only it, may be tempted to offer it at lower prices in order to obtain the necessary income for his survival. The practice may lead towards underestimating the real environmental cost caused by the recourse's use; hence the "biological crucial level" might be more easily violated. This conclusion becomes stronger when contemplating a recourse for which the offered price is attractive for a poor owner. In fact, it is the discounting of the uncertain future income expected from the future use of the resource. Any future event bears a degree of uncertainty, compared to the present poverty which may induce the owner to offer the resource by such a pattern that probably violates the "BCL".

Second, we examine the cultural characteristics of the society to which the owner belongs. Particularly, we refer to those cultural elements that influence the human attitude towards the natural environment.
They co-determine the respect the owner feels for his natural environment. Cultural determinant apply more to those natural elements which are not offered directly in the market for income, but rather they are used as self-consumption by the owner.
The relevant resources are usually used according to subjective "respect" of the owner. That respect is influenced strongly by the cultural matrix of the relevant society.

Concluding, we may say that there are several factors influencing the subjective concern the owner devotes to his natural resources. These factors might be at such a level which might lead towards violating the biological sustainability of the relevant resources.

3.6.4 "The interest for the future generations"

The above examined "time span effect", which is the strongest and more plausible than the other effects, comes under question when we assume a concern developed by individuals of each generation for individuals of future generations. This sections examines whether such a concern is able to eliminate the "time span effect".

The exact form of this affinity may be described as a situation in which each individual perceives the (economic) effect his (economic) decisions have on his direct descendants who will posses his own property, hence also his natural resources, after his death.
In the field of environmental economics and specifically in the present part of the study which examines the effects of altering the ownership regime of the natural resources from common to private, the above assumption takes the following form. An individual possessing a natural resource adjusts his own decisions concerning the resource so that these decisions would not affect the economic profits his direct descendants would obtain from the

resource's use. So, each individual safeguards the economic profit of his direct offspring. Note that we emphasize the term "economic profits". Otherwise, if we had assumed that each economic unit protects the relevant resources it possesses in order to bequeath them to its descendants in a good biological condition regardless the economic profits the resources would bring, we simply would have introduced in the analysis an additional non-economic criterion. This criterion certainly confines the relevant economic criteria. In other words, this criterion describes the willingness of the owner to maintain the resource in a good biological condition, to ensure its biological sustainability, and to deliver it in a good condition to his own descendants. In a nutshell, the owner would not undertake such decisions which affect the biological sustainability of the resource at his own time and at the time span of his direct descendants.

Indeed once such a criterion exists, the economic criteria have been suitably confined by it. Specifically, the owner does not permit those uses which affect the biological sustainability of the resource regardless of the magnitude of the economic benefits these uses may offer and the owner permits only uses of the resource which do not affect its sustainability.

However, such a non-economic criterion could equally arise under common and private ownership since it depicts a cultural element of society; obviously such a cultural element does not alter by changing the ownership regime of a resource. This criterion belongs to the cultural matrix of the relevant society.

Note that the difference between common and private ownership lies on the very fact that the economic criteria take different values in each case and so they lead to different decisions which implies a higher level of protection under private ownership. But once the economic differences have been excluded the cultural effects are the same under both ownership regimes.

In broad terms, let us assume that the economic profits of an individual is at H1 when the resource belongs to him and H2 when it is common. Economic theory says, in general, that since H1 is larger than H2 the resource would be protected better as a private element.

If we introduce now cultural elements in the decision-making process, we can conclude that they influence the biological sustainability of the resource for reasons other than economic. The relevant decision, now, is based on a combination of economic and cultural criteria; in particular, it is based on the vector (H, E), where H the economic component and E the cultural one.

Whatever the cultural criteria of a society they are constant under any ownership regime. So, the cultural component of the decision vector remains the same under private and common property for the same society.

Thus, under private ownership the decision vector is (H1, E), while under common property it is (H2, E). As a result, the two vectors differ only at the economic component while the

cultural one remains the same for the same society. Concluding, we may say that advocating privatization of the common resources as a policy for their protection we assume that privatization brings about an economic rationale which leads to higher protection than that of common ownership.
On the other hand, privatization does not alter the cultural concern for future generations. Thus, any theory that refers to the cultural effect of privatization alone is an empty theory, because privatization influences only the purely economic criteria and the purely economic interest for future generations.

We will step back to the clear assumption that each economic unit would protect its own resources for its own benefits and for the economic benefits that these resources would offer to its direct descendants.
Rationally, an economic unit may regard the economic profits of its descendants for a certain range of future time. However, we have never met, in economic theory and practice, economic entities which consider the economic effects of their decisions after a hundred years. They usually consider a future time of 40-50 years at the most. The projection time of each individual is limited; besides his own life time span he may consider the time of his direct descendants also, but nothing more (Boulding 1980). We could hardly assume that individuals investigate the negative biological effect on their own natural resources which brink profits to them now when that effect starts becoming perceivable 60 years after their decisions. Decisions which have long term effect are undertaken by individuals. These decisions might lead to a violation of the "biological crucial level" of private resources after a number of years (Passet, 1979). As a result, the economic affection individuals feel for their own direct descendants may temper the "time span effect" by augmenting the time span in which individuals consider the negative effects of their decisions. However, these effects are still present in the long run.

Note: Static analysis.
The above analysis is an oversimplification of the reality concerning the characteristics of natural resources. However, such simplification is necessary in order to understand better the economics of natural resources exploitation. On the other hand, we need some additional assumptions in order to simulate reality.
The most useful assumption is the following. The analysis given above and depicted on Figure 7 presents a static process which, in order to enter into dynamic reality, it should be assumed that this process is repeated at each time period. We should also accept that the

analysis presents the cumulative effect of a sufficiently great period of the resource's use. That period should be sufficient to include all the possible effects of the process.
Thus, when we examine the effects of a renewable-exhaustible resource use, we assume that the same process is repeated at each time period. For example, when the analysis concludes that the resource is exploited above its "biological crucial level" or above its generation capacity, we assume that either it is repeated at each period or it is the outcome of a long period of use which brings the relevant effects on the resource. Similarly, for a non-renewable resource the analysis gives the outcome of a sufficiently long period of the resource use.

3.7 Concluding remarks

The first part of this chapter that examines the standard economics of a resource exploitation makes no distinction between a resource extinction and the violation of the "biological crucial level" of this resource. In fact, the assumption made is that as far as the resource remains into being its "biological crucial level" is ensured. However, this assumption is not always valid. For there are cases where, although a resource has not been led into extinction, it has eliminated so many of its characteristics so that its "biological crucial level" has been violated. Generally, the "biological crucial level" of a resource is violated, unless a given crucial stock of the resource exists. Yet, that crucial level of stock might be well above than the level of extinction.
This conclusion does not alter considerably the results of the analysis. Simply it indicates that it is even more difficult to ensure the biological crucial level of a resource than it is the simple maintenance of the resource. As the analysis proves, neither the maintenance of the resource is not always ensured, even under private ownership, nor its "biological crucial level".
The advantage of privatization is that the exercised effort level on a resource is always smaller than the exercised level on an open access resource. Thus, under privatization the resource is harvested at a lower effort and therefore it is more possible to be harvested in such a level that ensures its "biological crucial level" and hence also its existence.

In the second part of the chapter, some interesting conclusions can be drawn. They concern the essential question of how possible is the maintenance of the biological sustainability of a resource under private ownership.
The private ownership increases the possibility of maintaining the biological sustainability

and of maintaining the resource into being, since the economic rationale of a profit maximizer defines a moderate intensity of harvesting compared with the open access ownership.

Besides this rationale there may exist some other reasons which lead to a better protection of the resource under private ownership. They are economic reasons. Specifically, they are related to some expectations for future profits arising from the future uses of the resource. In other words, the owner may protect the resource because of the expected future profits it will bring to him -unless this protection costs are perceived as real cost, the rationale of this protection cannot be included in the profit maximization procedure presented in Figures 1, 2, 3, and 4-.

On the other hand, the limited life time and the limited space span of the resource owner as well as his subjective perception of the resource's protection do not allow a generally ensured maintenance of the resource's biological sustainability or even of its simple existence. The rationale of protection is in fact economic, therefore, the economic unit protects the resource as far as it appropriates a profit by doing so.

It is, then, very possible that the relevant protection of the resource is not sufficient to maintain its biological sustainability. For this protection emerges from a rationale which does not concern the biological sustainability but rather it is related to some certain properties and utilities of the resource.

Specifically, it concerns those properties which give some economic benefits.

In other words, since the rationale for protecting a resource is not logically grounded in relation to its physiology and the maintenance of its "biological sustainability", it is expected that only by coincidence the resource will be effectively protected by its owner.

Annex 1: Mathematical explanation of the two production patterns

1. The normal pattern of production is a common mathematical function $H = f(x)$ where H stands for the harvest and X stands for the effort.

2. The "reading pattern" of production is a specific type of mathematical function.

We assume that $H = z(v)$ presents a "reading pattern" of production where H stands for the harvest and V stands for the effort. Then we have $H_v = H_{v-1} + z(v)$ which means that the value of H at a certain v is equal to the value of H at v-1 plus a function z(v) which presents the additional production caused by the last unit of v. Obviously, $z(v) = dH / dv$. As a result, Hv cannot decrease since the function z cannot be negative. Z(v) is a natural quantity that measures the additional production of each additional effort level (v); that quantity cannot be negative since there is no negative real production. Z(v) presents a real element which due to its physiology cannot be negative.

We should pay attention in order to sort out z(v) function than the marginal production function $H= f(x)$ derived from the normal production function. That marginal production function, in the normal production pattern, is $dH/dX = B(X)$. However, that could also take negative values since it is not a number that correspond to the real world. The marginal production function, in that case, is a device explaining the pattern of the total production, the pattern of the function $H = f(x)$.

Why is it not a realistic value? The value of the function f at a level of X presents the outcome of a distinct process from any other production at levels of X different from x. So the value of f at $x+1$, $f(x+1)$, is the outcome of a different process, that of exercising at once $x+1$ level of effort.

The marginal production at level $x+1$ is $f(x+1) - f(x)$. Obviously, that is not a real world magnitude, since the production at $x+1$ level does not derive from the production at x level if we add another unit of X. The production at level $x+1$ comes from a new process, that of exercising at once $x+1$ units of effort. If it was not a new process, the production f(x) could not be decreasing beyond a certain level of X since f(x) is the cumulative production like the function F(v); however we know that f(x) is decreasing after a quite large quantity of X. So, the marginal production of the production function f(x) is a mathematical device explaining its pattern and it mostly helps the producer to decide which process of production is the most profitable for him.

CHAPTER 4

ECOLOGICALLY SUSTAINABLE ECONOMIC DEVELOPMENT VIA GOVERNMENT INNERVATION. THE INTERNALIZATION OF THE ENVIRONMENTAL EXTERNALITY

4.1 Introduction

4.1.1 Introductory remarks

This chapter examines that direction of environmental economics which aims first at determining and second at enforcing the optimum environmental protection. The question in this chapter, remains whether the examined approach is able to identify and to preserve the "biological crucial level" of an environmental function or element so that the relevant "biological sustainability" can be assured. In particular, the direction of environmental economics examined in this chapter accepts that several economic activities create an external cost in the form of environmental degradation. Furthermore, it states that the cost of environmental degradation should be imposed to the economic activity creating it so that this activity will bear the entire social cost of its function. The result of the entire process is that the activity affecting the environment produces its socially optimum magnitude and so it creates the socially optimum level of environmental degradation or symmetrically the optimum level of environmental protection.

The basic precept of this process is the estimation of the external cost each activity creates, and which should be imposed on it.

The theoretical approach under examination accepts the government as the agency which measures all environmental cost imposed on the whole society by each polluting activity. Also, the government is responsible for finding ways to "internalize" this cost.

This governmental intervention differentiates the approach examined in this chapter from those examined in previous chapters. The present approach accepts governmental intervention as an agency estimating the "environmental externality" and internalizing it. On the contrary "Coase's approach" regards as superfluous such a practice while the "privatization of commons" approach accepts only an institutional change which would solve the relevant environmental problems.

Evidently, "Coase's approach" may be regarded as a marginal case of the externalities approach. For one may consider that "Coase's approach" assumes an externality estimated by individuals and internalized via the bargaining between "polluters" and "sufferers",or via any other form of voluntary actions. However, if in the framework of Coase approach there is an agency which performs the task of estimating and imposing the externality then the relevant externality will have a two direction form: one polluters' externality imposed on sufferers and simultaneously one sufferers' externality imposed on polluters.

Finally note that, whatever the form of an externality which could be managed by any voluntary action among "polluters" and "sufferers" theoretically it could be included in

"Coase analysis" and so it is superfluous to analyze it here again.

Essentially, the acceptance of an external environmental cost imposed on the whole society or on a part of it when this cost cannot be managed by any voluntary action among the involved members requires a representative agency which measures it and finds ways of internalizing it.
The direction of environmental economics that accepts at least a minimum of governmental intervention in order to perform the above tasks is examined in the present chapter.
This direction originates theoretically from the Pigovian externality. Several authors have developed also the particular subject of environmental externalities. To mention some of them: Baumol and Bradford (1972), Baumol and Oates (1988), Perrey (1988), Kottis (1974), Pearce and Turner (1991), Mishan (1980).

4.1.2 Structure of the chapter

Chapter 4 initially presents the standard economic theory about environmental externalities. Specifically, paragraph 4.2 gives the methods for determining the optimum level of environmental externalities. Then, paragraph 4.3 examines all the processes which internalize the non optimum level of environmental externalities. Some new elements of the analysis are also given here.
Next, paragraph 4.4 investigates whether the internalization of the non optimum level of environmental externalities preserves the biological sustainability. The conditions required for the maintenance of biological sustainability are examined. Some interesting conclusions are drown here. Finally, chapter 4 closes with its general conclusions.

4.2 A general review of environmental externalities literature

4.2.1. Introductory Remarks

In the present section a general review of the literature concerning the subject of environmental externalities is presented. The aim is to present the fundamental theoretical points of this approach avoiding a detailed analysis.

The "environmental externalities" approach is constituted by two processes which are the followings: first, the determination of the optimum level of the externality; second, the process of the internalization of the non optimum level. Section 4.2.2 is devoted to the literature of the process of determining the optimum externality level while paragraph 4.3 presents the existing ways of internalizing the non optimum externality.

4.2.2 Determining the optimum level of environmental externality

The optimum level of environmental externality is estimated on the basis of the marginal economic theory. The process of determining it is presented in Figure 1 which is borrowed from Pearce and Turner (1991) for the sake of compatibility.

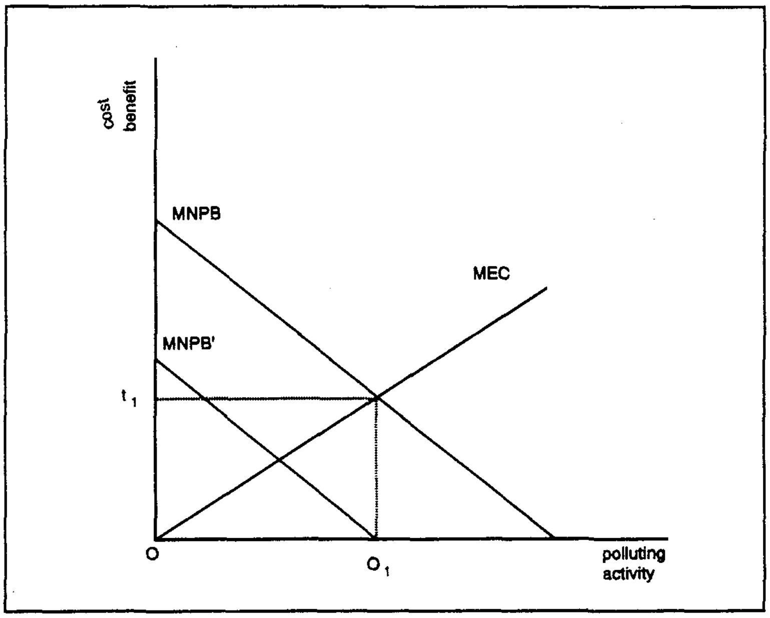

Figure 1 The optimal level of environmental externality

Curve MNPB presents the marginal private benefits arising from the polluting activity which is depicted on the horizontal axis.
Curve MEC presents the marginal external costs caused by the polluting activity and imposed on the whole society or on a part of it.
Noticeable is the relationship between figure 1 and all those figures we used in analyzing "Coase's approach". In those figures curve MEC of Figure 1 is replaced by a curve which depicts the marginal benefits of the sufferers when they exercise their right "not to be polluted". Theoretically, the marginal benefits of the sufferers are exactly equal to the

"external" cost imposed on the sufferers or on the whole society in the "externality approach".

The optimal level of the polluting activity is OO_1 since at this level the marginal benefit of the polluting activity is equal to the marginal external cost it causes. If the polluting activity level is lower than OO1 the society will gain a net benefit from increasing the level of that activity; in particular by doing so it gains a net benefit equal to MNPB-MEC. On the other hand, for a polluting activity level higher than OO_1 the society has a profit from reducing that level because MEC is larger than MNPB. Therefore, the equilibrium level is at OO_1 level of the polluting activity.
An alternative process for determining the optimum level of environmental externality is the one which examines the marginal external cost of pollution and the marginal cost of pollution's reduction. Figure 2 presents this process.

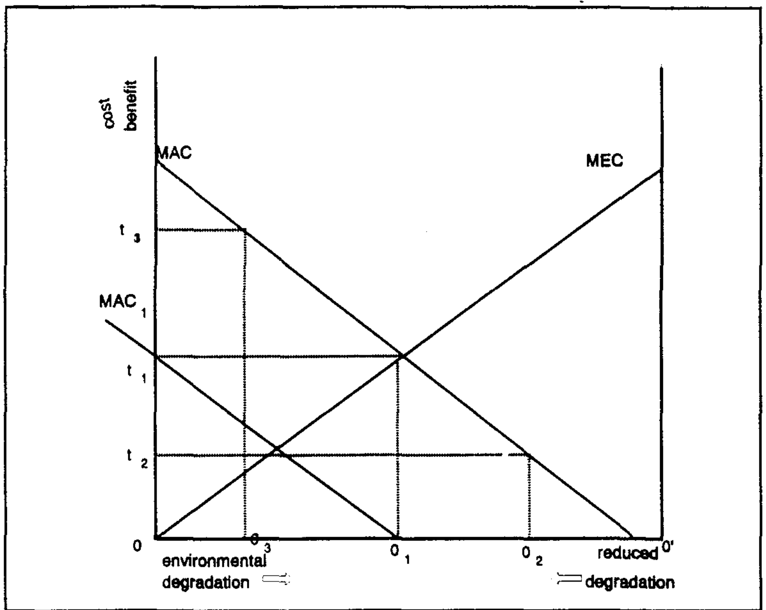

Figure 2 Alternative way of determining the optimal externality

Curve MEC of figure 2 presents the same variable as curve MEC of figure 1. Curve MAC (marginal abatement cost) curve represents the marginal cost of reducing the environmental degradation in respect to environmental degradation level (horizontal axis). Note that curve MAC coincides with curve MPNB in case that the only way to reduce pollution is to reduce the level of the polluting activity (Pearce and Turner 1991). For, then, the abatement costs are just equal with the foregone benefits, caused by the polluting activity reduction.
In the relevant literature figure 2 is often given in another form in which the horizontal axis represents the reduced degradation. That version is presented in our Figure 2 if it is read from right to left -from the O' origins-. In that case MEC curve -read from right to left-

presents the marginal benefits arising from the reduced degradation (curve MB) while curve MAC -read from right to left- depicts the marginal costs of degradation reduction (marginal abatement cost)(Kottis 1974, Kneese and Bower 1968, Karagiorgas 1980).

All of the above mentioned processes for determining the socially optimum level of environmental degradation lead theoretically to the same outcome and therefore one may use whichever one likes.

Once the optimum externality level has been identified what remains to be examined is the process to reach that level.
There are several procedures proposed. Coase, believes that the optimum level would be identified and then reached by the market's function alone. In the present chapter we examine those procedures which assume the governmental interference as an agency which estimates the optimum externality level and then induces the internalization of the non-optimum level of it by the creating activity. In the next paragraph we will examine the main ways a governmental agency acts in order to achieve the optimum level of environmental externality.

4.3 Achieving the optimum level of environmental externality

4.3.1 Internalizing the externality

This section presents briefly the effect of the internalization of the non-optimum level of the environmental externality on the decision making process of the polluter (the owner of the polluting activity).
Internalization usually implies that "the polluter" will bear an extra cost equal to the external cost of the polluting activity (MEC) at the optimum level of that activity. In Figure 1, the optimum level of the polluting activity is the level OO_1 and so the "external cost" which should be internalized by the polluting activity is Ot_1. This cost is mentioned as "the optimal Pigovian tax" or as the "optimal external cost", since once it is imposed on the polluting activity it leads to the reduction at the optimum level of the relevant externality.
Let us assume that this optimal external cost is imposed on the "polluter"; what effect does it have?
To examine it we will use figures 3 and 4. Figure 3 presents the curves of the marginal

(MC) and the average (AC) costs of the polluting activity before (MC_1, AC_1) and after (MC_2, AC_2) the optimal external cost has been imposed. Figure 4 presents the supply curve of the production of the polluting activity before (S_1S_1) and after (S_2S_2) the infliction of the optimal (Pigovian) external cost respectively; the demand curve remains constant.

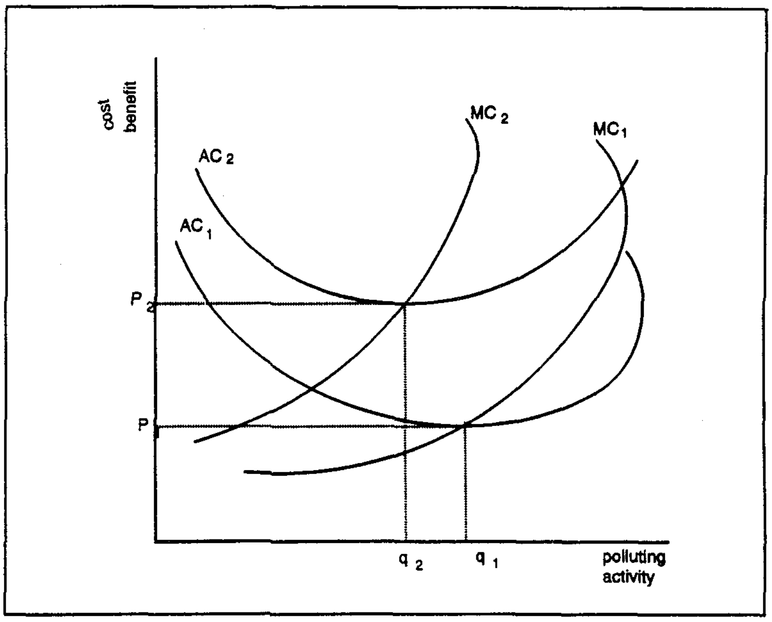

Figure 3 Internalizing the non optimal externality, for the firm

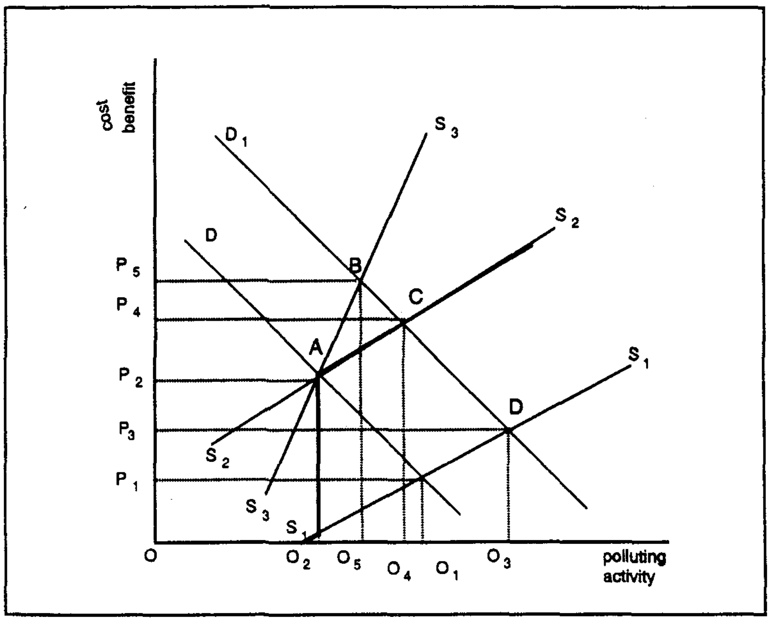

Figure 4 Equilibrium and internalization of the non optimal externality, for the industry

The imposition of the "optimum external cost" moves parallel upwards-left both the curves of marginal and average benefits of the polluting activity. As a result, the optimum production level of the polluting activity is now lower (OO_2) and therefore only the optimum externality level results. Evidently OO_2 level of figure 3 coincides with level OO_1 of Figure 1 which is the optimum level of the polluting activity.
The same conclusion may be drawn from Figure 4; the effect of the infliction of the optimum external cost (t1 of Figure 1 or 2) on the "polluter" is that he faces the S_2S_2 supply curve. Note that when the optimum external cost is not imposed his supply curve is S_1S_1. From microeconomic theory we know that the supply curve in perfect competition depicts the marginal cost of producing an additional unit of the relevant product. Assuming a constant demand curve, the equilibrium level of the relevant market is now lower (OO_2) than that (OO_3) arising without imposing the optimum external cost to the polluting activity (Karagiorgas 1980).

From the above analysis we conclude that the result of imposing on the polluting activity the optimum external cost (determined via the process described on Figures 1 and 2) is that the market conditions prescribe a lower production level of that activity so that only the optimum externality level (OO_1 of Figure 1) results. This lower production level is the socially optimum level of the relevant product since the external cost of its production has been taken into account.

The following sections examine the ways that induce the "polluter" to consider the external cost his activity creates. We will assume, as in the present section, that the "polluter" should bear the "optimum external cost" or otherwise the "optimum Pigovian tax". In some later paragraphs we will further examine several alternatives of the "correct" external cost that should be borne by the "polluter".

4.3.2 Taxes system

The tax system implies the existence of a governmental agency that imposes a tax equal to the above determined "optimum Pigovian tax" on the polluting activity.
Specifically, the "optimum Pigovian tax" is a price paid by the polluter for each "pollution unit" he creates. If this "tax" is related to the level of the polluting activity, a constant

proportion between polluting activity and pollution level should be assumed (S_t). -This proportion, actually, is equal to the sum of the polluting activity units which cause a unit of pollution. In other words, it should be assumed that each unit of the activity produces a standard quantity of pollution. Then the "optimum tax" imposed on each unit of the polluting activity is equal to the friction: number of polluting activity units creating a unit of pollution / optimum tax imposed on a pollution unit.-
For the sake of simplicity, we may assume that the optimum tax is imposed on each unit of the variable presented on the horizontal axis of the scheme we use in order to estimate that tax. Therefore, when on the horizontal axis the polluting activity is presented, we may assume that the pollution unit is that produced by each unit of the polluting activity (then the above mentioned proportion between polluting activity and pollution equals 1).

Essentially, once the optimum tax has been imposed, the optimum externality level is achieved by the process described in Figures 1, 3 and 4. According to figure 1, when the optimum tax is paid, the marginal net private benefits of the activity are given by curve MNPB'. MNPB' derives from MNPB as it moves parallel towards left-down by t1 distance. Obviously the new curve MNPB' depicts the marginal benefits of the polluting activity when the non-optimum level of the externality has been internalized. That internalization has been induced by governmental action by imposing the optimum external cost. We have to emphasize that once the optimum tax has been imposed, the polluter should be left alone to determine his activity level and no further negotiation with "sufferers" or with any other body is desired. The polluter deciding on curve MNPB would produce the socially optimum level of his activity.
The tax system has been criticized for several aspects of its implementation and specifically for its acceptability by polluters for reasons of justice (Pezzey 1988). On the other hand, it is accepted as a system superior to other instruments which induce pollution reduction such as standard setting and subsidies. In fact, it is viewed as the system providing the least costly method of pollution reduction and as the way to have the most "allocative" superiority (Baumol and Oates 1971, Kneese and Bower 1968, Pearce and Turner 1991, Mishan 1980).

4.3.3 Standard setting

Aiming at reducing externality at its optimum level, this method implies the setting of a standard in the emission of pollution. The standard refers to a particular level of the concentration or of the quantity of the pollutant (pollution) which should not be transgressed.

Obviously, the standard is imposed at the optimum level of pollution or alternatively at the level of polluting activity producing the optimum externality.

In Figure 2, a standard is set at level O_1 of the pollution which means that the polluters cannot produce more than O_1 pollution. Such a standard is accompanied by a "penalty" that is imposed if the standard is transgressed. In our example of Figure 2 the penalty is equal to Ot_1. For if it is lower than t_1 the polluter gains by emitting more than OO_1 pollution and pays the relevant penalty ; for instance, if the penalty is Ot_2 then the polluter would pollute up to OO_2 level and pay the penalty. On the other hand, if the penalty is higher than Ot_1, let us say Ot_3, then the polluter stops polluting at OO_3 level which is lower than the optimum pollution (OO_1). As a result, the penalty accompanying a standard designed to reduce the externality at its optimum level should be equal to the "optimum Pigovian tax" required to achieve the optimum externality in the tax system. Generally, this penalty should be equal to the marginal external cost of pollution at the pollution level at which the standard is to be set.

That is a point which has raised a lot of criticism, since it is believed that in practice only by coincidence the penalty is equal to the external cost of pollution at the level where the standard has been set. However, it seems that the only thing we should know for setting a standard is the MAC curve even when we design a tax system. Consequently, there is no superiority of taxes over standards.

The penalty in the standards setting works similarly to the tax in the tax system so both systems are analogous. Therefore, we do not need to examine separate taxes as a least-cost solution in enforcing a standard (Baumol-Oates 1971) because a penalty functions economically as a tax.

The only difference between the tax system and standard setting to consider is the following: a different interpretation of the externality and of the property rights assuming implicity by each system. In the framework of the tax system where the optimum Pigovian tax is imposed on each pollution unit (or polluting activity unit) it is assumed that the polluter is penalized for all pollution he creates. In other words, the polluter perceives that he will pay for each pollution unit he creates and therefore for all, optimum and non optimum, externality he causes. In figure 2, the polluter causes OO_3 pollution he will pay for each unit of the pollution the t_1 tax, although OO_3 externality is within the limits of the optimum externality OO_1. Note that the outcome of this procedure is the reduction of the externality to ita optimum level. In fact, in the case of a tax system it is assumed that all environmental rights

are assigned to the society as a whole, so whoever wants to use the environment and to deteriorate it should pay for all this use (Pezzey 1988).
On the other hand, the standard setting accompanied by a penalty system implicitly assumes that the polluter should pay only for the non-optimal externality he creates, so he has the right to use the environment up to the level of the optimum externality without any cost. That is to say, the polluter can use the environment up to level OO_1 of Figures 1 and 2 without any punishment. But once he transgresses that level he is penalized by the "optimal Pigovian tax" (optimal external cost), in the form of a penalty, so that he returns to level OO_1. At this level only the optimum externality is produced.

The equilibrium level of the polluting activity (and of the pollution) is exactly the same under both systems. However Figure 4 shows a difference in the supply curve of the product produced by the polluting activity in each of these systems. The supply curve of this product when the standard setting system is established is the thick line S_1AS_2 while in the tax system the supply curve is S_2S_2. Obviously, the two systems transfer a different message to the market although they lead to the same equilibrium level.

We mention here that the tax system can be designed in such a way that only the non optimum externality would be penalized by the optimum tax. That is to say the optimum tax Ot_1 of Figures 1 and 2 might be imposed only on the non-optimum externality which is anything larger than the OO_1 level (Perrey 1988, Pearce and Turner 1991).
In that case, the supply curve is identical to that of the standard setting system aiming at the same optimum externality level.

4.3.4 Subsidies system

In several cases the government assumes that it is preferable to encourage the polluter(s) to install an abatement mechanism by offering him (them) a subsidy for the quantity of the reduced pollution. That is to say the government offers a sum of money (in any form) for each pollution unit that has been reduced by the polluter. So, the polluter has a profit if he undertakes such a reduction.
This practice is usually followed when the abatement equipment is considerably expensive (purchasing cost and function cost), thus, it is believed that the polluters may install that abatement mechanism after being subsidised.
The result of the entire process is profitable for the whole society. So it is fair to levy all

society in order to subsidise the polluters since the society's welfare increases by doing so.

In economic terms, the subsidy system has a function analogous to the tax system. Consider Figure 2: curve MEC presents the marginal external cost of pollution and MAC presents the marginal abatement cost of pollution. The subsidy system assumes a subsidy equal to t_1, for each unit of pollution reduced. That moves the MAC curve towards down-left at the MAC_1 position, if and only if the abatement process takes place. So the polluter is indifferent between staying at the conditions described by MAC and losing the subsidy or installing the abatement equipment and gaining the subsidy (MAC_1). Therefore, it is assumed that he would moves to MAC_1 conditions for social sensibility.
Obviously, that process implicitly assumes a voluntary action by the polluter(s) since they are not forced to install suitable equipment. The analysis denotes that they are indifferent between installing that equipment and gaining the subsidies or not installing the first and losing the later.
Note that the subsidy is just equal to the "optimum Pigovian tax". A larger amount of subsidy induces strongly the polluter(s) to install the abatement mechanism which reduces the pollution to its optimum level since he has a net profit. However, such a practice it is not "fair",since the society bears greater cost than it gains from the reduction of pollution.

There are strong objections to the subsidy system since it may induce further pollution than the initial situation because that system induces the entry of new firms in the relevant industry.
This is formally depicted on Figures 5 and 6 (which are borrowed by Pearce and Turner 1991). The polluting firm is depicted on the left and the relevant industry on the right.

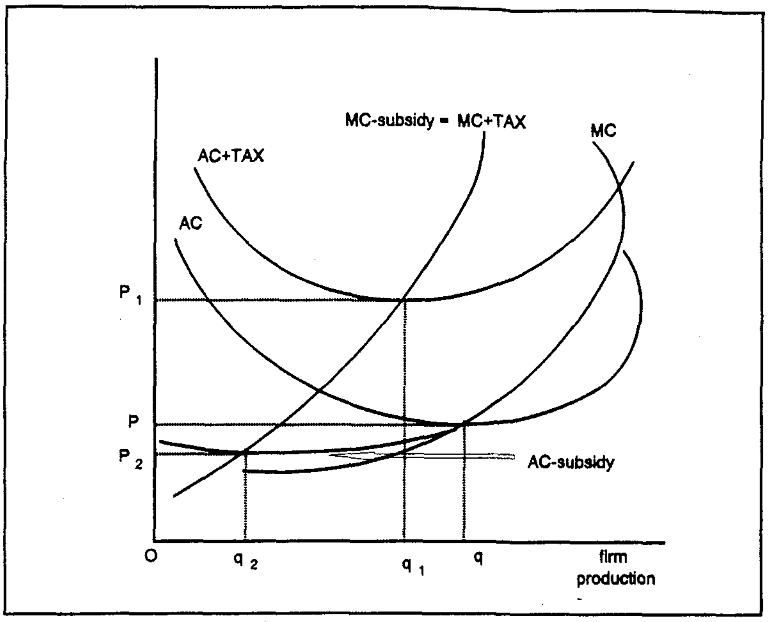

Figure 5 Firm production

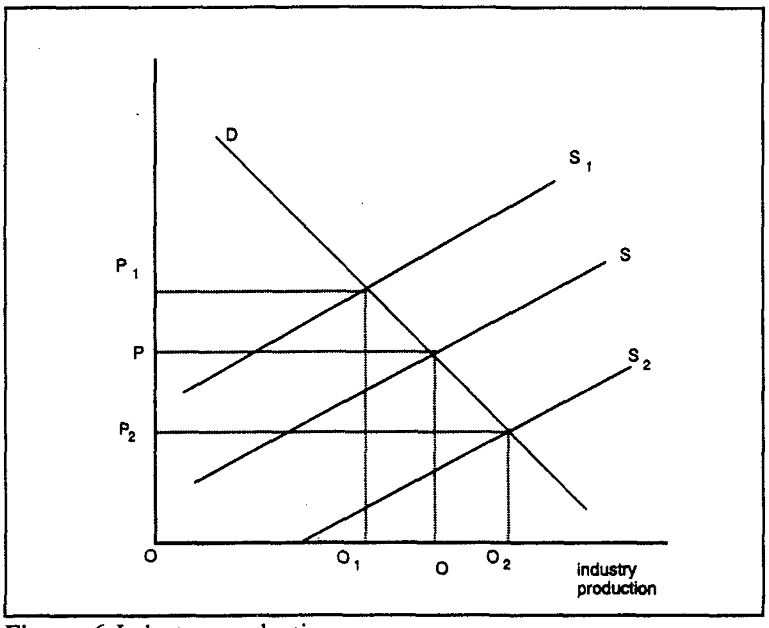

Figure 6 Industry production

The amount of the subsidy is equal to the optimum Pigovian tax (optimum external cost). The firm when it is subsidized to reduce pollution faces a marginal cost curve (MC - subsidy) just equal to the marginal cost curve when it is charged by the optimum tax (MC + tax). As the firm increases its production it looses part of the subsidy since it creates more pollution. Loosing a subsidy is analogous to paying a tax. So, MC - subsidy = MC + tax when tax=subsidy. Obviously MC is the marginal cost before any cost or subsidy has been imposed.

The average cost, when the firm is subsidized, is AC - subsidy since it gains by reducing its production. On the other hand, when it is charged, the average cost is AC + tax (Pearce and Turner 1991).

When the firm is charged, the equilibrium level is determined at the point where the initial price (P) equals the new marginal cost (MC + tax) and so the production level is q_1 for the firm. Now the price P is lower than the average cost AC + tax and so the firm will run out of the industry. Thus the supply curve of the industry shifts to S_1S_1 curve and the new equilibrium price is P_1. The only firm that will remain in the industry is the one for which the P_1 equals its average cost AC + tax at its lower level. Therefore, the equilibrium point of this firm is (p_1q_1).

On the contrary, when the firm is subsidized, the equilibrium is initially and of a short time where the initial price P intersects the new marginal cost curve MC - subsidy. However, the initial price P is above the new average cost AC - subsidy, at the short run equilibrium level which is (Pq_1). Consequently, new firms will enter the industry shifting the supply curve to S_2S_2 location. The new equilibrium of the industry is at (P_2Q_2). For each firm now, the long run equilibrium is at (P_2q_2) where P_2 intersects the average cost curve at its lowest level (Pearce and Turner 1991). Obviously, we mention as long run equilibrium that equilibrium arising when the relevant industry adjusted to the altered conditions of the market.

As a result, a subsidy may alter market conditions by inducing new firms enter the business so that the total pollution increases. Furthermore, subsidy system has been criticized also on ethical grounds. It is considered as not-acceptable for a society to subsidize those who create problems in order to stop causing them.

4.3.5 Prices mechanism

The price mechanism may be seen as an attempt to compromise governmental interference with the market's proper function. Governmental interference aims at protecting the environment and the market mechanism undertakes to perform it efficiently. There are two alternatives of the "prices mechanism" which will be examined below.

The first alternative assumes that the government estimates the social external cost of each

polluting activity. Then each polluting activity is charged by a price equal to the optimum external cost i. e. the cost of reducing the relevant externality at its optimum level (on Figure 1 that cost is Ot_1). That cost is the optimum Pigovian tax of each polluting activity. This process is undertaken for all polluting activities taking place in a society. So each of them has a price determined by government on the basis of the optimum Pigovian tax (Kotis 1975).
The problem of this alternative is that the required information for determining the price for each polluting activity may be overwhelming and prohibiting.
Actually, this first alternative bears all the analytical characteristics of the previously analyzed processes of estimating and internalizing the relevant external cost and therefore, there is no theoretical interest in examining it any further.

The second alternative is viewed as more attractive since it introduces a new process of internalizing the external cost. This process is usually called the system of the "marketable pollution permits" (Dales 1968).
Figure 7 clarifies the main characteristics of this approach.

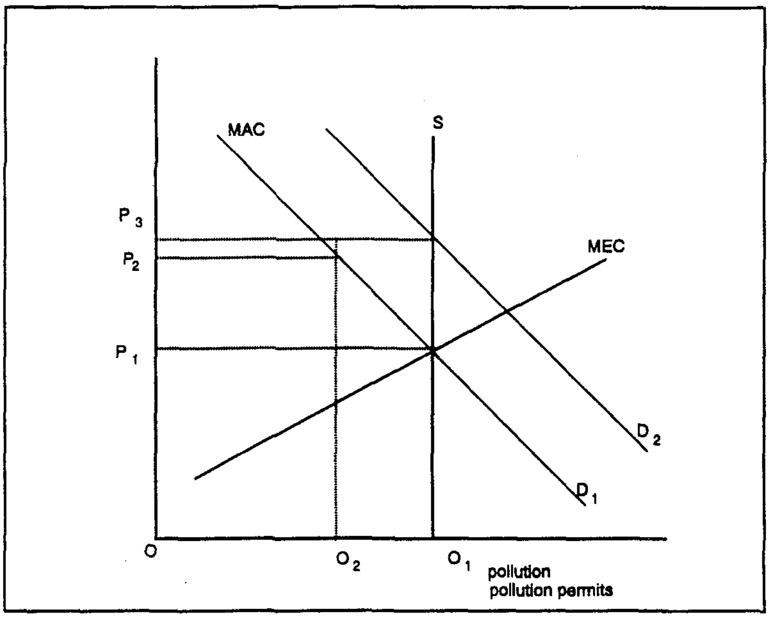

Figure 7 The market mechanism on pollution

Figure 7 repeats the analysis of Figure 2 with an additional variable; on the horizontal axis the "pollution permits" are presented. It is assumed that if one wishes to emit one pollution unit he should hold exactly one "pollution permit". That is to say the government legislates that the only way to emit X units of pollution is to buy and to hold X number of pollution permits and this procedure holds for all the kinds of pollution. Figure 7 then presents just an example of one pollution kind. Let us assume that the government desires to reduce pollution to its optimum level (the optimum level of the relevant externality).
Then it has to issue just O_1 number of permits and to legislate that the only way to emit a unit of pollution is for the relevant "polluter" to buy and hold a pollution permit. Under these
conditions, the price of each pollution unit will be P_1. Note that curve MAC presents the demand curve for pollution permits and the O_1S curve their supply curve (Pearce and Turner 1991).
P_1 being the price of pollution permits, the polluter(s) would slow down pollution to OO_1 level since for more pollution it is more expensive to buy permits in P_1 than to reduce pollution installing suitable equipments, whose marginal cost is depicted on MAC. So polluters would install that equipment only to reduce pollution to OO_1 level.
For pollution levels lower than the OO_1 level it is cheaper to buy permits than to use equipment since at this pollution range P_1 is lower than curve MAC. As a result, the equilibrium level of pollution is OO_1 which is also the optimum level of the relevant externality. Thus, determining the price of pollution permits (which equal to the "optimum Pigovian tax" the optimum level of the relevant externality) is achieved by the market mechanism on the pollution permits.

We emphasize that permits should be marketable. That leads to a way of minimizing the cost of achieving the optimum pollution level. This way equals the marginal cost of pollution reduction for all pollution resources (Dales 1968, Pearce and Turner 1991).
Therefore, the government has only to determine the level of pollution which is acceptable and then to issue the relative number of permits. The price of them should be initially equal to the marginal abatement cost of the pollution at its desired level; afterwards the market would achieve this level by itself. For example if the desired level is O_2 we have to issue OO_2 permits, with a price P2 for each one of them.
We used above the phrase "initial" price in order to give a significant characteristics of the price of the permits. This is the price at which the government sells the permits when the demand level is MAC. However, that level may change if new activities develop and emit additional quantities of pollution. Then the demand level changes and the demand curve shifts, let us assume, to D_2 level (figure 7). The competition among polluters to buy permits

increases their price to P_3, -assuming that the government desires to reduce the pollution to the same level and thus it does not issue more permits-.
So, the government should be inactive when the market conditions change if the desired pollution level remains the same. That level of pollution is ensured by the market; by the competition among the polluters for the already issued permits.

The market on the pollution permits induces an overall adjustment of the relevant market of the activities that cause the pollution, so that the non optimum external cost of each activity is internalized. We shall present briefly the effect of this adjustment on the relevant producers and consumers. Let us consider a representative producer who uses two production factors labour (L) and capital (C), and assume that the use of capital creates environmental problems.
The producer faces the market conditions depicted on Figure 8. Figure 8 presents the isoproduction curves (I_1, I_2, I_3) which depict the required combination of the two factors for a standard production quantity for each curve , obviously $I_1 < I_2 < I_3$ production. Figure 8, also, gives the isocost curves AB, A_1B_1, A_2B_2, presenting each of them a standard cost of production; their slopes are equal to the ratio of the prices of labour and capital. Before any intervention, the producer works at point "a"using capital OC and labour OL. However, when the external cost has been imposed the capital becomes more expensive so the isocost curves change slope. Let us assume that AB becomes A_1B_1. These curves both present the same total cost of production; note also that under the new conditions the production cost increases due to the higher price of capital. So, for the same total cost, the production takes place at point "b"using capital OC_1 and labour OL_1 and producing a lower amount ($I_1 < I_2$). Evidently, under the new conditions the ratio of "used capital" to "used labour" has decreased since the relative price of capital has become higher due to the internalization of the environmental externality it creates. As a result, the market mechanism changes the relative prices of the production factors making the factors which contribute to the environmental degradation more expensive. This induces the use of the "clean" factors by diminishing the use of the polluting factors.

The representative consumer demonstrates a behaviour analogous to that presented in Figure 9. Figure 9 presents two goods X and Y; X creates environmental problems. In Figure 9 we can see the indifference and the budget curves. If the budget curve is AB, before any intervention, the consumer choose the point "a"and buys the quantities OX_1 and OY_1 of products X and Y respectively.
The system of marketable permits on pollution becomes X relatively more expensive. So, the slope of the budget curve changes, and from AB shifts to A_1B (both of them present the

same budget restriction). Deciding on A_1B budget line the consumer will choose "b" point, buying the quantities Ox_2 and Oy_2 respectively. "b" lies on a lower interference curve than "a" so the utility level of the consumer has decreased since I_1 represents a lower level of utility than I_2. Besides, the consumer has increased the consumption of product Y which is now relatively cheaper than X, the consumption of which has decreased (Kottis 1975).

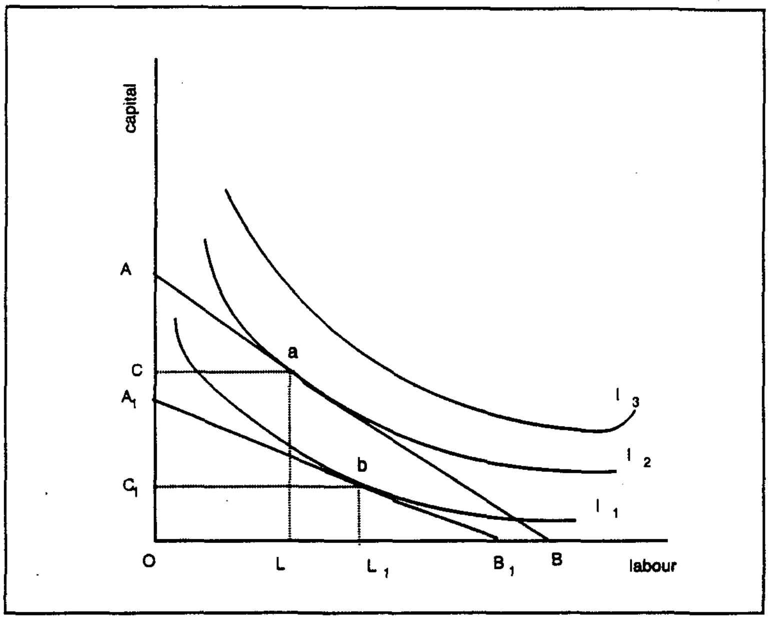

Figure 8 Producer behaviour

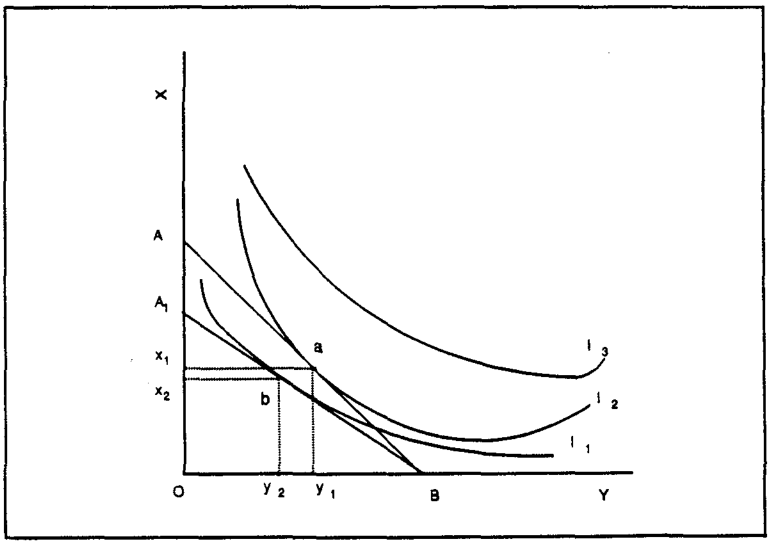

Figure 9 Consumer behaviour

4.3.5 Some thoughts on a "fair" environmental tax

All the above paragraphs assume that the external cost that should be inflicted is equal to the optimum Pigovian tax (Ot_1 on Figure 1) which is determined according to the process presented by figures 1 and 2. Then, we say that there are two alternative processes of imposing the external cost, especially in the case of the "tax system".
The first alternative accepts that the polluters should be penalized for the non-optimum damage they cause. This alternative is usually mentioned as the "standard polluters pay principle" (SPPP). The second alternative accepts that polluters should be charged for all damage caused (for both the non-optimum and optimum damage). This alternative is mentioned as the "extended polluters pay principle" (EPPP)(Pezzey 1990).
The alternatives are illustrated in Figure 10 which repeats the analysis of Figure 2. According to the SPPP, polluter should be charged only for O_1B level of pollution and thus when he produce at OO_1 pollution level there is no charge to pay.
According to the EPPP the polluter should be charged for the whole O_2B range of pollution. So he will pay O_1ARO_2 amount in form of a charge even when he produces OO_1 pollution. Notice that OO_2 pollution creates no external cost since that level corresponds to the assimilation capacity of the environment for the pollution.
If the polluter would be charged even for OO_2 range, and so for the whole OB level of pollution, then we may speak of an "over extended polluters pay principle" (OEPPP).
Which of the above three principles holds depends on the ethical assignments of the property rights of the environment (Pearce and Turner 1991).

All above tax systems raise the question of fairness. If SPPP holds, the question is why the polluter does not pay any tax although he creates an external cost equal to O_2O_1A, if for example he works at the optimum pollution level OO_1.
When EPPP holds, the question which arises is whether it is fair for the polluter to pay for the optimal externality he causes; note that the optimal externality is at O_2O_1 level. Moreover a stronger objection may arise due to the charge amount depicted by the O_2RA area which is payed in excess of any damage made. For the damage made in this case equals the O_2O_1A area while the polluter pays an amount equal to the O_2RAO_1 area.
If OEPPP holds, the same objections as in the EPPP case may arise. However, a further problem may come up due to the Ot_1RO_2 area which is paid while no damage is made.

In order to confine the above mentioned problems of fairness we propose another form of taxes. This form is based on the principle that "the polluter should pay exactly the external cost he creates regardless of the pollution level he emits". The external cost, at each level of pollution, is given by curve MEC. So, if the above principle is to be applied, the tax-price paid for each pollution unit should be exactly the marginal external cost that the unit creates.

For example, the O_8 pollution unit pays t_8 tax, the O_7 unit pays t_7 , the O_6 pays t_6, the O_5 pays t_5, the O_4 pays t_4, the O_3 pays t_3, the O_2 pays nothing since it creates zero marginal external cost (figure 7).

Evidently, this system leads to the same equilibrium-optimum level of pollution as the other tax systems. This is the OO_1 level of pollution. However, according to the proposed system, when the polluter works at the optimum level he pays the area O_2AO_1 in form of taxes since this area depicts the external cost he creates working at OO_1 level.

The above proposed "fair tax system" might be regarded as superior to all other systems in two aspects.

First, the feeling of fairness it gives to both the polluter and to the society since the polluter pays exactly the cost he creates to the society.

Second, a superior allocation effect may be induced since every pollution unit is penalized by what it costs exactly.

That could be seen better in Figure 4, where the supply curve of the good produced by the polluting activity is given for the whole industry. S_1S_1 is the initial supply curve when the polluter acts free; S_2S_2 is the supply curve when he pays for the whole caused damage, for the whole externality he creates; and curve S_1AS_2 depicts the supply curve when only the non-optimal damage is charged. If the proposed taxes system holds, then the supply curve takes the form of S_3S_3. That leads to the same equilibrium level as that of all other supply curves arising from any of the above "tax systems". On the other hand, S_3S_3 gives a considerably different meaning to the respective market. This mainly concerns the allocation outcome of the market.

In order to clarify this allocative difference of the proposed tax system let us consider a change of the demand of the polluting-product shifting the demand curve to D_1D_1 which lies above DD (figure 4). The equilibrium then is (O_5, P_5) if the proposed tax system holds. The equilibrium is (O_4, P_4) when either SPPP or EPPP holds. Thus, the proposed tax system determines an equilibrium at a higher price and a smaller quantity of the polluting-product when the demand level has increased. For the satisfaction of the increased demand requires the production of additional quantities. These additional quantities cause a sequence of larger marginal external costs that, in turn, are now internalized by the producers.

On the other hand, SPPP or EPPP lead to the infliction of the standard optimum Pigovian tax whatever the produced quantity of the polluting-product. That optimum pigovian tax is lower than all marginal external costs on the right of quantity O_2 of figure 4 or on the right of q_2 of Figure 3. Notice that at O_2 and q_2 the external cost is equal to the optimum pigovian tax; also notice that level O_1 of Figure 1 and 2 corresponds to level q_2 of Figure 3 and to level O_2 of Figure 4, when figures 1 and 2 refer to the firm and to the relevant industry respectively.

If now the demand level decreases compared with DD in such a way that the equilibrium level would be determined on the left of O_2 of Figure 4 then, S_3S_3 determines an equilibrium at a larger quantity and a lower price compared with the curve S_2S_2 . For the marginal external costs internalized in the "fair tax system" leading to S_3S_3 are lower than the optimum Pigovian tax internalized in the EPPP leading to S_2S_2. On the other hand, the equilibrium of S_3S_3 defines a higher price and a smaller quantity compared with the equilibrium of S_1AS_2 supply curve of the PPP, since the PPP requires no tax for lower than O_2 production levels.

As a result, the proposed "fair tax" system, charging the polluter exactly the external cost he causes at each one level of his production, leads to a superior allocatively outcome than the other tax systems.

Another advantage of the proposed "fair tax system" is the required information for its application. In order to apply either the SPPP or the EPPP, we have to identify the optimal Pigovian tax (optimum external cost) that is to be inflicted. So, we need to know either curve MPNB (marginal private net benefit) of Figure 1 or the curve MAC (marginal abatement cost) of Figure 2 and of course, curve MEC (marginal external cost).

On the other hand, in order to apply the "fair tax" system we only need to know curve MEC since we do not estimate the optimum tax because we charge the polluter for each pollution unit with the external cost that the unit causes. The external cost is depicted on the curve MEC. Therefore the information that is contained in this curve is sufficient.

The importance of this advantage is noticeable when we keep in mind that the information included in either MPNB or MAC is an internal information of the relevant firm which is not easily obtained by any other agency.

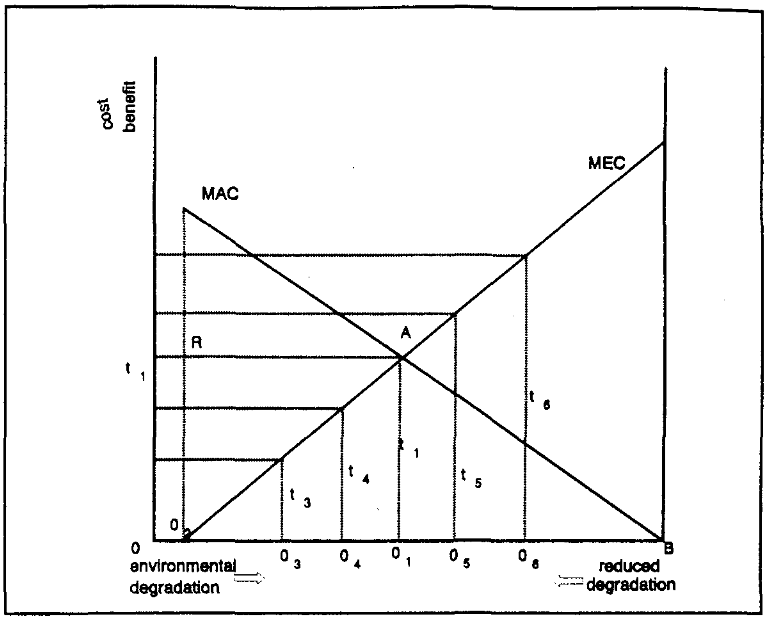

Figure 10 "Fair" tax system

4.4 Does the internalization of the environmental externality leads to the preservation of the "biological crucial level"?

4.4.1 Optimal externality level and biological crucial level

The target of the present section is to examine whether the procedure of confining the pollution to the optimum pollution level and so preserving the optimum environmental protection level suffices to ensure the "biological crucial level" of the relevant natural element or function.

In order to avoid repeating the analysis of the preceding chapters, we exclude from the analysis the "time span effect" and "space span effect", although they are also relevant here. That allows us to emphasize some other issues present even when the above effects are excluded.

Thus, we assume that the decision units involved in the procedure of determining the optimal pollution are first quasi-immortal and second quasi-global.

Let us consider, (figure 11) which repeats the procedure of determining the optimal pollution. The optimal pollution level is OA and so the optimal protection level could be regarded as the O'A.

If we wish the optimum protection (pollution) level to ensure generally the "BCL" it is sufficient for the optimum protection (pollution) level to be always higher (lower) than the protection (pollution) level which corresponds to BCL. For example, if OB is the highest pollution level that does not violate BCL, OB may be perceived as the indicator of BCL. Hence, B should be always to the right of A if BCL should be preserved.
We can assume, for simplicity, that the optimum pollution level coincides initially with the level indicating BCL -A coincides with B- therefore, BCL is initially ensured.
There remains to prove that there is no case in which B lies on the left of A. Only then the procedure of determining and enforcing optimum pollution ensures generally the BCL.
Let us consider an increase of the marginal private net benefits of the polluting activity. Such an evolution could arise from a change in the preferences of individuals or from a change in the production cost of that activity. The change moves curve MPNB to the right-up. The new private benefits curve may be MPNB'. Under the new conditions the optimum pollution level is OA'. As figure 11 presents, A' lies on the right of A and therefore on the right of B. In that case the BCL is violated.
Actually, confining pollution to the optimum pollution level, and so preserving the relevant protection level is not sufficient to secure the BCL. Obviously, the market conditions, may lead to the violation of the BCL and of the biological sustainability.

From the above it can be concluded that the process of internalizing the non-optimum level of externality results in the maintenance of the biological sustainability only by coincidence, since the non-optimum externality only by coincidence corresponds to the reduction of the externality -and therefore to the reduction of the relevant pollution- which is required to ensure the BCL.

4.4.2 A considerably modified externality's curve

If we wish the restriction of the externality down to the level of the optimal externality to ensure always the BCL, then the curve depicting the external cost of polluting activity should be modified significantly. Particularly, it should take the vertical direction at the largest pollution level which does not violate the BCL (the pollution level OB in figure 11) or similarly, at the minimum protection level that preserves the BCL (protection level OB'). -For simplicity, point B may be perceived as that corresponding to BCL-. Then the external cost for pollution levels higher than OB tends to infinity. In figure 11 the modified curve MEC remains intact for the range of OA pollution however, exactly at OA level the curve takes the vertical direction depicted by curve MEC'. Under these new conditions whatever the shape of curve MPNB (the curve of the marginal benefits of the polluting activity and so of the marginal benefits arising by the pollution), the optimum pollution level cannot exceed the level corresponding to the "biological crucial level" (BCL).

Essentially the proposed modified curve of the external cost forms, up to now, a pure technical modification of the curve and of the relevant functional relationship. The real world conditions which are implied by the modified curve remain to be examined. In other words, we should examine those real world conditions which could lead to the modified curve.

Two distinct conditions could lead to the modified curve. Let us examine them separately.

First, the modified curve could arise when the real external cost imposed to the sufferers tends to infinity for pollution levels higher than OA.

In all probability, such an immense cost implies two distinct things. Either the relevant good, depicted on the horizontal axis and being affected by pollution, is essentially destroyed when the pollution transgresses the OA level or the sufferer is then destroyed. -Evidently, it is assumed that the pollution and the protection levels, on the horizontal axis, refer to some natural element or function which is implicity represented on this axis. Obviously, the utilization of this element increases as the pollution increases on the contrary its protection increases with the antipollution-. Otherwise, the modified scheme cannot emerge. For such a scheme contradicts the law of diminishing returns; this law speaks of gradual increases or decreases of the marginal economic quantities and it is regarded as one of the few universal economic laws (Norgaar 1989).

In order to explain this let us consider the physiology of the external cost imposed on the sufferers.

This cost has the form of a lost economic utility (welfare). This utility arises from the relevant natural element-function and is lost because this element is affected by the pollution. As pollution increases gradually, the relevant natural element-function looses some of its characteristics and so it contributes a decreased utility. On the other hand, as pollution increases gradually the marginal lost utility of sufferers increases also gradually since the relevant element-function continues to give some amounts of utility even when it becomes polluted. The functioning of this natural element as a source of utility ends when it has been destroyed totally by pollution or it has lost all its economic characteristics, which, in turn, means essentially the total destruction of any useful economic form of this

element.
As a result, the external cost tends to infinity at that level of pollution which tends to destroy the relevant element or to impoverish it from all its essential characteristics.
On the other hand, one may assert that the external cost tends to infinity even when the pollution destroys the sufferer. For curve MEC (or MEC') is the one depicting the external cost which is perceived by the sufferer. So, if there is a level of pollution which leads sufferer into extinction, he should regard that the total external cost and the marginal external cost at this level is becoming infinite.
Concluding the first condition leading to the modified curve of the external cost of pollution it could be said that this condition implies two very rare events. Namely, they are either the total destruction of the relevant natural element or the extinction of the sufferer. In all probability, they are really marginal real world events.

The second condition which could lead to the modified curve is quite different from the first one. The first one explains the phenomenon within the boundaries of the economic domain while the second mentions beyond these boundaries.
According to the second condition, the modified curve arises when a criterion exists. This criterion denotes that the preservation of biological sustainability is an upper target, which confines the range where the economic decision rules apply. In other words, the maintenance is established as a predetermined target, so that the cost of transgressing it becomes immense. Hence, the external cost curve trends to infinity beyond the pollution (protection) level corresponding to BCL.
Some further remarks are required here. The external cost curve presents the perception of the sufferer about the cost caused by the pollution. So, the sufferer is the decision making entity which adopts the criterion of establishing biological sustainability as a superior target. This directly implies the adoption of a criterion which confines the application of the "marginal decision rule" to the range of the pollution levels which are lower than the level corresponding to BCL. In our example the "marginal rule" applies in the OA range, in figure 11.
The above reasoning leads to some thoughts about the nature of the sufferer. When the sufferer is an individual and he comes to a bargaining process with the polluters then two scenarios may be distinguished. First, if the sufferer holds the right "not to be polluted" then he must prove that the violation of biological sustainability imposes an immense cost to him and so he has the right to ask for this cost from the polluter. Second, if the polluter has the right "to pollute" then the sufferer should be economically able and willing to bear the cost of maintaining the biological sustainability under any condition. That is to say he must

be able to bear a potentially infinite cost presented in the modified curve beyond the level OA.

In both cases, there are serious obstacles prohibiting their application in reality. It is very difficult for the sufferer either to prove that he is burdened by an immense cost or to pay that cost.

The problem is quite different when an agency, which represents the entire society, measures and imposes the external cost. Indeed, the government as a representative of the relevant society may adopt an additional criterion, that of maintaining biological sustainability regardless of the rest economic condition. So, it may perceive as infinite the cost of violating the biological sustainability.

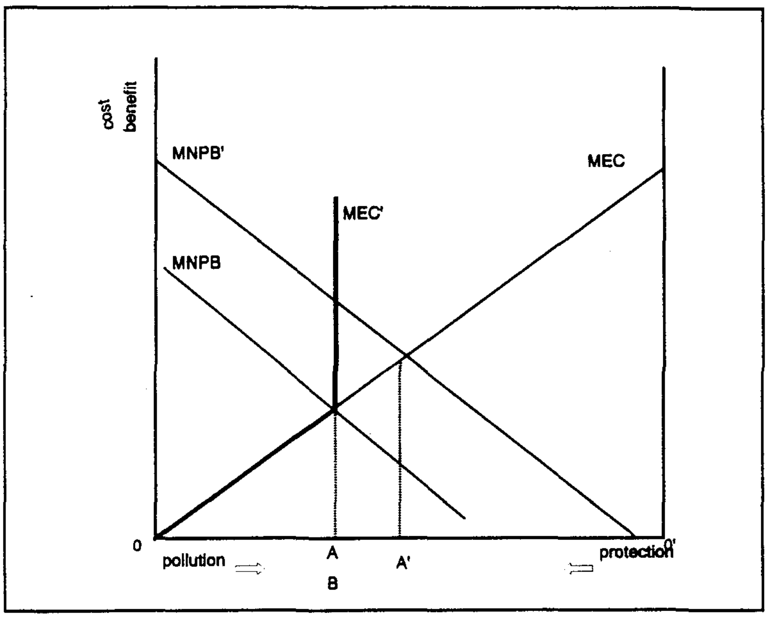

Figure 11 Optimal pollution and the preservation of "BCL"

4.4.3 Alternative approaches of the modified externality's curve

Obviously, the above analysis and its conclusions hold also if the marginal private benefits curve (MPNB) is replaced by the marginal abatement cost curve (MAC).

Indeed, a change of the level of the abatement cost may lead to violating BCL, in an analogous way with a change of the marginal benefits of the polluting activity. Therefore, only when the external costs curve follows its modified scheme BCL is always ensured. No more analysis is needed in this case.

Let us now examine what happens when curve MEC receives an alternative interpretation. Specifically consider that curve MAC presents the marginal benefits of the anti-polluting activity; anti-polluting activity being just the opposite of the polluting one. In fact it is not any specific activity, we are rather talking about the exercise of the sufferer's right "not to be polluted-affected" by the polluting activity.
Evidently, as the anti-polluting activity increases the polluting one decreases and vice versa. Certainly the formal analysis does not alter under the new conditions, however some significant conclusions arise from the new conditions.
Specifically, assume that MEC must follow the modified scheme so that BCL is always ensured. Under the new interpretation of MEC, the marginal benefits of the anti-polluting activity tend to infinity for anti-polluting levels lower than O'A (figure 11). It is interesting to examine the real world conditions which lead to the modified MEC, when MEC presents the marginal benefits of the anti-polluting activity.

In fact, the modified curve now implies that the benefits actually tend to infinity for some levels of the relevant activity. However, this is an extremely rare case in the economic domain, since it contradicts the law of diminishing returns as we have seen above. In effect, it cannot be expected that BCL, of any natural element or function, would be ensured via the above reasoning.
Only when these marginal benefits appertain to an abnormal economic good, the modified scheme may refer to reality. The assumption of an abnormal economic good is equivalent to the assumption of an additional criterion concerning the maintenance of biological sustainability. For biological sustainability could be ensured via the reasoning presented by the modified curve MEC, if biological sustainability is perceived as an abnormal good. In particular, biological sustainability in the modified curve is perceived as a target which should be persuaded since its achievement brings immense benefits. Note that the marginal benefits tend to infinity just where the protection activity preserves the biological sustainability. Indeed, a good that is persuaded since it brings immense benefits is an abnormal good. The existence of an abnormal good is tantamount with the existence of an additional criterion that confines the range of the application of the economic decision rules.

However, which is the entity which regards biological sustainability as an abnormal upper good?
If an individual adopts the additional criterion of maintaining the biological sustainability and so regards it as superior good then there exist two cases.
The first case refers to the bargaining between polluter and sufferer and the sufferer should

prove that his benefits of sustainability maintenance are actually immense.
In the second case the government intervention occurs estimating and imposing the external cost of polluting activity, then the sufferer should also prove that his benefits of sustainability maintenance tend to infinity and so do the costs (lost benefits) of sustainability transgression.
Obviously, both cases are considerably difficult to be realized, since an individual can hardly negotiate convincingly for extra-ordinary economic sums.
Therefore, the conclusion reached in the previous section 4.4.2 emerges also here. Specifically it is the society as a whole that could more easily than any other entity adopt the additional criterion of maintaining biological sustainability at any economic cost. This criterion, in turn, confines suitably the spectrum where the economic criteria apply so that economic decisions, which are taken according to the economic criteria-rules, do not affect biological sustainability. Society may regard without any practical problem that the cost of transgressing sustainability is immense and therefore the benefits of its maintenance tend to infinity. Besides, society is able to impose the internalization of the cost of a polluting activity to its creators. So imposing the immense cost of sustainability violation leads to ensuring sustainability under any economic condition. The internalization of the immense cost of sustainability violation in fact prohibits such an action.

4.5 Concluding Remarks

a. The perception of environmental externalities as a distinct theoretical issue arises only when it is acceptable that there is an agency authorized to measure and to find ways of imposing the internalization of the externality. Otherwise, the whole issue pertains to "Coase's approach" and specifically to the case where sufferers have the right "not to be affected", since only then we could speak of an externality caused by the polluting activity.

b. The process of determining and permitting only the optimum externality level,is not sufficient to form a general tenet which could lead to maintaining biological sustainability. A change either in the level or in the form of the marginal benefits of polluting activity may lead to the violation of the relevant BCL if it is assumed that the BCL is ensured before this change takes place.

c. If, and only if the process of determining the optimum externality takes place according to the "modified curve" of the external marginal costs, as the biological sustainability ensured under any economic condition. That is a technical prerequisite.

d. The above technical prerequisite corresponds to two real world conditions:
-First, a society which perceives the maintenance of biological sustainability as desired target which confines suitably the application of the economic decisions. This is the more possible case.
-Second, individuals who adopt the above target in a similar way. However, there are some serious obstacles. Specifically, individuals can hardly undertake the actions permitting the realization of the above target since then they have to negotiate for extra ordinary economic magnitudes. Besides, the above target should be adopted by all involved individuals, namely by all sufferers.
Note that in some cases the group of sufferers contains the majority or even all of the members of the relevant society. It is then required almost a social consesous for preserving biological sustainability at any cost.

CHAPTER 5

RENEWABLE RESOURCES ECONOMICS AND ECOLOGICALLY SUSTAINABLE ECONOMIC DEVELOPMENT

5.1 Introduction

5.1.1 Introductory remarks

The present chapter examines that branch of environmental economics which fits under the title of "Renewable resources economics". This branch regards the pattern of use of a renewable natural recourse and specifically it researches whether a pattern of use is sustainable or not. In other words, the present chapter examines the effect of a specific pattern of use on the recourse stock.

In the beginning of the chapter, a brief analysis of the main theoretical approaches of the subject is presented. Next, certain problematic topics of renewable resources economics are re-examined and some alternative approaches are proposed. Finally, all approaches are examined in relation with the fundamental concepts of the "biological sustainability" and the "crucial biological level" developed in Chapter 1. Essentially, the crucial issue is whether the analysis of renewable resources economics, the standard or the modified by the present chapter, is able to identify the effects of a specific pattern of use on the "biological crucial level" of the recourse. Furthermore, it is examined whether the analysis leads towards some conclusions that can be used in developing a policy which ensures the preservation of the "biological crucial level" and hence of the "biological sustainability" of a renewable resources.

5.1.2 Structure of the chapter

Initially, paragraph 5.2 presents the standard analysis of renewable resources economics. Specifically, some crucial points of standard analysis are examined so that their relevance to real world conditions are revealed. Actually, the assumptions of the model of standard analysis are imposed to further investigation.
Then, paragraph 5.3 presents an alternative analysis of renewable resources economics that aims at refuting the problematic considerations of standard analysis. Some interesting policy conclusions are drown here.
Finally, paragraph 5.4 re-examines the effects of the open-access regime, in the light of the conclusions of paragraph 5.3. Actually, the differences of open-access regime against private ownership are investigated.

5.2 Renewable resources standard economics. The standard analysis

5.2.1 Static approach

The aim of this section is to delineate the well-known analysis of renewable resources economics and to investigate its policy implications concerning the (Sustainable) use of these resources. Our analysis in this first section will be confined to the investigation of the "static approach" of renewable resources economics, that means that time dimensions are not introduced explicitly in the analysis. Therefore, the analysis takes the well-known form of the comparative static analysis.

We start by presenting the static approach as it is described in any classical book of environmental economics (see among others Pearce and Turner 1990, Clark 1976, Maler 1974, Nijkamp 1979, Walker 1987).

A single renewable resource follows a logistic growth function, as that presented in Figure 1, if it is left without any harvesting disturbance. This growth curve means that the recourse, if it is left alone, grows rapidly in the low levels of its stock, but as the stock increases the growth rate slows down and finally annihilates, then the recourse stock reaches its maximum.

The concept of a minimum critical stock presented in Figure 1 simply implies that there is a critical level and if the recourse stock falls below this level the recourse takes the road to extinction.

The usual result of the above Figure 1 is another figure presenting the rate of growth of the recourse stock (X) as a function of the recourse stock (X). This is performed by figure 2. Note that the minimum critical level is left out in the presentation of the rate of growth in respect to the resource stock in Figure 2.

Figure 2 shows that the rate of growth increases as the stock increases until the stock reaches the level X_1, then as the stock increases the growth rate decreases until it reaches the maximum stock. The maximum stock is usually mentioned as the "currying capacity" of the ecosystem for the considered recourse.

Figure 2 permits us to introduce the concept of the maximum sustainable yield (MSY). Note that the amount of MSY is the rate of growth on stock X_1. In other words, MSY is the additional stock of the resource which is generated by stock X_1.

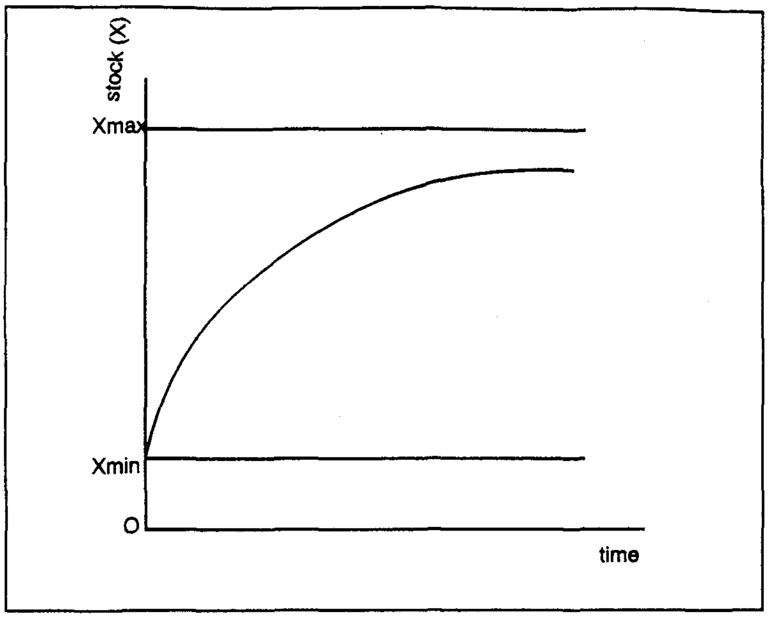

Figure 1 The growth curve

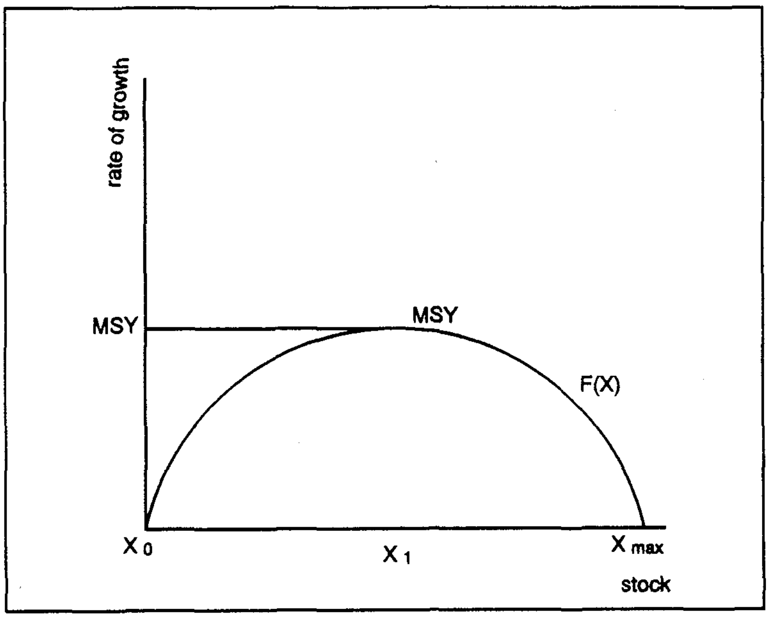

Figure 2 Rate of growth

Specifically, when the stock reaches level X_1 we are able to harvest the recourse taking a quantity equal to the growth-regeneration capacity that corresponds to stock X_1 (taking the additional stock that is generated by X_1). The regeneration capacity of X_1 stock is called "maximum sustainable yield" since it is the largest harvest that can be derived without diminishing the stock which generates this harvest. Therefore, we can repeatedly harvest

MSY in the next time intervals since the recourse stock remains at X_1 after each harvesting process. Then X_1 generates again a quantity equal to MSY that can be harvested by the next harvesting process.

MSY has two important characteristics. First, it is the highest yield that can be derived without affecting the respective recourse stock. This implies that the respective harvesting process is a sustainable one. That is to say we can repeat the harvest since the remaining, stock generates an additional stock equal to the yield that was harvested. Second, from all sustainable yields, the maximum sustainable yield is the highest, and it can occur only when the stock level is X_1.

It is important to underline here that all the resource stocks presented in Figure 2 can be sustained by harvesting, for each one stock only the additional stock regenerated by this resource and by leaving it to recover until it generates again the specific additional stock indicated by the rate of growth that corresponds to each one stock. Hence, the resource stock and its harvest are sustainable. Evidently, the sustainable harvest that corresponds to each one stock is the growth rate which corresponds to the stock; moreover, each stock is sustainable as far as we take from it only its respective sustainable harvest.

5.2.2 The introduction of the effort

The economic analysis of renewable resources encompasses the concept of the effort spent on the resource harvesting. The hypothesis made here is that the actual harvest (H) is analogous to the effort (E) spent in harvesting as well as to the particular stock (X) on which the effort applies. To phrase it differently, the effort is equal to the ratio of actual harvest H to stock X, hence $E = H / X$ (Pearce and Turner 1991).

The analysis now continues by introducing the effort level in Figure 2. If we consider the effort level as the decision variable, which means that we determine the effort level then, figure 3 shows how the stock level and the harvest actual level are determined by the decision of the effort level. The decision concerning the effort level is depicted by the E's (effort) curves, where $E_1 < E_2 < E_3 < \ldots\ldots E_5$Note that the determination of the stock and harvest level via the effort decision is assumed to be an equilibria reaching process.

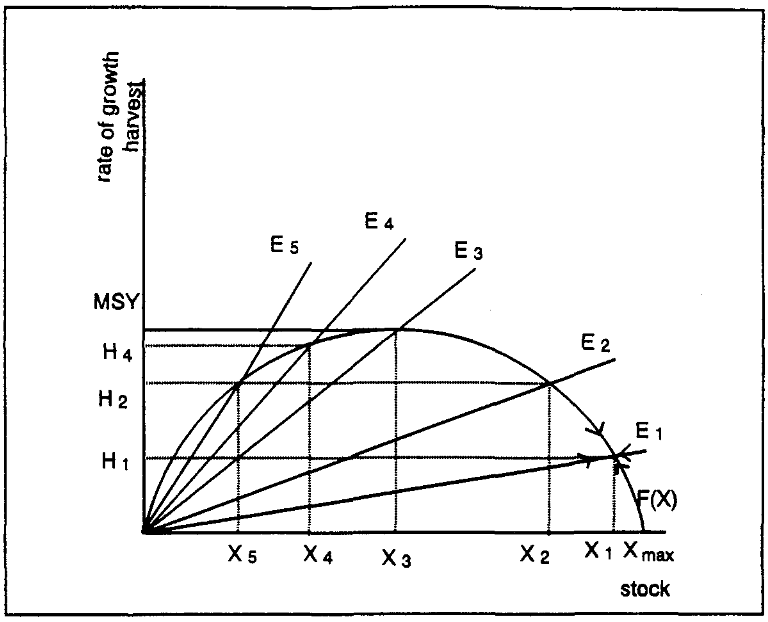

Figure 3 Growth-effort function

This equilibria process implies that for a given effort level the harvest and the stock will be determined at those respective levels which do not change as far as the effort remains the same. For instance, when the effort level is E_1 the harvest and the stock will be X_1 and H_1 respectively. All the stock levels to the right of X_1 (on OE_1 line) imply a harvest level greater than the sustainable harvest on X_1, which is H_1 and hence the stock falls. Symmetrically, all the stock levels to the left of X_1 (on OE_1 line) imply a harvest level lower than H_1, which is the sustainable harvest of X_1, and so the stock increases as far as X_1. The sustainable harvest H_1 is the only harvest level which could be derived by effort E_1 while leaving the stock at the equilibria level X_1, hence H_1 is the equilibria harvest level. In effect, when the exercised effort level is decided, the system will develop those forces which bring it back to the equilibria if random events disturb it.

Note that the equilibria, in this case, indicates also the existence of an equilibrium harvesting process. Equilibrium process denotes that its actual harvest is exactly equal with the regeneration capacity of the resource stock; therefore, the equilibrium process could be repeated. As a result, an equilibrium process is also a sustainable process. It is important to be clarified that the concept of equilibria differs from the concept of equilibrium. Specifically, the equilibria position is the position at which any harvesting process takes place. So, any process is characterized by its equilibria harvest and stock. On the contrary, all the harvesting processes are not equilibrium processes. However, note that all harvesting processes of figure 3 are also equilibrium processes.

This equilibrium process is the corner stone of the analysis since it implies in fact a sustainable extraction pattern. As a result, the problem of standard analysis becomes that of intendifing the levels of harvest and stock which correspond to a determined level of effort, so that the harvest level is sustainable. Hence the respective harvesting process is sustainable.

The crucial assumption of the above analysis is that the exercised effort remains constant, once determined, and therefore it brings the harvesting process to an equilibrium position, as described above. Once the equilibrium process has been reached then, the actual harvest is equal to the regeneration capacity of the corresponding recourse stock and so, this stock remains unchanged.
Any disturbance of the equilibrium generates those conditions which bring harvesting back to equilibrium process due to the very fact that the exercised effort remains constant. As a result, the described process at each point of the harvest-effort curve of figure 4 could be repeated as long as the respective effort level remains the same and therefore this process may be characterized as sustainable.

The problem with this crucial assumption is whether the exercised effort actually remains constant during the equilibrium approaching procedure and whether effort remains constant when the harvesting process exhibits a non-equilibrium pattern. In other words, it should be examined whether a departure from the relevant equilibria causes a change of the exercised effort level. This question is the subject of the paragraph below.

We present, via figure 3, the effects of different levels of effort on the harvest and stock levels. We examine sequential higher level of effort, $E_1 < E_2 < E_3 < E_4 < E_5$ and we obtain the relative $X_1 > X_2 > X_3 > X_4 > X_5$ stock levels and the relative $H_1 < H_2 < H_3 > H_4 > H_5$ harvest levels. The X_3 is the stock level which the MSY corresponds to, so the MSY is $H_3 = X'_3$ $(dX/t = X'_3)$.

5.2.3 The determination of the harvest and the stock level for a single owner. The standard analysis

The assumption here is that the owner of the recourse acts according to the well-known economic principle of "profits maximization". This means that the single owner aims at maximizing the profits he takes from the resource harvesting.

In order to examine now the implications of the "profits maximizing" tenet we should translate the growth-effort curve of Figure 3 to an effort-harvest function presented in Figure 4 (see Pearce and Turner 1990). Since figure 3 presents only equilibrium and hence sustainable harvesting processes, figure 4 also presents by definition only equilibrium and hence sustainable harvesting processes.

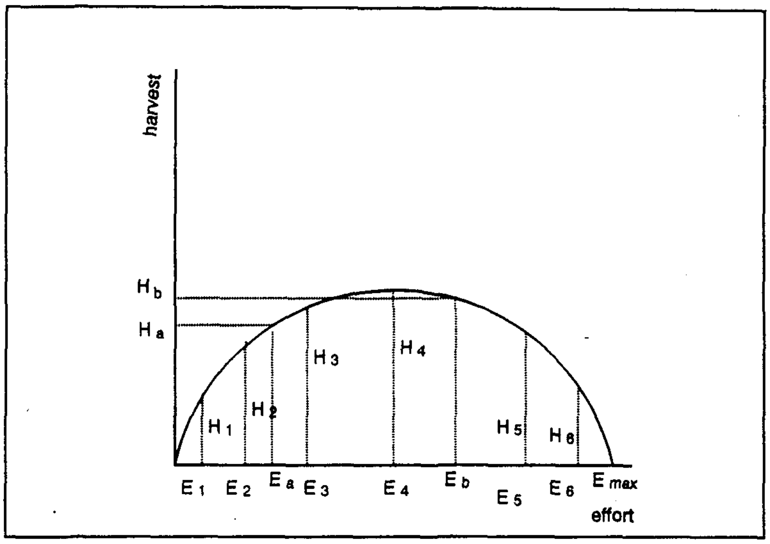

Figure 4 Equilibrium-sustainable harvesting processes

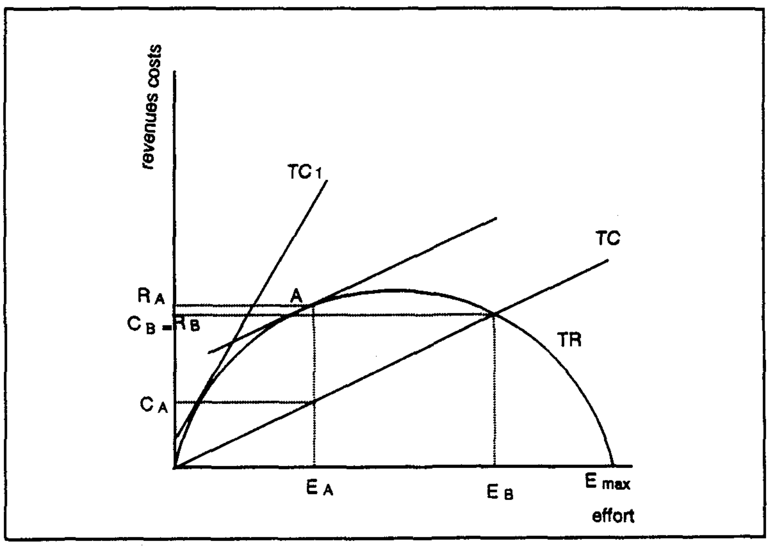

Figure 5 Costs-revenues curves

The costs, involved in the recourse extraction, are assumed to be only a function of the wage (which may include any other opportunity cost as capital cost etc.) As a result of this assumption we can formulate the function of total cost of the harvesting-extraction, $TC = W * E$, with the simple meaning that total cost is analogous to the effort spent on extraction and to the wage of the effort (the cost of the effort). The total revenue, on the other hand, is a function of actual harvest (H) and of the price of the harvest in the market. We assume that the harvest price is constant P, so we obtain the following formula expressing the total revenue: $TR = P * H$

We know from the economic analysis that if the recourse belongs to a single owner he will seek the maximization of his profits which means that the expression: $TR - TC = Profits$, will be maximized.

Here we have reached a crucial point in the analysis. From Figure 4 we derive Figure 5 which presents the curves of the total costs and of the total revenues. It is notable that the total revenue curve has the slope of effort-harvest curve presented by Figure 4. The revenue-effort curve of Figure 5 originates from the effort-harvest curve by multiplying each harvest with the price (P).

The total cost curve is a linear function of the effort so it is a straight line starting from origins of the axis.

Economic analysis denotes that, if the relevant curves are those of Figure 5, the single owner is going to choose point A, since at this position he maximizes his benefits: max (TR-TC).

The effort level is then Ea, the total cost Ca and the total revenue Ra.

The effort level EA is determined in Figure 5 by the profit maximization rationale. Then in Figure 4, we are able to indicate the corresponding harvest level Ha. By harvesting Ha the single owner maximizes his revenues.

Note that at point A of Figure 5 the relevant equilibria is indicated.

5.2.4 Determination of the stock and harvest level for an open-access recourse. The standard analysis

This case differs in one characteristic from the above analysis. Here, we do not assume that the recourse is owned by a single owner but rather that everyone is free to harvest the recourse. As a result, new harvesters are able to come up as well as existing harvesters to go out of business. From the economic analysis we know that the equilibria will be reached when the profits from recourse exploitation are dissipated among the exploiters-harvesters. In equilibria, each exploiter will be able just to earn the cost involved in the exploitation process.

Going back to Figure 5 we can indicate the equilibria point for an open-access renewable recourse. This point is where TR and TC curves intersect. Then, the effort level is Eb and the revenues are Rb = Cb.
Taking the effort level Eb in Figure 4 we indicate the harvest level (Hb) which is lower than that respective harvest (Ha) that would be determined if the recourse would belong to a single owner; on the contrary the exercised effort level is higher when the resource is open access. The higher exercised effort level, which emerges under the open access regime, corresponds to a harvesting process that takes place at a lower stock level than the respective one determined when the recourse is harvested by a single owner. This is realised as we identify on Figure 3 the effort levels of Figure 5.
As a result, it is generally accepted in the standard analysis that the open access regime leads to an equilibria at a lower stock than that of the private ownership, therefore open access increases the peril of the recourse extinction. However, such a peril is present only if there is a crucial minimum level below which the recourse is led into extinction. Otherwise, simply the recourse stock tends to come down to very low levels.

5.2.5 Policy inferences of the above analysis

The analysis usually leads to the following results (see Pearce and Turner 1990 for further clear details) which we want to impose in further examination below.

The case of a single owner:
a. The process of seeking maximum profit does not extinct the recourse. As we saw in figures 4 and 5 the harvest level (Ha) is always less than the MSY. Only if the effort is costless (W = 0) the TC curve coincides with effort (E) axis (OX axis) and then the profit maximation strategy leads towards harvesting at MSY, since at MSY the TR-TC is maximized.
b. In the case of a single owner if the cost of effort (W) is considerably high the total cost curve (TC1) does not have any common point with the total revenue curve (TR) and so no exploitation-harvesting takes place.
On the other hand, in the worst case, when the effort is costless (W=0) the resource will be harvested at MSY. In any other case, when the cost is positive, the harvest will be less than MSY.
c.In the case of open-access we have not significantly different results. We can observe in figures 4 and 5 that the open-access does not imply the extinction of the recourse at least

if there is no minimum crucial level for the resource (see figure 1). Simply, open access leads to an equilibrium at a smaller stock compared with that of the private regime. Besides, in the open access regime, the cheaper the cost of effort the smaller the equilibrium stock is, since the exercised effort level is larger under the open-access regime. Note that the figures of our study are made by the assumption that there is no minimum critical level of the relevant recourse.

5.3 Renewable resources economics. A revision

5.3.1 Introduction

The standard analysis indicates that at each stock level of a renewable recourse only the additional stock, self-generated by this initial stock, is harvested in the equilibria. Therefore, the equilibria implies also the existence of an equilibrium process. Moreover, this equilibrium process is finally attained in any case. The equilibrium harvesting process is also a sustainable harvesting process. As a result, the recourse is in peril only if there is a crucial minimum level and the exercised effort level is large enough so that the corresponding equilibria stock is smaller than this crucial stock (Pearce and Turner 1991). In fact, the examined pattern of harvesting presented in Figures 3 and 4 is a sustainable pattern. The analysis proves this, since for every effort level there is one stock and one harvest level which can be sustained as far as the effort level remains the same; these levels will finally be reached as the effort level remains the same since then the harvest and stock levels approach gradually their equilibrium position which corresponds to this particular exercised effort level. Thus the harvesting process described in each point of harvest-effort curve of figure 3 represents an equilibrium process which can be repeated when accomplished. Therefore it is also a sustainable process.

Clearly, the crucial assumption which leads to the above outcomes is that the effort level, once given, remains the same even when the relevant harvesting process moves from the equilibrium position. Then, the equilibrium is reached again at the same position corresponding to the given effort level.

However, this assumption is a douptfull one. Therefore, the way of determining the exercised effort level in a consequence of harvesting processes must be examined. Thus an individual harvesting process which starts from a given initial stock should be analyzed; this analysis will indicate the procedure of deciding for the effort level. In other words, a real harvesting-production process should be analyzed since the harvesting-production process of standard analysis, figures 3 and 4, does not represent an individual production process. Specifically, the curves of figures 3 an 4 represent at each one of their points an individual harvesting process which is pro-determined to be an equilibrium one, and hence a sustainable process.

The analysis of an individual real harvesting process permits the examination of two main issues.

First, how the harvest level is determined, and what is its relation to the self-generation capacity of the resource initial stock. It goes without saying a harvesting process starts from a given initial stock, and then the effort and the corresponding harvest level are determined.

Second, we will examine whether the effort level remains the same when the harvesting process is non-equilibrium. Non-equilibrium process implies that the equilibria harvest is not equal to the self-generation capacity of the initial stock. Non-equilibrium is called every harvesting process which can not be repeated when it is accomplished. In other words, non-equilibrium is every process which when accomplished leaves the recourse with smaller or larger stock compared with the initial stock.

Evidently, since the recourse initial stock generates during the harvesting process period an additional stock (dX), a harvesting process a non-equilibrium if its equilibria harvest differs than dX[1]. If a harvesting process is a non-equilibrium then the next process will be a different one since it starts from a different initial stock.

Actually, every equilibrium harvesting process is also a sustainable process. On the other hand, a non-equilibrium process could be sustainable or unsustainable. Specifically it is sustainable if and only if the stock of the recourse, when the process has been accomplished, is larger than the initial stock. For the natural potentials of the recourse have been increased after the end of the harvesting process (the particular harvest level can be caught again and again under suitable harvesting conditions). By contrast, a non-equilibrium process is unsustainable if the initial stock of the resource has been decreased when it is accomplished.

In a nut shell, it should be examined if the new process, starting when the non-equilibrium process has been accomplished, is performed with the same effort level as the previous one.

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[1]The concept of an equilibrium process and the concept of equilibria differ. Equilibrium is a process which exploits a resource by a sustainable way and therefore the process could be repeated when accomplished. On the other hand, equilibria is reached finally in any process of harvesting, equilibrium or not. Equilibria refers to the condition under which a process of harvesting takes place. Therefore, in any harvesting has its own equilibria's effort, stock and harvest levels. Note that in standard analysis the equilibria refers always to an equilibrium process. In effect, in the analysis of paragraph 5.2 equilibrium and equilibria are tantamount.

To repeat, this is the crucial assumption of standard analysis: if a harvesting process is non-equilibrium the effort level will remain the same so that the system will gradually adjust the equilibrium process that corresponds to the particular effort level. This gradual adjustment to the equilibrium process is described in figure 3.

The two issues are examined below under the titles "An individual harvesting process" and "The determination of the effort, revised" respectively.

5.3.2 Analysis of an individual harvesting process

If the assumption of the equilibrium harvesting process and hence of a sustainable is removed then the following problem should be examined: what will happen if a recourse is harvested. In other words, when an individual process is analyzed we are forced to research weather the equilibria harvest will be above below or equal to the regeneration capacity of the initial stock. If it is equal the stock remains stable, if it is larger the stock decreases and if it is smaller the stock increases.
The crucial question, when a harvesting process is represented analytically, must be whether this process could be repeated once it has been accomplished. In other words, the crucial issue is whether the given initial stock, after the end of the process, has increased, decreased or remained constant.
Note that, the analysis now starts from a given initial stock and the effects on it will be examined.

Let us assume that X is the initial stock of the recourse. This stock generates the additional stock dX if it is left alone. Our further assumption is that dX is generated during the time of the harvesting process regardless of the kind and the density of the effort. Evidently, this assumption is not realistic however it does not deprive the analysis of any useful conclusion.
We will use the following example to examine an individual process. The initial stock of a recourse is X = 40 units while the self-generated stock is dX = 6 units.
This recourse is harvested by three different kinds of effort, of course they would result in different harvest levels. Table 1 gives the harvest levels captured by different levels of each effort. E_1, E_2 and E_3 are the three kinds of effort and H_1, H_2 and H_3 the respective harvests. Figures 6, 7, 8 present the harvesting-production functions of the three kinds of effort. It should be mentioned that the scheme of the harvest curves is due to the law of diminishing

returns. The causes of this law, in the case of a renewable recourse harvesting and for a normal production pattern, are the congestion of the effort -effort's technical characteristics- and the stock limit; for a "reading production pattern" besides the above causes there is also the gradual depletion of the initial stock (for the distinction between normal production and reading production patterns see Chapter 3).
Assuming that the price of harvest is constant and equal to the unit, the harvest curves of Figures 6, 7, 8 are also the total revenues curves. The costs of each unit of effort are those that give the total cost curves TC^1, TC^2, TC^3. For a profit maximizing owner these curves determine H^1_1, H^2_1, H^3_1 levels of equilibria harvest for each kind of effort respectively. Suppose that $H^1_1=3$, $H^2_1=5$ and $H^3_1=5$. None of these harvests is above $dX = 6$. In effect the left stock, when the harvesting process has been finished, would be larger than the initial stock. Thus, the new harvesting process would start from a larger initial stock in all three cases. This will continue until the captured level reaches or exceeds $dX=6$.

However, there is no rule which always keeps the equilibria harvest below the self-generated stock dX, as it happens by chance in the three above cases. The equilibria harvest level, for a given initial stock and its natural characteristics depends on two factors. The first is the technical characteristics of the particular effort and the second is the price of effort which determines the slope of the total cost curve (assuming that the price of effort is constant).
The technical characteristics of a specific effort determine the scheme and the absolute level of the harvest curve, for the given natural characteristics and magnitude of the initial stock of the recourse. Generally, a technically advanced effort tends to capture a larger harvest by each exercised unit than a less advanced effort.
In the above example depicted in table 1, E_1 represents a low density effort. Its larger possible harvest is 3,2 units which is smaller than the $dX = 6$. Actually, the technical characteristics of E_1 bring early congestion in the exercised units of effort and so the low of diminishing returns confine the harvest to levels, below dX. Therefore, regardless of the price of effort the equilibria harvest would be always below dX. This holds even in the marginal case of a costless effort. Then the determined equilibria harvest is 3,2 since the total cost curve coincides with the effort axis and the parallel to this axis intersects harvest curve at its highest point where harvest (H) is 3,2.
E_2 effort is a very effective one, its largest possible harvest is 8,1 units, well above dX. The equilibria harvest level depends on the slope of the total cost curve, hence on the price of effort. This harvest could be larger, equal or smaller than dX. The more expensive the effort the less the possibilities for the equilibria harvest to be larger than dX. However, a generally valid conclusion concerning the relation between dX and the equilibria harvest

cannot be drawn in this case.It depends on the particular conditions of the harvesting process.

E_3 is a middle density effort compared with E_1 and E_2. Its highest possible harvest is 6 units. The equilibria harvest depends on the slope of the total cost curve, hence on the price of effort. It is easily realised that only if the effort is costless the determined equilibria harvest is 6 units, that is equal to dX. Hence, for a costless effort the stock of the recourse remains the same and the particular process may be repeated. Evidently, if the effort has a positive price the harvest level would be lower than dX since the parallel to the total cost curve intersects the total revenues on the left of the highest point (Hmax) of this curve. However, in case E_3 a generally valid conclusion concerning the relation between dX and equilibria harvest cannot be drawn. The outcome depends on the particular conditions of each harvesting process.

The assumption of the above analysis is that the recourse is harvested by an owner who aims at maximizing his profits. He excludes other harvesters from using the recourse.

Let us examine briefly the case of an open-access recourse. Consider Figure 6, and assume that the E_2 harvesting takes place under a common access regime. The harvesters stop exercising additional effort when the total cost (TC) just covers the total revenues (TR). So the optimum effort level is E^2_2 and it captures harvest H^2_2. The equilibria is determined at the intersection of the total cost curve with the total revenues curve. As a result, the harvest under the open access regime is larger than that determined by a profit maximizing owner, all other conditions remaining constant.

Generally, the analysis of the harvesting process cannot lead to a general rule concerning the relationship between the equilibria harvest and the self-regeneration capacity of the initial stock (dX). Indeed, the equilibria harvest could be equal, larger or smaller than dX. The only generally valid conclusion is that in the case of an open access recourse the exercised effort level is higher compared with the effort exercised in the private ownership.

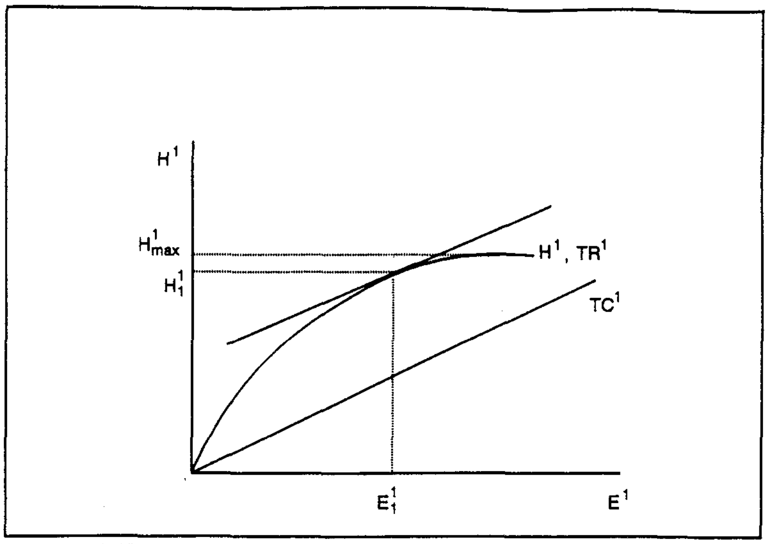

Figure 6 Harvesting process for E_1 effort

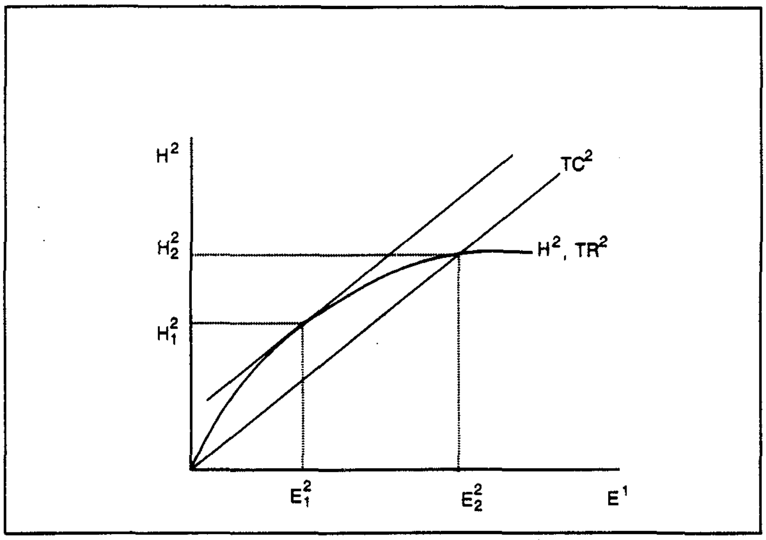

Figure 7 Harvesting process for E_2 effort

Undoubtly, there are two general trends of this relationship which should be mentioned and analyzed here. First, the more effective the effort the larger the equilibria harvest for a given effort price. Therefore the more effective the effort the higher the possibilities for the equilibria harvest to be larger than the regeneration capacity of the initial stock.
Second, the cheaper the effort the larger the equilibria harvest, for given the technical characteristics of the effort. Thus, the cheaper the effort the more possible for the equilibria harvest to be above the regeneration rate of the initial stock.

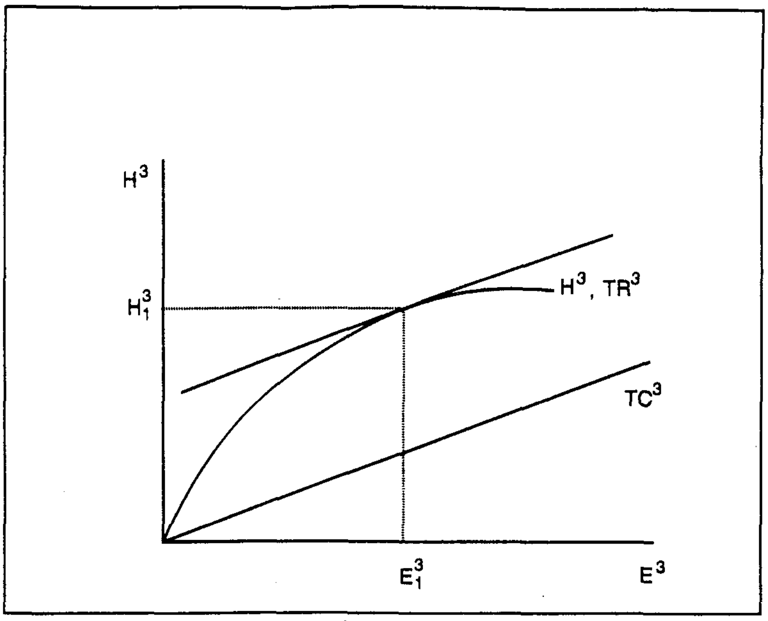

Figure 8 Harvesting process for E_3 effort

Table 1: Harvesting processes for three kinds of effort

E^1	H^1	E^2	H^2	E^3	H^3
10	0.5	1	1	5	1
20	0.7	2	2.2	10	1.5
30	1	3	3.6	15	2.5
40	1.4	4	5	20	3.6
50	1.9	5	6.5	25	4.7
60	2.5	6	7.3	30	5
70	3	7	8	35	5.5
80	3.2	8	8.1	40	6

Let us now, mention some historical observations which may be explained by the above trends. We have seen, in our examples, there may be some kinds of effort which, due to their own technical characteristics, cannot harvest a renewable recourse stock above its

regeneration capacity, even when relatively large effort levels are exercised. Actually, this conclusion may hold even if these kinds of effort are costless.
The outcome is that, in these cases, the harvesting processes are sustainable and therefore the recourse cannot be led into extinction. This conclusion explains the very fact that in the past, the traditional harvesting efforts hardly led natural resources into extinction. For even when a traditional harvesting effort was regarded as costless, since it was based on human power which had no opportunity cost due to insolation or other social factors, the technical characteristics of this effort, expressed by the law of diminishing returns, confined the actual harvest to levels below the self-generating ability of the recourse. The law of diminishing returns caused congestion of the effort and finally it led to negative marginal harvest, before the actual harvest transgressed the recourse regeneration capacity.
An example of such a mild harvesting effort can be found if we consider the hunting in Greece in the periods before and after 1970. Before 1970 the actual number of hunters was almost twice as big as the present one. Besides hunting instruments were much more cheaper since some of them were produced by the hunters. On the other hand, hunters spent much more time than today on hunting due to the traditional life conditions. In spite of these hunting conditions, we are quite sure that wildlife was incredibly richer, in stock and variety, than today.
It can be explained if we compare the characteristics of the traditional hunting with contemporary ones. Indeed, the contemporary seven cartridge carbines are comparably much more effective than the one or two cartridge guns that were used in the past; the former increase the possibility for a lucky shot more than 500%. As a result, for equal units of hunting effort (the effort variable measures the number of hunters) the contemporary hunting captures much more harvest than the traditional one, provided that the recourse stock is the same. It seems that the magnitude of the contemporary harvest of the wildlife exceeds its regeneration capacity. So, the stock started to decrease. Time passing this evolution led to a lower harvest level than the traditional one. The cause for this evolution is the gradual exhaustion of the recourse; in other words, the process of harvesting today starts from a smaller initial stock.
One may assert at this point that the difference between today wildlife and that before 1970 is caused by the use of pesticides. This is partially correct. However, the difference between past and present stocks and variety of wildlife occurs also in the mountainous areas where the use of pesticides is almost unknown. This validates our explanation about the negative evolution of the wildlife in Greece.

On the contrary, there are kinds of effort which are technically so effective that even small quantities of them, could capture a high proportion of the existing stock. This might lead

to capturing a harvest level higher than the regeneration capacity of the relevant stock. Hence, the stock decreases and therefore it might be led into extinction, if this practice goes on. As a result, even if these efforts are relatively quite expensive they may bring the extinction of the resource.
Indeed, this may account for the contemporary problems of some renewable recourse extinction. For example, consider the drastic decreases of the stock of several fish species during the recent years. The stocks has been diminished although there are quants concerning the number of fishing boats and the duration of the fishing period. The technical effectiveness of the new fishing methods make them able to catch relatively large quantities of fish within short periods although using a relatively small number of units of capital equipments (boats).

5.3.3 Determining the effort level, revised

An individual harvesting process has been sufficiently analyzed in the preceding text. Now we are able to examine whether the exercised effort level remains the same in a new harvesting process which succeeds a non-equilibrium process. Non-equilibrium implies that the actual harvest level (equilibria harvest) is unequal to the regeneration capacity dX of the initial stock X. For example, consider that the initial stock X is 40 units and the self-regeneration capacity of this stock is dX=b units. Let us assume an unsustainable process whose the harvest level is higher than the regenerated stock dX. So, the new process starts from a lower initial stock than the initial stock of the first one.
E_2 will be the effort of our example and we assume further that the price of effort determines a slope of that total cost curve which in turn defines 6 units of effort and therefore 7,3 units of harvest. Obviously, this process cannot be repeated since after its end the remaining stock of the recourse is smaller than the initial one. Thus, the new process starts from a smaller initial stock which is 40 + 6 - 7,3 = 38,7 units.
For a constant price of effort, the exercised effort level differs in the process X2 compared with X1. Thus the determined in X2 harvest may be such that X2 is either an equilibrium or a non-equilibrium process. Let us assume that this harvest is higher than the regeneration capacity of the initial stock of process X2. Hence X2 is non-equilibrium process. Therefore, the initial stock of process X3, which succeeds X2, will be smaller than 38,7 units.
X3 may be either equilibrium or non-equilibrium process. If X3 is an equilibrium process then the remaining stock after its end is equal to its initial stock. Therefore X3 will be repeated, once it has been accomplished, unless an exogenous event disturbs the conditions

described by X3. Such exogenous events may be, for example, a change of the effort price or a change in the stock level by a random event. It should be mentioned that such an event removes the system from the equilibrium position described by X3. Then it cannot be said ex-ante whether the succeeding process will be an equilibrium one or not. This depends on the particular characteristics of the harvesting process which succeeds X3.
From X1, X2, X3 processes only X3 can be described by Figures 4 and 5. For only X3 is an equilibrium process and hence a sustainable process.

Generally, a succession of unequilibrium-unsustainable processes will stop if an equilibrium-sustainable process is reached. Whether or not an equilibrium process is reached depends on the particular conditions of each harvesting. Note that only equilibrium processes are presented in figures 3, 4.
Concluding, the figures 3 and 4 describe at each point of their curves an equilibrium-sustainable harvesting process. Yet, the approach of equilibrium, when disturbed, is technically correctly described by them. The problem is that the relevance of this equilibrium approach to real world is not proper. The apparently innocuous assumption, that the effort level remains the same when the system removes from the equilibrium, accounts for this problematic representation of reality. For, the analysis represented by these figures assumes that for each effort level there is a harvesting process which can be sustained -an equilibrium process-. Yet this harvesting process is reached gradually if the system is found at non-equilibrium. For when the system departures from equilibrium the effort level remains the same; this restores gradually the equilibrium which corresponds to the particular effort level. This gradual adjustment to the equilibrium process is described in Figure 3.
However, things differ in the real world. The exercised effort level changes when the harvesting process changes. A harvesting process changes if it is an non-equilibrium one. It is noted that a process is characterized as non-equilibrium if it cannot be repeated after its end. As non-equilibrium is characterized a process whose the left stock, after the harvesting, is higher or lower than the initial stock. For the new process starts from a larger or smaller initial stock compared with the respective one of the accomplished process and therefore the new process is different.
This conclusion can be reached when an individual harvesting process is analyzed, then the mechanism of determining the exercised effort level is described as in Figures 8, 7, 6 and 5.
Specifically, when the equilibria harvest -the actual harvest captured in every harvesting process- of a harvesting process is higher than the regenerated capacity (dX) of the relevant initial stock this stock decreases. Therefore the harvesting process is a non-equilibrium and

hence an unsustainable one. Such a process will be succeeded by other processes until an equilibrium-sustainable process is reached. But the arrival to an equilibrium process is not sure; it depends on the particular conditions of each harvesting. Thus, if all sequential processes are unequilibrium-unsustainable and moreover, the actual harvest in each of them is larger than the respective initial stock then the recourse is led into extinction.

5.4 Renewable recourse exploitation under the open access regime. A revision

In 5.2 paragraph according to the standard analysis, we have concluded that the harvesting of a renewable recourse will reach an equilibrium at a smaller recourse stock under the open access ownership than if it is private. For in the open access the exercised effort is higher. However, this conclusion has been reached under the assumptions of standard analysis. That assumption implies that the equilibrium-sustainable process is reached in any case. Under this assumption the equilibrium-sustainable process that corresponds to the exercised effort level in the open access regime takes place at lower stock level compared with a private recourse, as figures 5 and 3 indicate.

Having analyzed an individual harvesting process in paragraph 5.3, the unrealistic assumptions of standard analysis have been removed. We can now examine what the open access regime really implies. Let us consider Figure 9 where a harvesting function F(x) is presented; note that all the harvesting processes, represented by each point of this function, start from a given initial stock which is the same for all of them. Thus, the effort axis presents effort levels which would be exercised on this given initial stock and so, the determination of the effort level determines also which particular harvesting process, of all presented on F(x), will take place. For instance, B and O points represent two different processes.

If the exercised effort is E_1^p the process indicated by B comes up and the actual harvest is H_1^p, while if E_2^p is the exercised on the initial stock effort then the process indicated by D occurs and the harvest is H_2^p. Note that (E_1^p, H_1^p) is the equilibria of B process while (E_2^p, H_2^p) is the equilibria of D process. These equilibria are defined regardless of weather these processes are equilibrium processes or not. Evidently, both of them cannot be equilibrium, only one may be so. Equilibrium is a process if the equilibria (actual) harvest is equal to the initial stock's regeneration capacity therefore such an equilibrium process could be repeated. In our example both processes B and D start from the same initial stock so only one of them may be an equilibrium process.

Obviously, the particular scheme of F(x) function depends on the natural characteristics of the resource and on the technical characteristics of the effort.

Figure 9 presents two distinct cases of harvesting, each of which implies a different cost of effort; in the first case the effort is more expensive than in the second case. MC_1 and TC_1 are the marginal cost and the total costs curves for the first kind of effort (the more expensive one), while MC_2 and TC_2 are the analogous curves for the second kind of effort. For each one of these cases the outcomes of the open access regime and of the private ownership are given. Thus, in the first case the open access harvesting takes place at A while the private one at B. In the second case, the open access leads to C and the private ownership to D. The two cases of figure 9 are suitably selected to depict two different outcomes.

In the first case, the open access harvest (H_1^o) is larger than the private harvest (H_1^p). Obviously, in this case the general conclusion, which is that a recourse under open access regime is harvested more extensively, holds.

However, in the second case the open access harvest (H_2^o) is smaller than the private harvest (H_2^p), therefore the general conclusion does not hold. In the second case, it is more possible for the recourse to be harvested by an unsustainable pattern when it is private than when it is an open access recourse.

Note that in all cases the exercised effort level on the open access regime is higher than the exercised effort level on a private recourse.

In general, determining whether a harvesting process is equilibrium-sustainable or not depends on the harvest level of the specific process and not on the effort level. Thus, an open access recourse might face less possibilities to be harvested unsustainable than the same recourse under private ownership. For the law of diminishing returns may lead the higher effort level, exercised under the open access, to capture a smaller harvest than the lower level that is exercised under the private ownership. This is explained by the congestion which is caused by the higher exercised effort level.

However, it is important, to note that theoretical analysis cannot lead to a general valid conclusion indicating when the open access captures a larger and when a smaller harvest compared with the private ownership. The particular conditions of each harvesting process determine the exact outcome.

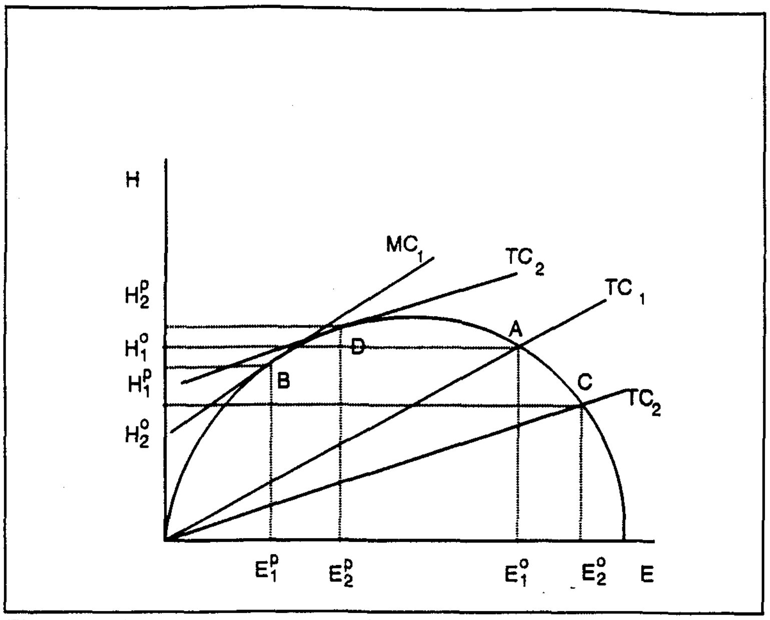

Figure 9 Open access versus private ownership

5.5 Concluding Remarks

1. The standard analysis assumes and examines an equilibrium harvesting process which directly turns to be a sustainable one. However, the crucial question must be whether a harvesting process is equilibrium or not; and if not what would happen? Thus, the standard analysis transforms the essential question to the assumption of the analysis and therefore it does not offer a basis for searching what actually takes place in a process of harvesting.

As a result, standard analysis leads to some very unrealistic conclusions. They may be summarized as follows. First, the recourse faces the peril of extinction only if it has a crucial minimum stock, below which the recourse tends to extinction, and in addition the exercised effort level determines an equilibria stock that is below the minimum crucial one.

Second, the recourse is harvested at that stock which attributes the maximum sustainable yield (maximum regeneration capacity) dX, compared with all other stocks, if the effort is costless. Of course, since it is always assumed an equilibrium harvesting process, that stock maintains because only the regenerated stock dX is harvested.

2. If the assumption of an ex-ante equilibrium harvesting process is removed then a realistic harvesting process may be analyzed.

The outcome is that there is generally no valid relationship between actual (equilibria) harvest and regeneration capacity dX of the recourse stock. This relationship depends on the particular condition of each harvesting and on the characteristics of the specific recourse. However, one may recognize two trends in this relationship.

First, the cheaper the effort the higher its exercised level and so the higher the harvest level; this trend holds in the area of the harvesting curve where the marginal harvest is positive.

Besides, the technical effectiveness of the effort influences considerably the above relationship. Specifically, the more effective the effort, the higher the harvest level captured by a given effort level. Thus, the more effective the effort the more the possibilities for the recourse to be harvested by an unsustainable pattern, all other factors remaining constant. On the contrary, there are kinds of effort technically so "ineffective" so that even if they are costless they utilize a recourse by a sustainable pattern. Usually, the traditional harvesting procedures pertain to this class.

3. Up to this point the analysis and the conclusions concern the existence of a renewable recourse; this implies that they concern the relationship between the equilibria stock level (the stock level which a harvesting process leaves when it is accomplished) and the "extinction" (minimum) crucial level. However, what should concern such an analysis is the maintenance of the "biological crucial level" of a recourse.

Generally, the biological crucial level may be a level quite larger than the minimum crucial level.

Note that the above mentioned conclusions, concerning the minimum crucial stock, hold similarly when the "biological crucial level" is under investigation, only with one modification. Clearly, this means in all above cases the "biological crucial level" may be violated more often than the minimum crucial level. For the former may be higher than the latter and therefore it could be violated by smaller effort levels, which are easier to occur.

4. This chapter examines the effects of harvesting on the stock of a renewable recourse. So the effects imposed on any other characteristic of the recourse are not considered by the analysis. However, this analysis can be extended in order to include any other kind of impact that is related with any characteristic of the recourse; provided that economic rationale governs the relevant use.

CHAPTER 6

THE TRADITIONAL PRINCIPLES OF ECOLOGICALLY SUSTAINABLE ECONOMIC DEVELOPMENT, IN RETROSPECT

6.1 Introduction

The aim of the present chapter is to briefly present and examine the ability of the most common principles-rules of ecologically sustainable economic development to fulfill their objective. These principles-rules emerge as decision-making rules which suitably confine the outcome of the decision-making rule of marginal theory as it is applied in economics. In other words, these principles-rules aim at influencing the outcome of the market's function, so that ESED may be achieved when the market function alone is not sufficient for ESED's achievement.

At this point, we will briefly repeat the conditions necessary for ESED as they have been derived from the definitions of ESED by the analysis presented in the first chapter of the present study.

Initially, we will distinguish the two main functions of the natural environment referred to as the biosphere system.

First the biosphere system forms the natural-biological frame of human existence and therefore it also forms the framework of the existence of the economic system; note that the economic system is just a subsystem of the human one. James and others refer metaphorically to this function of the biosphere as the "living room" of society or the "infrastructure" (James et.al 1989).

Second, the biosphere system provides the natural inputs for the economic production. One may also include here the capacity of nature to absorb the waste of economic production. Generally, this function of biosphere system may be perceived as that of "fueling economic system".

It goes without saying that ESED requires, first of all, the preservation of the first role-function of the biosphere system. For without its natural basis economic system can not exist, at least in the long run. Therefore, the proper functioning and the self-regeneration of the biosphere system should be preserved. By preserving them the "biological sustainability" is ensured. Actually, "biological sustainability" may be defined by those conditions which ensure the well-functioning of the natural system both in short and long run. In turn, for preserving "biological sustainability", the "biological crucial level" of any significant natural element must be preserved (see the first chapter of the present study). It seems that the concept of the "biological crucial level" is close to the concept of "safe minimum standards" (Bishop 1978), to the concept of "ecological stock constraint" (James et.al 1989), and to the concept of "critical zones" (Ciriacy-Wantrup 1952). The rationale behind these relationship is that the natural-biological basis of life must be preserved.

Next, ESED requires the supply of economic system with those natural inputs which would

be needed by the desired level of economic production e.g. growth, steady state, declining. Evidently, the desired level of economic production cannot be determined today for future generations since it requires the knowledge of these generations' preferences. Actually, ESED implies that the potentials for a sufficient supply of any desired "reasonable" level of economic production with natural inputs should be left open in the future.
This second requirement of ESED results in some uncertainty. First, there is the uncertainty concerning the desired level of production which mainly determines the level of demand for natural inputs. Second, there is the uncertainty about the supply level of natural inputs. Indeed, we do not know the future discoveries of natural resources as well as the future technical knowledge to utilize natural resources.
Besides, there exists a kind of competition between generations since the present use of resources is certainly depriving future generations of some of them (Georgescou-Roegen 1979). This implies the involvement of an ethical consideration in prescribing the conditions for achieving the second requirement of ESED.

Consequently, one may realize that there is a kind of considerable difference between the two main requirements of ESED. The first one, to maintain the natural basis, may involve an uncertainty due to our limited knowledge about the function of the biosphere system and therefore, about the exact determination of the relevant "biological crucial levels". However, since this uncertainty is rather superficial this problem is overcome by the gradually increases of knowledge and, finally by estimating approximately the relevant "biological crucial levels" until further knowledge becomes available. As a result, one may define the conditions of achieving the first requirement of ESED.
On the contrary, the second requirement involves some insurmountable uncertainties and ethical problems since we cannot predict the evolution of mankind. Therefore, no definite condition-rule can be proposed for satisfying this requirement. Characteristically, Georgescou-Roegen says that the only thing mankind may do, as far as the problem of the constant supply of natural resources is concerned, is to "minimize future regrets" (Georgescou-Roegen 1979, p.102).

In consequence, we confine the aim of the present chapter at examining whether the application of the most popular principles-rules for achieving ESED satisfy at least the first condition-requirement of ESED. Specifically, we will research weather they lead towards preserving the "biological crucial levels" and hence the "biological crucial level" of the significant environmental functions or elements.

6.2 The Principles and the achievement of Ecologically Sustainable Development

6.2.1 The Principles of ecologically sustainable development

The issue of the present section is to examine the most well known principles underlying the achievement of sustainable development. Especially, it aims at investigating their ability to lead to sustainable development.

These principles form the cornerstone of non-traditional economic policy aiming at sustainable development. As a non-traditional economic policy we mean any policy that accepts additional criteria for securing sustainability. This additional criterion stands above the traditional economic decision criteria and suitably constraints them. Traditional economic decision criteria are based on the marginal decision rule where the decisions are taken at the point at which marginal economic costs are equal to marginal economic benefits. Note that according to the marginal rule the "economically optimum protection" as well as the "optimum pollution" are determined.

The policies underlined by the existence of these additional criteria emerge as an attractive practice for securing sustainability.

We may distinguish three main principles.

a. We have to utilize renewable resources in such a way so that their harvest is not (constantly) above their sustainable yield (Pearce and Turner 1990, Pearce et. al 1988, Clark 1976).

b. The depletion of non renewable resources should be compensated by analogous increase in some renewable resources (Daly 1989a, Pearce and Turner 1990, Barbier et.al 1990).

c. The depletion of a renewable or a non renewable resources is permitted by as much as the efficiency of its use increases so that the output of the resources' use can be constant over time.(Pearce and Turner 1990, Barbier et.al 1990).

Besides the above three principles, there is the principle of maintaining the natural capital intact in order to preserve sustainable development. This principle usually takes two alternative directions: that of maintaining the existing natural capital and that of maintaining the optimum natural capital (Pearce and Turner 1990, Pearce et. al 1988).

We will examine now the ability of these principles to secure at least the prime condition of sustainable development; or in other words, to preserve the "biological crucial level" of the examined natural elements or function.

6.2.2 The Principle concerning the renewable resources

Let us start with the first principle (a). We remind two well known schemes depicting the first one the evolution of a renewable resource in respect to the time, and the second one the sustainable yield in respect to the stock of a renewable resource (see figure 1 and 2 respectively),(for further information we mention our analysis in chapter 5; see as well Pearce and Turner 1990, Clark 1976).

The first principle simply says that we secure sustainability by harvesting the resource at a point of the curve F(x) of figure 2. By doing so, we are able to sustain the corresponding stock forever. For example, consider that the stock is B then the sustainable harvest is A. The first principle denotes that by harvesting the resource by A amount each period, we secure the sustainability of the resource at the stock A. However, the principle does not say anything about what is the "optimum" level of the resources stock.

Let us go back to the concept of the "biological crucial level". In the present case, this concept implies that there is a stock level of the examined resource which must be secured in order for the "biological sustainability" of the resource to be preserved. This, in turn, means that the biological function in which the resource participate is preserved.

Note that "biological crucial level" can be, in principle, any level of range OX of the stock axis on figure 2. Let us assume that the "biological crucial level", in our case is OC. For a level of the resource lower than OC its "biological sustainability" is not ensured.

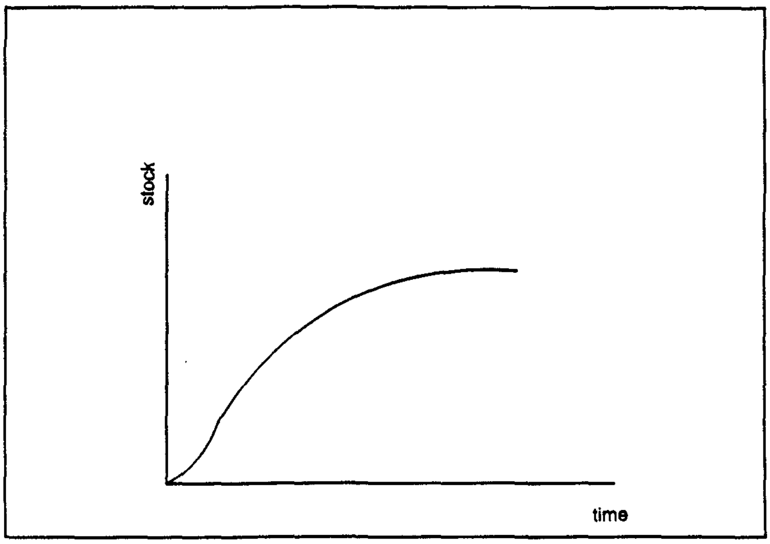

Figure 1 *Renewable resource stock*

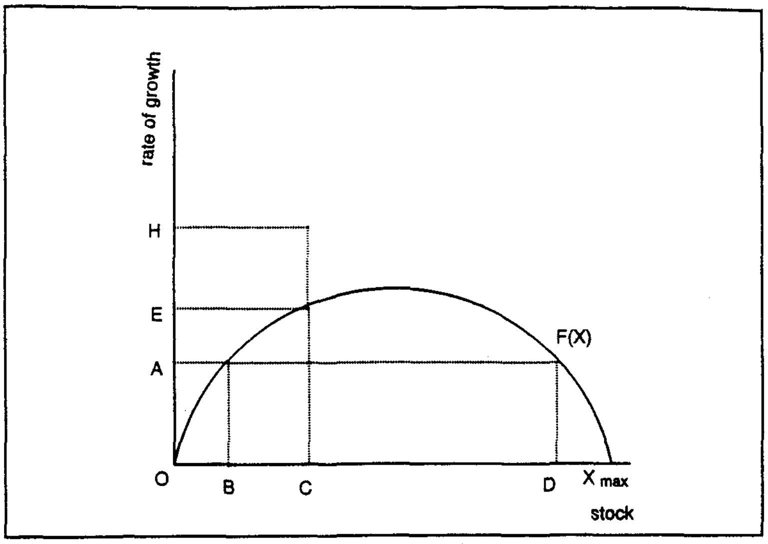

Figure 2 The rate of growth of the stock

The first principle says nothing about determining OC. As a result, we may follow the first principle and still practice a non sustainable use on the relevant resource. Suppose, for instance, that we harvest the resource by taking each time period OA harvest, then the resource stock would be either OB or OD. If OB is the stock the resource's "biological crucial level" will not be preserved, even if the principle "a" applies.

Thus, it is now evident that we need an additional criterion. That is a criterion for determining and imposing the maintenance of the "biological crucial level". This criterion is complimentary and therefore does not substitute the first principle.

Specifically, the imposition of the additional criterion simply confines the space of the resource's stock where the first principle applies alone. Indeed, imposing the additional criterion implies that the first principle applies as the sole decision rule for higher levels of the stock than the relevant "biological crucial level".

Another reason for not applying the first principle in lower resource stock than OC is the following: If the resource's stock is found for some reasons below OC level then the application of the first principle leads to disastrous results since the resource would remain below OC as long as the first principle applies. Specifically in this case, we must harvest the resource by an amount smaller than the sustainable yield of the relevant stock. Note that this sustainable yield is the self regeneration capacity of the relevant stock. So if we take a harvest smaller than the self regeneration capacity the resource's stock increases gradually towards OC level ("biological crucial level").

For example, if the resource's stock is at OB level the first principle implies a harvest level equal to OA. However, the outcome is not the desirable one; therefore the harvest level should be lower than OA so that the resource's stock increases towards OC hence, towards the "biological crucial level".

In a nutshell, the existence of an additional criterion, that of maintaining the "biological crucial level" (BCL) of a renewable resource, confines the application of the first principle to those stocks of the resource which are higher or equal to BCL. Specifically, when the resource's stock is larger than BCL then the first principle may apply ensuring BCL, when the stock is equal to BCL then the first principle must apply, and when the stock is smaller than BCL the harvest should be lower than the sustainable yield of the resource stock.
A remark is necessary in this point, if we consider that the only natural function of the resource is simply its existence, then the "biological crucial level" is close to the origins of figure 2. And when there is a minimum critical stock below which the resource is driven into extinction the "biological crucial level" may be equal to the minimum critical stock.

6.2.3 The Principle concerning nonrenewable resources

The present section examines the ability of the second principle to secure "biological sustainability".
The second principle concerns the way of using nonrenewable resources and specifically, denotes that the nonrenewable resources can be used, and therefore exhausted, as long as they are substituted by the development of some renewable resources.
However, a careful examination proves that such a management practice does not secure the "biological sustainability" of a resource but rather it disturbs it.
As we have seen in Chapter 1, each element of the natural world performs or contributes to a specific environmental function whose existence depends on a certain quantity and quality of this particular element. Thus, millions of environmental functions are performed via the existence of non renewable resources (species). Each resource contributes in a unique way to one or more environmental functions. Often, this particular contribution to the corresponding environmental function cannot be replaced by the contribution of another natural element.
As a result, the "biological sustainability" of some natural function is often based on the existence of some non renewable resource (species) in a unique way, -the same is also true for renewable resources-. There is a specific quantity and quality of the non renewable resources' stocks that warrant the sustainability of the corresponding biosphere functions. Therefore, if we substitute with another (renewable or non renewable) resource for this

specific resource beyond a level, we will disturb the relevant environmental function and since the resource is non renewable the disturbance will be irreversible.
Of course, such a substitution is possible in some cases however, it is not a general principle for securing "biological sustainability".

The managerial principles which allow for a substitution of a renewable or non renewable resource for a given non renewable one is presented in the following lines.
Each time we face a problem of substitution we are obliged to investigate the corresponding natural function to which the examined non renewable element contributes. Generally, there are three possibilities:

a. the contribution of the examined element can be replaced by the contribution of another renewable, nonrenewable or even anthropogenic element.

b. The replacement can occur only for a certain level of the non renewable resource depletion. That is to say, the element could be decreased and replaced to a certain level; however, beyond this level the relevant environmental function is endangered.

c. No decrease of the resource could be undertaken without jeopardizing the biological sustainability of the concerned part of the biosphere.

Depending on which possibility holds(a, b or c) we have to formulate our actions.

Concluding, we realize that the second principle concerning the management of a non renewable resource is not able to lead towards "biological sustainability" and therefore to secure the prime condition of an "ecologically sustainable economic development".

Let us devote here a few lines to point out why the sustainability principle concerning non renewable resources -the second principle- does not secure sustainability although it attracts really serious scientific attention. This occurrence is attributed to a misunderstanding. It seems that when somebody accepts this principle he only refers to the second role of the environment, that of providing the economic system with natural inputs, while he ignores the first role of the environment that of the biological basis of the human and economic system (Nijkamp 1989).
Indeed, under this misunderstanding, natural elements are viewed as an input to economic production, and not mainly, as elements sustaining the biosphere system. According to this limited view point -which is truly valid when "biological sustainability" is ex-ante guaranteed- ESED will occur if the second principle holds. For any elimination of non renewable natural resources will be compensated by an equal substitution of some renewable and non renewable elements. So, even in the long run, no problem will emerge

in fueling the economy with natural inputs because of this process of substitution.

The third principle does not require a separate examination, since the above mentioned criticism applies here, as well.
This principle regards natural elements only as the natural inputs of production so, it ignores the contribution of a resource acting as a component of the biosphere system. In other words, it leaves out the examination of the "biological sustainability" based on the following two statements:
a. the "biological sustainability" is given and only the second condition of ESED (the natural elements as inputs) needs to be examined.
b. the "biological sustainability" in not important, therefore natural elements are treated only as inputs to the economic production.

The first statement cannot be valid since all the principles refer to the criteria securing sustainability in general.
The second statement does not recognize that the economic system is a subsystem of the biosphere system, and hence that biological sustainability is a pre-condition for the economic system's long term survival. For example, it is tantamount to assume that the economic system will work perfectly when the temperature on earth has risen about 20 degrees, simply because there will be enough natural inputs for economic production.
We certainly know that beyond a certain temperature people will survive in limited areas of our planet and maybe for a relatively short period.

The analysis up to this point indicates that the sustainability principles of management do not guarantee the prior-condition of ecologically sustainable development (ESED), which is the "biological sustainability" and therefore they do not secure sustainability in general.

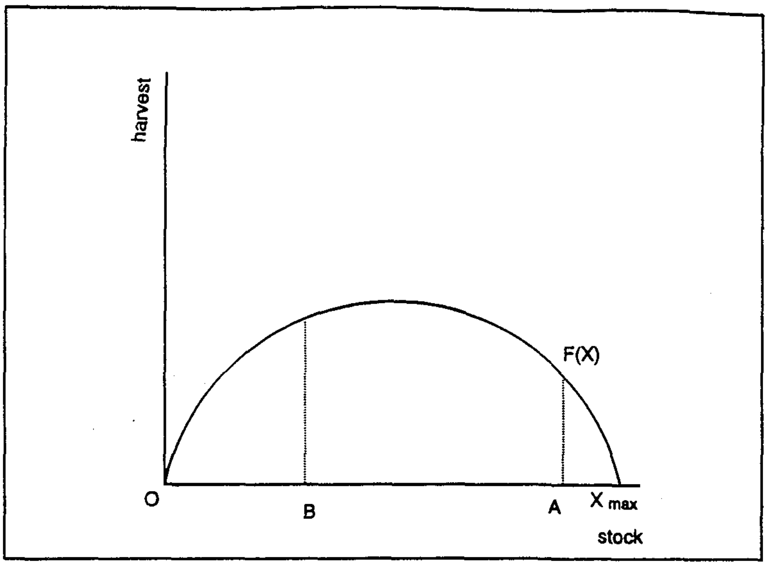

Figure 3 Harvesting a renewable resource

6.2.4 The principle of maintaining the natural capital stock

This principle rises as an attractive alternative to the three examined above, rules-principles. This principle may take two directions so it may imply either the maintenance of the current or of the optimal natural capital. We will examine the two directions separately.

MAINTAINING THE EXISTING NATURAL STOCK

Let us start with the principle of maintaining the current stock of the natural capital. This rule is based on the following rationale. The natural capital performs two unique functions: first, that of sustaining the "life support system" and second, that of fueling the economy (James, 1990, Pearce et.al 1988). There is no serious reason to believe that the future generations are not going to have the same requirements-needs for natural capital as the present one. Thus, we have to maintain almost intact our natural capital in order to bequest it to the future generations.

Let us examine now the relationship between "maintaining the current natural stock" and securing "biological sustainability".

We can distinguish three possibilities.

a. the current natural capital stock secures "biological sustainability", since the existing stock is above the critical stock and quality which we have called "biological critical level" and which suffices to maintain "biological sustainability".

b. the existing stock lies below the "biological critical level".

c. the existing natural capital is significantly bigger than the "biological critical level".

In case "a",the principle of maintaining the natural capital obviously preserves "biological sustainability" and no further examination of the subject is needed.

Case "b" implies that the currently existing natural elements do not preserve "biological sustainability", since they are below the levels which would permit unproblematic functioning of the biosphere system. As a result, maintaining natural capital simply offers either an illusion that the sustainability is secured or a temporal relief to a very serious illness, which is the unsustainable evolution of the biosphere system. Indeed, if "biological sustainability" constitutes a target to be attained, we have to augment the existing natural capital as far as the "biological critical level". However, this is not always a feasible strategy. It is only possible, when we refer to renewable element(s) whose stock is not below a minimum critical level(s) preserving the existence of the element(s) (Pearce 1990). -Note that, as we have seen in chapter 5, this crucial for the existence level does not coincide, at least always, with the "biological critical level"-. On the other hand, when we refer to a non renewable element or to a renewable one, which is below its "critical minimum level", the only feasible solution is to stop any immediately further reduction of the element; if there is any available stock left.

Let us consider now the case "c"which assumes a natural capital which is significantly above the "biological critical level". The principle of maintaining the existing capital implies no reduction of the element's stock can take place. We can easily prove that such a practice is an unnecessary constraint to economic activities. Let us consider, for example, the case of a renewable resource, for which figure 3 presents the sustainable yield in respect to the stock levels. In addition, we assume that there is no "critical minimum level".

The "biological critical level" lies on stock OB. Assume that the existing stock is OA. The rule of maintaining the natural rule capital requires to preserve stock OA. However, there is no rational reason preventing us from decreasing the stock from OA towards OB since it does not disturb the "biological sustainability" of the resource's functions.

Concluding, we may say that the principle of maintaining the existing natural capital emerges as an unclear principle. Therefore, it might lead either to preserving "biological sustainability" or to tolerating serious environmental disturbances. Neither of these results is, however, conscious. As a result, the principle is not an attractive one. However, there is a real world case in which the principle become an efficient management tool. When we face uncertainty about the "biological critical level" and its relative position compared with the existing level, we find that by maintaining the existing level is a reasonable strategy, until additional knowledge can be available.

MAINTAINING THE OPTIMAL NATURAL CAPITAL

Obviously, this second alternative implies that we estimate the optimal natural capital and then we sustain it (Pearce and Turner 1990, Pearce et. al.1988). The determination of the optimal natural capital is performed according to the following rationales:

a. the optimal natural capital is ex-ante determined equal to the "biological critical level".

b. the optimal natural capital is estimated by using the marginal rule (Pearce and Turner 1990, Zolotas 1982).

In the first case obviously, biological sustainability is preserved, since maintaining the "biological crucial level" of a natural element directly implies maintaining the "biological sustainability" of the corresponding biosphere function(s) in which the examined element is a member.

In the second case, we can prove that the marginal rule does not lead to sustaining "biological sustainability", except by coincidence. Let us regard Figure 4 which represents the process of determining the optimal natural capital via the marginal theory. Curve B presents the marginal benefits of maintaining successive stocks of the natural capital, while curve C represents the marginal costs of the same process.

Then, we should maintain quantity X_1 of the natural capital since curves B and C intersect at point O.

Assume that the level X_1 is also the "biological critical level". "Biological sustainability" then is ensured.

Assume now that the costs of maintaining the natural capital change, while the benefits remain at the same level. Such a change is very possible in the spectrum of the real world economic life. A cause could be a change in the prices of the equipment or in the measures needed for maintaining the natural capital. -Assume that such a change does not induce an equal increase of the total costs at each level of the stock. Specifically, assume that such a change causes an unequal increase of the total cost for maintaining different levels of the natural capital. This in turn causes a movement of the relevant marginal costs curve-.

For instance, this change may move the marginal costs curve to the new position C'. The optimum level of natural capital, indicated by the marginal rule under the new conditions, is X_2. Evidently, the new optimum level is lower than the "biological critical level" and therefore, "biological sustainability" is not ensured.

This process indicates the sensitivity of the optimal natural capital, as it is determined via the marginal decision rule, to changes of some economic and social factors. That sensitivity may lead towards to not preserving "biological sustainability".

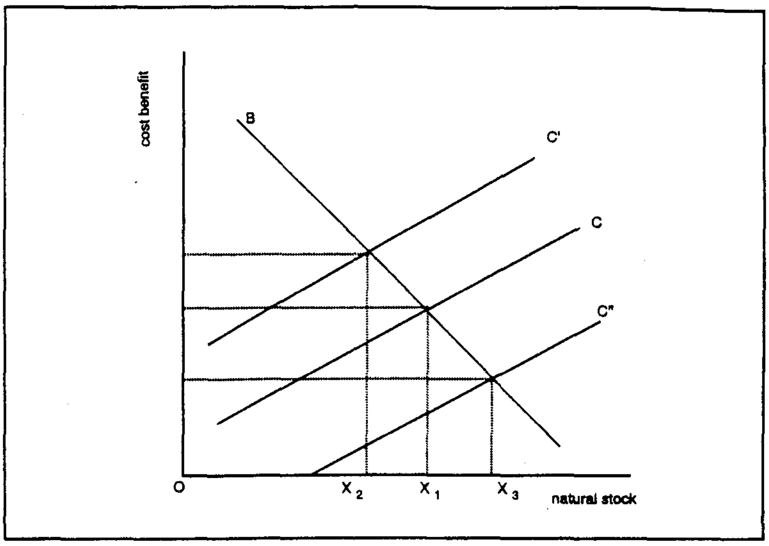

Figure 4 Determining the optimum natural capital

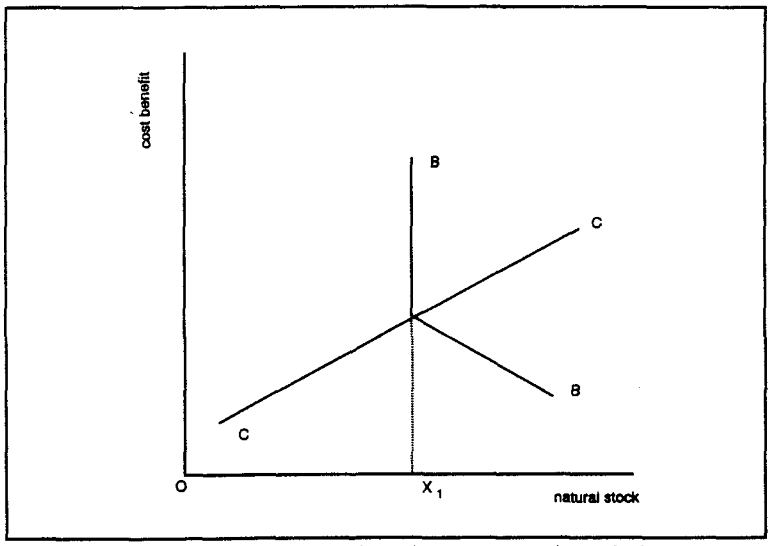

Figure 5 Modified benefits and optimum natural capital

The above analysis does not imply that the marginal rule is not valid in the case of estimating the optimal natural capital; it simply indicates that the decision rule is not adequate for the preservation of the "biological critical level" and hence of "biological sustainability".

However, if an additional criterion preserving ex-ante the "biological sustainability" exists, then the marginal decision rule may determine the optimal level. In other words, if it is ex-ante decided that the preserved capital should be higher than the "biological crucial level" then the marginal rule may be applied; in case that the optimal capital determined by the marginal rule is lower than BCL, the BCL will be preserved because of the existence of the additional criterion.

Consider again Figure 3, if an additional criterion implies that the natural capital stock cannot be less than X_1 at which it secures "biological sustainability", then the marginal rule can work for all levels above X_1. Thus, the optimum level of capital can be any level determined by the intersection of the curves B and C, above X_1. For example, if the marginal costs curve is C'' then the natural capital stock is X_3 as determined by the marginal rule.

The additional criterion would not be necessary if we faced a marginal benefits curve (B) similar to curve B of figure 5. Specifically, at the natural capital stock X_l the marginal benefits curve B tends to infinity (vertical direction). This implies that for increases of the natural capital stock as far as level X_l the marginal benefits tend to infinity, hence we have to undertake such a maintenance or augmentations of the relevant stock. For levels higher than X_l we have the familiar smooth marginal benefits curve.
To what conditions in the real world does the modified marginal benefits curve correspond? In order to get such a modified marginal benefits curve we have to assume a decision-making entity which regards that its benefits increase rapidly as the maintenance of the natural capital increases. Such a case contradicts the law of gradually diminishing (increasing) marginal benefits, a law based on the experience of the real world and is one of the fundamental tenets of economics (see for example the great acceptance of one expression of this tenet, that of downward slope of demands curve in Norgaard 1989). The validity of the law is derived by the fact that in practice almost any activity's marginal benefits are gradually diminishing as the activity increases.
As a result, we may say that the case of unlimited benefits above is an extraordinary one. Specifically, the unusual shape of the marginal benefits curve simply depicts at point X_l a rare event.
That is true, below level X_l biological sustainability is not ensured and the existence of the decision-making entity is in peril in the long run since the natural environment, in which the division unit lives decays. So the entity will reject the decision space for those levels of the resource stock less than X_l; in other words, the entity will maintain at least quantity X_l. Note that we have assumed no space span effect and no time span effect.
However, it seems that an ordinary entity (a human being or a company), considering the

ordinary benefits in the presence of space span and time span effect, cannot have the modified marginal benefits scheme. Then, we have to assume that for such a scheme to exist the relevant entity accepts an additional criterion. That criterion is maintaining the biological sustainability regardless of the economic cost and benefits associated with it.
The existence of this criterion confines the decision space where the marginal rule applies to those levels of natural capital which are higher than X_1. So, the assumption of the modified marginal benefits curve is tantamount with the assumption of the existence of an additional criterion which preserves "biological sustainability".

6.3 An Alternative Sustainability management

Having indicated the shortcomings of the most common principles underlying the strategy towards ecologically sustainable economic development (ESED), we will try to establish an alternative sustainability management preserving the advantages of these principles and expelling their drawbacks.
This alternative management confines its role to maintaining the "biological sustainability" which in turn means to ensuring the well-functioning of the biosphere system. The biosphere system is the hyper system that includes economic and human systems.
Note that we do not examine the second condition of sustainability, that of ensuring the supply of the economic production with natural input. This is the subject of chapter 7.

The general tenet of the alternative strategy is to preserve the "biological crucial level" of any environmental element which contributes decisively to and therefore determines the biosphere's function so that the biosphere's function and the "biological sustainability" are preserved regardless of what other economic conditions exist.
The issue of sustainability arises here since we are able possibly to substitute another element for the original one without violating the "biological sustainability" of the environmental function to which the original element contributes. A general principle applies to the practice of substitution and is the following: substitution is permitted only where serious conditions lead to use of the original natural element below its "biological critical level" and provided that substitution is a safe way of ensuring the "biological sustainability" of the relevant environmental function. Usually, the practice of substitution determines a new lower "biological critical level" to be preserved, since substitution has a limit. In other words, the examined element can be replaced only to a certain level. Therefore, we have to confine suitably the substitution process.

In order to clarify the above principle we use the following table.

TABLE 1

	environmental function A	economic input B
Renewable	1.substitutes	1.substitutes
	2.no substitute	2.no substitute
Nonrenewable	1.substitutes	1.substitute
	2.no substitute	2.no substitute

Table 1 follows the usual distinction between renewable and non renewable resources (species). In the horizontal dimension there are the possible function-uses of a natural resource.

First, there is the environmental function of an element; this function indicates its contribution to the biosphere system's functioning. For simplicity this function is represented by A. As a result, the function A refers to the prior condition of sustainability which is the maintenance of the biological sustainability.

Second, there is the economic function of a natural resource. Generally speaking, it is the use of the resource as input of the economic production; it is represented by B. Obviously, B refers to the second condition of sustainability, that of maintaining the supply of the natural inputs for production.

Probably there is also another function, C, that includes all the other potential functions of an element. We consider it inferior to A and B. Thus, when functions A or B are combined with function C we should only examine the functions A or B alone.

Let us examine the case of a renewable resource. There are three possibilities for it. First, the resource contributes only to the biosphere's functioning, hence it pertains to A. Second, the resource works only as an economic input without a significant role in the biosphere

functioning, hence it pertains to B. Third, the resource performs a significant environmental service simultaneously with its use as an economic input. The last possibility is the most frequent in the real world.
Table 1 examines also whether there is a substitute of the examined resource, in each one of its functions.
We will examine now each one of the above mentioned possibilities apart.

First, the resource belongs to A. The strategy here is quite clear, we identify and secure, at least, the "biological critical level" of the resource no matter what other conditions exist. Certainly, this happens independently of the existence of substitutes.

Second, the resource belongs to B, it is an economic input without performing a unique environmental role. The strategy in this case, is examined in chapter 7 of this volume.

Third, the resource belongs both to A and B. This means that the resource performs a significant environmental service simultaneously with its function as an input of the production. Then we examine whether there is or not some substitute for the resource in function A; whether the resource belongs to A1 or A2 class of table 1.
If A2 is the case -there is no substitute in the environmental function-, then in order to ensure "biological sustainability" we secure at least the "critical biological level" of the resource; no matter how it affects its function B -no matter if the resource belongs to B1 or B2 class-. This is the only practice for preserving "biological sustainability".
If A1 is the case -there are substitutes in the environmental function of the examined natural element- we research whether B1 or B2 is the case in its economic function - whether there are, or not, substitutes in its economic function-. Then, if B2 -there are no substitutes, under the current knowledge and technology, in the economic function- then we use the resource as an economic input while, simultaneously, we substitute it in its environmental function. As we have already mentioned, substituting a resource in its environmental function, usually has a limit. We have to respect such a limit so that the biological sustainability is preserved.
On the other hand, if B1 is the case -so there are also substitutes in the economic function of the resource-, since we are in case A1 we face several alternative paths towards "biological sustainability". An attractive path which strictly secures the prior condition of sustainability is the one which prescribes substituting the resource in its economic function and keeping it intact in its environmental function. However, we can substitute the resource in its environmental function, at least as far as it is possible, while consuming it for the economic production.

Finally, any compromise between these two extreme ways can be chosen.

The above analysis holds for a non-renewable resource, however, there is an important characteristic of non-renewable resources that should be taken into account when managing them for sustainability. Non-renewable resources, when used, are gradually led into extinction. As a result, in case A1B2 -the resource has substitutes in its environmental function, but there is no substitute for its economic function-, if the resource is used as an economic production input then it is led to the extinction without however, violating "biological sustainability". In case A1B1 also, if the policy of giving priority to the economic function of the resource holds then the resource is also gradually led into extinction. However, by substituting the resource in its environmental function the "biological sustainability" of the relevant environmental functioning is simultaneously preserved.

6.4 Concluding Remarks

It seems that the standard proposed principles do not lead towards ESED since they do not ensure the prior condition of ESED, that of maintaining the natural basis of life (the biological sustainability). This result is due to the fact that usually these principles were developed in order to prescribe the rules of servicing the second requirement of ESED, that of maintaining the supply of the economic production with natural inputs. Thus, it seems that the relevant authors develop these principles in order to deal with the problem of natural resources' scarcity for economic production. However, these principles are usually established as those rules which once followed lead to ESED. This is the result of the confusion between the two main roles of the natural system, as they have been developed in the introduction of the present chapter.

Consequently, we should examine separately the two roles of the natural system in the framework of ESED. Although the two rules are in reality interwoven they should be examined separately since by preserving one of them we may not simultaneously preserve the other one. Obviously, the two roles of a particular natural element are interrelated; however, when designing for sustainability, the rules-principles which preserve one role may treat the other one.

Therefore, the rules-principles for preserving each one of the roles of natural environment, each one of the requirements-conditions of ESED, should be prescribed separately.

Actually, we should first prescribe the rules preserving the first order requirement of ESED and therefore servicing the prior condition of it. They are the rules of maintaining the "biological crucial level" of any natural element which contributes to the well-functioning and self-reproduction of the natural system. Then, we may proceed with tracing those tenets that deal with the second order condition of ESED. This second order condition refers to the supply of the economic production with natural inputs.

CHAPTER 7

NATURAL RESOURCES SCARCITY AND ECONOMIC DEVELOPMENT

7.1 Introduction

7.1.1 Introductory remarks

In the preceding chapters the necessary condition of ecologically sustainable development were examined. Specifically the role of the natural environment in the existence of the human and the economic system were examined. We studied whether the solutions to the environmental problems in the framework of standard economics are sufficient to ensure the prime (first order) condition of ecologically sustainable economic development (ESED). In the present chapter a different role that the natural environment plays in ESED is examined. That role is the direct contribution of nature to the economic process as an input in the economic production. Note that it is generally possible for the natural system to sustain the human and economic systems, while it cannot sustain economic production, at a certain level at least, providing it with sufficient natural inputs. Therefore, the two roles of nature, first its function as the basis of the economic system's existence -the living room of economy- and second the provision of input in the economic production, should be examined in separately.

The present chapter inquires into the scarcity of natural resources that are used as inputs in the economic process.

Another characteristic may distinguish the analysis of the present chapter from the analysis of the previous chapters. Note that the analysis of the prime condition of ESED in fact is performed micro-economic analysis. The examined problem is the economic behavior of each user of a natural element as well as the cumulative outcome of the behavior of all relevant users. In other words, in the analysis of the prime condition of ESED we have one specific element and we investigate its utilization. Therefore, the methods of the analysis come from the domain of micro-economics.

On the contrary, when the scarcity of natural resources is examined the method is derived from the macro-economics domain, because the problem of scarcity refers to an aggregate level. Specifically, scarcity is established in the comparison of the aggregate demand for natural resources, as this demand depends on the aggregate production. On the other hand, the supply with natural inputs refers to the aggregate level of natural resources or at least to some great classes of them.

The problem of scarcity of natural resources has attracted much scientific inquiry from the very origins of economic science.

Ricardo refers to the scarcity of land as a crucial factor of economic process and therefore as a factor of social evolution. (Ricardo 1929). Malthus and Mill examine the role of natural inputs in relation to population's evolution (Malthus 1926, Mill 1900).

Since then, several contributions on the role of natural resources have been made (Jeoven 1924, Georgescou-Roegen 1971, Solow 1974). Over the past few years, however, the problem of natural resources scarcity has received a distinguished attention due to some evidence of severe scarcity of some natural resources. In addition, the delayed echo of some scientific inquires in fields other than economics, for example thermodynamics, have stimulated a serious discussion on the issue. We may mention some representative contributions to this issue. Georgescou-Roegen regards the implications of entropy law on the economic system's function and concludes that there are absolute scarcities of natural resources which will confine economic growth in the future. In addition, he speaks of the privilege of the earlier generations to use the natural resources depriving them from the future ones, as a form of dictatorship (Georgescou-Roegen 1979). These approaches are similar to those by other scientists such as Daly, Enrilich, etc. (Daly 1979, 1981, Enrilich 1981).

On the other hand, there are those scientists who assert that there is no absolute scarcity of natural resources. Specifically, as Solow implies even if there is a limited stock of natural resources, mainly technical progress and the substitution of natural inputs with produced capital may relieve mankind from the burden of natural resources scarcity; mankind may even produce without natural resources inputs (Solow 1974). Although, some scientists of this approach are not in full agreement with Solow's assertion in fact they believe that there is no crucially absolute scarcity of natural inputs (Stiglitz 1979, Young 1991).

As a result, the target of this chapter is to examine whether there is an absolute scarcity of natural resources and its implications on the economic system's function. Besides it investigates whether there are some non-absolute scarcities which may prove crucial for economic development.

Then, the "scarcity mitigating actions" and their effects will be researched. In particular, the effects of technological progress, at the discoveries of new reserves as well as of new natural resources, the substitution between natural resources and the substitution between natural resources and capital will be examined. The only criterion by which an event or an action is characterized as "mitigating natural resources scarcity" is that is not excluded by the law of thermodynamics.

Next, the human biological limits will be projected against these mitigating actions so that we will examine which of these actions cannot be achieved due to human biological limitations although these actions are not excluded by the physical laws.

Finally, the results of the whole study will be examined in the light of the present knowledge concerning the accecibility of natural resources as well as in the light of the current state of technology.

The concepts of absolute and relative scarcity should be clarified. They will be used as the corner-stones of the following analysis. Absolute scarcity refers to a resource which will be irrevocably depleted if it is used, regardless of the time of depletion and of the pattern of use. The pattern of use will co-define the time of depletion; however its depletion is a certain event if the resource is used. Obviously, absolute scarcity refers to a resource of a fixed quantity which cannot be augmented either by human or by natural processes.
On the other hand, the concept of relative scarcity refers to those resources which are not irrevocably led to depletion when being used. In fact, they are not quantitatively fixed by nature. In this case, there exist some natural or human induced processes which regenerate or augment the resources, at least, at some rate. The problem of scarcity, now, is defined in relation to the demand for these resources. If the demand exceeds their supply then we speak of relative scarcity. The effects of relative scarcity, we have learned, are depicted on the relevant prices. However, what is the effect of these relative scarcities on economic process especially in the long run?

7.1.2 Structure of the chapter

Paragraph 7.2 gives some analytical material goals which are useful in analyzing the problem of scarcity. Specifically, it introduces model that represents the natural factors of the production process.
Next paragraph 7.3, in the light of the model developed in 7.2, examines the optimistic effects of the technology improvements and of the capital substitution for natural resources inputs. Here, we try to resolve the problem concerning the importance of natural inputs in economic production, in the long run. Are natural inputs indispensable or may we produce without them?
Then, paragraph 7.4 estimates the accecible magnitudes of natural resources. These magnitudes determine, essentially, whether there is an absolute or relative scarcity of natural resources for economic use.
These magnitudes are estimated on the basis of the present knowledge of the existing reserves of resources as well as on the basis of the expectation of discovering new reserves.
Paragraph 7.5 introduces some more realistic issues than those of paragraph 7.4. Specifically, paragraph 7.5 estimates the magnitudes of natural resources only on the basis of the present scientific knowledge as well as on the basis of the certain future evolutions that can be envisaged today. Therefore, paragraph 7.5 establishes the problem of natural resources scarcity on the realistic ground.

Finally, paragraph 7.6 presents theses of some distinguished scientists on the problem of scarcity. The presentation is a critical one since the conclusions of these scientists are re-examined against our conclusions reached on paragraphs 7.4 and 7.5. Some useful conclusions are drown, then, and some misunderstandings are resolved.

7.2 A physiology model for the aggregate function of the economic process

This paragraph proposes a simple model which represents the physical elements involved in the aggregate production function and not analytically the production process. Rather, it presents the physical requirements and the physical outcome of a production process and hence of the aggregate production.

The model is : $q,w = f(k,l,m,e)$

q. stands for the useful output of the economic process (the economic goods) measured in physical terms.
w. stands for all of the rest of the output of the economic process which is not economically useful and therefore it may be called "waste"; it is also measured in physical terms.
k. stands for the physical "wear off" of the capital element. This "wear off" occurs during the production of q. quantity of the economic output.
l. stands for the physical "wear off" of the labor during the production of q. Evidently, it should be measured in physical terms, for example in kcal.
m. stands for the matter which is required for the production of q. It is measured in mass units.
e. stands for the energy consumed for the production of q. It is measured in energy units.

The m and e elements seem to be clearly understood while the k and l may need some further elaboration for neither capital nor labor are physically consumed during the production. Specifically they are service funds that provide production with capital and labor services. Their services are "consumed" during production while their material basis might be perceived to be intact (for fund elements of production see Georgescou-Roegen 1971). As far as capital is concerned, as its services are "consumed" it is also physically degradated; indeed the service "consumption" is accompanied by a physical degradation. Therefore, if the service funds are to be maintained at the same level after the production process as they

were before that, the relevant capital requires some kinds of "repairments" which involve some physical replacements. Otherwise, the fund element is totally a physical waste when the services embodied to it are used up. To mention an example, the computer by which I am writing now is built up by 10 kgrms of plastic, 5 kgrms of glass and 5 kgrms of metal; if we assume that it is designed to work for 500 hours, servicing me, each hour of service in fact degrades it by 10:500 kgr of plastic, by 5:500 kgr of glass and by 5:500 kgr of metal. Providing suitable replacement I can use it for more than a 500 hours. Then the physical degradation should be estimated by taking into account the materials for replacement. In effect, the capital fund is degradated physically during the production process; the exact amount of degradation may be estimated as equal to the amount of materials required by the hypothetical replacement for maintaining the amount of capital services intact.
Analogously, labor is physically degradated during the production process. The amount of this degradation is easily quantified by estimating the food provision that is required for maintaining the labor services intact; in fact it is equal to the energy consumption of the labor's entity during the production process; the measurement unit is then in kcal.

It is assumed that a part of the physical output q of the production is suitably transformed and then used for replacing k and l so that the production process is able to be repeated when finished. Also, there is no assumption concerning q which may be declining, increasing or constant, overtime.
Note that q is the physical outcome of the production process and not the economic output, Y measured in economic units. Indeed, Y is the economic output of the production process described by the following production function: $Y = f(K,L,E,M)$; K stands for capital, L for labor, E for energy and M for matter (Young 1991). As a result, Y may take any value in our analysis.
Noticeable, also, is that Y might increase regardless of q, at least for some range of Y. Note that it is generally possible for the economic output to increase without being accompanied by more physical output q. For economic output might include products of small physical mass (for example services) which however, have a considerably high economic value.
Attention: this evolution of Y -independently of q- has certain limitation, for all economic outputs have a material basis, information services included, and therefore whatever the qualitative characteristics of Y it cannot increase beyond some levels without respective increases in q.
All the more, if it is considered that the economic output Y applies to human uses then it should have certain natural dimensions; for example consider clothes, houses, automobiles which require those dimensions fitting to human ones.
To wit, it will be contrary to the law of matter conservation, first law of thermodynamics,

to believe that we can produce continually increased quantities of economic product Y without increasing, at least after a level, its material basis as well as q (Ayres and Miller 1980).
More important, it is impossible to envisage $Y>O$ without envisaging simultaneously q strictly greater than zero.

7.3 The effects of the technological improvements and of the capital substitution for natural resources. A resolution

The issue of how essential are natural resource inputs for economic production has been introduced in the beginning of the chapter. Here the issue will be reconsidered in the light of the conclusions of the previous paragraph.

Let us briefly repeat these conclusions.
First, we introduce a model representing the material basis of the economic production process: $(w,q) = f(k,l,m,e)$.
This model should be considered parallel to the production process model $Y=F(K,L,E,M)$. The elements of the production process are distinguished in fund elements (K,L) and flow elements (E,M). Fund elements are the agencies that perform the production while flow elements are the materials which the agencies work on, transforming them during the production process (Georgescou 1971).
Second, economic production requires the existence of a material basis, q. Thus, due to the law of matter conservation and to the human biological requirements, $Y>o$ implies $q>o$. For we cannot get a Y which could service the human needs without simultaneously producing the material structures, q for it.

From the relationship $(q,w) = f(k,l,m,e)$, representing the material basis of the production process, it follows that a strictly positive q implies directly strictly positive m and e. On the other hand, k and l are not transformed to the material basis of the production output, q or w. Rather, k and l represent the physical degradations of the K and L production factors during the production process. Simply, k and l are dissipated so that K and L provide with their fund services the production process; this degradation is irrevocable. For example, only by accident I might find a human finger or a screw-driver in my computer, however, certainly human beings and capital equipment, used for the production of my computer, have incurred a physical degradation. This physical degradation is dissipated and not

transformed to the materials of my computer.
As a result, $Y>o$ means $q>o$ which in turn implies $k, l >o$.
On the other hand, $q>o$ implies m and $e>o$, where e is the energy used during the transformation of m to q. This result comes directly from the matter conservation law. Young has reached the same conclusion based on the same law, but following a different reasoning (Young 1991, p.172). Also, Georgescou-Roegen, draws the same conclusion based on the fund flow production model (Georgescou-Roegen 1979, p.98).
To repeat the result, $Y>o$ implies $q>o$ which, in turn, implies $k, l, m, e>o$; all of them due to the first law of thermodynamics and the natural-biological dimensions and the biological needs of man.

What may the technology that augments natural input productivity offer then?

The first outcome of technological innovations may lead to increasing the ratio of Y/q. In other words, the production of some greater economic output Y with the same material output q or the production of the same Y with some decreased q is possible.
Technological improvements lead to the production of an economic output using less material elements. However, the material form of the economic output q cannot disappear altogether.
Actually, q cannot be less than some considerable large matter. Otherwise we envisage the dimensions of human beings, and hence of human needs, to be diminished to infinitisimental small quantities. As a result, technological improvements may diminish the mass in which the economic output is embodied up to a level.

The second effect of technological improvement is that it decreases the useless matter of the production process, that is, the w in the production function model. Actually, a diminished w directly implies a decreased m and e. Therefore, the natural inputs of the production process are reduced. Evidently, although this outcome is significant, it does not lead to the earth shuttering conclusion that economic production may dispense with natural inputs.

The third effect of technology innovations is that it decreases the required, k and l for the production of a given quantity of q. Practically, it means that the physical decay of capital K and labor L, required for the production of a given quantity of the economic output, decreases. This effect is the result of a qualitative advanced capital and of a more sophisticated labor which are able to provide the same amount of services with less physical decay. We can also see that the same amount of service funds of K and L are embodied in smaller physical materials. Therefore, as a given amount of services are "consumed" less amount of materials or energy are dissipated.

What are the effects substitution of capital for natural inputs?

Since capital uses technology the substitution of natural resources with capital incurs of the effects mentioned above concerning technological improvements.
Nevertheless, we will examine here the pure effects of the substitution of natural inputs with capital treating the capital as a production factor like any other. Clearly, substitution of natural resources with capital refers to $Y=f(K,L,M,E)$ production function, where K increases while M and E decrease. The effects of this substitutions may be traced as follows:
First, K is a produced element and therefore at least initially the additional capital, as a part of Y, should be produced out of M and E, in the presence of K and L.
Second, the use of K and all the more the use of increased K, directly implies the presence of k which is the physical decay of K during the production process. Therefore, K in order to maintain its ability of providing capital services requires some replacements; in fact, it requires some produced capital K_1 that has some physical dimensions. The physical dimensions of K_1 cannot be produced out of the physical dissipation of capital (k). Hence the use and the transformation of useful matter in the form of M is required for the production of K1 which substitutes the dissipated capital k.
This reasoning becomes more clear when we put before us the picture of the fund and flow production model (Georgescou-Roegen 1971, 1979). The fund elements, of which capital is one, cannot produce in the absence of some flow elements such as matter, since fund elements are the agencies of the production process. These agencies, in order to produce, require some inputs of flow elements (matter and energy). Therefore, the produced capital cannot be produced out of capital and labor alone.
On the other hand, the produced capital is required in order to substitute the natural inputs. Note that moreover, the produced capital is also needed for replacing the dissipated part of the existing capital K.
As a result, the substitution of the natural inputs with the capital is possible up to a certain level. However, since the aggregate economic outcome Y cannot be produced without natural inputs, the produced capital can not be produced without them.

Consequently, the technological improvements and the capital substitution of natural inputs may lead to the use of less materials and energy for the production of a given economic output. However, there is a strict, although undefined, limit to this evolution. Actually an economic product has some physical dimensions and so it requires some material for its production; behind this requirement is the law of matter conservation. On the other hand, the capital that substitutes these materials -natural inputs- as well as the capital embodying new technology require their production which, in turn, demands materials and energy inputs.

7.4 The problem of natural resources overall absolute scarcity and relative particular scarcities

7.4.1 Introduction

Since natural inputs are necessary for economic production, the question arising is whether natural resources suffice to feed continuously this production process. In fact, this question refers to the time horizon in which natural resources are sufficient to maintain production. This question regards the scarcity of natural resources in physical units (for other concepts of scarcity see Fisher 1979 p.249-250). Note that, the subject of what quality of natural resource reserves is used first is not examined here, since it is not relevant.
Let us put before us the model presenting the physical requirements and the outcomes of production process $(q,w) = f(k,l,m,e)$. The k and l are provided-substituted by a part of the output of the same production process. Specifically, the flows of k and l are substituted by a part of the flow q; this substitution is indispensable if the production process is to be continued at the same level in the long run. The problem, then, becomes that of examining whether the resources of m and e suffice to sustain the production process in all time -if it is to continue at the same level-.

RENEWABLE AND NON-RENEWABLE NATURAL RESOURCES

The natural resources of matter seem to be of two kinds. First, there are those material resources which are fixed in the form of material reserves. They can regenerate neither in the short nor in the long run. Probably they regenerate in geological or astronomical time horizons but this is irrelevant to human needs (Van den Bergh 1991, p. 29). This category

contains resources such as mineral reserves.
Second, there are those resources which regenerate with time under some specific conditions. Specifically, there are specific physicochemical procedures which cause this regeneration process. For example, consider photosynthesis which leads to the regeneration of plants and therefore of wood.
Almost any analysis concerning environmental economics or sustainable development follows this distinction between nonrenewable and renewable resources. We only apply this distinction on material resources only.
The sum of the accessible for economic use stock of matter of nonrenewable resources will be symbolized by Mn.
The accessible matter of renewable resources at a given time period will be symbolized by Mr.

Analogously, the resources of energy can be separated to renewable and nonrenewable. Renewable are the resources which regenerate over time, for example the solar energy reaches the earth's crust. Non-renewable are the resources which are fund in nature in certain quantities for example, the fossil fuel reserves.
The accessible quantity of renewable energy resources at a given time period will be symbolized by Er while the accessible stock of nonrenewable energy resources will be symbolized by En.

ACCESSIBLE ENERGY AND MATTER

The concepts of accessible energy and matter have been introduced in order to distinguish the possible huge amounts of energy and mass available in physical units but are not-accessible to man's use from those amounts which may be used by human beings. Obviously, this distinction is important since there are amounts of energy and mass which due to their physical conditions cannot serve human needs. For example, consider the thermical energy embodied in a cold glass of water; such amounts are largely available in the earth, and even more in the universe.
The arising question now is how are the accessible energy and matter determined?
In the case of energy the answer is clear and it is drawn from the following reasoning: Energy resources attribute energy that is measured in single energy units (for example in cal). Thus, in the process of becoming ready for use, a specific energy resource is translated in to an energy balance since some energy is used up during this procedure.
As a result, an energy resource is characterized as accessible if and only if this resource

attributes more energy ready for human use than the energy that is consumed in becoming "ready for human use".

Evidently, the amount of the consumed energy depends on the state of technology and it diminishes as technology improves. However, there is a certain limit imposed by nature on this improvement. There are two reasons behind this limit. First, it is not possible for an energy resource to consume less energy than a theoretically given amount during the process of "becoming ready for use" -or generally during any real world procedure-. This theoretical amount is independent of the state of technology and in fact cannot be reached in real world conditions (Georgescou-Roegen 1976, p.10-11). Second, a unit of every energy resource can attribute theoretically a maximum amount of energy units which is defined independently of the state of technology. At each technological stage, a unit of an energy resource attributes an amount of energy that is considerably smaller than the respective maximum. Technological improvements approach this theoretical efficiency. However it cannot be reached in reality and all the more to be overcome (Carnot 1864). As a result, the sum of the accessible energy resources includes those resources which consume while "becoming ready for human use" less energy than they attribute when they are used. Although it depends on the state of technology, there are energy resources which cannot be transformed to "accessible" resources under any technology due to the relatively small amount of energy they embody and the relatively large amount of energy which is required in order to become "ready for use".

The case of matter is quite different. The distinct point is that there are numerous kinds of matter for which there cannot be a common measure as far as their use in economic production is concerned. Let us proceed to this conclusion gradually. Like energy, accessible matter depends on the amounts of matter and energy that are spent during the process of bringing an existing kind of matter to a site and form that are suitable for economic use. These amounts depend on the state of technology; however there are some limits technology cannot overcome. These limits are specific for each kind of matter. Unlike the case of energy the existence of many kinds of matter and the millions of it's uses in the production process prohibits establishing a general rule concerning the distinction of matter between accessible and non accessible. It is generally possible to consume a large amount of a specific kind of matter (and energy) so that a small quantity of another kind becomes accessible; this could be economically profitable since the economic value of "the becoming accessible" matter is greater than the economic value of the consumed matter plus the economic value of the consumed energy.

Essentially, economic terms determine the amount of accessible matter. However, even here there is a natural limit imposed by the consumed energy during the process of becoming accessible a particular matter. If the required amounts of energy is huge and hence not

accessible then the respective matter cannot become accessible.
In order to evade the arising complicated problem of determining which part of matter is accessible, we will assume for further analysis the very optimistic thesis that all the matter of earth's crust is accessible -the problem of recycling will be introduced later-.

Having traced the concepts of accessible energy and matter, it is now possible to research the problem of natural resources scarcity. In other words, the amounts of accessible matter and energy will be estimated. These amounts will be examined in both earth's and universe's dimensions.
Specifically the problem is what particular kind of scarcity the Mn, Mr, En and Er impose on the supply of economic production with matter and energy. Therefore, the dimensions of Mn, Mr, En and Er should be estimated. Actually, this chapter deals with this estimation at two levels. First, the study is confined to earth and second, the study investigates the same issue at Universal conditions. This because of the continuous exploration of universe by mankind.

7.4.2 Absolute and relative scarcity of energy

EARTH'S DIMENSIONS

The earth is an open thermodynamic system as far as energy is concerned since it accepts continuously the solar energy flow. Besides there are some other energy reserves which are embodied in certain material forms in the crust of earth. Note that no other energy resource is involved in earth's energy balance.

What part of these energy resources is accessible for economic-human use? Although the answer is related to the technological state, marginally, we may assume that all the unused energy reserves of earth are potentially accessible. Besides, a high proportion of the solar energy flow may become accessible. Specifically solar energy becomes partially accessible without energy spending because of the intervention of photosynthesis. Besides that, human beings may use some man made instruments to capture another portion of solar flow; this last portion has a limit due to the energy consumption for capturing solar energy. Hence, the total amount of solar energy that intersects the earth cannot become accessible. Mankind is confined to harness a small portion of it.
Let us symbolize the portion of the accessible flow of solar energy, at a given time period,

as Er since this flow regenerates. On the other hand we symbolize the sum of earth's embodied energy resources as En since undoubtly they cannot regenerate.

THE PROBLEM OF SCARCITY

En can not be augmented either by new discoveries or by technological improvements. Clearly, new discoveries are excluded by the finite status of the earth, while technological improvements enable only to efficient use of En. However, even in the theoretically maximum efficiency, each use of a part of En renders En irrevocably smaller. In addition, substitution among the terrestrial energy resources does not effect En since it is the sum of all these resources.

As a result, En imposes an absolute scarcity which cannot be overcome with technological improvements, exploration or substitution.

However, En is not the sole energy resource; there is the flow of solar energy reaching earth which at a given period is Er. Whatever the use of Er, it will continue to flow in the next time interval. Solar energy will reach earth until the irrevocable death of our solar system. This death is the only absolute scarcity that solar energy imposes; before it, we envisage no other absolute scarcity. Moreover, solar energy reaches earth independently of human will at a rate which cannot be changed by man and therefore, the use of solar energy does not deprive its "deposit".

In effect, the sum of energy resources (En + Er) does not result in absolute scarcity but except at the occurrence of the death of the solar system. However, there may be a kind of relative scarcity similar to that of Ricardian land. Namely, if solar energy reaches earth, it can be envisaged as a renewable resource imposing contemporarily an upper supply limit, each time, then it can perceived to function as the Ricardian land. Although, the Ricardian land dose not impose an absolute scarcity it brings a quasi-important relative scarcity for the agricultural production in the long run (Ricardo 1829).

In the other hand, it should be professed that there is the absolute scarcity of terrestrial sources of energy.

UNIVERSE DIMENSIONS

The crucial question arising now concerns the implications of thermodynamics laws on the human exploration for new energy resources in universe. Certainly, this question sounds very vague however, we are forced to examine exploration of the universe in relation to energy

accessibility due to the human orientation towards this exploration. The study excludes those evolutions which contradict the laws of thermodynamics. In other words, we will try to exclude those evolutions which are excluded by current scientific knowledge.
Thus, it is not excluded by thermodynamics laws that some materials embodying energy might be discovered in the universe. Provided that there will be the suitable technology for transferring them to earth as well as for exploring them, these materials might prove to be accessible energy resources. It should be stated that "suitable technology" means the technology which makes possible the transportation and use consuming less energy than the energy attributed by the "imported" materials.
As a result, discoveries of energy resources in the universe are not excluded by the entropy law. However, undoubtly relevant indications have not become available up to now.

EVOLUTIONS MITIGATING SCARCITY

Such evolutions, include technological changes, discoveries of new resources and substitution among resources.
In the case of terrestrial energy resources all these evolutions have been already examined. On the other hand, the solar energy may raise some interesting hopes for harvesting it more intensively. Therefore it is interesting to trace the limits of the relevant hopes.
First, not all the solar energy flow that reaches earth can be accessible for human use. Besides the direct accessible solar energy captured by photosynthesis, any other use of solar energy implies some energy spent on capturing that solar energy. Technological changes may diminish this energy consumption, however there is a physical limit. In effect, although we do not know the exact limit of the proportion of the accessible solar energy flow to the total energy flow, this limit does not allow the use of all solar energy flow.
Second, one may hope to increase the solar energy flow that intersects earth's atmosphere. Certainly this hope is not well-established since we cannot harvest the sun directly. For example, even if we put mirrors above earth's surface we simply diminish equal amounts of earth's surface which captures the solar energy flow.

HUMAN BIOLOGICAL LIMITS

These limits probably will prove crucial in the exploration of space for energy resources; the idea comes from Georgescou- Roegen (Georgescou-Roegen 1976).
Human beings cannot survive in universe without some specific instruments since human

life requires oxygen in a specific form; besides, human beings cannot survive in the presence of several radiations. Both requirements impose certain constraints to human ability to explore, and all the more to exploit universe.
In addition, there is another constraint, that of time. If it is assumed that an energy resource would be found outside our solar system, by the speed of light, we would need 18 years to move a part of that resource to earth (Georgescou-Roegen, 1976). Could the industrial production process wait for such an indirect resource of energy which certainly would be accompanied by breaks due to accidents etc.?

CONCLUSIONS

Concluding the issue of energy scarcity we may mention the following results: First, there is the absolute scarcity of terrestrial energy resources.
However, this absolute scarcity does not impose a general absolute scarcity of the accessible energy resources. For the solar energy will continuously supply human activities with energy until the death of our solar system.
Second, although the present knowledge does not allow exploring and exploiting energy resources in the universe, such an evolution is not excluded by the thermodynamic laws. Is, therefore, such an evolution possible? We cannot answer this question today.

7.4.3 Matter scarcity

EARTH'S DIMENSIONS

The matter resources raise a very interesting issue. Are the accessible matter resources quantitatively fixed by nature and therefore they do not regenerate or are there some matter resources that regenerate by time?

The common thesis is that the earth is endowed by nonrenewable matter resources because the earth is a closed thermodynamic system as far as matter is concerned (Georgescou-Roegen 1976, Daly 1976, Young 1991).
On the contrary, we assert that the earth is endowed by both nonrenewable and by renewable matter resources although certainly we accept that the earth is a materially closed thermodynamic system. Essentially, the sum of earth's matter is fixed and given by

astronomical procedures. However, there are numerous kinds of matter, some of which are regenerated by some processes that transform one kind of matter to another.
These processes are some physicochemical natural procedures which rely on the earth's geological and meteorological conditions; they involve the presence of some energy forms originated by the solar system, such as solar energy, winds, etc.
All these procedures lead to the physical regeneration of some specific kinds of materials. Note that these processes may be explained by analogy with the example of water circle in nature. The sum of water, ground, resources and seawater, could be considered as roughly constant; however, due to some geo-meteorological procedures some water resources regenerate continuously although they are irrevocably flowing.
The most important example of physicochemical processes that regenerate some kind of matter is photosynthesis. Indeed, photosynthesis transforms several materials to wood, vegetables and oxygen. Of course, photosynthesis requires the presence of solar energy for the material transformation to take place and therefore it depends on the uniquely specific geo-meteorological conditions of earth.
Consequently, although the earth is a closed material system there are transformations from some kinds of matter to others and therefore several specific kinds of matter are renewable in earth's conditions.

As noted above, there are, in aggregate, two kinds of matter resources, renewable and non-renewable; let us symbolize their quantity at a given time Mr and Mn respectively.
The effect of the existence of renewable resources on the scarcity of matter is very important since it implies that there is no absolute scarcity of matter. In other words, the resource's material base is not fixed (Ayres and Kneese 1989 p.105). -To repeat, we have assumed optimistically that the sum of earth's crust matter is accessible if it is in unused form. The result of this assumption obviously, is that any scarcity problem which arises can not be mitigated by new discoveries- .
On the contrary, if the matter resources of the earth had been fixed (they had all been non renewable) there would have been an irrevocably absolute scarcity of matter. -Here it should be stated that Yough, asserts that there is no absolute scarcity of matter, although he regards the matter resources as fixed; this approach shall be examined later (Yough 1991).
Why? Because then the resource base would have been the initially given quantity Mn. Economic production uses for each economic output, a quantity equal to m strictly greater than zero. Then, whatever large the Mn and small the m there would have been an end of Mn. This end would have been the absolute scarcity of matter. The only evasion of this absolute scarcity would have been a 100% recycling. But, as it shall be indicated below

100% recycling is impossible (Yough 1991).

Consequently, the renewable resources may be used without the danger to run out. However, there is a serious additional constraint. Some of the renewable resources are exhaustible (Van de Bergh 1991). That is to say, they might be led into extinction or to drastical reduction of their ability to provide new accessible matter if they were utilized at high intensity or by some specific patterns. For example, consider photosynthesis that is performed by plants. If the stock of plants is reduced certainly, diminished photosynthesis will take place. Note that in the marginal case that all the plants of the earth were cut, then photosynthesis would not occur but only to an infinitesimal quantity sustained by some kinds of grass.

On the other hand,there are some renewable resources which are inexhaustible and therefore, they keep their ability to regenerate matter almost intact under any pattern of use. For example, consider land's ability to grow plants, although this ability may be decreased by extensive use it cannot be reduced to an infinitesimal quantity.

As a result, some renewable resources pertain to the class of exhaustible resources therefore, under some utilization patterns they become extinct. However, there are renewable resources that are almost in exhaustible under any pattern of use. Note that photosynthesis which is the most essential process of regenerating accessible matter pertains to the class of exhaustible resources.

Finishing the analysis of scarcity of matter in earth's dimensions we may draw the following conclusions: First the accessible matter resources are of two kinds, renewable Mr and non-renewable Mn. So, there is no absolute scarcity of matter since renewable resources and specifically the non-exhaustible ones provide continuously new accecible matter. On the other hand, the non-renewable resources sooner or latter will be used up if they are utilized.

UNIVERSE LEVEL

Here, we examine whether laws of thermodynamic exclude the possibility of finding resources of accecible matter in the universe. It seems that entropy laws do not exclude suchan evolution. However, it would require some specific provisions. Specifically, a sufficient large amount of energy as well as of matter is required so that matter resources found in the space can be transported to the earth.

EVOLUTIONS MITIGATING SCARCITY

From the assumptions of our analysis, it stems that neither a substitution among matter resources nor a technological change that would augment resources nor new discoveries lead to any alteration of the above reached conclusions. Only the marginal case of 100 % recycling offers some new prospects. Specifically only 100% recycling leads to the condition of no absolute scarcity of the non renewable resources since they could be used repeatedly without any loss. Unfortunately, an infinite amount of accecible energy is required for 100% recycling therefore it is impossible(Georgescou-Roegen 1976). In addition, 100% recycling is excluded by the fact that all real world processes, biological and industrial, are less than 100% efficient and so is recycling (Ayres and Kneese 1989 p.103). In effect, although the feasible recycling may lessen the problem of material scarcity, it cannot solve the problem of the absolute scarcity of non-renewable resources.

To summarize the problem of matter scarcity, we repeat that there is no absolute scarcity of matter resources because photosytnesis mostly and some other hydrogeochemical processes transform some materials to others and so they regenerate naturally some accessible matter forms. More importantly these processes also constitute the bases of human life by providing the most indispensable materials for life such as oxygen. However, all renewable resources are not non-exhaustible. Indeed, there are some patterns of use which may exhaust the exhaustible renewable resources.
On the other hand, there is an absolute scarcity of non-renewable resources. This implies that when they are used gradually, they are dissipated irrevocably at some rate and therefore, they will come to an end. However, this absolute scarcity of nonrenewable resources does not imply an overall absolute scarcity of matter. There exist the renewable matter resources which, under the constraint of excluding some patterns of their use, will provide with matter in all time until the death of our solar system.

7.5 Some Pragmatic Issues

7.5.1 Introductory remarks

Paragraph 7.4 examined the implications of the thermodynamics laws on the scarcity of natural resources and specifically, on the limits imposed by the respective physical laws. Therefore, these limits were defined regardless of the current anthropogenic involvement with the issue on hand. In effect these limits were determined, regardless of the known reserves of matter and energy, from the current state of technology and the current demand of natural resources. The present section addresses the problem of scarcity in the light of present conditions as well as in the light of the certain future evolutions. To clarify, future events which are certain to occur are taken into account while no uncertain speculations about future are made. Generally, the issue of natural resource scarcity is now examined under the conditions which are determined by the current knowledge about accecible natural resource for now and for the future, about the technology for using these amounts, and about projections-indications for their demand.

7.5.2 Energy scarcity

ACCECIBLE ENERGY

Let us examine first the prospects concerning the accecibility of energy resources. From the beginning it should be clarified that there is neither currently available knowledge nor a certain prospect of obtaining such knowledge permitting "imports" of energy resources from the universe. Therefore a pragmatic analysis should only examine the earth's energy resources and the solar energy available to earth.

The main current energy resource are the deposits of fossil fuels. They are certainly limited and the new discoveries are not expected to mitigate considerably the relevant scarcity. Almost all areas on earth have been searched for fossil fuel and so the available reserves can be approximately estimated.

The second energy resource is nuclear power. According to current technical knowledge about it, the nuclear power cannot be considered as an unlimited resource since the raw material required for its applied form, uranium-235, is available in limited quantities. Besides, we should bear in mind the formidable risk of pollution that nuclear power implies. The hopes for other forms of nuclear energy like that coming from the deuterium-deuterium reaction have not materialized because there is no available knowledge currently, concerning their practical use.

There is still the renewable solar energy. It is available on earth at greater amounts than the portion used. Therefore, as the current knowledge and the certain future technological evolutions imply, it is possible to increase the portion of solar energy that is used. This becomes more feasible as the economic cost of capturing solar energy decreasing.

DEMAND FOR ENERGY

The demand for energy inputs is determined by four factors. First, the production of "sophisticated" service increases in advanced industrial societies(Ayres and Kneese 1989). Their production often requires less energy inputs than the production of goods oriented towards satisfying basic human needs. However, this evolution is linked to the rate of economic growth, and hence to the rate of demand and not to their absolute level. It should be remembered that the production of services does not substitute the production of basic goods. Actually, the production of the former is additional and does not influence significantly the total production for basic goods and hence its energy requirements.
The second factor refers to the application of new production methods which are less energy consuming. This evolution is the more promising one.
The third factor in energy demand concerns the very fact that gradually several activities performed traditionally by human and animal labor are now performed by mechanical agencies. Note that human and animal were mainly based on renewable resource consumption, like foods produced by photosynthesis, while the modern agencies-machines-are based on the consumption of nonrenewable energy resources like fossil fuels. More importantly, in industrial societies human life and therefore human power are now increasingly based on non renewable energy resources for food production, transportation, shelter, heating etc. Thus, this third factor of energy demand works contrary to the first one.
The fourth factor originates from the very fact that only a proportion of the world's population lives under traditional conditions. This implies two main outcomes: First, the per capita consumption is relatively smaller than in industrial societies and second, this smaller consumption is based mainly on renewable energy resources. In effect if these populations living traditionally gradually adopted the western way of life, a radical increase in the energy requirements would be expected. This increase would be oriented towards nonrenewable resources as in industrial societies.

As a result of the above considerations concerning the availability of accessible energy and the prospect of evolution of its demand, it is not possible to draw a solid conclusion for the prospects of the energy scarcity, although it is certain that there is no absolute scarcity. The scarcity that concerns mankind today is not absolute but relative. The relativity is defined here according to the relationship between demand and supply of energy in physical units. This relative scarcity may prove to be a quasi-absolute limit to economic growth.
In order to evade any possible misunderstanding, it should be stated that any possible scarcity of energy which might impose a quasi-absolute limit to economic growth does not imply also the end of mankind due to energy deficit. Indeed, mankind may survive any other

energy scarcity but the absolute scarcity imposed by our solar system's death. In any other case, there would be solar energy that would continue to flow and thus to maintain mankind. However, the population level, the organization of the relevant societies etc. cannot be forecasted today.

Finally, another issue related to energy scarcity should be clarified. Namely, the confusion between total demand for energy inputs and the respective demand per unit of CNP must be avoided. Every analysis concerning the problem of energy scarcity must examine the total demand for energy inputs since it determines the respective scarcity. Of course, energy demand per unit of GNP is an important indicator since it reveals the margins of economic growth in the light of a given scarcity, absolute or relative. However in order to conclude whether there is an absolute or relative scarcity, and the time of its occupance, we have to examine the total requirement for energy inputs. Let's illustrate this with a simple example. Consider that the total amount of non-renewable accecible energy is 100 units; moreover the total amount of renewable energy becoming accecible at each time period is 10 units. The ratio of energy inputs to GNP is 2 (the consumed energy's units for the production of a unit of GNP). Obviously, this ratio does not say anything about the energy scarcity. Only if the total GNP is known and therefore the total energy input can be estimated, we can estimate the energy scarcity of the relevant society. For example, if GNP=50 units, the required energy is 2*50=100 units and then a serious energy scarcity exists, while if GNP=5 the required energy is 2*5=10 units which is equal to the supply of renewable energy there is no serious scarcity.

7.5.3 Matter scarcity

ACCESSIBLE MATTER

The current technical\scientific knowledge as well as the knowledge about the supplies of matter lead to the following conclusions concerning the amounts of the accecible matter resources.

First, there is no feasible way of importing matter from the universe. To wit, the feasible reserves are the non-renewable together with the renewable resources of the materials on the earth's crust.

The non-renewable resources are quantitatively fixed and therefore they will be exhausted sooner or later. However, since there are several kinds of matter the substitution among them may send away the time of a serious absolute scarcity of non-renewable materials. On the other hand, renewable resources prohibit an absolute scarcity of matter. However, it should be noted that some renewable resources have been eliminated in stock and variety because of their intensive use. Indeed, since some of the renewable resources are exhaustible their stock has been decreased so that their regeneration capacity has been reduced drastically. More over, this evolution will continue as far as some of the present patterns of their use continue. For example, consider the case of the Amazon's forests, which are obviously a renewable material resource. Due to the current use, they have decreased and therefore their regeneration capacity has been dramatically reduced. Consequently, some of the renewable resources of matter, the exhaustible ones, are in danger of extinction or of drastically decreasing of their quantity. This evolution, although it does not imply an absolute scarcity of matter, since there remain the quasi-inexhaustible resources, results to a drastic decrease of the accessible matter and hence, to a considerable problem of relative scarcity.

As far as the prospects of demand for material inputs are concerned the conclusions are similar to those developed in the case of energy.

Concluding now the issue of matter scarcity in the light of the current knowledge concerning the prospects for the availability of matter resources as well as the prospects for their demand for economic production the following conclusions may be drawn.

First, the current and the past growth has been based on both renewable and non-renewable material resources. Specifically, the tremendous industrial growth has been based on some particular kinds of material resources. Since the matter of earth's crust is not homogeneous, some important materials have become or are becoming relatively scarce. In particular, mankind faces today the absolute scarcity of some crucial nonrenewable materials. While, some renewable-exhaustible resources have been drastically decreased so mankind faces their relative scarcity.

Second, responding to the problem of these particular scarcities mankind enters the process of recycling matter. Moreover, new production methods allow the substitution of new materials for the scarce ones. However, this substitution will sooner or later render the new material scarce.

As a result, mankind cannot avoid the problem of absolute scarcity of non-renewable matter resources. Rather, this scarcity might be directly envisaged today. Besides, the growth requirements and the current population needs seem to exceed the regeneration capacity of renewable resources, at least of those currently being used. In effect we harvest not the regenerated amount of them but rather a significant portion of their stock. Therefore, renewable exhaustible resources have been decreased.

In general, it should be stated that the above results do not lead to a solid conclusion concerning the exact form of future scarcity of material resources, but, it only reveals some sides of the problem. In other words, we cannot say when and what economic activities will face serious material scarcities. Certainly there is an absolute scarcity of the nonrenewable material resources but neither the time of end can be estimated nor the effects of this scarcity can be anticipated.
Similar to the conclusions reached in the case of energy scarcity, the scarcity of matter will not lead to the extinction of mankind but there is no absolute scarcity of matter; there will exist renewable nonexhaustible matter resources which will not become extinct under any pattern of use.

7.6 Ayres, Kneese, Young and Georgescou Roegen in retrospect

7.6.1 Introductory remarks

The aim of the present section is to examine some crucial conclusions, concerning the scarcity of natural resources for economic use, which have been drawn by some distinguished scientists. From the beginning it should become clear that the present section does not offer a critique on the entire work of these scientists. Rather, only some problematic conclusions in their works are re-examined here in the light of the conclusions reached in the preceding paragraphs.

7.6.2 Ayres and Kneese

The first conclusion of their analysis which needs re-examination is that there is no lower limit to the extracted materials required for producing a unit of GNP. In other words, the ratio of extracted material to GNP does not have a lower limit (Ayres and Kneese 1989 p.99 and p.114). Here, it should be clarified that this approach differs from the optimistic approach that the above ratio may take a very small figure compared with today's figures. This optimistic approach has been expressed by several scientists. Among them are Ayres and Kneese. Note that this optimistic approach is based on the effects of first, recycling, second new "lean" production methods and third the future orientation of production towards service goods.

There is certainly, a lower limit to the ratio of extracted matter/GNP, although it cannot be quantitatively estimated at present. At each time the figure of the ratio depends both on the state of technology and on the form of the economic output (GNP). Since we cannot know the projection of these two factors we do not know the exact future value of the extracted matter/GNP ratio.

Actually, to believe that there is no lower limit to the extracted matter/GNP ratio is tantamount to believe that we can produce GNP without material input. Note that the exclusion of 100% recycling implies that each time we use some matter, a portion of it is dissipated irrevocably. Therefore the infinite reuse of a given amount of matter is an impossible dream since finally all this matter will be dissipated. In effect, to believe that there is no lower limit to the extracted matter required for the production of a unit of GNP simply means that the material input, per unit of GNP, tends to zero.

The reasoning is quite clear: the material inputs of economic production originate either from recycled matter or from newly extracted matter. Since 100% recycling is impossible after a certain time of reusing an already extracted and used matter, it will be dissipated and hence useless. Therefore the new production either requires new extraction of matter (first possibility) or it can be performed without material inputs (second possibility). Let us examine the first possibility. Assuming that there is no lower limit to the extracted matter/GNP ratio simply implies that the requirements for matter extraction may tend to zero. This, in turn, leads directly to the second possibility, that the production may be performed without material inputs.

However this possibility is a fallacious one. Why? Consider the function $Y=f(K,L,M,F)$, which has been explained in preceding sections. Producing without material inputs simply means that M tends to zero and therefore m tends to 0. This in turn, leads to the conclusion that the material form of the q tends to zero; this conclusion is based on the material balance principle. But the conclusion that q tends to 0 is fallacious in real world conditions. Because humans require for satisfying their needs an economic output which has at least some considerable physical dimensions and therefore some considerable material basis. This becomes clearer by considering, for example, the needs for food and shelter; it is not possible to built a house with nil physical dimensions or food in an immaterial form.

The same conclusion has been reached correctly by Young and Ayres (Young 1991, Ayres and Miller 1980, Ayres and Kneese 1969, Ayres 1978). Specifically, they conclude that the material inputs (R), in the production process and therefore in the production function, should be greater from a minimum quantity R_0 ($R>R_0$) where Ro is so strictly greater than zero (Young 1991 p.172).

From the above discussion the following conclusion is reached. Ayres and Kneese, envisaging the opportunities for lowering the ratio of extracted matter/GNP, overemphasize

these opportunities so that finally they falsely state that there is no lower limit of the relevant ratio.
Indeed, there may be large margins of diminishing the new extracted matter required for producing a unit of GNP, in three ways. First, by increasing the efficiency in which matter is used, second by orienting GNP towards services and third by increasing the recycled portion of the already used matter. However, there is a certain limit to all these margins. As a result, there is a lower limit to the new extracted matter required for the production of a unit of GNP, although this limit cannot be defined numerically today.

The second problematic conclusion of Ayres and Kneese concerns the accessibility of matter resources for economic use. First, Ayres and Kneese indicate correctly that 100% recycling is not possible. Furthermore, they conclude that there are some natural processes of reconcentrating several kinds of material; these materials are called renewable in this study (Ayres and Kneese 1989).
Next, they strangely conclude that "there is no danger of actually running out of materials even the scarcest ones". Obviously, this conclusion does not refer to the substitution of the scarcest materials with others when the first will have finished. Rather, it implies that even the scarce material will never be finished. However, it is self-evident that if these materials are quantitatively fixed and they are being used in economic production sooner or later they will be depleted. Therefore, the relevant economic production will run out of them in the long run since they cannot be recycled 100%.
Under these conditions the only possible reasoning that could lead Ayres and Kneese to their conclusion is that they may envisage that all materials, the scarcest included, are reconcentrated -are renewable in our terminology- by physicochemical or hydrogeochemical processes.
Unfortunately for the prospects of mankind this is not the case. A great number of the materials used currently in the economic process are quantitatively fixed; they are not regenerated by natural processes. In effect mankind sooner or later will run out of the nonrenewable materials. This holds regardless of the quality of the materials which are used first. Note that substitution of non-renewable materials with others is different issue than their irrevocable exhaustion.

7.6.3 Young

Young's approach is also problematic. In fact, the problem is not with Young's conclusions but rather with his reasoning.
Young concludes that there is no absolute scarcity of matter and this is correct. However, he draws this conclusion from the assumption that there is a fixed resource base, in other words, he assumes that there is only a given stock of matter (nonrenewable) resources, which is used as an input to economic production. Indeed, with this assumption, the conclusion that there is no absolute scarcity of matter is not correct. If there had been only a fixed stock of material resources it follows that there would have been an absolute scarcity of matter.
Reconstructing to gradually Young's analysis two reasoning are followed. The first is that, as technology improves, some material resources which have not been accessible matter due to technological problems will become accessible since new technology allows their use. The second reasoning is that technological improvement and knowledge, in general, will permit the reuse of the already used and therefore dissipated matter. This second reasoning is the most important of Young's approach.

Let us examine now the reasoning in Young's analysis in view of the analysis of the present chapter.
Assuming as Young did that the resource base is quantitatively fixed, the potential of discovering new resources is limited. New resources will be discovered, however it will end sooner or latter. This limit is imposed by the finiteness of the earth's crust. Indeed when all resources of earth's crust have been discovered -have been accessible- what new resources shall we wait for? Evidently, the finiteness of the earth's crust imposes an absolute limit to new discoveries of resources, and hence to the substitution of new resources for the already discovered ones.
More important is the second evolution, that mitigates scarcity, envisaged by Young. Young asserts that the future state of knowledge may permit the reuse of an already used matter. This is the well known processes of collecting and recycling regardless of the form these processes may take.
In fact, Young believes that future knowledge may make feasible the collecting and recycling process even at the rate of 100%; moreover he believes that 100% recycling could be a continuously repeated process. Specifically, Young asserts that the high entropy of matter of the earth's system is defined according to the human knowledge at each time. So, due to augmentation of knowledge the high entropy -the used and therefore dissipated matter- may decrease instead of increasing. In other words, the dissipated matter may be

reused and thus may become again accessible matter (low entropy matter).
It is correct that the proportion of used matter that can be recycled and reused is defined according to the level of human knowledge. However, regardless of the level of the knowledge there is some portion of the used matter which is irrevocably dissipated since its recollection requires some physical conditions that cannot exist. Specifically, it requires a huge amount of energy and time. Defining, now, as high entropy the irrevocably dissipated portion of the already used matter we can assert safely that the high entropy of the matter of the earth's system increases irrevocably. Young oversees this fact. So he essentially envisages as possible that 100% recycling may occur when the future knowledge will have been increased sufficiently. Otherwise, a less than 100% recycling leads to an irrevocable and absolute scarcity of material that is rejected by Young. There are two reasons which lead to an absolute scarcity, in Young's model, if 100% recycling is excluded. First, as Young correctly notices, the production is impossible without a strictly greater than zero material input. Second, the material resources are quantitively fixed, in Young's model.
The problem in Young's reasoning is that he fails to recognize that for a mankind's evolution two conditions (elements) are required. First, the anthropogenic element embodying technological and general knowledge and second, the physical element which would make the relevant evolution feasible.
Young considers only the anthropogenic element. Thus he correctly envisages that mankind may obtain that technological knowledge which permits a continuous recycling at a rate of 100%. There is no reason to exclude this future evolution.
However, mankind's physical environment unfortunately does not permit such an evolution. As it has been analyzed in preceding sections, 100% recycling, -the concept of recycling includes all possible forms of reusing an already used matter- is impossible. As a result, it is impossible to reuse all the quantity of a used and therefore relatively dissipated matter. For such an evolution infinite amounts of accessible energy as well as infinite time horizon are required so that the evolution can be performed (Georgescou-Roegen 1976, Kneese and Ayres 1989).

7.6.4 Georgescou Roegen

Georgescou-Roegen is one of the most eager scientists in the study of the problem of natural resources. We present in summary his conclusions concerning the scarcity of energy and matter resources. The target of this section is essentially, to present some unclear conclusions of his analysis which have led some authors to misinterpret them.

ENERGY RESOURCES

Regarding energy resources, he concludes that there is no absolute scarcity of energy due to the existence of solar energy. However, he is very pessimistic about the sustainability of the current rates of growth. Specifically, he indicates that the energy resources which feed industrial growth are mainly the non-renewable energy resources of the earth. Since there is an irrevocable depletion of these resources, growth will be deprived gradually by the respective energy inputs. Besides, as today's growth depend extensively on these non-renewable resources, their irrevocable end is approaching.

In addition, the renewable energy resources, cannot provide the amount for energy required for the current industrial growth, even if used the highest efficiency permitted by the current technology. Moreover, the foreseen development of technology does not lead to more optimistic results.

Therefore, renewable resources of energy would be able to sustain drastically on decreased growth as compared with the present.

As a result, although there is no absolute scarcity of energy, it seems that the current growth rates cannot be sustained in the long run because they are based on the rapid depletion of the non-renewable energy stocks.

Another effect of the extensive use of the non-renewable resources, is that the future generations are left with a smaller stock. In effect, sooner or later some future generations will run out of non-renewable energy resources. This is a kind of dictatorship imposed by the present generation on the future ones.

MATTER RESOURCES

Georgescou-Roegen regarding material resources reaches some unclear conclusions.

Namely, what is unclear is whether Georgescou regards that there is an absolute scarcity of material resources or he sees only a relative scarcity which is defined according to the present needs for material inputs. In other words, does Georgescou regard that there are only non-renewable material resources or does he consider that there are, besides nonrenewable, some renewable resources, too?

Let us trace this problem. In almost any quantitative example of Georgescou's analysis he assumes a finite resource stock and then he delineates the use of this finite stock by the successive generation.(Georgescou-Roegen 1976 p.23, 30-31. and 1979 p.101-102). The assumption of a finite resource stock is tantamount to its depletion sooner or later. The only way to evade this depletion would be 100% recycling which however is impossible. Then, this depletion implies an absolute scarcity of matter in which Georgescou seems to believe since he assumes a finite stock of material resources. The above reasoning supports well the pessimistic conclusions of Georgescou about the present growth rates as well as about the existence of mankind in the long run (Georgescou-Roegen 1976).

Up to now, the situation is quite clear: a finite stock of material resources implies an absolute scarcity of them and this in turn, implies an absolute, constraint to the economic process.

However, when Georgescou examines the population issue he asserts that the only population, which can be sustained in the long run, is that which can be maintained biologically by organic agriculture (Georgescou-Roegen 1976 p.34 and 1979 p.103). Interpreting this conclusion, this population does not face any absolute scarcity in long run; hence it does not face matter absolute scarcity. Therefore, we can safely assume that besides the finite material stock there are some other material resources which cannot be exhausted. Specifically, they can provide continuously a certain amount of matter. This specific amount is able to sustain that population which can be fed by organic agriculture. Here Georgescou does not estimate a particular population number since he considers that it may vary according to the state of technology also.

It seems that, the reference to organic agriculture is not coincidental. Georgescou possibly believes that the processes involved in organic agriculture, and possibly some other similar processes, are able to provide the material basis which maintains some population in the long run. Which are then these processes? Evidently, photosynthesis is the most essential process which regenerates certain material kinds, among them the most essential such as foods and wood. Besides, there are some other processes which regenerate some other indispensable for life material kinds, such as water in some particular forms. As a result, Georgescou seems to believe that there are also renewable matter resources. However, they can maintain a specific population which is much smaller than today's population.

The suggestion of Georgescou for a population maintained by organic agriculture brings two further issues into focus. First, let us assume that the population comes to the suggested level. Then this population can be maintained almost only by renewable matter and energy resources. In effect, the respective non-renewable resources would be left intact by the population. The arising ethical question is then, for whom are they left intact; obviously they pass on to future generations. Will they use them? Is that a kind of dictatorship of the future generation over the present? All these questions reveal some ethical considerations of the issue which can hardly be ignored.

Second, it may be perceived that Georgescou's analysis about the population maintained by organic agriculture is not a suggestion but rather the possible outcome of mankind's evolution. That is to say when the essential part of non-renewable energy and material resources are exhausted, mankind should rely only upon the respective renewable ones. However, renewable resources are able to maintain only a specific population, which is roughly defined as the population that can be sustained by organic agriculture. In other words, this population is what can survive in a stationary or steady-state economy when almost all nonrenewable resources have been depleted.

7.7 Concluding Remarks

1. The problem of natural resources scarcity as inputs to economic production, to the economic system function, is different than that of ensuring the biological sustainability of the natural system. The scarcity of natural resources co-determines the performance level of the economic system operation. On the other hand, the biological sustainability of the natural system is related to the problem of whether there will exist the human and hence the economic system in the long run.
As a result, when we examine the issue of natural resource scarcity in an aggregate level we take it for granted that the biological sustainability is ensured by the maintenance of all natural elements and functions which are indispensable for the proper function of environmental system. In other word, when a specific natural resource is investigated about its scarcity as an economic input, it should be kept in mind that its biological sustainability, is another subject that should be examined separately since the research of scarcity does not reveal what happens with the respective biological sustainability.

2. There is no absolute scarcity of energy or matter in earth's conditions due to the continuous flow of solar energy and the regeneration capacity of the renewable material resources.

3. There may be a problem of relative scarcity especially in the long run. The outcome of this relative scarcity is not clear today since it depends on the state of technology, on the discoveries of new resources, on the population magnitude and on the form of economic goods.

4. Current industrial growth relies upon the nonrenewable resources of energy and matter. Therefore they are being irrevocably depleted. This depletion forms a dictatorship of the present generations over the future ones since they will be left with a reduced stock, if any,

of the relevant nonrenewable resources.
This depletion of the nonrenewable resources will prove crucial for the prospects of economic growth. The remaining stocks of non-renewable resources as well as the use of renewable resources probably will not suffice to maintain the present rates of growth. Serious indications of this evolution are evident today.

5. The illusion of an economic production without natural inputs or with infinitisimental amounts of natural inputs must be excluded. Labor and capital are the agencies of economic production and they are not transformed to the material shape of economic output (economic goods). So some material and energy inputs are required for the material transformation, specifically they will be transformed to the material form of the economic output. Moreover, since real natural world process is 100% efficient, a proportion of the material inputs will exit from the production process as useless matter (waste). In effect, the material inputs are quasi-larger than the material form of economic goods.

6. A second illusion is that the problem of the inter-generational mis-allocation of non-renewable natural resources can be eliminated by the increased productivity of natural inputs inherited to the future generations, in the form of capital equipments. Certainly, the increased productivity of natural inputs is a crucial factor for mitigating scarcity. However, whatever the rate of use of nonrenewable resources they are irrevocably depleted. When their absolute depletion occurs, what productivity shall we speak about? Indeed, the capital elements, oriented to the use of these non-renewable resources, can hardly be re-oriented to the use of any other resource. So this capital will be a waste. As a result, to the far future generation beside the depletion of some non-renewable resources we will also some waste of capital equipments related to these resources' use.

7. The only feasible policy mitigating scarcity is formed by the following tenets. First, it is the orientation towards the use of solar energy. Second, the use of renewable resources should be confined to the levels which do not exhaust the exhaustible-renewable resources. Third, the use of nonrenewable resources should be "wise"; that is to say, to induce the technology which utilizes these resources efficiently by reducing their waste as well as to reduce economic goods' depreciation and finally, to induce the recycling of these resources.

CHAPTER 8

TRADITIONAL ENVIRONMENTAL ECONOMICS AND ECOLOGICALLY SUSTAINABLE ECONOMIC DEVELOPMENT, REVISITED

8.1 Introduction

The present chapter does not offer any new analysis; it is rather a summary of all the conclusions of the preceeding chapters. Specifically, the scientific meaning of the concept of "ecologically sustainable economic development" is re-examined here. This meaning is examined further using the traditional environmental economics theory. This aims at defining the conditions of achieving the sustainable development through environmental economic analysis. In other words, do the the solutions to the environmental problems, proposed by environmental economics, lead to the achievement of sustainable development? Next, the problem of the aggregate scarcity of natural resources is also examined and some useful conclusions are drawn.

8.2 Ecologically sustainable economic development, what does it imply?

The concept of ecologically sustainable economic development (ESED) emerged as a policy issue which however has atracted a lot of scientific interest in the recent years. ESED actually deals with all the current environmental problems, their causes and their implications on human life and economic development. In the end, ESED emerges as an attempt to efficiently confront all the crucial aspects of the environmental problems.
On the other hand, traditional environmental economics has dealt with the same problem before the concept of ESED emerged and they have offered some scientifically based solutions.
So, what is the new element that the concept of ESED brings in the spectrum of the efficient confrontation of environmental problem?

By analyzing the meaning of ESED it seems that its first requirement is the maintenance of the natural system in a proper function and form. That in turn, involves the preservation of the "biological sustainability" in all the crucial functions of the natural system. Incidentally, the biological sustainability of natural functions requires the biological sustainability of the involved natural elements, (biotic and unbiotic). This biological sustainability demands, in turn, the maintenance of the "biological crucial level" of the relevant environmental elements.
In fact, an element's biological crucial level is defined as the minimum level at which the

relevant element can be decreased without risking its existence and without disturbing the functions of the natural systems where it participates. As a result, by ensuring the existence of the "crucial biological levels" for the crucial natural elements, the entire function of environmental-biological system is maintained.

A second requirement of ESED is that the natural inputs of the function of economic system, of the economic production should be sufficiently supplied in all time. "Sufficiently" here means that they should be supplied to the extent that they are necessary.
As we have seen in chapter 7, the second implication of ESED involves some kind of future projections that cannot be scientifically established today. Therefore, each generation cannot conclude whether the second implication will be fulfilled and to what extend in the future.

The first requirement of ESED is not burdened by that kind of future uncertainty which is involved in the second requirement. The causes and the effects of biological unsustainability are traceable. Note that, the issue of "biological sustainability" bears some uncertainty; however, this uncertainty concerns the limited human knowledge of several natural phenomena. This knowledge increases gradually so that human beings understand better the causes and the effects of biological unsustainability.
In a nut shell, the issue of natural resources scarcity as inputs to the economic system bears an uncertainty which cannot be evaded by any generation since it involves the knowledge of the future evolution of mankind, which cannot be projected. On the contrary, the issue of biological sustainability bears only the burden of a factual knowledge which is gradually becoming available. Moreover, the relevant existing knowledge suffices to determine, even roughly, the boarders of biological sustainability. That is to say that the "biological crucial level" of a natural element may be defined even with some uncertainty about its exact magnitude. Thus, we are able to know what we should preserve in order to maintain biological sustainability.
Besides, biological sustainability is useful, almost equally, for the present and the future generations. The destroyed natural system strikes at the present as well as at the future although the future impacts may be heavier. On the other hand, the benefits for each generation from the use of natural resources as inputs to economic production are opposite ones.

As a result, mankind is technically able to pursue biological sustainability and this is to the benefit of every generation; while the issue of natural resources' scarcity involves some additional ethical considerations as well as some speculations about mankind's evolution.

So, ESED leads primarily to one clear target: that of maintaining the biological sustainability of the natural system. Actually, this target also forms the prime condition of ESED's achievment, as we have already seen in the first chapter.
The question which now arises is whether the solutions to environmental problems and the policy implications of the standard theory of environmental economics lead towards the preservation of the "biological crucial levels". This was the subject of chapters 2-5.

8.3 Environmental economics vis-a-vis "biological crucial level"

ESED implies primarily the preservation of the "biological crucial level" of all the prominent elements, in the environment. This preservation leads to the good function of the biosphere system. On the other hand, environmental economics investigates the optimum protection of nature and therefore, offers solutions to the environmental problem. In chapters 2-5 we have extensively analyzed the efficacy of those solutions to preserve the biological crucial level of the natural elements or function. Let us briefly examine the outcome of this analysis.

First, let us examine the essence of environmental economics. Environmental economics bring environmental problems to the spectrum of the economic theory. So, for the first time in the framework of this subdiscipline, environmental elements and functions are no longer perceived as "free gifts" of nature to the economic process. Due to their increasing use, environmental elements enter the spectrum of scarcity. Then the use of an environmental element for some purpose excludes irrevocably its potential use for some other purposes and hence the competition for its use emerges.
Environmental elements are perceived as scarce economic goods. Then, in the framework of environmental economics, the optimum allocation of environmental goods among their competitive potential uses is pursued.
The protection of these good comes into the economic spectrum. The protection of environmental elements restricts some of their uses. In fact, protection supports those uses that require "clean" environment. Hence, protection is an indirect use of the environmental elements.
As a result, the allocation of environmental elements between decaying and protecting uses will be done according to the rule that underlies economic decisions. This rule prescribes the equality of the marginal utilities arising from the competitive uses. So environmental

protection will take place as long as it is economically beneficial to the relevant society. Next, environmental economics examines how, in the real world, the optimum protection level is achieved. There are approaches asserting that the optimum protection level will be achieved by the market function alone (Coase 1959). On the other hand, there are approaches suggesting that either some modifications in the market's legal framework or some kind of governmental interventions are required (Hardin 1968, Kneese and Ayres 1974, Mishan 1972). Note that all these approaches aim at preserving the optimal level of environmental elements. In other words, that level of protection, which is socially desirable when compared with the relevant decaying uses, is pursued. -At this point, it should be stated that, generally speaking, it is possible that the way of achieving/enforcing the optimum protection level may also influence the magnitude of the optimum protection level. However, this influence does not alter the rationale of determining the optimum level; this influence is rather a side effect (Mishan, 1980)-.

The analysis in chapters 2-5 indicates that the optimum protection level can only by chance coincide with the "biological crucial level". Therefore, regardless of the method achieving the optimum protection level, it can lead only coincidentally to preserving the "biological crucial level".

Consequently, the protection of the environmental elements which results from seeing these elements as scarce goods in economics terms is not related to their biological crucial levels. The biological crucial levels may or may not be preserved by ensuring the "optimum protection levels".

Let us briefly trace the reasons of the independence between the "economically optimum protection level" and the "biological crucial level".

The economically optimum protection level is defined when environmental elements are introduced to the rationale of the economic systems. Specifically, using economic rationale the optimum protection level is determined by the comparison between the social desirability of protection and the desirability for uses which downgrade the natural elements. In fact, the comparison between the two antagonistic desires is established on the basis of individual preferences, that is on the basis of the preferences for clean environment on the one side and for the consumption of goods downgrading the environment on the other side. Furthermore, we know that the spectrum of individual preferences is subjective and therefore both the preferences for the "protected environment" and for the economic goods degradating nature are subjective and unique to each individual (Jevons 1924 p.9 and Fisher 1925).

Moreover, individuals do not consider all the effects of an "unprotected environment", because of the "time span" and the "space span" effect as we have seen in chapters 2-5. On the other hand, the "biological crucial level" is a physical magnitude determined by the physical properties of the relevant environmental element and according to the respective properties of the natural functions to which this element participates. Thus, the biological crucial level is defined in relation to certain rules of nature.

The economically optimum protection level determined when evaluating environmental elements by the rules of the economic system. The rules of the economic system are defined as those rules servicing the economic system's functions and targets. In turn, the economic system's target is to maximize the production of economic goods by allocating in the best way the scarce means available for producing these goods; this allocation is performed according to the relative desirability of economic goods (Samuelson 1970).
On the contrary, the "biological crucial level" is determined according to the natural system's targets. The oversimplification of this target may be defined as the well-functioning and the reproduction-evolution of the biosphere system (Passet 1979). Thus, the biological crucial level is a magnitude related to the rules of the biosphere system which are obviously irrelevant to the rules of the economic system; the biosphere system's rules are the rules which govern the processes of achieving the biosphere system's targets. In fact, they govern the well-functioning and the regeneration processes of nature.
As a result, the biological crucial level is defined in accordance with the natural system's targets and determined according to nature's rules; while, an economically optimum protection level is defined in such a way that services the targets of economic system and it is determined by economic rules. Figure 1 represents the relationship between targets,and rules of the natural system and the biological crucial level on one side, and the between the targets and rules of the economic system and the optimum protection level on the other.

Obviously, the biological crucial level and the optimum protection level are determined by following two irrelevant and unconnected procedures. Probably, there is a relationship since they both refer to the protection of the environment; however, the rationales behind the determination of each one of them are unrelated. Therefore, these magnitudes are unrelated since two different rationales may only by coincidence lead to the same outcome. In other words, the economically optimum protection level only by chance coincides with the biological crucial one. Therefore, by protecting the environment at the "economically optimal" level only by accident the "biological crucial level" of the respective element is preserved hence, only by accident the proper biological function and reproduction of the relevant environmental element is ensured.

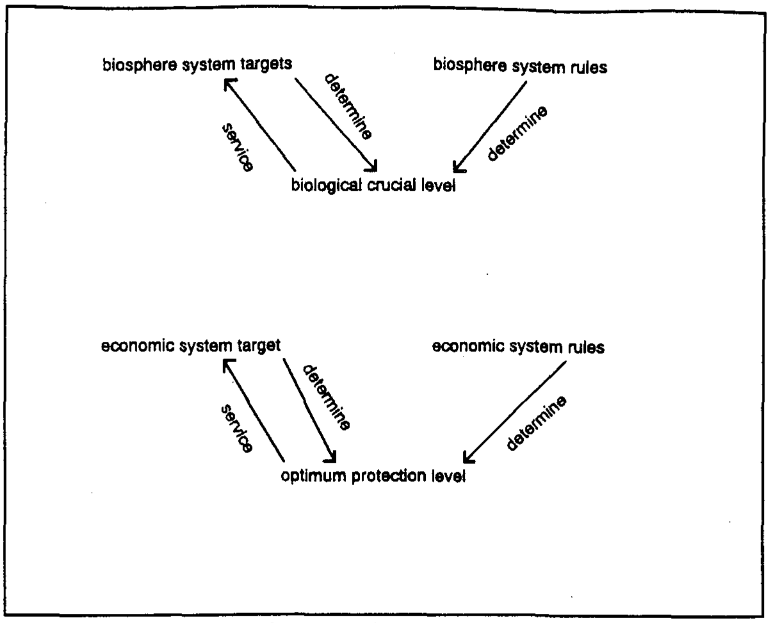

Figure 1 Biosphere and economic system functioning

8.4 How could ESED be preserved?

To repeat in order to follow a pattern of ESED we must preserve the BCL(s) of those natural elements which contribute to the good functioning of the biosphere system.

Let us trace now the way of preserving the relevant BCL(s). First, the BCL(s) should be determined by using the suitable natural sciences which study the natural functions and processes. Then, BCL(s) must be preserved via the existence of an additional criterion which suitably confines the spectrum where the economic-marginal decision rule applies to. This means that BCL(s) must be protected regardless of the estimated "economically optimum protection levels".

In practice, the above strategy means that the actual protection level must at least be equal to BCL. As a result, if the "economically optimum protection level" is higher than BCL then, the "economically optimum protection level" should be the actual protection level.

However, if the reverse holds then BCL should be the actual protection level.

Essentially, as far as the design of ESED is concerned, the economic-marginal rule applies only in case it leads to a larger protection level than BCL. Therefore, the range of its application is restricted in such a way that BCL is always safeguarded.

Indeed, the existence of the additional criterion implies that the economic decision framework is suitably confined in such a way that ESED is maintained regardless of the outcome of this framework application.

In other words, what matters when deciding for ESED is the BCL and not the "economically optimum preservation level". The BCL could be characterized as the "ecologically safe protection level".

The arising question, now, is which is the entity that may adopt the above mentioned additional criterion?
Individuals decide about environmental issues according to the economic rules. The whole process forms the subject of environmental economics subdiscipline. In fact, environmental economics regards the outcome of individuals preferences for "protected" environment. In fact, environmental economics regard individual relative preferences for "protected environment" in relation with the preferences for other economic goods, some of which degrade environment. In accordance with these preferences, the "economically optimum protection level" is defined. However, we have concluded that the "economically optimum protection level" may only by chance coincide with BCL.
As a result, it turns up that individuals do not self-adopt that additional to the economic ones, criterion which leads to the preservation of BCL and hence to the maintenance of ESED. Otherwise, the "economically optimum protection level" would coincide or be higher than the BCL(s).

Therefore, it seems that the entity unit which may adopt the relevant additional criterion is the society as a whole. Indeed, society is not influenced by those factors that lead towards an "underestimated" protection level. Specifically, the society is not influenced by the "space span" and the "time span" effects. Besides, the society is able to adopt certain "social preferences" which, by servicing the society's prime targets, confine the spectrum of individual preferences. There are many witnesses of such "social preferences"; consider, for example, national defence and reallocation of income.
The crucial point is the way of determining the spectrum of "social preferences". However, as democratic societies have found ways of dealing with analogous issues, they are certainly able of discovering the proper ways to establish that criteria which suitably preserve the natural environment.

8.5 Environmental-economic Policy

From the above discussion it seems that the establishment of a policy aiming at Ecologically Sustainable Economic Development is necessary. This implies the necessity for a policy preserving, at least, "biological sustainability" and hence the relevant "biological crucial level(s)". In the present section, the main steps of such a policy design are delineated.

1. The question whether the explicit establishment of the additional to the economic ones criterion of preserving the BCL(s) of certain natural elements is necessary or whether such an establishment is redundant should be answered. How can it be answered? Clearly, the environmental effects of economic, as well as of social activities, should be investigated in the short and long run. Specifically, it should be revealed how and to what extent economic activities influence the relevant natural system. Then, the crucial biological level(s) [BCL(s)] of the affected natural elements must be identified, even roughly.
If the environmental impacts of economic activities transgress the relevant BCL(s), in the present or probably in the future, the establishment of the additional criterion of preserving that level(s) should be explicit.

2. If the establishment of the additional criterion is necessary since economic activities threaten potentially biological sustainability then, the ways of establishing it should be found. Specifically, the particular activities that affect the natural environment must be specified. Then, the cheapest way of confining environmental impacts to those level(s), which correspond to lower level(s) than the relevant BCL(s), should be traced and finally determined. Towards this target traditional environmental economics has a lot to offer. Indeed environmental economics are based on the standard economics that is the science of achieving a target with the lowest cost; in other words, it is the science of allocating in the best way some scarce means so that some given ends are attained. Indeed, in the examined case the target is "to constrain environmental impacts to a given level" while simultaneously maintaining the largest possible level of economic activities. In fact, it might imply either the development of some alternative economic activities while reducing the polluting ones or the adoption of some technical methods reducing the environmental impacts, or even to the reduction of the general level of economic activities when there is no other solution.

3. Finally, the policy measures which induce the above mentioned processes of maintaining biological sustainability should be traced and determined. This will be performed by taking into account the institutional and social framework of the examined society-economy. Of course, economic instruments, as they are examined by standard environmental economics, will be of great help. Note that these economic instruments and practices should not be used in order to determine the "optimum protection level". Rather, they are used to preserve a pre-determined protection level while they may co-operate, towards this target, with other non economic instruments.

8.6 Envirnmental Impact Assessment and Environmental-Economic modelling

One of the main issues of environmental policy is the estimation of the environmental impacts of both economic and social activities. There are several direct and indirect ways for the environmental impacts assessment(PADC 1983)
Generally, the quantification of environmental-economic interactions which may lead to a quantitative estimation of environmental effects of economic-social activities is ideal. Towards this direction several attempts have been made during the last years (Van Lieop and Braat 1989). Environmental-economic modeling forms an indispensable part of environmental impact assessment. Therefore, Environmental-Economic models are required in the design of Environmental Policy.

In the second part of the present study we present a modeling methodology applied in a specific territory. The crucial characteristic of this methodology is the quantification of the environmental-economic interactions when there are limited statistical data and knowledge concerning the functions of economic and natural systems. This subject will be further analyzed in the second part of the present study where a brief analysis of some other modeling procedures will also be presented.

PART B

MODELING

CHAPTER 9

MODELING ENVIRONMENTAL - ECONOMIC SYSTEMS

9.1 Introduction

The first part of the present study deals with the theoretical research of the concept of the Ecologically Sustainable Economic Development. Specifically, the first part focuses on analyzing the concept of ESED in such a way that the conditions for its achievement are revealed. Next, the first part examines whether the popular solutions to environmental problems, mainly arising in the framework of traditional environmental economics, suffice to ensure the achievement's conditions of ESED. In other words, it is investigated whether the application of the policy implications of standard environmental economics leads towards ESED.

From the analysis of the first part it becomes evident that there is the need of designing an explicit policy aiming at ESED since the market function alone cannot lead towards this direction.
An essential part of the design of this policy is the estimation of the environmental effects of the economic decisions. These effects will be compared with some crucial values of the relevant environmental elements -usually, they are compared with the respective biological crucial levels- so that the relevant economic decisions are evaluated on environmental grounds, too.
Also, the feedback effects, caused by the environmental effect and imposed back to economic and human systems, should also be estimated.
The above needs become more rigid if we have to choose among several alternative economic policies which differ on both their economic and environmental effects.

Formal environmental-economic models, which somehow represent formally the functions of the environmental and economic systems, serve the need of estimating the environmental effects of economic decisions as well as the feedback effects. Usually, these models adopt as exogenous the variables which represent the economic decisions and then the effects on the other variables of the model may be calculated.
However, environmental-economic models do not serve only the need of estimating the consequences of an economic policy, project or decision. Actually, these models are used for several other purposes. We shall mention only some of them.
First, by using these models we are able to form hypotheses concerning the function of both economic and natural systems and then to check the resemblance of the results arising by the model against the relevant real world magnitudes. If these results fit to the real world ones then we are closer to accept the validity of the relevant hypothesis. As a result, we augment our knowledge about the function of economic and natural systems.

Another aim that may be attained by the use of environmental- economic models is the projection of the future functions and inter-relationships of economic and environmental systems. Adopting some plausible assumptions we may be able to examine some crucial parameters of the function of both systems, especially in the long run. Thus, if some unwanted evolutions are foreseen we could trace the ways to avoid these evolutions.
Finally, environmental-economic models may serve also some pedagogical aims. That implies two main things. First, by using formal models the knowledge of environmental and natural systems passes easier to other members of the society and especially to the decision-makers. They may obtain a relatively clear picture of the effects of their decisions. Second, the relevant knowledge becomes accessible to other scientists who do not originate from the same disciplines which build up the environmental-economic models.Thus, the scientific dialogue could be advanced.

Let us come now to the crucial question: which are the prerequisites for constructing a formal environmental-economic model? Evidently, the prerequisites refer to the knowledge of both the economic and natural system as well as of their inter-relationships. Generally, for the construction of a formal model representing the function of a system we should perfectly know that function so that we can represent it with functional relationships (equations).
Mainly, there are two ways of constructing the relevant functional relationships; each of these ways is based on a different kind of knowledge of the system on hand. We use the first way when we dispose a sufficient scientific knowledge concerning the exact functions and the detailed characteristics of a system. Then we are able to describe them by a system of equations. The second way adopts the statistical methodology according to which the relationships among the elements of the system are expressed by a system of equations, although we probably do not know the exact function of the examined system. This is pursued by using statistical observations of the relevant relationships; then, by processing suitably the statistical observations the corresponding equations are obtained. Usually, in the second case, the investigated relationships have the form of "cause-effects" mechanisms developed among the elements of the system.
Evidently, it is generally possible to construct a system of equations representing the relationships among the elements of a system although the function of the system is to some extent obscured. In this case, it is assumed that the relevant statistical observations, if they obey to certain assumptions, enclose implicitly the information which describes the function of the system. The statistical observations are the outcome of this function.

The target of this chapter is to examine how it is possible to construct a model

representing the relationships among the elements of a system if the existing statistical observations do not suffice for the application of the usual statistical methodology.
The proposed solution asserts that we may resort to the scientific knowledge of the system on hand. Specifically, we may try to substitute the missing but necessary statistical observations by utilizing the existing scientific knowledge. This knowledge, evidently, pertains to the type of knowledge which is used in the first way, mentioned in the preceding paragraph, of building up a model. However, if such knowledge were statistically available, we would follow the first way of constructing the relevant model and so no statistical observation would be needed.
Actually, in the present study we examine those cases in which the available scientific knowledge does not suffice for following the first way of building up a model. For this knowledge, though existing, is limited. As a result, we neither dispose the scientific knowledge which is necessary to build up a model nor have we the required statistical data for using the statistical methodology. Therefore the subject of the present chapter is: how we could use the limited but existing scientific knowledge so as to overcome the problem of missing statistical observations. In other words, how we could utilize the existing scientific knowledge in order to substitute for the missing statistical observations, so that the finally obtained data set would suffice for employing the statistical methodology.

9.2 Types of environmental-economic models

The classification of environmental-economic models can be attained according to the adopted criterion. We present some of the more popular classifications of the recent literature. As an environmental-economic model could be regarded "a set of mathematical relationships describing any connections between economic and ecological systems" (Braat and van Lierop 1982).

According to their intention environmental-economic models are classified as follows (Braat and van Lierop 1987) :

a. Descriptive or explanatory
b. Predictive
C. Prescriptive (control or management models)
d. Evaluative-Appraisal models

According to the origination of the models' equations, environmental-economic models may be distinguished as follows (Nisjamp 1987):

a. Materials balance models (Ayres and Kneese 1969)
b. Input-output models
c. Dynamic stock-flow models

Taking as a criterion the evolution of the time variable in the models we may sort out the following categories of models :

a. Static
b. Comparative static
c. Dynamic

When the geographical scale of economic-ecological models is their classification criterion, they may qualified as:

a. Local
b. Regional
c. National
d. Multi-national
e. Global

Finally, we mention a classification of the models in accordance to the kinds of knowledge used for constructing them. Of course, there are cases where more than one kinds of knowledge are used.

The first sort of scientific knowledge, upon which a model could rest, is the accurately "descriptive" and "causal" knowledge which concerns the actual operation of the investigated system (or subject). That is to say we command the exact properties and characteristics of the system operations. Then, we are only one step behind obtaining a mathematical representation of the system operation-functioning. Moreover, we do not need to resort in using statistical observations and employing the relevant methods in order to form these mathematical relationships but only afterwards in order to test the accuracy of the model and to estimate the exact value of some coefficients.

It goes without saying that this procedure for constructing a model is mainly used when the investigated system is rather a natural system or phenomenon. Socio-economic phenomena are hardly well-known enough to be directly described by mathematical (numerical)

relationships.
The second sort of knowledge, on the basis of which a model could be built in, is the one enclosed in the statistical observations of the operation of a system. Actually, this knowledge takes rather the form of accurate information enclosed in the statistical observations.
Certainly, the collection of statistical observations presupposes the existence of some kind of factual knowledge concerning the operation of a system. However, this knowledge does not suffice to describe in a sufficient way this operation. Essentially, we know the cause-effects relationships which, however, have an abstract form. In addition, sometimes all the effects of a certain cause are not fully known and therefore, the statistical observations could be helpful in revealing also some unknown effect (some new cause-effect relationships).
Generally, we can derive a set of mathematical relationships by making use of the relevant statistical observations. It is, then, assumed that the set of these mathematical relationships depict the operation of the system. Precisely, we should accept that these mathematical formulas are the formal representation of the cause-effect relationships which, in turn, convey a kind of information-knowledge about the system's functioning.
Probably, we do not dispose the internal-factual operation of the cause-effect relationships but only their functional relationship. Therefore, in this case, we cannot speak of exhaustive knowledge of the system but, rather, of some limited knowledge. It goes without saying that this limited knowledge forms some basis for further research so that more detailed knowledge can become available.

9.3 The proposed methodology

9.3.1 Introductory remarks

The examined methodology concerns the type of environmental- economic models which is based on the utilization of the existing statistical observations in order to represent formally the cause-effects relationships that are developed between the components a system.
We may assert that this type of environmental-economic models represents the interactions developed between the elements of economic and environmental systems. Indeed, the cause-effects relationships betray, in fact, how each component would react if it accepts a specific action of another component or of an exogenous event. Thus, we may call the models raised on the base of cause-effects mechanisms as "Environmental-Economic

interaction models".
To repeat, in order to represent formally the cause-effect mechanisms, a set of statistical observations of each individual cause-effect relationship is required; this set should meet some prerequisites imposed by the statistical methodology.

The proposed methodology examines how we could model the interactions of an environmental-economic system when the number of the available observations of each individual cause-effect relationship is not sufficiently rich and therefore the direct application of the statistical methodology cannot be employed.
The target of the proposed methodology is then how we might utilize the existing, in any possible form, scientific knowledge so as to built up a model representing formally a cause-effect relationship; provided that simultaneously we would make use of the relevant existing observations. Specifically, the distinguished element of the proposed methodology is the utilization of the available scientific knowledge for the completion of the set of the existing observations. The available knowledge leads to the creation of pseudo-observations. Then, we would be able to process with statistical methods the final set of observations so that the relevant functional relationship is attained.

9.3.2 Methodology steps

A. SYSTEMS AND INTERACTIONS ANALYSIS

At this first step the target is the collection, utilization and depiction of all available knowledge (direct or statistical) about the functioning of the system on hand. Specifically, we distinguish the main elements of the system and then we try to conceive the interactions among them. Essentially, we aim at identifying the individual relationships between these elements, usually in the form of cause-effects relationships. Next, we collect all available statistical observations corresponding to each one relationship. As a result, finally we dispose a detailed picture representing the main relationships between the elements of the system. If this picture takes the form of a scheme consisting of geometrical symbols that reveal some aspects of the relevant relationships then, we may call it "Interactions scheme" or "Impact scheme" (Nijkamp 1990, 1993).

Note that the assumption of the present chapter is that the set of the available statistical observations corresponding to each individual relationship of the "Interaction scheme" does not suffice for deriving the respective functional relationship.

B. MODELING AN INDIVIDUAL INTERACTION

The target of this step is to complement the incomplete set of the available observations corresponding to an examined relationship. The source of this complementing process will be the available scientific knowledge.

Whatever the nature of this knowledge, it should be accepted that its conveyors would be the scientists who work on the relevant specific topics. Therefore, the methodology proceeds as follows:

1. Assembling an interdisciplinary scientific group

A suitably selected interdisciplinary group of all the relevant scientists should be collected. The interdisciplinary nature of the group is dictated by the interdisciplinary nature of environmental-economic phenomena.

Indeed, the analysis of any environmental-economic problem requires the contribution of a series of sciences, for example, physics, chemistry, economics, mathematics, planning, etc. The inter-disciplinary group gathers and examines all possible information concerning the examined relationship-interaction. Therefore, besides any other information, the existing statistical observations will be available to the group. However, these statistical observations probably form just an indication of the properties of the examined relationship.

Next, the members of the interdisciplinary group could undertake any feasible action which would augment the scientific knowledge on the specific problem. A very helpful but usually unfeasible action is the performance of experiments which would give some additional statistical observations of the relationship.

Then, the members of the interdisciplinary group discuss extensively the nature of the examined interaction so that all its aspects become an almost "common place" for all members. As a result, we may speak of an, at least, minimum level of some abstract "common knowledge" which is now established in the minds of the members of the interdisciplinary group.

2. Coining observations (data)

This action aims at complementing the missing statistical observations of the examined relationship-interaction. This target will be performed by utilizing the outcome of the previous action; that is the "common knowledge" established among the members of the inter-disciplinary group.
Specifically, the members of the group will be asked to create a number of observations. Each observation will present a specific instance of the relationship-interaction operation. Actually, each observation will give numerically the values of both the causes' variables and the effects' variables at one specific instance of the interaction's operation.

How could this be achieved? Generally, the established "common knowledge" of the relationship could formally be represented by an abstract relationship of the form of $(y_1, y_2, y_3) = f(x_1, x_2, x_3)$ (1). Where yi are the effects and xi the causes of the examined interaction.
Any further quantitative determination of the above relationship should take the form where each effect is examined in separately. So, the above abstract relationship should break to the following three functional relationships:

$y_1 = f_1 (x_1, x_2, x_3)$ (2)
$y_2 = f_2 (x_1, x_2, x_3)$ (3)
$y_3 = f_3 (x_1, x_2, x_3)$ (4)

Evidently, the existing statistical observations of the relationship (1) lead to the existence of an equal number of statistical observations for all descendant functional relationships (2),(3) and (4). The problem, now, is exactly the same: obtain a sufficient number of observations for the relationships (2),(3) and (4) so that their quantifications are achieved by statistical methods.
It should be assumed that the "common knowledge" established for the relationship (1) directly implies the existence of analogous "common knowledge" for the relationships (2),(3) and (4).
Let us assume, for the sake of simplicity, that the relationship (1) leads only to the relationship (2) and so we have to investigate the quantification of the relationship (2) alone. Then, there is a certain number of actual statistical observations available but not complete for statistical processing. So, the problem becomes: how may we create observations in order to complement the existing ones?
Furthermore, the problem is that the created observations should reveal all possible phases/aspects of the relevant interaction, so that, the finally determined quantitative

relationship could depict reliably the examined interaction.
In other words, the target is the creation of a number of observations which will be representative of the whole range of the interaction's operation. Note that this relationship is analytically represented by the abstract functional relationship (2).
We proceed as follows. The members of the inter disciplinary group give a random value for each of the independent variables of (2) -these variables are x_1, x_2 and x_3-. These values should originate from the definition field of each variable. So, a combination of random values of the independent variables are created. This combination represents a specific phase of the operation of the respective real world interaction. The quantitative representation of the above particular phase is not complete since the value of the dependent variable has not been determined yet. Thus, the problem becomes that of determining the value of y_1 which corresponds to the specific, above created, combination of values of the independent variables. This task will be performed by the interdisciplinary group. Specifically, the members of the group will determine the value of y_1 which pertains to the examined particular combination of the values of x_1, x_2 and x_3. This determination/assessment will be performed on the basis of the "common knowledge" concerning the interaction.
In effect, we will dispose a "created observation" for the interaction represented by the functional relationship (2). In other words, a combination of values of y_1, x_1, x_2, x_3 has been created via the rationale that the combination obeys the functional relationship (2) and hence therefore, depicts a specific phase of the interaction represented by (2).
Essentially, the main problem, at this stage, is the estimation of y_1 value that corresponds to the given combination of x_1, x_2 and x_3 values. This estimation would have been done strictly, if we had either known the exact numerical expression of the functional relationship (2) or obtained the value by observing an actual event.
However, neither of these alternatives occurs. Therefore, the only way for estimating y_1 is the utilization of the scientific knowledge that the members of the interdisciplinary group possess. Indeed, it is assumed that the relevant "common knowledge" would lead to estimating a unique value of y_1 for a given combination of x_1, x_2, x_3 values.
If more than one estimations of y_1 value are proposed -there is disagreement among the members about the y_1 value-, we may handle the issue in the following alternative ways. First, we may induce the members of the group to further discussion about the examined interaction so that they might agree on one value via scientific criteria. Second, if the above procedure fails then we could either adopt the mean value of the proposed values or take into account all proposed values, assuming that each of them presents a distinct observation of the reality.

The above described procedure of creating an observation should be repeated until a sufficient number of observations is obtained. The concept "sufficient" is defined according to the need of obtaining the observations which represent the whole range of the operation of the interaction-relationship on hand. This could be achieved by creating random combinations consisting of values of x_1, x_2 and x_3 which derive from the whole range of the values of these variables.

Once these procedures have been accomplished we dispose a sufficient number of created observations. The remaining problem then is how we could utilize these observations in order to define the function f_1 of the functional relationship (2). This problem is handled by the following action.

3. Determining the quantitative expression of a relationship

The target of the present action is how we can determine the function f_1 of the functional relationship (2).
The hypotheses underlying this determination are:

a. the functional relationship $y_1 = f_1 (x_1, x_2, x_3)$ exists permanently and relates the y_1 variable with the x_1, x_2, x_3 variables. This relationship forms the model of our statistical problem (Theil 1971). Specifically, (2) is the analytic form of an interaction/ relationship of the real world.
At this point a restriction of the examined interaction/relationship must be stated. That is: the interaction/relationship should concern only a relationship between some elements which are related via a physical/technical process and not via a socio/economic behavior. In other words, the function f_1 must represent a phenomenon which does not involve any social stochastic factor. This does not mean that we should confine our research to the natural phenomena domain alone. Rather, we can examine relationships/phenomena among economic, human and natural elements/quantities provided that the investigated relationship does not concern a social/human behavior.
The examined subject should refer to a pure physical/technical interaction/relationship that may be developed between economic, human and natural elements (Malinvaud 1981). For example, we cannot examine the relationship between income and consumption because it concerns a social/economic phenomenon/behavior; on the contrary, we may examine the relationship between consumption and waste disposal, in a particular case, since it does not involve an explanation of any human/social behavior. The last relationship regards a

physical process which is rather deterministic, since it does not involve any social stochastic factor.

In a nut shell, the proposed methodology deals with the quantification of physical/technical relationship and not with the investigation of socio/economic processes.

b. Further, it should be ensured that the members of the interdisciplinary group know sufficiently the real world interaction/relationship so that all the factors, which are permanently involved in it, are included in the functional relationship (2). Moreover, it should be accepted that there is no factor -in the form of a variable- which is not really involved in the relevant phenomenon although it is included in (2).

In other words, it should be ensured that the members of the group dispose the sufficient scientific knowledge of the examined subject which permits the inclusion in (2) of all the factors involved, and only them.

c. It is assumed that the set of the created observations will lead to determining actually the same function f_1 with any other possible set of created observations. In fact, the present assumption establishes the validity of f_1 function. This assumption ensures that f_1 obeys not only to some given observations but to all possible observations of the relevant phenomenon.

d. The created observations are random. This indispensable prerequisite could be fulfilled since we are able to create these observations by a random selection of the values of x_1, x_2, x_3 variables. So, random combinations of these values are created; these combinations together with the respective estimated values of y_1 constitute the created observations.

The statistical problem is then very simple. That is: how can we determine the function f_1, by making use of the existing actual and created observations? At this stage, there are two alternatives: either we could use only the created observations or both the created and the existing real observations.

Thus, the actual problem is that of fitting a curve (surface) to the points determined by the observations in the n dimensional space.

The more common statistical mathematics method for performing the above task is the regression method as it is used in econometric problems without stochastic elements (Johnson 1963 and Malinvaud 1980). In fact, the criterion for choosing a particular curve out of a set of possible curves is the "least square" criterion. This criterion is being used in our case study.

The problem of selecting a particular curve which obeys a given data set is examined below in the paragraph "Mathematical fitting process" of chapter 10.

4. Tests against reality

The determination of the function f_l of the functional relationship $y_l = f_l(x_1, x_2, x_3)$ bears some arbitrary elements which stem from the use of the created observations. These observations do not depict real instances. Rather they petray the limited scientific knowledge of the investigated phenomenon. Therefore, we should try to overcome the problems arising from this probably limited perception of the reality. -Note again here that we use this method because there is no other way more rigorous for quantifying the relevant phenomenon-.
The following procedure could test the validity of the determined function f_l, to describe sufficiently the examined real world's relationship.
When we decide for the set of observations, which will be used for estimating f_l, we keep some real (as opposed to created) statistical observations out of this set. Thus, once f_l is determined we can test whether the numerical expression of f_l obeys the real statistical observations which have not been used for its estimation.
To be precise, by using f_l we estimate the value of the dependent variable y_l corresponding to those values of the independent variables which constitute a given real observation. Then, if the estimated value of the dependent variable y_l approaches sufficiently the real observed value y_l we may assert that there is an evidence of the reliability of f_l.
We repeat the same test for all available real observations that have not been used for estimating f_l. If the estimated by f_l values of the dependent variable lie within some certain margins around the observed values, we conclude that f_l represents reliably the examined relationship/interaction. Otherwise, f_l is not accepted. In that case, the only action which could be followed is to ask again the members of the interdisciplinary group to construct a new set of created observations. This set, now, will be processed so that a new f_l function is determined. In turn, this new formal expression of f_l will be tested against reality.

As a result, it seems that finally we can obtain the function of f_l which will be accepted as a reliable quantitative representation of the investigated real world's relationship/interaction/ /phenomenon. Evidently, the finally reached functional relationship has been raised on the data/observations which have been created by the interdisciplinary group. Therefore, the distinguished characteristic of the proposed method is the role of this interdisciplinary group. Actually, the scientific knowledge of the group substitutes the shortage of the existing statistical observations.

C. BUILDING UP AND TESTING THE WHOLE MODEL.

The above described procedure that leads to the quantification of an individual interaction/relationship should be performed for all individual interactions/relationships which have been identified by the "system interactions analysis" of the environmental-economic system on hand. In effect, all the interactions/relationships of the examined system will be quantified. Therefore, the environmental-economic system could be represented by a mathematical model consisting of a number of individual numerical relationships (equations).

Then, we could proceed by performing a reliability test for the whole model. This could be performed if we would dispose some real statistical observations of the system's operation which have not been used for determining the functions-equations of the model. Actually, these observations may be the ones used in the previous step for testing each individual function f. Specifically, by assigning the real observed values for the exogenous variables of the model we estimate via the model the values of the rest variables. If these values approximate sufficiently the respective observed values the model is reliable. On the contrary, if the model fails to fulfill this requirement it should be rejected. Then, the suitable corrective actions should be performed. We start by tracing the particular individual equations from which the relevant problem arises. Then we might be able to correct the problematic functions.

D. USES OF THE MODEL

Once the quantitative model has been established we can use it for examining the operation of the relevant system under alternative conditions -alternative scenarios of the evolution of the exogenous variables-. In other words, we may perform conditional projections of the system.

However, we cannot do a strict forecasting -we cannot foresee what will happen in the system without making explicit assumptions concerning the evolution of the exogenous variables- since the existing statistical data do not offer a serious indication for the future behavior of the exogenous variables. In other words, we cannot assert that the system, provided that it maintains its structure intact, would evolve according to the projections of the past trends because the exogenous variables would follow their trends also in future. For we simply know only a little about the exact past operation of the system and specifically about the past trends of the exogenous variables. In fact, we do not dispose the time invariant element which is indispensable for a solid projection or solid forecasting (Georgescou-Roegen 1974).

As we have already mentioned, the models built up according to the proposed methodology can not be used in cases of the socioeconomic behavior because of the presence of social stochastic factors in these phenomena. In fact, these factors may lead to the presence of some effects that cannot be explained by a single data set alone. Indeed, the presence of a stochastic factor might lead to estimating the function f out of a given data set while this function does not fit to another possible data set. Therefore, this function cannot be perceived as the qualitative law of the relevant phenomenon. In these cases, a theoretical model is required since it handles suitably the relevant stochastic factors so that the determined function f approaches better the real world phenomenon and hence fits any relevant data set.

9.4 The proposed methodology against the rigorous statistical/econometric one

The target of this paragraph is to present and to examine the proposed methodology in relation to the statistical/econometric one. Both methodologies aim at determining a quantitive relationship that describes formally a real world phenomenon by making use of statistical observations of the relevant phenomenon. Despite the above similarity there are fundamental differences between them.

Statistical/econometric methodology, on the one hand, aims at determining a quantitative relationship which represents formally the operation of a real world phenomenon. Then, we may assert that we dispose of the "quantitative law" which delineates the relevant phenomenon. As a result, the statistical/econometric methodology seeks to define the quantitative law which underlines a real world phenomenon. Essentially, this methodology follows the next steps.

a. The scientific knowledge and the factual experience usually lead to a set of theses-propositions which, as assumed, describe the examined phenomenon. These theses form a theoretical model. It consists of a set of abstract functional relationships as well as

of some statistical hypotheses.(Malinvaud 1980)
The theoretical model will be completely determined in the following steps provided that it is first proven valid.
Otherwise, it will be rejected and another theoretical model should be proposed. In the latter case the newly proposed theoretical model will present some new theses/propositions about the examined phenomenon.
Sometimes a theoretical model is not established. Then, it is the statistical observations, as they will be processed in the following steps, that would lead to defining a quantitative relationship. In this case, and if the phenomenon is of socio/economic nature, one cannot assert that the determined quantitative relationship is the general "quantitative law" of the relevant phenomenon. One can, rather, only speak of a quantitative relationship that obeys to the used statistical observations. For a quantitative law should obey every observations set of the phenomenon and not only the existing ones.
Note that if there is a the theoretical model, it is validated and quantitively estimated by the real observations. This procedure gives a generality to the estimated function -quantitative relationship-, since the theoretical model encloses the scientific knowledge which is confirmed and formally represented in the light of the statistical observations. In other words, the formal-quantitative representation of the scientific knowledge enclosed in the theoretical model is the estimated function; therefore, this function is generally valid since the respective knowledge is also assumed to be generally valid. In a nutshell, in the case of a theoretical model the statistical observations confirm the validity and estimate/represent quantitively the scientific knowledge embodied in the model. Therefore, the quantitative expression (the functions) of the model is as general as the respective scientific knowledge.
As a result, we speak of a quantitative law. This law is the formal representation of the respective scientific knowledge of the relevant real world phenomenon. On the contrary, if the estimation of the function -the quantitative relationship- is performed in the absence of a theoretical model, this function is reliable to describe only the observations used for its estimation since the general validity of this function is not scientifically established. Therefore, we should hesitate to speak of a "quantitative law" at least until some further proofs of the general validity of the function become available.
In case of absence of a theoretical model, all the above mentioned restrictions are mainly valid when socio/economic phenomena are investigated. Indeed, in cases of physical/technical phenomena, the existence of a set of observations which fulfills certain statistical requirements suffices to establish the relevant quantitative law. In cases of a physical/technical phenomenon a representative set of observations encloses all needed information for establishing the respective quantitative law, because it is expected that any

other representative set of observations will actually lead to the same quantitative expression-function. Of course, this function is generally valid and constitutes the formal expression of the scientific knowledge concerning the real world phenomenon. Thus, the knowledge embodied in a theoretical model is actually established and formally defined by searching a representative data set and therefore there is no profit for establishing this knowledge ex-ante in the form of the theoretical model.

The difference between physical/technical and socio/economic phenomena consists in the presence of social stochastic factors in the latter ones. In fact, the stochastic factors may lead to the presence of some effects that cannot be taken into account by processing a single data set alone. Indeed, the presence of stochastic factors might lead to determining a function f which does not fit another possible data set except the one used for its determination. Therefore, this function cannot be conceived as the quantitative law of the relevant phenomenon. In these cases, the theoretical model, consisting from the abstract functional relationships the relevant statistical assumptions is required, since it take into account-manipulate suitably the relevant stochastic factors so that the determined function f could approach better the real world phenomenon. Hence, it fits reliably every relevant data set.

b. The existing statistical observations are used in such a way that the exact quantitative form of the theoretical model can be determined. In this step several methods of statistical mathematics may be employed, for example the least square method.

c. Once the quantitative relationship of the investigated phenomenon has been defined, we should test it. To be more precise, we should examine whether the quantitative relationship is actually "the quantitative law" of the examined phenomenon.

Thus, the tests of homoscedasticity, autocorrelation and multilinearity should be performed. Indeed, if the defined law is not sufficient the above tests may lead to establishing a better one. For instance, this could be achieved by introducing an additional variable that is missing from the defined quantitative relationship although it participates in the real world phenomenon (autocorrelation test) (Theil 1971, Brennan 1973).

The proposed methodology, on the other hand, aims at quantifying a physical/technical relationship developed between elements of an environmental-economic system.

The specific problem of our study is the deficit of a sufficient number of statistical observations. On the other hand, the scientific knowledge concerning the examined phenomenon is available, to some extent. However, this knowledge does not suffice to lead

to a direct mathematical representation of the phenomenon.
The proposed methodology, then, utilizes suitably the available scientific knowledge in order to create a sufficient number of observations which will be used for quantifying the relevant phenomenon.
In fact, the scientific knowledge of the members of the interdisciplinary group is transformed to "created observations". The essence behind this process is the following: The members of the interdisciplinary group understand the logic law that underlies the examined phenomenon. However, they do not dispose the quantitative expression of this law -the quantitative law of the phenomenon-. Therefore, they create observations which obey this law; these observations are based/defined according to the rationale of the logic law-. Next, these observations will be treated in such a way that the quantitative form of the law will be determined. In effect, the creation of observations is an intermediate step which leads from a known logic law to its quantitative form.
Therefore, the observations are constructed in the light of the law existence. On the contrary, according to the statistical/ /econometric methodology, the law is traced in the light of a number of existing observations.
In the framework of the proposed methodology, the logic law that leads to the creation of data may have an abstract-conceptual form which is formally represented only by an abstract functional relationship, for example $y=f(x_1,x_2)$.
The basis of the proposed methodology is that whatever the formal initial form of the law, its essential-conceptual perception suffices to lead towards creating some data (created observations).
In consequence, the steps of the proposed methodology are briefly the following:

a. The assembly of the interdisciplinary group and the discussion among the members of the group establish a level of "common knowledge" which can be perceived as a pattern of a logic law governing the relevant phenomenon.

b. In the light of the above established logic law ("common knowledge") the members of the group create some observations which obey this law.

c. Processing the created observations we obtain a quantitative relationship that fits sufficiently to them. It is assumed that the determined relationship represents formally the logic law which lies behind the examined phenomenon so this expression may be perceived as the quantitative law of the real world phenomenon.

Once this law has been determined, the use of any test such as homoscedasticity,

autocorrelation and multilinearity, is deprived of any essential meaning. All these tests aim at establishing a good (quantitative) law, while in the proposed methodology that law is preassumed; indeed, the existence of this law has led to creating the relevant data.
In other words, the use of any of these tests lead to a vicious circle. To be more clear, these tests check the ability of quantitative relationship to fit sufficiently the used data set and so to form the quantitative law enclosed in this data set, while in the examined cases these data have emerged by an even shady presumption of this law.
The only test which could be performed is to check the determined quantitative law against real observations. That is to say, we should examine whether the quantitative relationship determined by the created observations fits also to the existing real observations. If this relationship passes this test, we may assert that it probably fits to any set of observations of the relevant phenomenon.
Therefore, it depicts the quantitative expression of this phenomenon and hence the quantitative law of the phenomenon.

From the above analysis the field of the proposed methodology application becomes evident. The methodology applies when a physical/technical relationship is investigated. In these cases it could be assumed that some qualified scientists know the determinant factors of this relationship and so, to some extent, the logic law behind it.
However, if a socioeconomic phenomenon is examined then we cannot assume that a group of scientists know all the factors involved, as well as their operations. Because, by doing so, we assume complete knowledge of human behavior while, actually, the human and social behavior is the main question of social sciences. The use of real statistical observations serves a process of confirming/rejecting hypotheses about the human/social behavior and permits us to approach the knowledge of this behavior.

In consequence, the proposed methodology is not antagonistic to the statistical/econometric one. Rather, its use is complementary to the statistical/econometric one.Specifically, the proposed methodology is employed when the real statistical observations, which would permit the use of the statistical/econometric one, are not available.An indispensable prerequisite for employing the proposed methodology is the existence of a considerably high level of scientific knowledge of the examined phenomenon. Then, although this knowledge may not suffice to quantify directly the phenomenon, it can create a data set describing particular random instances of the phenomenon. The processing of these data leads to the quantitative expression of the phenomenon.

THE PROPOSED METHODOLOGY AGAINST THE ECONOMETRIC ONE

The statistical/econometric	The proposed methodology
1. It aims at establishing the quantitative law of a natural phenomenon or of a socio-economic relationship. relationship/interaction among some natural quantities.	1. The target is the establishment of a quantitative function that describes a technical
2. A theoretical model is assumed that describes the examined phenomenon. The target is the numerical estimation of the model. (This step is often skipped)	2. A suitable selected interdisciplinary scientific group is established. It is assumed that this group is able to perceive an abstract functional relationship that describes the examined phenomenon
3. Statistical data is used for for estimating the quantitative form of the theoretical model.	3. The scientific group creates data that describe some instances of the phenomenon. Of course, the created data obeys the abstract functional relationship established in the previous step.
4. By using the created data we estimate the quantitative expression that obeys this data (mathematical fitting)	
5. The quantitative model is imposed to certain statistical/econometric tests. They aim at testing the ability of the estimated model to describe the real world phenomenon. Suitable corrections are undertaken. The target of this step is the establishment of the best quantitative law.	5. The quantitative expression is tested against real existing statistical data (verification). Suitable corrections of the quantitative expression are undertaken.

9.5 Concluding Remarks

The usefulness of commanding a quantitative representation of an environmental/economic system is beyond any doubt. The problem is often the procedure of obtaining this representation. The specific problem examined by the present chapter is how we could quantify a real world phenomenon for which we dispose only an insufficient number of statistical observations.

In fact, the present chapter examines a somewhat hybridic procedure. The hybridic characteristic of this procedure consists in utilizing both the scientific knowledge of a particular phenomenon and its existing statistical observations.

Actually, the scientific knowledge create a number of "shadow observations" for completing the existing-real ones. The reliability of the determined quantitative relationship is tested by examining its ability to fit real statistical observations which have not been used for its determination.

As a result, the proposed methodology offers a rather rigorous procedure which could be utilized in cases in which no other procedure can quantify a phenomenon. Indeed, in these cases, neither the direct knowledge nor the existing statistical observations suffice for quantifying the examined phenomenon.

However, the nature of the methodology confines suitably the range of its application. Thus, it could be employed for quantifying physical/technical phenomena and not socioeconomic ones. Socioeconomic phenomena involve stochastic factors which, although present in the real observations, cannot be taken into account ex-ante and therefore, they cannot be included in the created observations. Note that such a practice presupposes the complete knowledge of socioeconomic behavior by those who create the observations. On the contrary, these stochastic factors are not present in the physic/technical domain.

The proposed methodology, in effect, applies in cases of interactions/relationships phenomena of physic/technical nature.

This methodology is employed in the next chapter so that the interactions developed among the components of a particular environmental-economic system are quantified

CHAPTER 10

CASE STUDY

10.1 Introduction

The target of the present chapter is twofold. First, it aims at defining the limits of the economic development in a particular region so that the development in question could be ecologically sustainable. The examined region is the mountainous and semimountainous area of Olympia Province in Greece. Second, we try to apply the methodology, developed in the previous chapter, in order to quantify the interactions among the economic, the human and the natural systems of the examined region. Note that the quantification of these interactions serves the first target since the mathematical relationships will be used for examining the boarders of the ecologically sustainable development in the region.

In a first place, the description of the region as well as its relationships with the broader geographical region are presented. Then, the regional system is analyzed and represented schematically. Next the analysis of the relationships among the elements of the system are presented. The problem resides in the quantification of these relationships. Towards this direction, we employ the methodology analyzed by the preceding chapter. As a result, we obtain the analytical tool, the quantitative representation of the system, which could be used in order to examine the effects of alternative economic development's paths. By investigating these effects, we may reveal those directions of economic development which lead towards an "ecologically sustainable development".
In consequence, we use the methodology examined in chapter 9, for the formal representation of the regional system which will permit us to trace the economic and environmental impacts of alternative-hypothetical economic and environmental policies. So the boundaries of the ecologically sustainable development are revealed. Noticeable is that each one of the alternative set of economic-environmental policies (each of the scenarios), is a sum of measures-activities, resulting to effects that will be assessed. In effect, a real policy aiming at an ecologically sustainable development may be formed by measures/activities belonging to more than one of the examined scenarios.

10.2 Description of the Region

Olympia is located on the west part of the Peloponnese, which forms the south part of Greece's mainland. The name "province of Olympia" goes back to the days of Ancient Greece since in this area the Olympic games used to take place. Here we are only concerned with a part of the province, namely the mountainous and the semi-mountainous part.

This region covers a space of $264.000m^2$, constituting 10% of the total area of the Nomos Ilias (the overlapping administrative region). The area contains nineteen communities, while in the town of Andritsaina its administrative center and its capital are situated.
The population comes up to about 6.300 people (census 1981).

Geographical characteristics: The region is a relatively closed geographical area surrounded by the Alfios river at the east and the mountains "Minthy" and "Lykeion" at the west. In fact the region is a large watershed which descends to the Alfios river.
Because of the relatively high mountains the area shows a landscape of great variety. The highest point is calculated at 1224m above the sea level, while the lowest point reaches 300m. The latter is situated near the Alfios river in a relatively large valley where agriculture is the dominating economic activity. As the remaining part is mountainous, the dominating activity is the livestock production.

Climate characteristics: Generally, the climate is mild. Because of the gradually increasing altitude there are dominating western winds which bring along relatively strong rainfalls.
The speed of the winds is about 3 BEAUFOUR(50-60%) to 4 BEAUFOUR(30-40%).
The moisture level reaches 75%. The average rate of sunshine hours is 3.000 hours per year.
The average temperature comes up 10-15 ^{0}C during the winter and 20-25 ^{0}C during the summer.

Economic characteristics: The region is economically oriented towards agricultural production (58%) and towards the industrial treatment of the agricultural products (30%).
Since economic development is lagging behind the national trends, the region is characterized by the government as a region in need of economic aid.
The area presents strong economic interactions with the other parts of the Nomos Ilias and especially with the capital, Pyrgos. This town serves both as a transport center for the region and as an administrative center at a level higher that the one of Andritsaina.

Social characteristics: The region forms a traditional Greek society.
In the area, socio-public facilities are mostly lagging behind; this concerns services such as health care, education, communication, and other facilities.

Special elements: The region is characterized by a unique scenic beauty which is threatened by social and economic activities such as use of pesticides and fertilizers for the agricultural

production, and the hobbies of hunting or fishing.
There are several ancient monuments deserving attention and protection. The most important among them is the "temple of Apollo Epicurus", which is considered after the Parthenon of Athens as the most important ancient temple in Greece. It was designed by the same architects that were responsible for the construction of the Acropolis of Athens.

10.3 System Analysis

10.3.1 Introductory remarks

In this section we examine the components of the economic, human and environmental systems forming the regional system in hand. Later we will try to find out the fundamental relationships among these components.
For each subsystem there will be a brief text presenting its main aspects. Next a figure including all elements and their relationships related to ecological sustainable development, will be given for each subsystem.

10.3.2 Natural subsystem

Soil and subsoil: There is a high variety of the soil quality and productivity in the area due to a varied altitude.
To be precise, the area near the Alfios river has a rich and highly productive soil, while the mountainous area is characterized by rocky, sterile soil. That difference determines to a considerable extent the economic activities taking place in the respective areas.

As far as the subsoil is concerned, there are no serious available investigations which permit solid conclusions in this respect. However, we know that the region suffers from damages caused by earthquakes due to unstable subsoil. Besides, the existence of fossil stocks of coal having been attested.

Watershed: The region is bounded by Alfios river (the longest river in Peloponnese) and by its tributaries.
The Alfios' surface is 3.300km^2 and its water supply is 3.100m^3 per second (max) to 50m^3

(min).

There are 6 tributaries in the region which form a big watershed that reaches Alfios. There are no data on groundwater; so relevant assumptions are based on data concerning the water resources. By using such data we know that the groundwater is affected by the disposal of industrial and houses' waste, as well as by the overutilization of water resources.

Vegetation: The high level of moisture and the quality of the soil foster a rich variety and quantity of natural vegetation.

An area of about 50.000m^2 can be characterized as forests consisting of pine-trees and bushes. These forests suffer seriously from fires exploding during the summer period. Smaller problems are created by the extensive pasturage in the mountainous areas.

Wild-life: Two main characteristics may be recorded here: First, the wildlife is distinguished for its unique quality. Second, its quality is decreasing today because of some human activities taking place inside and outside the area. Indeed, some rare wild species may disappear if these human activities continue to follow the present trend.

Special ecosystems: We can distinguish three places with important natural values. First, the Alfios river which generates a unique waterland; second, the mountain range of "Minthy" which forms a special mountainous ecosystem (maybe one of the last resorts for wildlife in the area) and third, the area around the temple of Apollo Epicurus in favor of the importance of that monument.

Sustainability threats: Summarizing the main threats to the sustainability of the environmental system, the following problems may be mentioned:

1. The use of fertilizers and pesticides for agricultural production.
2. The free disposal of wastes in places randomly selected.
3. The groundwater depletion caused by overconsumption for agricultural uses and drinking water.
4. The Alfios river is polluted by the free disposal of wastes of an electric power generating unit which is located in a neighboring region. Besides, several fish species are exhausted by illegal fishing.
5. Natural vegetation is affected by fires and by unreasonable exploitation of trees.
6. Wildlife suffers from hunting, fires, and the use of pesticides for agricultural production.

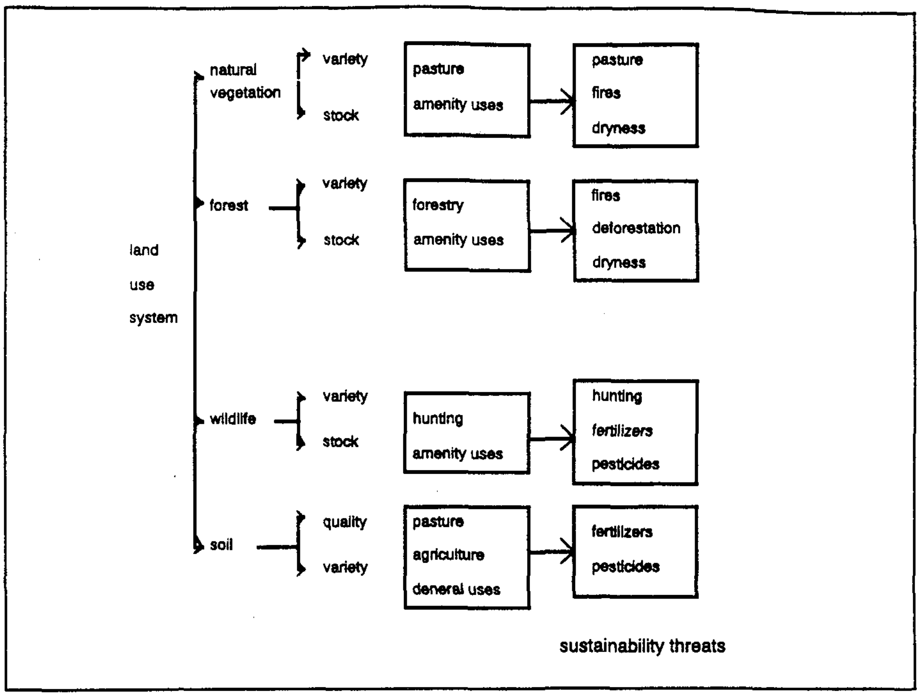

Figure 1 Terrestrial system

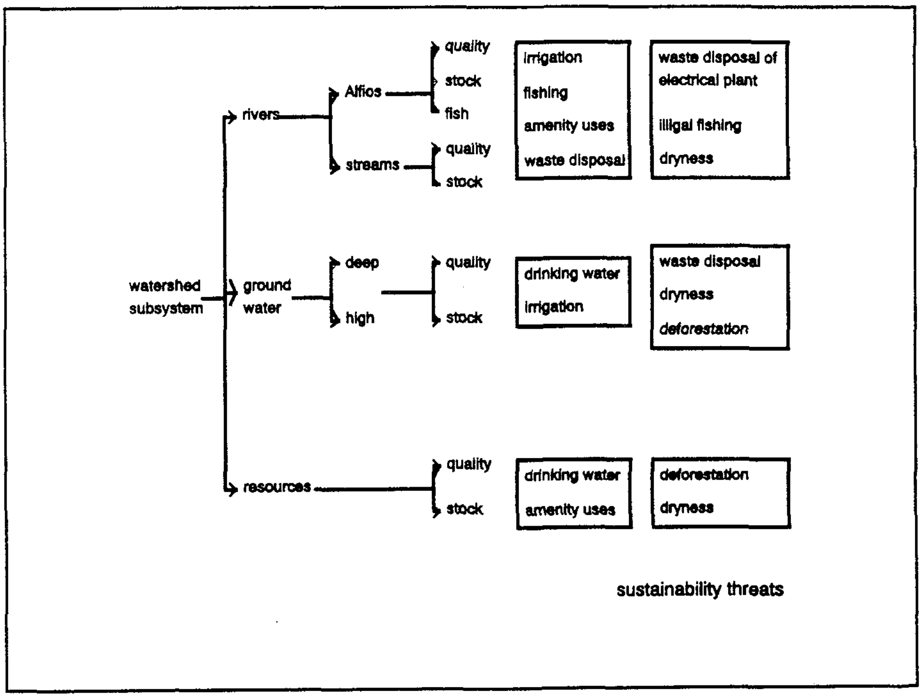

Figure 2 Watershed system

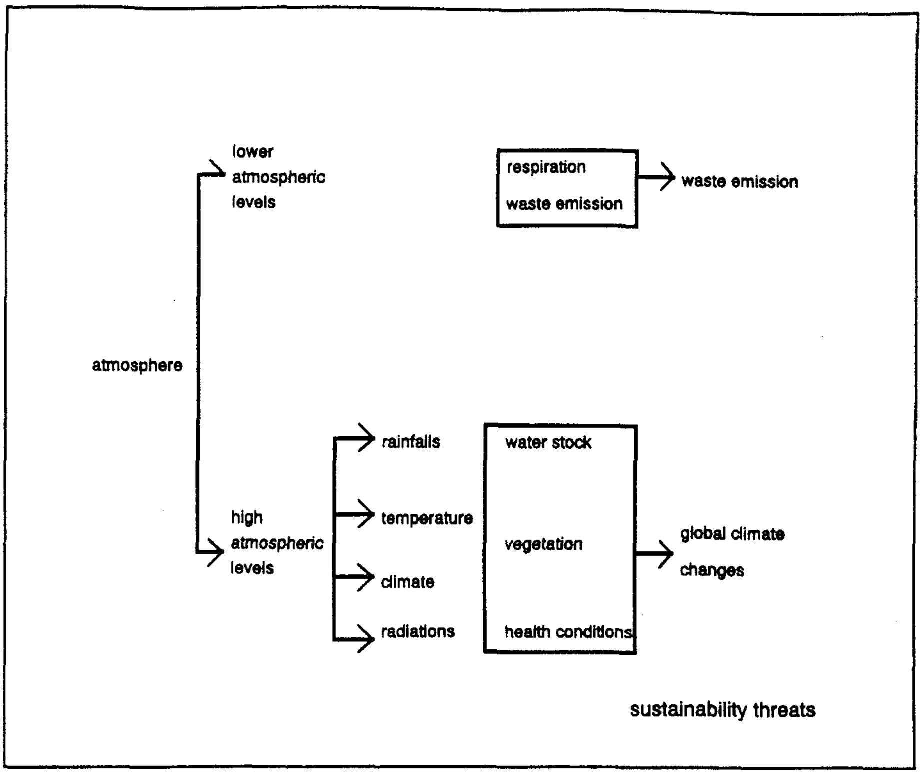

Figure 3 Atmospheric system

10.3.3 Human system

As we have already indicated, the human species in our area is forming a traditionally organized greek society. That means: (1) agriculture is the dominant economic activity, (2)self-employment is a common phenomenon, (3) the educational level is low, (4) the public facilities are lagging, (5) culture is co-determined by traditional elements and by the spreading of the western-world style of life.

Evidently, the human system in the examined region is not a closed system. Rather, it accepts serious influences which, penetrating the traditional structure, gives some new elements in the examined society. Specifically, the spreading of the mass media, the new production and especially consumption patterns as well as the membership to European Union influence strongly the social processes.

<u>Sustainability aspects/threats</u>: As far as the ecological sustainability is concerned, there is

an influence due to some elements of the human system. They are rather some social hobbies such as hunting and fishing, especially illegal fishing. They originate from some traditional hobbies which however, considering the contemporary technical equipments as well as the present magnitudes of human and natural species, lead to disastrous impacts.

Cultural characteristics-monuments: We mention here some "cultural characteristics" which are distinguished. The town of Antritsaina has an important architectural tradition which has been characterized as "under protection" by the Ministry of Culture. In the same town there is also a valuable library possessing a large number of extremely important publications of European books.

The temple of Apollo Epicurus designed by the architects' of the Acropolis of Athens, as well as some other ancient monuments like those of ancient Alifira give a relatively high cultural value to the region.

On the other hand, as far as the cultural maintenance is concerned, one may assert the following. Although the particular monuments of the region receive a governmental aid aiming at their protection, the whole plan is unconnected with any cultural and economic activity which could have arisen from this protection. Therefore, the monuments concern only a negligible minority of the relevant population. The arising indifference of the majority might bring the degradation of the monuments.

Finally, all the main characteristics of the regional human system are presented schematically by figure 4. Also, in this figure, the relationships between human system's elements and sustainability are given.

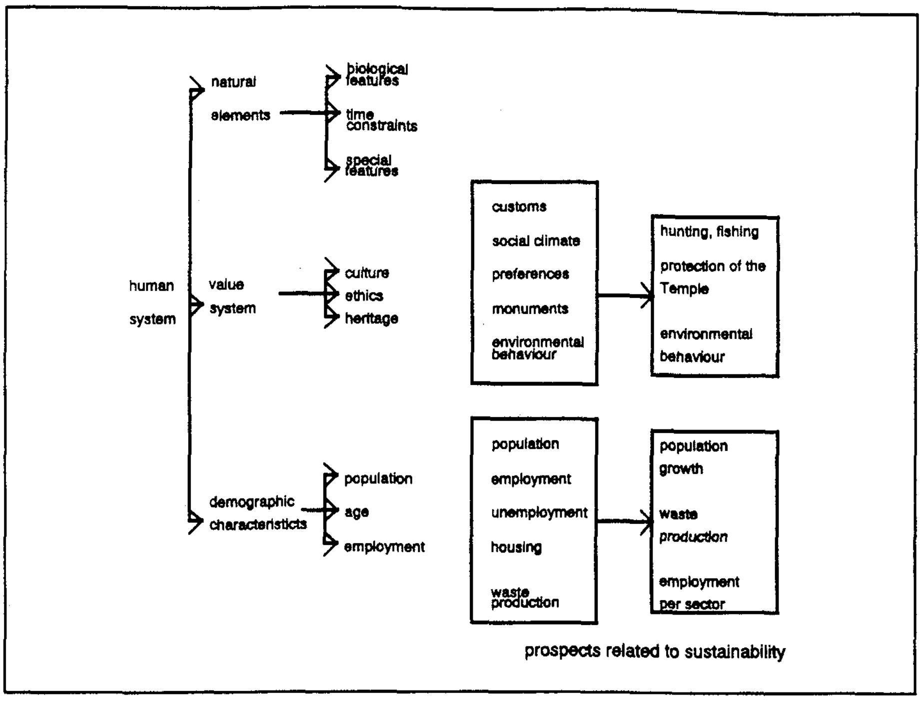

Figure 4 Human system

10.3.4 Economic system

The region is a traditional agricultural region (58% of the employment resides in agriculture). Production in agriculture concerns mainly arable and olives' cultivations. The products are being processed by local small industries or they are "exported" to the rest of Greece for further processing.

A significant proportion of the agricultural production is consumed within the region, while the self-consumption is a common phenomenon.

The services sector takes an increasing part of the total activity during the last years (mainly public services, tourism, and trade).

Due to their small magnitude, the economic activities are passive receivers of the messages coming from the rest of the Greek market. So, the prices of the relevant products are determined in the national level and so do the prices of the goods "imported" to the region. In a nut shell, the level of the economic activities are lagging behind the relevant national trends. For this reason, the region is characterized by the government as "needing economic incentives".

<u>Sustainability threats</u>: Although the patterns of the economic activities are unintensive, they

impose some serious impacts to the relevant environmental elements. The origins of these impacts are:

-The unreasonable use of pesticides and fertilizers during the last years in some specific cultivations. The relevant producers think that they have found the easy way of solving any problem connected with their cultivations via the use of chemical pesticides and fertilizers.

-The free disposal of the waste produced by some small industries which process agricultural products. Although this problem is not an acute one, it receives gradually more serious dimensions. For example, the disposal of the waste of oil-factories creates a considerable problem during winder.

-A serious problem comes from another direction and affects the economic activities. That is the problem of the water supply. Specifically, during the last years of relative droughts, there has been a water deficit in some economic activities as well as in the supply of water for house uses.

Figure 3 represents the main aspects of the regional economic system and connects them with the issue of sustainability.

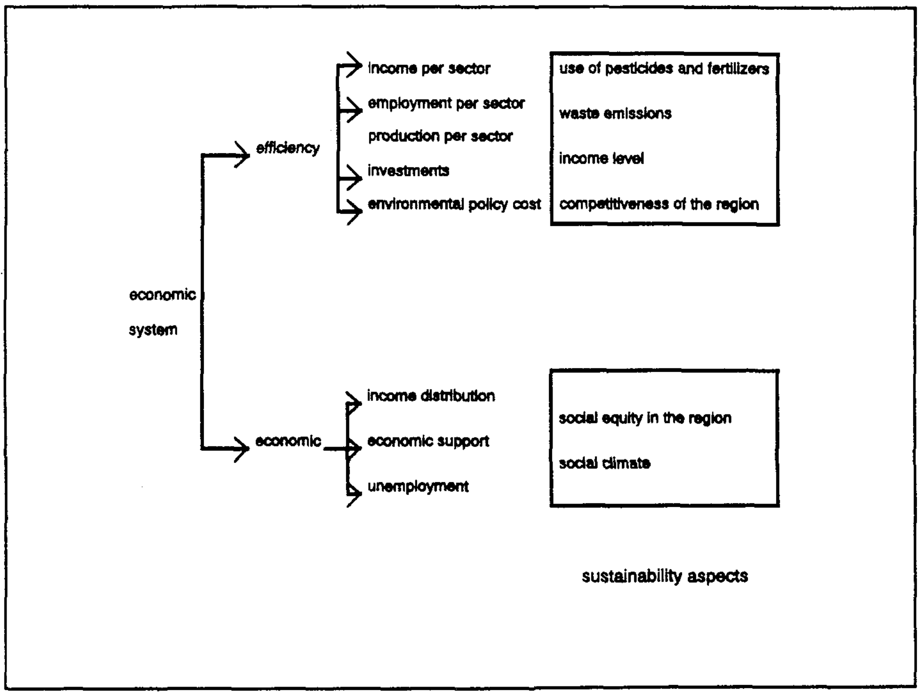

Figure 5 Economic system

10.4 Interactions Model

10.4.1 Interactions (Impact) Analysis

At this section, we investigate the fundamental relationships developed among the elements of the three subsystems (economic, human and natural) composing the regional system on hand. Specifically, we examine those relationships which are necessary for investigating the effects of economic and human activities on the natural elements as well as the feedback effects. Essentially, we inquire the technical interactions taking place among some physical quantities. Therefore, we do not aim at investigating the social/economic processes of the region, but some obvious and too simple ones. Rather, the state and the evolution of the social/economic processes will be handled as given via (alternative) hypotheses and then their effects will be examined.

So, the examined relationships will be of the form "causes-effects" where causes are the physical direct/indispensable outcomes of the social/economic activities, while the effects will be the influences of these physical quantities upon the elements of the system.

For the sake of simplicity, the above mentioned causes-effects relationships are represented in figure 1, where the main elements of the system are presented. On the other hand, table 1 gives the way, positive or negative, by which the causes and the effects are related in each particular case.

Let us present now systematically each individual interaction that will be handled by the quantitative model.

The main operation of each individual interaction is given by figure 1. However, when each interaction is examined alone some additional factors may be investigated. Besides, we will examine some interactions/relationships though they are not included in figure 1; they are some second order relationships which, for the sake of simplicity, are not presented in figure 1.

The operation of each individual relationship, the factors involved and their functions are based on the knowledge of the
interdisciplinary group that was gathered for the investigation of the regional system on hand.

As a result, each individual interaction is presented as a functional relationship between a number of independent variables and one dependant variable. The remaining problem is then the estimation of the exact numerical function of the functional relationship. The order in which the interactions are presented below is that of the final model representing the whole regional system.

The magnitude of the arable cultivations are a variable handled as exogenous by the model, so it is influenced by no other factor. The magnitude of the arable cultivations is given separately for the mountainous and semi-mountainous subregions.
The productivity of the arable cultivations is determined by an exogenous variable represented the target/assumption of this productivity. However if the soil quality is below a certain level, the actual productivity is lower than the exogenous target. Then the productivity is a function of both the relevant exogenous variable and the soil quality. Specifically, the relevant relationship is:
Arable production per km^2=Target (exogenous)productivity of arable production per km^2 if soil quality is above a certain level; while if soil quality is below this level, we have: arable production per km^2_t = F (target -exogenous- of arable production per km^2_t, Soil $quality_{t-1}$)
The productivity of the arable cultivations is defined separately for the mountainous and semi-mountainous areas.

The olives cultivation is measured by the existing olive-trees. The existing olive-trees are handled as an exogenous variable depicting a target/assumption; no other factor influences this variable.
The productivity of the olives' cultivations is defined as the produced oil per tree. The last variable is determined as an exogenous variable depicted a target/assumption, if the soil quality is above a certain level. However, if the soil quality is below this level, then: olives' productivity = F (target -exogenous- of olives $productivity_t$, soil $quality_{t-1}$).

The magnitude of the livestock is defined as an exogenous variable depicting a target/assumption. However, if the waterstock is below a certain level, then it influences negatively the exogenous target. Thus: if water stock is above a certain level, then livestock = exogenously defined livestock; otherwise, $livestock_t$ = F (exogenously defined $livestock_t$, water $stock_t$).

The industrial activities are measured by the number of the relevant employees. The last variable is determined by the arable production, by the olives production, by the activities of the construction sector and finally by an exogenous variable depicting the creation of opportunities for employment by the government. Thus, industrial $activities_t$ = F (arable $production_t$, olives $production_t$, construction $activities_t$) + directly created industrial $activities_t$.

The recreational activities are determined by a variable defined as environmental amenities, by the state of the monuments, by a variable defined as disseminates and, finally, by an exogenous variable that presents the direct creation of recreational activities mainly by the governmental policy. Thus, recreational $activities_t$ = F (environmental $amenities_t$, state of the temples and $heritage_t$, $disseminates_{t-1}$) + exogenously determined creations of recreational $activities_t$.
However, if the waterstock is found below a certain level, then the recreational activities are influenced negatively. Therefore we have, in this case, recreational $activities_t$ = F (envir. $amenities_{t-1}$, state of the temple and $heritage_t$, $disseminates_{t-1}$, $waterstock_t$) + the exogenously determined creation of recreational $activities_t$.

The construction activities are determined by the income level of some previous years as well as by the population increases during the last years. So, Construction $activities_t$ = F (Income $level_{t-1}$, Population $increases_{t-1}$).

The increases of the private cars are determined by the income and the employment levels. Therefore, increases of the private $cars_t$ = F ($Income_{t-1}$, $employment_t$).

The increases of the professional cars are influenced by the increases of industrial activities, of arable and of olives production. Thus, Increases of professional cars = F (Increases of industrial $activities_t$, increases of arable $production_t$, increases of olives $production_t$) - a depreciation rate.

The quality of the river's water is influenced by the production level of the electricity generating unit, by the population level (sewage) and by the arable production in the semimountainous area. Therefore: River water $quality_t$ = F (Electricity unit $production_t$, $Population_t$, arable production in the semimountainous $area_t$).

The water demand is determined by the arable production, by the production of livestock, by the industrial activities, by the recreational activities, by the construction sector activities and finally by the population level. The variable of water demand refers to the water demand during the summer period when any possible problem of water supply may emerge. The relevant functional relationship is: water $demand_t$ = F (arable $production_t$, livestock $production_t$, Industrial $activities_t$, Recreational $activities_t$, $Construction_t$, $Population_t$).

The stock of fishes in Alfios river is determined by the number of fishermen and by the quality of the water. Thus: the difference of the fishstock between two subsequent instances (years) = F (the relevant difference of fishermen number, the relevant difference of the river's water quality).

The soil quality is influenced by the arable production, by the olives' production and by the industrial activities. Therefore: the relevant difference between the two subsequent instances (years) = f (the relevant difference of arable production, the relevant difference of olives' production, the relevant difference of industrial activities).
The soil quality is defined separately for the mountainous and semimountainous areas.

The magnitude of the forests and the natural vegetation is determined as follows: forests-Vegetation$_t$ = Forest-Vegetation$_{t-1}$ - 0.1 * Forest-Vegetation$_{t-1}$ + A * Forest-Vegetation$_{t-1}$, if the arable cultivations do not exceed the 18,000 km^2. However, if the arable cultivations exceed 18,000 km^2, then from the above estimated value of Forest-Vegetation, we should subtract the sum: [Arable cultivations in semimountainous area + Arable cultivations in mountainous area -18,000]
The factor: 0.1 * Forest-Vegetation expresses the usual destruction of forests, mainly due to fires.
The factor: A * Forest-Vegetation depicts the annual reforestation. "A"expresses the annual rate of reforestation, this rate is handled as an exogenous variable.

The percentage of change of wildlife, between two subsequent instances (years), is determined by the relevant difference of the number of huntsman, by the relevant change of the arable production and of the olive production. However, if the number of huntsman exceeds a certain level, the wildlife starts to decrease drastically. Thus: Wildlife change = F (huntsman's change, arable production change, olives production change) if huntsman's number is below a certain level. If huntsman's number is above this level, then from the above expression, we should subtract the following factor: 0.01 * Huntsman number.

Migration is determined by the income and the employment changes over the last years. Thus: Migration$_t$ = F (Income$_t$ - Income$_{t-1}$, Employment$_t$ - Employment$_{t-1}$).

The changes of the population are defined according to the relevant changes of migration. Thus: Population$_t$ = Population$_{t-1}$ + Migration.

The changes of the state of the monuments and of the architectural heritage are determined by the changes of the relevant policy, especially by the changes of the relevant public investments. Therefore: Changes of the temples and heritage state$_t$ = F (Protection

$policy_t$).

The house waste as well as the sewage are determined by the population and by the recreational activities.

The level of noise within the bigger communities is determined by the magnitude of cars, private and professional, as well as by the activities of the construction sector.

The index of disseminates is influenced by the levels of noise, by the industrial activities and the house wastes.

The index of amenities is influenced by the states of forest-vegetation and by the wildlife.

The level of income is a function of arable production, of olives' production, of livestock production, of the industrial activities, of the construction sector activities and of the recreational activities.

The employment that is measured in number of employees, is a function of all those factors which determine also the income.

The River waterstock is a function of the annual rainfalls. Thus: River $waterstock_t$ = F ($Rainfalls_t$). The river waterstock is measured during the summer period and therefore it is influenced by the rainfalls measured in the winter and spring period of the same year.

The Waterstock (except that of the river) is also determined by the rainfalls of the same year. The water stock refers to the summer period, while the rainfalls refer to the participation of the whole year. Thus: $waterstock_t$ = F ($Rainfalls_t$).

The water supply is determined by the river waterstock and by the Waterstock. Specifically, we have: Water supply = 0,2 River waterstock + 0,8 waterstock. The water supply refers to the summer period.

The index of water deficit/surplus is defined as follows: index water $deficit/surplus_t$ = water $supply_t$ - water $demand_t$

The above text presents verbally the functional relationships of the quantitative model of the region. Where the role of time is not given explicitly, it will be presented in appendix

1 where the exact equations of the model are offered.

The above text indicates some of the exogenous variables of the model; however, all variables will be mentioned in appendix 1 and 3. The exogenous variables represent each time an evolution of which the effects will be estimated, therefore, the trends of the exogenous variables will be hypothetical. An exogenous variable may represent either an external influence to the system, or the evolution of an activity the effects of which should be revealed, or even a process that cannot be analyzed by the current knowledge and so its evolution is handled by assumptions.

10.4.2 Quantifying an individual interaction

The next step is the determination of the exact function of all the functional relationships mentioned in the previous section.
At the present section we will analyze as an example the process of quantifying an individual interaction. Next, we will give some useful information about the entire simulation model and its runs.

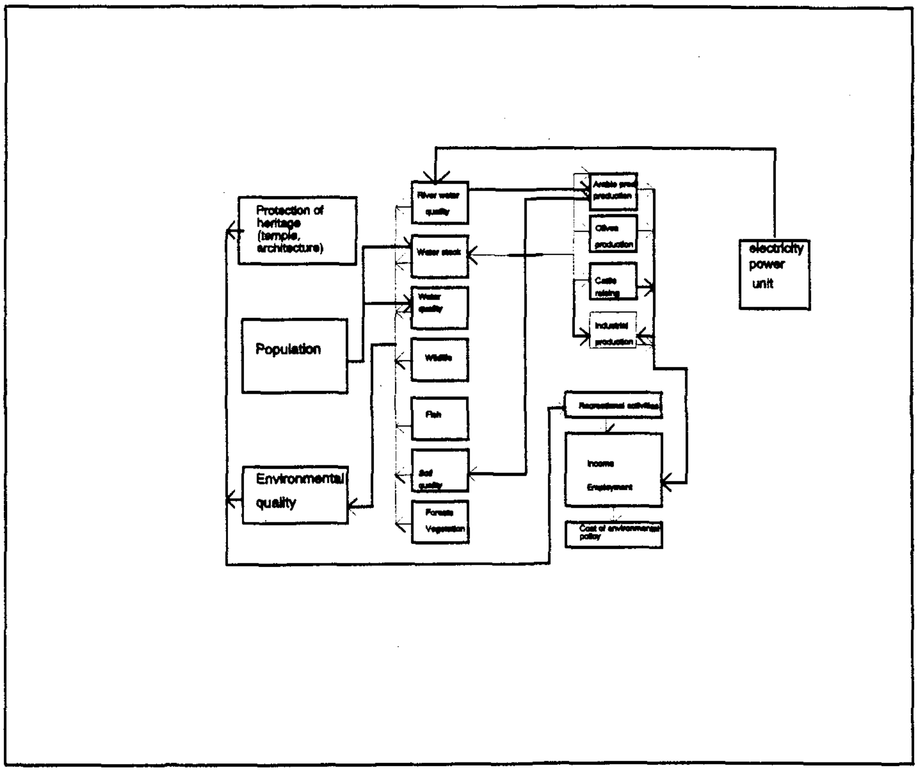

Figure 6 Impact model

The example concerns that functional relationship which presents the River's water quality as a function of the production of the Electricity generating plant, of the population and of the Arable production in the semimountainous region.
Let us give first the units/values of all these variables. The River water quality is measured by a compound index that takes values from the range [0 100]. The lower the value of the index is, the worse the water quality becomes. The initial value of the River water quality is 50.
The production of the Electricity generating unit is measured also by another index that takes values from the range [0 100]. The larger the production is, the higher the value of the index ascends. The initial value is 55.
Population is measured in real absolute values and the relevant initial value is 10,000.
Arable production in the semimountainous area is measured also in real values and its initial value is 1,100,000 kgr.

The remaining problem is the exactly quantification of the examined relationship. Although there are some statistical observations of the relationships, they are not enough for establishing a reliable numerical function. Therefore, the problem is handled according to the methodology developed in the previous chapter. Specifically, the suitable selected interdisciplinary group was asked to create some observations that describe particular instances of the operation of the examined relationship.
The interdisciplinary group knows sufficiently the operation of the real world relationship. Therefore, the members of the group are able to define the value of the dependant variable, that corresponds to a particular combination of the independent variables' values (surrogate experimentation). When a set of created observations has been obtained, this set could by treated so that a numerical function that fits these observations is determined. At this point, there are two alternatives: the set of the processed observations may include also some real observations or only the created observations. For our example, we have chosen that the data set are to be processed so that to include only the created observations. The real observations will be used for testing the determined numerical function afterwards.

The set of the created observations is the following:

Rq	E1	Pop	Arpsm
45	60	10.200	1.150.000
30	70	10.000	1.200.000
18	80	11.000	1.200.000
48	50	12.000	1.500.000
45	50	11.500	2.000.000
55	30	13.000	1.900.000
57	30	13.500	1.300.000
60	25	14.000	1.500.000
48	35	12.000	2.500.000
56	25	13.000	1.500.000
68	20	13.000	1.500.000
47	60	10.000	1.100.000

The problem, then, is the determination of a curve which fits the above data. In other words, the determination of a numerical function that describes sufficiently the relevant data is pursued.

In order to determine a numerical function that describes as well as possible the relevant phenomenon -the influences of the independent variables on the dependent one- we examine a plausible number of "candidate functions". Specifically, we assume that each of the independent variables act on the dependent by such a way which may be formally represented by either a linear or a logarithmic or an exponential or a rational mathematical expression. These four mathematical expressions in the case of three dependent variables create 66 candidate functions (when we examine only the linear combination of the independent variables). These functions are:

Candidate 1 : $y=A\ esp(x_1) + B\ esp(x_2) + C\ esp(x_3)$
Candidate 2 : $y=A\ esp(x_1) + B\ esp(x_2) + C\ esp(x_3)$
Candidate 3 : $y=A\ esp(x_1) + B\ x_2 + C\ 1/X_3$
Candidate 4 : $y=A\ esp(x_1) + B\ 1/X_2 + C\ 1/X_3$
Candidate 5 : $y=A\ esp(x_1) + B\ x_2 + C\ x_3$
Candidate 6 : $y=A\ 1/X_1 + B\ 1/X_2 + C\ 1/X_3$
Candidate 7 : $y=A\ 1/X_1 + B\ esp(x_2) + C\ x_3$
Candidate 8 : $y=A\ 1/X_1 + B\ x_2 + C\ x_3$
Candidate 9 : $y=A\ 1/X_1 + B\ x_2 + C\ esp(x_3)$
Candidate 10: $y=A\ x_1 + B\ x_2 + C\ x_3$
Candidate 11: $y=A\ x_1 + B\ esp(x_2) + C\ esp(x_3)$
Candidate 12: $y=A\ x_1 + B\ 1/X_2 + C\ 1/X_3$
Candidate 13: $y=A\ x_1 + B\ esp(x_2) + C\ 1/X_3$
Candidate 14: $y=A\ x_1 + B\ 1/X_2 + C\ esp(x)$
Candidate 15: $y=A\ 1/X_1 + B\ esp(x) + C\ x_3$
Candidate 16: $y=A\ 1/X_1 + B\ esp(x_2) + C\ esp(x_3)$
Candidate 17: $y=A\ x_1 + B\ x_2 + C\ esp(x_3)$
Candidate 18: $y=A\ x_1 + B\ x_2 + C\ 1/X_3$
Candidate 19: $y=A\ x_1 + B\ esp(x_2) + C\ x_3$
Candidate 20: $y=A\ x_1 + B\ 1/X_2 + C\ x_3$
Candidate 21: $y=A\ 1/X_1 + B\ 1/X_2 + C\ esp(x_3)$
Candidate 22: $y=A\ 1/X_1 + B\ esp(x_2) + C\ 1/X_3$
Candidate 23: $y=A\ 1/X_1 + B\ x_2 + C\ 1/X_3$
Candidate 24: $y=A\ esp(x_1) + B\ esp(x_2) + C\ x_3$
Candidate 25: $y=A\ esp(x_1) + B\ x_2 + C\ esp(x_3)$
Canditate 26: $y=A\ esp(x_1) + B\ 1/X_2 + C\ esp(x_3)$
Candidate 27: $y=A\ esp(x_1) + B\ 1/X_2 + C\ logx_3$

Candidate 28: $y = A\ esp(x_1) + B\ logx + C\ 1/X_3$

Candidate 29: $y = A\ esp(x_1) + B\ logx_2 + C\ logx_3$

Candidate 30: $y = A\ 1/X_1 + B\ esp(x_2) + C\ logx_3$

Candidate 31: $y = A\ 1/X_1 + B\ logx_2 + C\ logx_3$

Candidate 32: $y = A\ 1/X_1 + B\ logx_2 + C\ expx_3$

Candidate 33: $y = A\ logx_1 + B\ logx_2 + C\ logx_3$

Candidate 34: $y = A\ logx_1 + B\ esp(x_2) + C\ esp(x_3)$

Candidate 35: $y = A\ logx_1 + B\ 1/X_2 + C\ 1/X_3$

Candidate 36: $y = A\ logx_1 + B\ esp(x_2) + C\ 1/X_3$

Candidate 37: $y = A\ logx_1 + B\ 1/X_2 + C\ esp(x_3)$

Candidate 38: $y = A\ 1/X_1 + B\ esp(x_2) + C\ logx_3$

Candidate 39: $y = A\ logx_1 + B\ logx_2 + C\ esp(x_3)$

Candidate 40: $y = A\ logx_1 + B\ logx_2 + C\ 1/X_3$

Candidate 41: $y = A\ logx_1 + B\ esp(x_2) + C\ logx_3$

Candidate 42: $y = A\ logx_1 + B\ 1/X_2 + C\ logx_3$

Candidate 43: $y = A\ 1/X_1 + B\ 1/X_2 + C\ logx_3$

Candidate 44: $y = A\ 1/X_1 + B\ logx + C\ 1/X_3$

Candidate 45: $y = A\ esp(x_1) + B\ esp(x_2) + c\ logx_3$

Candidate 46: $y = A\ esp(x_1) + B\ logx_2 + C\ esp(x_3)$

Candidate 47: $y = A\ esp(x_1) + B\ logx_2 + C\ x_3$

Candidate 48: $y = A\ esp(x_1) + B\ x_2 + C\ logx_3$

Candidate 49: $y = A\ log(x_1) + B\ esp(x_2) + C\ x_3$

Candidate 50: $y = A\ log(x_1) + B\ x_2 + C\ x_3$

Candidate 51: $y = A\ log(x_1) + B\ x_2 + C\ esp(x_3)$

Candidate 52: $y = A\ x_1 + B\ logx_2 + C\ esp(x_3)$

Candidate 53: $y = A\ logx_1 + B\ esp(x_2) + C\ x_3$

Candidate 54: $y = A\ x_1 + B\ x_2 + C\ logx_3$

Candidate 55: $y = A\ x_1 + B\ logx_2 + C\ x_3$

Candidate 56: $y = A\ logx_1 + B\ logx_2 + C\ x_3$

Candidate 57: $y = A\ logx_1 + B\ x_2 + C\ logx_3$

Candidate 58: $y = A\ logx_1 + B\ 1/X_2 + C\ x_3$

Candidate 59: $y = A\ logx_1 + B\ x_2 + C\ 1/X_3$

Candidate 60: $y = A\ 1/X_1 + B\ logx_2 + C\ x_3$

Candidate 61: $y = A\ 1/X_2 + B\ x_2 + C\ logx_3$

Candidate 62: $y = A\ x_1 + B\ logx_2 + C\ 1/X_3$

Candidate 63: $y = A\ x_1 + B\ 1/X_2 + C\ logx_3$

Candidate 64: $y = A\ 1/X_1 + B\ 1/X_2 + C\ x_3$

Candidate 65: $y = A x_1 + B \log x_2 + C \log x_3$
Candidate 66: $y = A x_1 + B \operatorname{esp}(x_2) + C \log x_3$

By using the least square method, we estimate the coefficients A, B and C for each one of the above functions. Then we select the function that gives the least square sum, as the function which fits better the given data set (the data have been imposed a suitable scaling, see below).

Candidate 14 presented the least square sum and therefore this function is chosen. In effect, the numerical function of the relevant functional relationship is written as: $Rq=[-1.1El] + (116.2/Pop) - [0.1 * 10^{-10} * \operatorname{esp}(Arpsm)]$. However, due to the fact that during the runs of the whole model, the variable Arpsm may take a relatively high value - larger than the existing values in the relevant data set- so that its exponential expression will be extremely high, we have decided that when Arpsm > 20 (scaled value), then the second best candidate will be used.The second best candidate is the 12. Thus, when Arpsm > 20, then the relevant function is : $Rq = [-1.1 Fe] + [100.8/Pop] + [16.3/Arpsm]$.

Taking the opportunity from the just mentioned issue, we give here the rationale of the variables' scaling that is followed in the present study. Besides, some other procedures which are followed during the model runs are explained.

Some of the variables of the model are measured in absolute high values, although their changes during the model runs are a small percentage of these absolute values. Then, since what matters is the relative changes of the values and in order to examine also the exponential expressions of the relevant variables, we impose ex-ante the variables of the model to scale. Specifically, all variables are scaled by being multiplied by 10^{-1}, except the following variables: Arable production (Arp), arable production in mountainous area (Arpm), arable production in semimountainous area (Arpsm) and Olives production (Olp), they have been scaled by being multiplied by 10^{-5}. Livestock (Cb) and forest vegetation (FV) are scaled by being multiplied by 10^{-4}. Population (Pop) and recreational activities (rec) are scaled by being multiplied by 10^{-3}. Finally, rainfalls (R) are being multiplied by 10^{-2}.

Let us examine now a problem arising due to the use of exponential expressions -the same problem with that of the example given above-. If the selected numerical function includes one or more exponential expressions, then there is the following possibility during the runs of the model. The variable(s) corresponding to the exponential expression(s) may take a relatively high value, specifically, so high as no one of the values of the relevant data set. As a result, the chosen function may not be suitable for describing the phenomenon further, since this function has been selected by using more moderate values of the relevant variable(s) -those values included in the data set-. Note that the exponential expression

increases much more drastically than the value of the respective variable.
In these cases, we have the following solutions: either we impose the relevant variable to a further scaling beyond the ex-ante one when it takes a value larger than a certain one; or we choose another candidate function, the second best one; the second best candidate function is being applied when the relevant variable exceeds a certain value.

A last issue arises if the chosen function includes one or more logarithmic expressions. If, during the runs of the model, the relevant variable(s) take(s) a negative value, the chosen function is not suitable anymore. Then, we insert to the model the second best or another acceptable function, provided that this one does not bear the same problem. The substitute function is being used only when the variable with the logarithmic expression takes a negative value.

In the above example, we have examined 66 candidate functions created by the combinations of four mathematical expressions for three independent variables. In the cases of less than three independent variables, we have examined all the combinations of the four mathematical expressions. However, in the cases of more than three independent variables, we exclude the rational expression and so, the remaining mathematical expressions are the linear, the logarithmic and the exponential. In particular, in the case of six independent variables, we have 61 candidate functions consisting of the combinations of the three just mentioned expressions.

10.5 Results

10.5.1 Description of the scenarios

Once the simulation model that represents formally the regional system has been established, it will be employed for tracing the boundaries of the ecologically sustainable development at the region. In order to perform this target, we examine the effects, economic and environmental, of a number of alternative scenarios. These scenarios describe some economic/ environmental policies and activities. Essentially, these scenarios assume the evolution of certain activities-policies, within or outside the region, that determine both the ecological state and the economic performance of the region. These activities are represented by the exogenous variables of the model. As a result, the examined scenarios are constituted by a set of hypotheses concerning the evolution/ trends of the exogenous variables of the model.

The exogenous variables of the model may be classified to the following categories: First, those variables that concern the economic activities within the system. Second, those variables that represent some elements of the social behavior. Third, those variables which represent the public policy against some activities or elements of the region. Fourth, those variables that present certain evolutions at some larger spatial levels which influence the regional system.

Let us present the evolutions/trends of the exogenous variables for each of the scenarios. The first scenario examines the effect of a relatively extreme economic growth in the absence of any environmental policy; the absence of an environment protection policy characterizes currently the region. Besides, certain social hobbies (hunting and fishing) evolve rapidly, in a way similar to the present trends.

Specifically, the exogenous variables depicting the targets of the economic activities increase by an annual rate of 2.5% for a period of 20 years -this is the period of the model runs and therefore all the exogenous variables evolve during this time span-. The exogenous targets of the economic activities are: the target of the olive-trees (EOln), the target of the olives' cultivation density (EOld), the target of the area of the arable cultivations for both the mountainous and the semimountainous subregions (EArqm, EArqsm), the target of the productivity of the arable cultivation (EArdm, EArdm), the target of the production of the livestock (ECb), the target of the industrial production (EInd), and the target of the recreational activities (Erec). All these variables form the first group of the exogenous variables, the group of the economic activities targets.

The exogenous variables, depicting some social hobbies related to the environment, increase

by an annual rate of 2% for all the period of the model run. These variables are the index of fishermen (IndFm) and the number of huntsman (Hm). They form the second group of the exogenous variables.
Those exogenous variables that present certain evolutions outside the region however, being quasi-relevant for the evolution of the regional system, have the following trends: First, the waste disposal of the electricity unit increases by an annual rate of 2% for a period of 20 years since the production of the unit increases by a similar rate. Second, the rainfalls (R) remain at the same level during the time span of the model run.
Finally, those exogenous variables that represent the public policy, have the following trends: first, the index that depicts the public concern -expenditures and other measures- to the temples and to the rest of the monuments (IndPTH) remains constant for all periods. Second, the ratio (A) of the afforestated forest to the total forest is nil.

The second scenario aims at a strict environmental protection policy, while the economic activities grow by an infinitesimal rate.
Specifically, all the exogenous variables of the first group increase by an annual rate of 0.5% for the period of 20 years. On the other hand, the exogenous variables of the second group decrease by an annual rate of 3%, for the same period. The afforestation ratio is 15% per year standard for all period, thus A=0.15. The waste disposal of the Electricity unit decreases by an annual rate of 3%, due to suitable processing of the produced waste. The IndPTH increases by an annual rate of 2%, while the rainfalls (R) remain at the same level during all the examined period.

The third scenario aims at a moderate economic growth in the absence of any environmental protection policy.
Specifically, all the variables of the first group increase by an annual rate 1.5% for the period of 20 years. All the rest exogenous variables follow the respective trends of the first scenario.

The fourth scenario examines the effects of a moderate economic growth accompanied by a moderate environmental policy.
All the variables of the first group -targets of the economic activities- follow the respective trends of the third scenario. On the other hand, the rest of the variables evolve as follows: IndFm decreases by an annual rate of 2%; and so do the waste disposal of the Electricity unit (El). The huntsman (Hm) decrease by an annual rate of 1.5%, while IndPTH increases by 1.5% per year. The coefficient of afforestation (A) is 0.12 for all the period, that is to say the afforestated forest is 12% of the existing forest, at each time unit. Rainfalls (R)

remain at the same magnitude during all period.

The fifth scenario investigates the effects of a moderate economic growth, accompanied by a strict environmental protection. Therefore, all the variables of the first group of the exogenous variables evolve as in third scenario. On the other hand, all the rest exogenous variables of the model follow the respective trends of second scenario.

The sixth scenario aims at examining the effects of an external-global shock on the region. This shock is the diminishing rate of rainfalls. Indeed, the investigation of the effects of such an evolution is interesting since, during the last year, the decreased precipitation has created some serious problems in the region.
Therefore, in the present scenario, it is assumed that the rainfalls decrease by an annual rate of 1.5% for a period of 20 years, while all the other variables evolve like in the fourth scenario. Then, the effects of this shock on the economic and environmental system are estimated.

The seventh scenario is an extension of the previous one. Specifically, rainfalls follow the trends of the sixth scenario. However, the water demand is adjusted to lower levels because of a suitable policy in the water consumption.

The eighth scenario examines the effects of a qualitative differentiation of economic development. The specific change is that the agricultural activities and specifically the arable cultivations use those production methods that have very moderate effects on the environment (biocultivations). In order to reveal the impacts of such a practice we assume that all exogenous variables evolve like in the eighth scenario.

The ninth scenario is an alternative of the eighth scenario. Specifically, the qualitative change at agricultural cultivation holds also in the present scenarios. However, the trends of the exogenous variables are those of the first scenario. Thus, the present scenario investigates the effect of an extreme economic growth without any environmental protection policy, except the moderate impacts of agricultural activities.

10.5.3 Scenarios effects. The prospects of the ecologically sustainable development

By using the simulation model that represents formally the regional system and by adjusting suitably the exogenous variables of this model we estimate the results of each scenario. The estimation is for a period of 20 years and the time unit of the model run is one year. The initial year is 1985 and so all the variables of the model take as initial values the respective values of this year. The initial values of the exogenous variables are the same for all scenarios and they are given in appendix 1.

Thus, for each year, all the variables of the model are estimated for each scenario. For the sake of simplicity, appendix 2 presents diagrammatically the evolution of few chosen variables for all scenarios. The rationale for selecting these variables is that they should give a relatively clear picture of the evolution of the regional system, both from the environmental and economic aspects. Since what matters is the relative changes and the sign of each variable during the time span of the model, we have scaled suitably the selected variables, so that they can be presented in the same figure.

The exact numerical results of each scenario are given also in appendix 2, where the presented variables have the standard scaling of the model runs.

Based on the numerical results given in appendix 2, we could draw some conclusions concerning the prospects of the ecologically sustainable development in the regional system.

The first scenario leads to high increases of the income and employment variables; however, at the last year of the model run these rates reverse and then, it is expected to remain diminishing at least for some period. The extreme economic growth of some economic activities have affected strongly the relevant natural elements on which these activities are based and therefore, the feedback effects influence negatively the economic performance. For example, the agricultural cultivations have negatively influenced the soil quality; in consequence, the high density of these cultivations cannot be sustained.

On the other hand, the environmental variables evolve negatively. The causes of this evolution are, besides the economic activities, the examined social hobbies (hunting, fishing) and the unexisting environmental policy.

Noticeable is the serious problem of water supply that will emerge if the economic activities increase drastically.

The second scenario gives very positive trends for the environmental variables as a result of the strict environmental indicators policy. On the other hand, economic performance indexes remain almost constant. In addition, there is no serious problem with water supply, since the index water deficit/surplus remains positive, which means that there is a water surplus. However, during the end of the time span this index adjusts the zero value. In effect, there is a long run problem with water supply even if the economic activities have a smooth increase.

In the third scenario the moderate economic growth results in some positive rates in the economic performance variables, although these rates are lower than the respective ones of the first scenario. On the other hand, environmental variables follow negative trends although the economic activities do not develop rapidly. Therefore, we may conclude that the stability of the environmental system is not only influenced by economic activities. Rather, some other activities such as social hobbies and public policy determine strongly the evolution of natural system.

The fourth scenario gives positive rates for the evolution of economic variables. On the other hand, environmental variables also increase or remain at the same level. Only soil quality decreases however, remaining always in positive values and therefore, this evolution does not bear any serious problem. Water deficit takes negative values after the 10th year. However the negative trends of this variable does not imply any specific problem compared with the results of the other scenarios.
As a result, the moderate economic growth and the moderate environmental protection policy brings some relatively good results for both environmental and economic indexes.

The fifth scenario differs from the fourth as far as some environmental variables are concerned. Specifically, these variables are better in the because of the stricter environmental policy assumed by it.

The sixth scenario examines the effects of a diminishing rate of rainfalls. Then, the water deficit variable takes more negative values, which in turn influence the economic variables. Essentially, some of the economic activities are negatively influenced by the water deficit and so are the income and employment. As a result, the decreased precipitation, besides any other direct outcome, influences the prospects of economic development. This betrays the sensitivity of the regional system against serious global changes.

The seventh scenario is just an alternative of the previous one. The present scenario assumes that a policy is developed against the problem of water deficit. Specifically, certain measures aiming at confining the water consumption are undertaken. The outcome is that the water deficit increases by a lower rate and takes more moderate negative values. However, water deficit still exists and imposes problems on the development of social and economic activities.

The problems arising because of the water deficit are not insurmountable ones. In other words, they do not lead to the impasse of the economic and social activities. Rather, these problems may be overcome, provided however a noticeable economic cost and some inconvenience in the operation of the regional system.

The eighth scenario assumes the same trends for the exogenous variables with the seventh scenario. The only difference in comparison with the seventh scenario is that the agricultural cultivations impose relatively moderate impacts on the environment and specifically on the soil quality. In effect, soil quality is diminishing by a lower rate. On the other hand, the new methods of agricultural production are not so effective as those of the fourth scenario. Therefore, the variables of economic performance in the region take smaller values compared with those of the fourth scenario. However, in any case, these variables increase during the whole time span of the model run (20 years).
The water deficit remains the same with that of the seventh scenario.

Finally, the ninth scenario assumes the same trends for the exogenous variables with the first scenario. However, the methods of agricultural production are the same with the seventh scenario. So, the impacts on the soil quality are moderate. As a result, soil quality decreases by a lower rate than that of the first scenario. All the other variables evolve in a way similar to that of the first scenario. So, economic variables increase rapidly, although this trend seems to reverse in the end of the examined period. On the other hand, the environmental values decrease rapidly.

10.6 Concluding remarks

The present chapter deals with the investigation of the prospects for an ecologically sustainable development in Olympia. Towards this investigation, we use the methodology developed in the previous chapter, examining the quantification of a system under a lack of sufficient statistical data. This methodology is proved useful in examining Olympia's system. So, on the basis of the quantitative-simulation model, we investigate the boundaries of ecologically sustainable development by tracing the effects of nine scenarios forming each one a set of assumptions concerning the hypothetical evolution of some crucial activities.

Some useful conclusions may be drawn then. The examined region, though rather traditional and with relatively moderate density of economic activities, will face serious environmental problems. The causes are some traditionally developed economic activities, certain environmental behaviors and some external evolutions. Therefore, even if the present trends of economic activities continue, some environmental protection policy is required for permitting the maintenance of the environmental system.

Besides, the region is rather sensitive to some external socks like that of the diminishing rate of rainfalls. The effects of such an evolution have started to create one of the major problems during the last years. Of course, one is not able to declare yet whether the diminishing rainfalls is an accidental or a permanent phenomenon. However, in the light of the current research about the climate changes, this phenomenon should be seriously taken into account.

On the other hand, some friendly to the environment production methods, especially in the agricultural sector, could bring considerably positive outcomes to the economic system performance, while imposing relatively light impacts on the environment. Since these production methods require large areas (even of a semiproductivity soil), that exist in the region, and as the soil quality is now relatively good, these production methods emerge as an attractive way of an ecologically sustainable development.

Appendix 1

The equations of the model are presented below. The equations are written in fortran code and are given in the way they are used in the model run. Specifically, the initial values and the auxiliary variables are given as they exist in the model run. For further information about each one variable see Appendix 3.

First, it is presented the equations of the whole model for scenario 1; it is called model 1. Besides, the evolution of the exogenous variables are given seperately for each one scenarios. Note that some equations of the models of the other scenarios may differ from the respective ones of scenarios 1 (model 1), however, these equations are not presented here.

Model 1

INITIAL VALUES

```
l1=10.
l2=5.07
l3=22
l4=8.277
l5=20.
l6=0.35
l8=10.
l10=100.
l11=10.
l12=4.5
indinc=10.
dis=5.0
eoln=23.65 eardsm=20.
eardm=10.
earqsm=0.55
earqm=1.1
eold=0.35
ecb=3.3
eind=0.
erec=0.
indfm=10.
hm=100.
el=5.5
indpth=0.0
Am=7.
R=6.7
indsqm=10.
indsqa=10.
carw=42.
carp=10.
pop=10.
indf=10.
fv=10.
indwl=10.
indth=10.
```

```
a=0.0

read(*,*) n
do 1 i=1,n

Arqm = EArqm

if (IndSqm .lt. 5.5) then
ardm = 0.79*EArdm + 0.39*IndSqm
else
Ardm= EArdm
endif

Arqsm= EArqsm

if ( IndSqa .lt. 5.5) then
ardsm = 0.77*EArdsm + 0.91*IndSqa
else
Ardsm= EArdsm
endif

Arp= Arqm*Ardm + Ardsm*Arqsm

Oln=EOln

if (IndSqa .gt. 5.5) then
old = EOld
elseif (indsqa .gt. 4.5 .and indsqa .gt. 4.5) then
x1 = exp(indsqa)
old = 0.67*EOld + 0.0013*x1
else
x1 = 99
endif
endif

Olp=Oln*Old

Ws=0.82*R

Rws=0.82*R

if ( Ws .ge. 4.0) then
cb = ECb
else
Cb= 0.62*ECb + 1.1*LOG(ws)
endif

C=0.15*IndInc + 0.16*(Pop-L1)

Ind= 1.7*LOG(Arp) - 6.6/Olp + 0.41*C +EInd

IndTH=IndTH + 0.45*IndPTH

TH=6.0*IndTH/10.0
```

```
if ( Ws .lt. 5) then
rec = 0.31*Am - 0.42*Dis + 0.12*TH +6.5*LOG(Ws) + ERec
else
rec = 6.4*LOG(Am) + 2.2/Dis + 9.7*LOG(TH) +ERec
endif

Emp= 0.05*Arp + 0.07*Olp + 0.16*Cb + 0.22*Ind + 0.008*C + 0.04*Rec

Carp= Carp +0.84*LOG(IndInc) - 9.8/Emp

Carw= Carw - 0.05*Carw + 0.28*(ind - l2)+ 0.1*(arp - l3) +0.4*(olp - l4)

Arpsm=Arqsm*Ardsm

if (arpsm .lt. 20.) then
x2=exp(arpsm)
Rq=- 1.1*El+(116.2/Pop)-(0.00000000001*x2)
else
Rq = -1.1*el + (100.8/pop) + (16.3/arpsm)
endif

IndInc= 10.*(0.20*Arp/22.0 + 0.20*Olp/8.2775 + 0.20*Cb/3.3 + 0.15*Ind/5.0 + 0.15*C/1.5 +
      0.10*Rec/30.5 )

Mig= 0.38*(IndInc-L11) + 0.39*(Emp-L12)

L1= Pop

Pop= Pop + Mig

Wd= 0.07*Arp + 0.03*(Cb) + 0.07*(Ind)- 0.2*(Rec) - 0.1*(C) + 0.9*(Pop)

Sew=10.*(Pop+(1.5*Rec/365.))/(10.+ (1.5*33.8/365.))

IndRq=10.*Rq/5.5

if (rq .lt. 0) then
u5 = 0
else
u5 = log(indRq)
endif

indF = indF - 0.64*indFm + 2.9*u5

u1= old-l6
u2=ind-l2
u3=ardsm-l5
u4=ardm-l8
if (u1 .lt. 0) then
u1=0
else
u1=old-l6
endif
if (u2 .lt. 0) then
u2=0.0
```

```
else
u2=ind-l2
endif
if (u3 .lt. 0) then
u3=0.0
else
u3=ardsm-l5
endif
if (u4 .lt. 0) then
u4 = 0.0
else
u4=ardm-l8
endif

x3=exp(u3)

indsqa= IndSqa - 0.027*x3- 16.4*(u1) - 0.18*(u2)

x4=exp(u4)

IndSqm= IndSqm - 0.027*x4- 16.4*(u1) - 0.18*(u2)

if ( (Arqsm + Arqm) .gt. 2.5 ) then
FV = FV - 0.1*FV + A*FV - (Arqsm+Arqm - 2.5)
else
fv = FV - 0.1*FV + A*FV
endif

Nois=10.*((0.2*C+0.3*Carp+0.4*Carw)/(0.2*1.5+0.3*9.8+0.4*40))

Hw= 10.*((Pop+1.5*Rec/365.)/(10.+1.5*33.8/365.))

Dis= 0.31*Nois- 6.2/Ind + 0.27*Hw

IndWl= IndWl - 0.29*(Hm-L10) - 0.009*(Arp-L3) - 0.01*(Olp-L4)

Am= 2.1*LOG(FV) + 0.15*IndWl

Wsup= 0.2*Rws + 0.8*Ws

IndWdf= Wsup - Wd

l2=ind
l3=arp
l4=olp
l5=ardsm
l6=old
l8=ardm
l10=hm
l11=indinc
l12=emp
```

EOln= 1.025*EOLn
EArdsm= 1.025*EArdsm
EArdm= 1.025*EArdm
EArqsm= 1.025*EArqsm
EArqm= 1.025*EArqm
EOld= 1.025*EOld
ECb= 1.025*ECb
EInd= 0.02*Ind
ERec= 0.02*Rec
IndFm= 1.02*IndFm
indPTH = indPTH
Hm= 1.02*Hm
El= 1.02*El
end

EVOLUTION OF THE EXOGENOUS VARIABLES FOR SCENARIO 1

Model 2

EOln= 1.005*EOLn
EArdsm= 1.005*EArdsm
EArdm= 1.005*EArdm
EArqsm= 1.005*EArqsm
EArqm= 1.005*EArqm
EOld= 1.005*EOld
ECb= 1.005*ECb
EInd= 0.01*Ind
ERec= 0.01*Rec
IndFm= 0.97*IndFm
indPTH =1.02*indPTH
Hm= 0.97*Hm
El= 0.97*El
A=0.15

Model 3

EOln= 1.015*EOLn
EArdsm= 1.015*EArdsm
EArdm= 1.015*EArdm
EArqsm= 1.015*EArqsm
EArqm= 1.015*EArqm
EOld= 1.015*EOld
ECb= 1.015*ECb
EInd= 0.15*Ind
ERec= 0.15*Rec
IndFm= 1.02*IndFm
indPTH = indPTH
Hm= 1.02*Hm
El= 1.02*El

Model 4

EOln= 1.015*EOLn
EArdsm= 1.015*EArdsm
EArdm= 1.015*EArdm
EArqsm= 1.015*EArqsm
EArqm= 1.015*EArqm
EOld= 1.015*EOld
ECb= 1.015*ECb
EInd= 0.15*Ind
ERec= 0.15*Rec
IndFm= 0.98*IndFm
indPTH = 1.015*indPTH
Hm= 0.975*Hm
El= 0.98*El
A = 0.12

Model 5

EOln= 1.015*EOLn
EArdsm= 1.015*EArdsm
EArdm= 1.015*EArdm
EArqsm= 1.015*EArqsm
EArqm= 1.015*EArqm
EOld= 1.015*EOld
ECb= 1.015*ECb
EInd= 0.15*Ind
ERec= 0.15*Rec
IndFm= 0.97*IndFm
Hm= 0.97*Fm
El= 0.97*El
A=0.15

Model 6

EOln= 1.015*EOLn
EArdsm= 1.015*EArdsm
EArdm= 1.015*EArdm
EArqsm= 1.015*EArqsm
EArqm= 1.015*EArqm
EOld= 1.015*EOld
ECb= 1.015*ECb
EInd= 0.15*Ind
ERec= 0.15*Rec
IndFm= 0.98*IndFm
indPTH = 1.015*indPTH
Hm= 0.975*Hm
El= 0.98*El
R= 9.85*R

The exogenous variables of scenarios 7 and 8 follow the trends of the respective variables of scenarios 6. Therefore, models 7 and 8 have the same equations with model 6 for describing the exogenous variables.

The exogenous variables of scenarios 9 evolve like the exogenous variables of scenarios 1 so, the model 9 have the same with model 1 equations for describing the evolution of the exogenous variables.

Appendix 2

The present section gives the results of the model run for the important variables of the model for each one scenario, the first column gives the time variable.
Next some pictures present diagrammatically the evolution of a few significant variables.

SCENARIO 1

T	ARQM	EARQM	ARDM	EARDM	ARQSM	EARQSM	ARDSM	EARDSM	ARP	OLN	OLD	EOLD
1	1.10	1.13	10.00	10.25	.55	.56	20.00	20.50	22.00	23.65	.35	.36
2	1.13	1.16	10.25	10.51	.56	.58	20.50	21.01	23.11	24.24	.36	.37
3	1.16	1.18	10.51	10.77	.58	.59	21.01	21.54	24.28	24.85	.37	.38
4	1.18	1.21	10.77	11.04	.59	.61	21.54	22.08	25.51	25.47	.38	.39
5	1.21	1.24	11.04	11.31	.61	.62	22.08	22.63	26.80	26.11	.39	.40
6	1.24	1.28	11.31	11.60	.62	.64	22.63	23.19	28.16	26.76	.40	.41
7	1.28	1.31	11.60	11.89	.64	.65	23.19	23.77	29.59	27.43	.41	.42
8	1.31	1.34	11.89	12.18	.65	.67	23.77	24.37	31.09	28.11	.42	.43
9	1.34	1.37	12.18	12.49	.67	.69	24.37	24.98	32.66	28.82	.43	.44
10	1.37	1.41	12.49	12.80	.69	.70	24.98	25.60	34.31	29.54	.44	.45
11	1.41	1.44	12.80	13.12	.70	.72	25.60	26.24	36.05	30.27	.45	.46
12	1.44	1.48	13.12	13.45	.72	.74	26.24	26.90	37.87	31.03	.46	.47
13	1.48	1.52	13.45	13.79	.74	.76	26.90	27.57	39.79	31.81	.47	.48
14	1.52	1.55	13.79	14.13	.76	.78	27.57	28.26	41.81	32.60	.48	.49
15	1.55	1.59	14.13	14.48	.78	.80	28.26	28.97	43.92	33.42	.49	.51
16	1.59	1.63	14.48	14.85	.80	.82	28.97	29.69	46.15	34.25	.51	.52
17	1.63	1.67	14.85	15.22	.82	.84	29.69	30.43	48.48	35.11	.52	.53
18	1.67	1.72	15.22	15.60	.84	.86	30.43	31.19	50.94	35.99	.53	.55
19	1.72	1.76	15.60	15.99	.86	.88	31.19	31.97	53.52	36.89	.55	.56
20	1.76	1.80	15.99	16.39	.88	.90	29.51	32.77	54.06	37.81	.50	.57

T	OLP	CB	WS	IND	REC	C	INDRQ	WD	INDF	INDFM	INDSQM
1	8.28	3.30	5.49	5.07	30.27	1.50	10.13	4.81	10.31	10.20	9.97
2	8.70	3.38	5.49	5.30	30.05	1.51	9.86	5.11	10.42	10.40	9.75
3	9.14	3.47	5.49	5.45	29.72	1.58	9.27	5.43	10.22	10.61	9.54
4	9.60	3.55	5.49	5.60	29.36	1.64	8.66	5.77	9.69	10.82	9.33
5	10.09	3.64	5.49	5.74	28.98	1.69	8.07	6.12	8.82	11.04	9.12
6	10.60	3.73	5.49	5.88	28.57	1.75	7.47	6.48	7.59	11.26	8.90
7	11.13	3.83	5.49	6.02	28.13	1.81	6.87	6.86	5.97	11.49	8.67
8	11.70	3.92	5.49	6.16	27.65	1.87	6.27	7.26	3.94	11.72	8.45
9	12.29	4.02	5.49	6.30	27.13	1.93	5.66	7.68	1.47	11.95	8.21
10	12.91	4.12	5.49	6.44	26.56	2.00	5.05	8.12	-1.48	12.19	7.98
11	13.56	4.22	5.49	6.58	25.93	2.07	4.43	8.59	-4.97	12.43	7.74
12	14.25	4.33	5.49	6.72	25.23	2.14	3.81	9.09	-9.05	12.68	7.49
13	14.97	4.44	5.49	6.86	24.44	2.21	3.18	9.61	-13.81	12.94	7.24
14	15.73	4.55	5.49	7.00	23.54	2.29	1.75	10.18	-20.46	13.19	6.98
15	16.53	4.66	5.49	7.14	22.48	2.37	1.10	10.79	-28.63	13.46	6.72
16	17.36	4.78	5.49	7.28	21.22	2.45	.45	11.45	-39.55	13.73	6.46
17	18.24	4.90	5.49	7.42	19.64	2.54	-.20	12.19	-48.34	14.00	6.18
18	19.17	5.02	5.49	7.56	17.54	2.62	-.84	13.04	-57.30	14.28	5.91
19	20.14	5.15	5.49	7.70	14.22	2.71	-1.47	14.12	-66.44	14.57	5.62
20	18.73	5.28	5.49	7.73	1.50	2.79	-1.99	16.32	-75.76	14.86	5.58

T	INDSQA	FV	INDWL	POP	MIG	INDTH	AM	DIS	INDINC	EMP	INDWDF
1	9.97	9.00	10.00	10.02	.02	10.00	6.11	4.57	10.01	4.55	.68
2	9.74	8.10	9.41	10.20	.18	10.00	5.80	4.56	10.33	4.69	.39
3	9.52	7.29	8.80	10.39	.19	10.00	5.49	4.54	10.70	4.81	.06
4	9.30	6.56	8.18	10.58	.19	10.00	5.18	4.52	11.07	4.94	-.27
5	9.07	5.90	7.55	10.77	.19	10.00	4.86	4.52	11.44	5.06	-.62
6	8.84	5.31	6.90	10.97	.20	10.00	4.54	4.52	11.83	5.20	-.98
7	8.61	4.78	6.24	11.18	.21	10.00	4.22	4.54	12.24	5.34	-1.37
8	8.37	4.30	5.57	11.39	.21	10.00	3.90	4.56	12.65	5.48	-1.77
9	8.12	3.87	4.89	11.61	.22	10.00	3.58	4.59	13.09	5.62	-2.19
10	7.87	3.49	4.19	11.84	.23	10.00	3.25	4.63	13.54	5.77	-2.63
11	7.62	3.14	3.47	12.08	.24	10.00	2.92	4.69	14.01	5.93	-3.10
12	7.36	2.82	2.74	12.33	.25	10.00	2.59	4.75	14.49	6.09	-3.59
13	7.09	2.54	1.99	12.58	.26	10.00	2.26	4.82	15.00	6.25	-4.12
14	6.82	2.29	1.23	12.85	.26	10.00	1.92	4.89	15.52	6.42	-4.68
15	6.55	2.06	.46	13.12	.27	10.00	1.58	4.98	16.06	6.59	-5.29
16	6.26	1.85	-.34	13.40	.28	10.00	1.24	5.08	16.62	6.76	-5.96
17	5.98	1.67	-1.15	13.68	.28	10.00	.90	5.18	17.19	6.92	-6.70
18	5.68	1.49	-1.98	13.96	.28	10.00	.54	5.29	17.77	7.08	-7.54
19	5.38	1.27	-2.82	14.22	.26	10.00	.08	5.39	18.34	7.19	-8.63
20	5.35	1.00	-3.64	13.80	-.42	10.00	-.54	5.22	17.80	6.64	-10.83

SCENARIO 2

T	ARQM	EARQM	ARDM	EARDM	ARQSM	EARQSM	ARDSM	EARDSM	ARP	OLN	OLD	EOPD
1	1.10	1.11	10.00	10.05	.55	.55	20.00	20.10	22.00	23.65	.35	.35
2	1.11	1.11	10.05	10.10	.55	.56	20.10	20.20	22.22	23.77	.35	.35
3	1.11	1.12	10.10	10.15	.56	.56	20.20	20.30	22.44	23.89	.35	.36
4	1.12	1.12	10.15	10.20	.56	.56	20.30	20.40	22.67	24.01	.36	.36
5	1.12	1.13	10.20	10.25	.56	.56	20.40	20.51	22.90	24.13	.36	.36
6	1.13	1.13	10.25	10.30	.56	.57	20.51	20.61	23.13	24.25	.36	.36
7	1.13	1.14	10.30	10.36	.57	.57	20.61	20.71	23.36	24.37	.36	.36
8	1.14	1.14	10.36	10.41	.57	.57	20.71	20.81	23.59	24.49	.36	.36
9	1.14	1.15	10.41	10.46	.57	.58	20.81	20.92	23.83	24.61	.36	.37
10	1.15	1.16	10.46	10.51	.58	.58	20.92	21.02	24.07	24.74	.37	.37
11	1.16	1.16	10.51	10.56	.58	.58	21.02	21.13	24.31	24.86	.37	.37
12	1.16	1.17	10.56	10.62	.58	.58	21.13	21.23	24.55	24.98	.37	.37
13	1.17	1.17	10.62	10.67	.58	.59	21.23	21.34	24.80	25.11	.37	.37
14	1.17	1.18	10.67	10.72	.59	.59	21.34	21.45	25.05	25.23	.37	.38
15	1.18	1.19	10.72	10.78	.59	.59	21.45	21.55	25.30	25.36	.38	.38
16	1.19	1.19	10.78	10.83	.59	.60	21.55	21.66	25.55	25.49	.38	.38
17	1.19	1.20	10.83	10.88	.60	.60	21.66	21.77	25.81	25.61	.38	.38
18	1.20	1.20	10.88	10.94	.60	.60	21.77	21.88	26.07	25.74	.38	.38
19	1.20	1.21	10.94	10.99	.60	.60	21.88	21.99	26.33	25.87	.38	.38
20	1.21	1.22	10.99	11.05	.60	.61	21.99	22.10	26.59	26.00	.38	.39

T	OLP	CB	WS	IND	REC	C	INDRQ	WD	INDF	INDFM	INDSQM
1	8.28	3.30	5.49	5.07	30.27	1.50	10.13	4.81	10.31	9.70	9.97
2	8.36	3.32	5.49	5.15	29.75	1.51	10.41	4.96	10.90	9.41	9.90
3	8.44	3.33	5.49	5.18	30.00	1.52	10.67	4.97	11.74	9.13	9.84
4	8.53	3.35	5.49	5.21	30.24	1.53	10.88	4.98	12.82	8.85	9.78
5	8.61	3.37	5.49	5.24	30.47	1.54	11.09	4.99	14.14	8.59	9.71
6	8.70	3.38	5.49	5.27	30.69	1.55	11.29	5.00	15.67	8.33	9.65
7	8.79	3.40	5.49	5.30	30.90	1.57	11.49	5.02	17.42	8.08	9.59
8	8.88	3.42	5.49	5.33	31.10	1.58	11.67	5.04	19.37	7.84	9.52
9	8.97	3.43	5.49	5.36	31.29	1.59	11.85	5.06	21.53	7.60	9.46
10	9.05	3.45	5.49	5.39	31.47	1.60	12.02	5.08	23.87	7.37	9.40
11	9.15	3.47	5.49	5.42	31.65	1.61	12.19	5.10	26.41	7.15	9.33
12	9.24	3.49	5.49	5.45	31.81	1.63	12.34	5.13	29.12	6.94	9.27
13	9.33	3.50	5.49	5.48	31.98	1.64	12.49	5.15	32.00	6.73	9.20
14	9.42	3.52	5.49	5.51	32.13	1.65	12.64	5.18	35.05	6.53	9.14
15	9.52	3.54	5.49	5.54	32.28	1.66	12.78	5.21	38.26	6.33	9.08
16	9.61	3.56	5.49	5.57	32.43	1.68	12.91	5.24	41.62	6.14	9.01
17	9.71	3.57	5.49	5.59	32.57	1.69	13.03	5.27	45.14	5.96	8.95
18	9.81	3.59	5.49	5.62	32.70	1.70	13.15	5.31	48.80	5.78	8.88
19	9.91	3.61	5.49	5.65	32.83	1.71	13.27	5.34	52.59	5.61	8.82
20	10.00	3.63	5.49	5.68	32.95	1.73	13.37	5.38	56.53	5.44	8.75

T	INDSQA	FV	INDWL	POP	MIG	INDTH	AM	DIS	INDINC	EMP	INDWDF
1	9.97	9.00	10.00	10.02	.02	10.00	6.11	4.57	10.01	4.55	.68
2	9.90	9.45	10.87	10.05	.03	10.00	6.35	4.46	10.08	4.56	.53
3	9.84	9.92	11.71	10.10	.04	10.00	6.58	4.36	10.15	4.60	.52
4	9.77	10.42	12.52	10.14	.05	10.00	6.80	4.26	10.24	4.63	.51
5	9.71	10.94	13.32	10.19	.04	10.00	7.02	4.16	10.32	4.67	.50
6	9.64	11.49	14.08	10.23	.04	10.00	7.24	4.07	10.40	4.71	.49
7	9.58	12.06	14.83	10.28	.04	10.00	7.45	3.99	10.48	4.74	.47
8	9.51	12.66	15.55	10.32	.04	10.00	7.66	3.92	10.56	4.78	.46
9	9.45	13.30	16.25	10.36	.04	10.00	7.87	3.84	10.64	4.81	.44
10	9.38	13.96	16.93	10.41	.04	10.00	8.08	3.78	10.72	4.85	.42
11	9.32	14.66	17.59	10.45	.04	10.00	8.28	3.72	10.80	4.88	.39
12	9.25	15.39	18.22	10.50	.04	10.00	8.47	3.66	10.88	4.92	.37
13	9.19	16.16	18.84	10.54	.04	10.00	8.67	3.61	10.96	4.95	.34
14	9.12	16.97	19.44	10.59	.04	10.00	8.86	3.57	11.04	4.99	.31
15	9.05	17.82	20.03	10.63	.04	10.00	9.05	3.52	11.13	5.02	.28
16	8.99	18.71	20.59	10.68	.04	10.00	9.24	3.49	11.21	5.05	.25
17	8.92	19.65	21.14	10.72	.05	10.00	9.42	3.45	11.29	5.09	.22
18	8.86	20.63	21.67	10.77	.05	10.00	9.61	3.42	11.38	5.12	.19
19	8.79	21.66	22.18	10.81	.05	10.00	9.79	3.40	11.46	5.16	.15
20	8.72	22.74	22.68	10.86	.05	10.00	9.96	3.37	11.54	5.19	.12

SCENARIO 3

T	ARQM	EARQM	ARDM	EARDM	ARQSM	EARQSM	ARDSM	EARDSM	ARP	OLN	OLD	EOPD
1	1.10	1.12	10.00	10.15	.55	.56	20.00	20.30	22.00	23.65	.35	.36
2	1.12	1.13	10.15	10.30	.56	.57	20.30	20.60	22.66	24.00	.36	.36
3	1.13	1.15	10.30	10.46	.57	.58	20.60	20.91	23.35	24.36	.36	.37
4	1.15	1.17	10.46	10.61	.58	.58	20.91	21.23	24.06	24.73	.37	.37
5	1.17	1.19	10.61	10.77	.58	.59	21.23	21.55	24.78	25.10	.37	.38
6	1.19	1.20	10.77	10.93	.59	.60	21.55	21.87	25.53	25.48	.38	.38
7	1.20	1.22	10.93	11.10	.60	.61	21.87	22.20	26.30	25.86	.38	.39
8	1.22	1.24	11.10	11.26	.61	.62	22.20	22.53	27.10	26.25	.39	.39
9	1.24	1.26	11.26	11.43	.62	.63	22.53	22.87	27.92	26.64	.39	.40
10	1.26	1.28	11.43	11.61	.63	.64	22.87	23.21	28.76	27.04	.40	.41
11	1.28	1.30	11.61	11.78	.64	.65	23.21	23.56	29.63	27.45	.41	.41
12	1.30	1.32	11.78	11.96	.65	.66	23.56	23.91	30.53	27.86	.41	.42
13	1.32	1.33	11.96	12.14	.66	.67	23.91	24.27	31.45	28.28	.42	.42
14	1.33	1.35	12.14	12.32	.67	.68	24.27	24.64	32.40	28.70	.42	.43
15	1.35	1.38	12.32	12.50	.68	.69	24.64	25.00	33.38	29.13	.43	.44
16	1.38	1.40	12.50	12.69	.69	.70	25.00	25.38	34.39	29.57	.44	.44
17	1.40	1.42	12.69	12.88	.70	.71	25.38	25.76	35.43	30.01	.44	.45
18	1.42	1.44	12.88	13.07	.71	.72	25.76	26.15	36.50	30.46	.45	.46
19	1.44	1.46	13.07	13.27	.72	.73	26.15	26.54	37.60	30.92	.46	.46
20	1.46	1.48	13.27	13.47	.73	.74	26.54	26.94	38.74	31.38	.46	.47

T	OLP	CB	WS	IND	REC	C	INDRQ	WD	INDF	INDFM	INDSQM
1	8.28	3.30	5.49	5.07	30.27	1.50	10.13	4.81	10.31	10.20	9.97
2	8.53	3.35	5.49	5.91	33.99	1.51	9.86	4.49	10.42	10.40	9.70
3	8.79	3.40	5.49	6.16	34.20	1.64	8.91	4.67	10.11	10.61	9.54
4	9.05	3.45	5.49	6.29	33.88	1.67	8.32	4.90	9.46	10.82	9.40
5	9.32	3.50	5.49	6.38	33.46	1.69	7.88	5.13	8.52	11.04	9.26
6	9.61	3.56	5.49	6.48	33.00	1.72	7.45	5.38	7.28	11.26	9.12
7	9.90	3.61	5.49	6.58	32.50	1.75	7.02	5.63	5.72	11.49	8.98
8	10.20	3.66	5.49	6.68	31.97	1.78	6.57	5.90	3.83	11.72	8.83
9	10.50	3.72	5.49	6.78	31.39	1.81	6.13	6.18	1.59	11.95	8.69
10	10.82	3.77	5.49	6.88	30.75	1.85	5.68	6.48	-1.02	12.19	8.54
11	11.15	3.83	5.49	6.97	30.05	1.88	5.23	6.79	-4.03	12.43	8.39
12	11.49	3.89	5.49	7.07	29.27	1.92	4.77	7.12	-7.46	12.68	8.24
13	11.83	3.95	5.49	7.17	28.39	1.95	4.31	7.47	-11.34	12.94	8.09
14	12.19	4.00	5.49	7.26	27.39	1.99	3.85	7.84	-15.71	13.19	7.94
15	12.56	4.06	5.49	7.36	26.22	2.03	3.39	8.25	-20.62	13.46	7.78
16	12.94	4.13	5.49	7.45	24.83	2.06	2.92	8.71	-26.12	13.73	7.63
17	13.33	4.19	5.49	7.55	23.11	2.10	2.46	9.22	-32.29	14.00	7.47
18	13.73	4.25	5.49	7.64	20.85	2.13	2.01	9.84	-39.23	14.28	7.31
19	14.15	4.31	5.49	7.73	17.55	2.16	1.57	10.64	-47.06	14.57	7.15
20	14.58	4.38	5.49	7.82	11.33	2.19	1.16	11.95	-55.96	14.86	6.99

T	INDSQA	FV	INDWL	POP	MIG	INDTH	AM	DIS	INDINC	EMP	INDWDF
1	9.97	9.00	10.00	10.02	.02	10.00	6.11	4.57	10.01	4.55	.68
2	9.70	8.10	9.41	10.38	.35	10.00	5.80	4.74	10.54	4.94	1.00
3	9.53	7.29	8.81	10.57	.19	10.00	5.49	4.73	10.91	5.06	.82
4	9.38	6.56	8.20	10.68	.11	10.00	5.18	4.68	11.13	5.14	.60
5	9.24	5.90	7.57	10.78	.10	10.00	4.87	4.63	11.33	5.21	.36
6	9.09	5.31	6.94	10.89	.11	10.00	4.55	4.59	11.54	5.28	.12
7	8.94	4.78	6.29	11.00	.11	10.00	4.23	4.56	11.76	5.35	-.14
8	8.79	4.30	5.62	11.11	.11	10.00	3.91	4.53	11.98	5.42	-.41
9	8.64	3.87	4.95	11.22	.11	10.00	3.59	4.51	12.21	5.49	-.69
10	8.49	3.49	4.26	11.34	.11	10.00	3.26	4.49	12.44	5.56	-.98
11	8.34	3.14	3.55	11.45	.12	10.00	2.93	4.48	12.67	5.63	-1.29
12	8.18	2.82	2.83	11.57	.12	10.00	2.61	4.48	12.91	5.69	-1.62
13	8.02	2.54	2.10	11.69	.12	10.00	2.27	4.48	13.14	5.76	-1.97
14	7.86	2.29	1.35	11.80	.12	10.00	1.94	4.49	13.38	5.82	-2.35
15	7.70	2.06	.59	11.92	.11	10.00	1.61	4.50	13.63	5.88	-2.76
16	7.54	1.85	-.19	12.03	.11	10.00	1.27	4.51	13.87	5.93	-3.21
17	7.38	1.67	-.98	12.13	.10	10.00	.93	4.53	14.10	5.98	-3.73
18	7.21	1.50	-1.79	12.23	.09	10.00	.58	4.54	14.32	6.00	-4.34
19	7.05	1.35	-2.62	12.29	.07	10.00	.24	4.55	14.51	5.98	-5.14
20	6.88	1.22	-3.46	12.27	-.02	10.00	-.11	4.54	14.60	5.85	-6.46

SCENARIO 4

T	ARQM	EARQM	ARDM	EARDM	ARQSM	EARQSM	ARDSM	EARDSM	ARP	OLN	OLD	EOPD
1	1.10	1.12	10.00	10.15	.55	.56	20.00	20.30	22.00	23.65	.35	.36
2	1.12	1.13	10.15	10.30	.56	.57	20.30	20.60	22.66	24.00	.36	.36
3	1.13	1.15	10.30	10.46	.57	.58	20.60	20.91	23.35	24.36	.36	.37
4	1.15	1.17	10.46	10.61	.58	.58	20.91	21.23	24.06	24.73	.37	.37
5	1.17	1.19	10.61	10.77	.58	.59	21.23	21.55	24.78	25.10	.37	.38
6	1.19	1.20	10.77	10.93	.59	.60	21.55	21.87	25.53	25.48	.38	.38
7	1.20	1.22	10.93	11.10	.60	.61	21.87	22.20	26.30	25.86	.38	.39
8	1.22	1.24	11.10	11.26	.61	.62	22.20	22.53	27.10	26.25	.39	.39
9	1.24	1.26	11.26	11.43	.62	.63	22.53	22.87	27.92	26.64	.39	.40
10	1.26	1.28	11.43	11.61	.63	.64	22.87	23.21	28.76	27.04	.40	.41
11	1.28	1.30	11.61	11.78	.64	.65	23.21	23.56	29.63	27.45	.41	.41
12	1.30	1.32	11.78	11.96	.65	.66	23.56	23.91	30.53	27.86	.41	.42
13	1.32	1.33	11.96	12.14	.66	.67	23.91	24.27	31.45	28.28	.42	.42
14	1.33	1.35	12.14	12.32	.67	.68	24.27	24.64	32.40	28.70	.42	.43
15	1.35	1.38	12.32	12.50	.68	.69	24.64	25.00	33.38	29.13	.43	.44
16	1.38	1.40	12.50	12.69	.69	.70	25.00	25.38	34.39	29.57	.44	.44
17	1.40	1.42	12.69	12.88	.70	.71	25.38	25.76	35.43	30.01	.44	.45
18	1.42	1.44	12.88	13.07	.71	.72	25.76	26.15	36.50	30.46	.45	.46
19	1.44	1.46	13.07	13.27	.72	.73	26.15	26.54	37.60	30.92	.46	.46
20	1.46	1.48	13.27	13.47	.73	.74	26.54	26.94	38.74	31.38	.46	.47

T	OLP	CB	WS	IND	REC	C	INDRQ	WD	INDF	INDFM	INDSQM
1	8.28	3.30	5.49	5.07	30.27	1.50	10.13	4.81	10.31	9.80	9.97
2	8.53	3.35	5.49	5.91	33.99	1.51	10.30	4.49	10.80	9.60	9.70
3	8.79	3.40	5.49	6.16	34.68	1.64	9.79	4.59	11.28	9.41	9.54
4	9.05	3.45	5.49	6.29	34.94	1.67	9.61	4.71	11.82	9.22	9.40
5	9.32	3.50	5.49	6.39	35.12	1.70	9.58	4.84	12.47	9.04	9.26
6	9.61	3.56	5.49	6.49	35.29	1.73	9.56	4.98	13.23	8.86	9.12
7	9.90	3.61	5.49	6.59	35.45	1.76	9.54	5.12	14.10	8.68	8.97
8	10.20	3.66	5.49	6.69	35.60	1.80	9.50	5.27	15.07	8.51	8.83
9	10.50	3.72	5.49	6.79	35.75	1.84	9.47	5.43	16.15	8.34	8.68
10	10.82	3.77	5.49	6.89	35.89	1.88	9.43	5.59	17.32	8.17	8.54
11	11.15	3.83	5.49	6.99	36.02	1.92	9.39	5.76	18.58	8.01	8.39
12	11.49	3.89	5.49	7.09	36.15	1.96	9.35	5.93	19.94	7.85	8.24
13	11.83	3.95	5.49	7.19	36.27	2.00	9.30	6.10	21.39	7.69	8.09
14	12.19	4.00	5.49	7.29	36.39	2.04	9.25	6.29	22.92	7.54	7.93
15	12.56	4.06	5.49	7.39	36.51	2.08	9.20	6.48	24.53	7.39	7.78
16	12.94	4.13	5.49	7.48	36.62	2.13	9.15	6.67	26.22	7.24	7.62
17	13.33	4.19	5.49	7.58	36.72	2.17	9.09	6.87	27.99	7.09	7.47
18	13.73	4.25	5.49	7.68	36.82	2.22	9.03	7.08	29.83	6.95	7.31
19	14.15	4.31	5.49	7.78	36.92	2.27	8.97	7.29	31.74	6.81	7.14
20	14.58	4.38	5.49	7.88	37.01	2.32	8.90	7.51	33.72	6.68	6.98

T	INDSQA	FV	INDWL	POP	MIG	INDTH	AM	DIS	INDINC	EMP	INDWDF
1	9.97	9.00	10.00	10.02	.02	10.00	6.11	4.57	10.01	4.55	.68
2	9.70	9.18	10.72	10.38	.35	10.00	6.26	4.74	10.54	4.94	1.00
3	9.53	9.36	11.41	10.58	.20	10.00	6.41	4.74	10.93	5.08	.90
4	9.38	9.55	12.09	10.71	.13	10.00	6.55	4.69	11.17	5.18	.78
5	9.24	9.74	12.76	10.83	.12	10.00	6.69	4.65	11.39	5.28	.65
6	9.09	9.94	13.40	10.96	.13	10.00	6.83	4.62	11.63	5.37	.51
7	8.94	10.14	14.03	11.09	.13	10.00	6.97	4.59	11.87	5.47	.37
8	8.79	10.34	14.64	11.22	.13	10.00	7.10	4.57	12.12	5.56	.22
9	8.64	10.54	15.24	11.36	.14	10.00	7.23	4.56	12.38	5.66	.06
10	8.49	10.76	15.82	11.50	.14	10.00	7.36	4.56	12.64	5.77	-.10
11	8.33	10.97	16.39	11.64	.14	10.00	7.49	4.56	12.90	5.87	-.26
12	8.18	11.19	16.94	11.78	.14	10.00	7.61	4.57	13.18	5.97	-.43
13	8.02	11.41	17.48	11.93	.15	10.00	7.73	4.59	13.45	6.08	-.61
14	7.86	11.64	18.00	12.08	.15	10.00	7.85	4.61	13.74	6.19	-.79
15	7.70	11.88	18.51	12.23	.15	10.00	7.97	4.64	14.03	6.30	-.98
16	7.54	12.11	19.01	12.39	.16	10.00	8.09	4.68	14.33	6.41	-1.18
17	7.37	12.36	19.49	12.55	.16	10.00	8.20	4.72	14.63	6.53	-1.38
18	7.21	12.60	19.96	12.72	.16	10.00	8.31	4.76	14.94	6.65	-1.58
19	7.04	12.85	20.42	12.88	.17	10.00	8.42	4.82	15.26	6.77	-1.80
20	6.87	13.11	20.86	13.06	.17	10.00	8.53	4.88	15.59	6.89	-2.02

SCENARIO 5

T	ARQM	EARQM	ARDM	EARDM	ARQSM	EARQSM	ARDSM	EARDSM	ARP	OLN	OLD	EOPD
1	1.10	1.12	10.00	10.15	.55	.56	20.00	20.30	22.00	23.65	.35	.36
2	1.12	1.13	10.15	10.30	.56	.57	20.30	20.60	22.66	24.00	.36	.36
3	1.13	1.15	10.30	10.46	.57	.58	20.60	20.91	23.35	24.36	.36	.37
4	1.15	1.17	10.46	10.61	.58	.58	20.91	21.23	24.06	24.73	.37	.37
5	1.17	1.19	10.61	10.77	.58	.59	21.23	21.55	24.78	25.10	.37	.38
6	1.19	1.20	10.77	10.93	.59	.60	21.55	21.87	25.53	25.48	.38	.38
7	1.20	1.22	10.93	11.10	.60	.61	21.87	22.20	26.30	25.86	.38	.39
8	1.22	1.24	11.10	11.26	.61	.62	22.20	22.53	27.10	26.25	.39	.39
9	1.24	1.26	11.26	11.43	.62	.63	22.53	22.87	27.92	26.64	.39	.40
10	1.26	1.28	11.43	11.61	.63	.64	22.87	23.21	28.76	27.04	.40	.41
11	1.28	1.30	11.61	11.78	.64	.65	23.21	23.56	29.63	27.45	.41	.41
12	1.30	1.32	11.78	11.96	.65	.66	23.56	23.91	30.53	27.86	.41	.42
13	1.32	1.33	11.96	12.14	.66	.67	23.91	24.27	31.45	28.28	.42	.42
14	1.33	1.35	12.14	12.32	.67	.68	24.27	24.64	32.40	28.70	.42	.43
15	1.35	1.38	12.32	12.50	.68	.69	24.64	25.00	33.38	29.13	.43	.44
16	1.38	1.40	12.50	12.69	.69	.70	25.00	25.38	34.39	29.57	.44	.44
17	1.40	1.42	12.69	12.88	.70	.71	25.38	25.76	35.43	30.01	.44	.45
18	1.42	1.44	12.88	13.07	.71	.72	25.76	26.15	36.50	30.46	.45	.46
19	1.44	1.46	13.07	13.27	.72	.73	26.15	26.54	37.60	30.92	.46	.46
20	1.46	1.48	13.27	13.47	.73	.74	26.54	26.94	38.74	31.38	.46	.47

T	OLP	CB	WS	IND	REC	C	INDRQ	WD	INDF	INDFM	INDSQM
1	8.28	3.30	5.49	5.07	30.27	1.50	10.13	4.81	10.31	9.70	9.97
2	8.53	3.35	5.49	5.91	33.99	1.51	10.41	4.49	10.90	9.41	9.70
3	8.79	3.40	5.49	6.16	34.77	1.64	10.01	4.58	11.56	9.13	9.54
4	9.05	3.45	5.49	6.29	35.11	1.67	9.92	4.68	12.37	8.85	9.40
5	9.32	3.50	5.49	6.39	35.38	1.70	9.98	4.80	13.38	8.59	9.26
6	9.61	3.56	5.49	6.49	35.63	1.73	10.04	4.92	14.57	8.33	9.12
7	9.90	3.61	5.49	6.59	35.87	1.77	10.10	5.05	15.95	8.08	8.97
8	10.20	3.66	5.49	6.69	36.09	1.80	10.14	5.19	17.49	7.84	8.83
9	10.50	3.72	5.49	6.79	36.30	1.84	10.18	5.33	19.21	7.60	8.68
10	10.82	3.77	5.49	6.89	36.50	1.88	10.21	5.48	21.08	7.37	8.54
11	11.15	3.83	5.49	6.99	36.70	1.92	10.24	5.64	23.11	7.15	8.39
12	11.49	3.89	5.49	7.09	36.88	1.96	10.25	5.80	25.28	6.94	8.24
13	11.83	3.95	5.49	7.19	37.06	2.00	10.27	5.97	27.59	6.73	8.09
14	12.19	4.00	5.49	7.29	37.23	2.05	10.27	6.14	30.04	6.53	7.93
15	12.56	4.06	5.49	7.39	37.39	2.09	10.27	6.32	32.62	6.33	7.78
16	12.94	4.13	5.49	7.49	37.55	2.13	10.27	6.51	35.32	6.14	7.62
17	13.33	4.19	5.49	7.59	37.70	2.18	10.25	6.70	38.14	5.96	7.46
18	13.73	4.25	5.49	7.69	37.84	2.23	10.24	6.90	41.07	5.78	7.31
19	14.15	4.31	5.49	7.78	37.98	2.27	10.21	7.11	44.11	5.61	7.14
20	14.58	4.38	5.49	7.88	38.12	2.32	10.18	7.32	47.25	5.44	6.98

T	INDSQA	FV	INDWL	POP	MIG	INDTH	AM	DIS	INDINC	EMP	INDWDF
1	9.97	9.00	10.00	10.02	.02	10.00	6.11	4.57	10.01	4.55	.68
2	9.70	9.45	10.86	10.38	.35	10.00	6.35	4.74	10.54	4.94	1.00
3	9.53	9.92	11.70	10.58	.21	10.00	6.57	4.74	10.93	5.09	.92
4	9.38	10.42	12.51	10.72	.13	10.00	6.80	4.70	11.18	5.19	.81
5	9.24	10.94	13.29	10.84	.12	10.00	7.02	4.65	11.40	5.29	.70
6	9.09	11.49	14.05	10.97	.13	10.00	7.23	4.62	11.64	5.38	.57
7	8.94	12.06	14.79	11.10	.13	10.00	7.45	4.60	11.89	5.48	.44
8	8.79	12.66	15.50	11.24	.14	10.00	7.66	4.58	12.14	5.58	.30
9	8.64	13.30	16.20	11.37	.14	10.00	7.86	4.57	12.40	5.69	.16
10	8.49	13.96	16.87	11.51	.14	10.00	8.07	4.57	12.66	5.79	.01
11	8.33	14.66	17.52	11.66	.14	10.00	8.27	4.57	12.93	5.90	-.14
12	8.18	15.39	18.15	11.80	.15	10.00	8.46	4.58	13.21	6.00	-.31
13	8.02	16.16	18.76	11.95	.15	10.00	8.66	4.60	13.49	6.11	-.47
14	7.86	16.97	19.35	12.11	.15	10.00	8.85	4.62	13.77	6.22	-.65
15	7.70	17.82	19.92	12.26	.16	10.00	9.04	4.65	14.07	6.34	-.83
16	7.54	18.71	20.48	12.42	.16	10.00	9.22	4.69	14.36	6.45	-1.02
17	7.37	19.65	21.02	12.58	.16	10.00	9.41	4.73	14.67	6.57	-1.21
18	7.20	20.63	21.54	12.75	.17	10.00	9.59	4.78	14.99	6.69	-1.41
19	7.04	21.66	22.04	12.92	.17	10.00	9.76	4.83	15.31	6.81	-1.61
20	6.87	22.74	22.53	13.09	.17	10.00	9.94	4.89	15.64	6.94	-1.83

SCENARIO 6

T	ARQM	EARQM	ARDM	EARDM	ARQSM	EARQSM	ARDSM	EARDSM	ARP	OLN	OLD	EOPD
1	1.10	1.12	10.00	10.15	.55	.56	20.00	20.30	22.00	23.65	.35	.36
2	1.12	1.13	10.15	10.30	.56	.57	20.30	20.60	22.66	24.00	.36	.36
3	1.13	1.15	10.30	10.46	.57	.58	20.60	20.91	23.35	24.36	.36	.37
4	1.15	1.17	10.46	10.61	.58	.58	20.91	21.23	24.06	24.73	.37	.37
5	1.17	1.19	10.61	10.77	.58	.59	21.23	21.55	24.78	25.10	.37	.38
6	1.19	1.20	10.77	10.93	.58	.60	21.55	21.87	25.53	25.48	.38	.38
7	1.20	1.22	10.93	11.10	.60	.61	21.87	22.20	26.30	25.86	.38	.39
8	1.22	1.24	11.10	11.26	.61	.62	22.20	22.53	27.10	26.25	.39	.39
9	1.24	1.26	11.26	11.43	.62	.63	22.53	22.87	27.92	26.64	.39	.40
10	1.26	1.28	11.43	11.61	.63	.64	22.87	23.21	28.76	27.04	.40	.41
11	1.28	1.30	11.61	11.78	.64	.65	23.21	23.56	29.63	27.45	.41	.41
12	1.30	1.32	11.78	11.96	.65	.66	23.56	23.91	30.53	27.86	.41	.42
13	1.32	1.33	11.96	12.14	.66	.67	23.91	24.27	31.45	28.28	.42	.42
14	1.33	1.35	12.14	12.32	.67	.68	24.27	24.64	32.40	28.70	.42	.43
15	1.35	1.38	12.32	12.50	.68	.69	24.64	25.00	33.38	29.13	.43	.44
16	1.38	1.40	12.50	12.69	.69	.70	25.00	25.38	34.39	29.57	.44	.44
17	1.40	1.42	12.69	12.88	.70	.71	25.38	25.76	35.43	30.01	.44	.45
18	1.42	1.44	12.88	13.07	.71	.72	25.76	26.15	36.50	30.46	.45	.46
19	1.44	1.46	13.07	13.27	.72	.73	26.15	26.54	37.60	30.92	.46	.46
20	1.46	1.48	13.27	13.47	.73	.74	26.54	26.94	38.74	31.38	.46	.47

T	OLP	CB	WS	IND	REC	C	INDRQ	WD	INDF	INDFM	INDSQM
1	8.28	3.30	5.49	5.07	30.27	1.50	10.13	4.81	10.31	9.80	9.97
2	8.53	3.35	5.41	5.91	33.99	1.51	10.30	4.49	10.80	9.60	9.70
3	8.79	3.40	5.33	6.16	34.68	1.64	9.79	4.59	11.28	9.41	9.54
4	9.05	3.45	5.25	6.29	34.94	1.67	9.61	4.71	11.82	9.22	9.40
5	9.32	3.50	5.17	6.39	35.12	1.70	9.58	4.84	12.47	9.04	9.26
6	9.61	3.56	5.09	6.49	35.29	1.73	9.56	4.98	13.23	8.86	9.12
7	9.90	3.61	5.02	6.59	35.45	1.76	9.54	5.12	14.10	8.68	8.97
8	10.20	3.66	4.94	6.69	16.65	1.80	9.50	8.58	15.07	8.51	8.83
9	10.50	3.72	4.87	6.72	13.86	1.66	10.41	9.19	16.42	8.34	8.70
10	10.82	3.77	4.80	6.81	13.42	1.71	10.65	9.46	17.94	8.17	8.55
11	11.15	3.83	4.72	6.92	13.31	1.78	10.60	9.67	19.56	8.01	8.40
12	11.49	3.89	4.65	7.02	13.24	1.82	10.52	9.88	21.26	7.85	8.25
13	11.83	3.95	4.58	7.12	13.17	1.86	10.45	10.09	23.04	7.69	8.10
14	12.19	4.00	4.51	7.22	13.10	1.90	10.38	10.31	24.90	7.54	7.95
15	12.56	4.06	4.45	7.32	13.03	1.95	10.31	10.53	26.85	7.39	7.79
16	12.94	4.13	4.38	7.42	12.95	1.99	10.23	10.75	28.86	7.24	7.64
17	13.33	4.19	4.31	7.52	12.87	2.03	10.16	10.99	30.95	7.09	7.48
18	13.73	4.25	4.25	7.61	12.78	2.08	10.08	11.23	33.11	6.95	7.32
19	14.15	4.31	4.19	7.71	12.70	2.12	10.00	11.47	35.34	6.81	7.16
20	14.58	4.38	4.12	7.81	12.60	2.17	9.91	11.72	37.63	6.68	6.99

T	INDSQA	FV	INDWL	POP	MIG	INDTH	AM	DIS	INDINC	EMP	INDWDF
1	9.97	9.00	10.00	10.02	.02	10.00	6.11	4.57	10.01	4.55	.68
2	9.70	9.18	10.72	10.38	.35	10.00	6.26	4.74	10.54	4.94	.92
3	9.53	9.36	11.41	10.58	.20	10.00	6.41	4.74	10.93	5.08	.74
4	9.38	9.55	12.09	10.71	.13	10.00	6.55	4.69	11.17	5.18	.54
5	9.24	9.74	12.76	10.83	.12	10.00	6.69	4.65	11.39	5.28	.33
6	9.09	9.94	13.40	10.96	.13	10.00	6.83	4.62	11.63	5.37	.11
7	8.94	10.14	14.03	11.09	.13	10.00	6.97	4.59	11.87	5.47	-.11
8	8.79	10.34	14.64	10.69	-.40	10.00	7.10	4.40	11.50	4.81	-3.64
9	8.65	10.54	15.24	10.66	-.03	10.00	7.23	4.31	11.46	4.77	-4.32
10	8.50	10.76	15.82	10.79	.13	10.00	7.36	4.28	11.71	4.85	-4.66
11	8.35	10.97	16.39	10.93	.15	10.00	7.49	4.27	12.00	4.94	-4.95
12	8.19	11.19	16.94	11.07	.14	10.00	7.61	4.26	12.27	5.04	-5.23
13	8.03	11.41	17.48	11.22	.14	10.00	7.73	4.26	12.54	5.14	-5.51
14	7.87	11.64	18.00	11.36	.14	10.00	7.85	4.26	12.82	5.24	-5.79
15	7.71	11.88	18.51	11.51	.15	10.00	7.97	4.27	13.10	5.35	-6.08
16	7.55	12.11	19.01	11.66	.15	10.00	8.09	4.29	13.39	5.45	-6.38
17	7.38	12.36	19.49	11.81	.16	10.00	8.20	4.32	13.69	5.56	-6.67
18	7.22	12.60	19.96	11.97	.16	10.00	8.31	4.35	13.99	5.67	-6.98
19	7.05	12.85	20.42	12.14	.16	10.00	8.42	4.38	14.31	5.78	-7.29
20	6.88	13.11	20.86	12.30	.17	10.00	8.53	4.42	14.63	5.90	-7.60

SCENARIO 7

T	ARQM	EARQM	ARDM	EARDM	ARQSM	EARQSM	ARDSM	EARDSM	ARP	OLN	OLD	EOPD
1	1.10	1.12	10.00	10.15	.55	.56	20.00	20.30	22.00	23.65	.35	.36
2	1.12	1.13	10.15	10.30	.56	.57	20.30	20.60	22.66	24.00	.36	.36
3	1.13	1.15	10.30	10.46	.57	.58	20.60	20.91	23.35	24.36	.36	.37
4	1.15	1.17	10.46	10.61	.58	.58	20.91	21.23	24.06	24.73	.37	.37
5	1.17	1.19	10.61	10.77	.58	.59	21.23	21.55	24.78	25.10	.37	.38
6	1.19	1.20	10.77	10.93	.59	.60	21.55	21.87	25.53	25.48	.38	.38
7	1.20	1.22	10.93	11.10	.60	.61	21.87	22.20	26.30	25.86	.38	.39
8	1.22	1.24	11.10	11.26	.61	.62	22.20	22.53	27.10	26.25	.39	.39
9	1.24	1.26	11.26	11.43	.62	.63	22.53	22.87	27.92	26.64	.39	.40
10	1.26	1.28	11.43	11.61	.63	.64	22.87	23.21	28.76	27.04	.40	.41
11	1.28	1.30	11.61	11.78	.64	.65	23.21	23.56	29.63	27.45	.41	.41
12	1.30	1.32	11.78	11.96	.65	.66	23.56	23.91	30.53	27.86	.41	.42
13	1.32	1.33	11.96	12.14	.66	.67	23.91	24.27	31.45	28.28	.42	.42
14	1.33	1.35	12.14	12.32	.67	.68	24.27	24.64	32.40	28.70	.42	.43
15	1.35	1.38	12.32	12.50	.68	.69	24.64	25.00	33.38	29.13	.43	.44
16	1.38	1.40	12.50	12.69	.69	.70	25.00	25.38	34.39	29.57	.44	.44
17	1.40	1.42	12.69	12.88	.70	.71	25.38	25.76	35.43	30.01	.44	.45
18	1.42	1.44	12.88	13.07	.71	.72	25.76	26.15	36.50	30.46	.45	.46
19	1.44	1.46	13.07	13.27	.72	.73	26.15	26.54	37.60	30.92	.46	.46
20	1.46	1.48	13.27	13.47	.73	.74	26.54	26.94	38.74	31.38	.46	.47

T	OLP	CB	WS	IND	REC	C	INDRQ	WD	INDF	INDFM	INDSQM
1	8.28	3.30	5.49	5.07	30.27	1.50	10.13	4.60	10.31	9.80	9.97
2	8.53	3.35	5.41	5.91	33.99	1.51	10.30	4.35	10.80	9.60	9.70
3	8.79	3.40	5.33	6.16	34.68	1.64	9.79	4.44	11.28	9.41	9.54
4	9.05	3.45	5.25	6.29	34.94	1.67	9.61	4.53	11.82	9.22	9.40
5	9.32	3.50	5.17	6.39	35.12	1.70	9.58	4.64	12.47	9.04	9.26
6	9.61	3.56	5.09	6.49	35.29	1.73	9.56	4.75	13.23	8.86	9.12
7	9.90	3.61	5.02	6.59	35.45	1.76	9.54	4.87	14.10	8.68	8.97
8	10.20	3.66	4.94	6.69	16.65	1.80	9.50	7.40	15.07	8.51	8.83
9	10.50	3.72	4.87	6.72	13.86	1.66	10.41	7.85	16.42	8.34	8.70
10	10.82	3.77	4.80	6.81	13.42	1.71	10.65	8.05	17.94	8.17	8.55
11	11.15	3.83	4.72	6.92	13.31	1.78	10.60	8.22	19.56	8.01	8.40
12	11.49	3.89	4.65	7.02	13.24	1.82	10.52	8.39	21.26	7.85	8.25
13	11.83	3.95	4.58	7.12	13.17	1.86	10.45	8.56	23.04	7.69	8.10
14	12.19	4.00	4.51	7.22	13.10	1.90	10.38	8.73	24.90	7.54	7.95
15	12.56	4.06	4.45	7.32	13.03	1.95	10.31	8.91	26.85	7.39	7.79
16	12.94	4.13	4.38	7.42	12.95	1.99	10.23	9.09	28.86	7.24	7.64
17	13.33	4.19	4.31	7.52	12.87	2.03	10.16	9.28	30.95	7.09	7.48
18	13.73	4.25	4.25	7.61	12.78	2.08	10.08	9.47	33.11	6.95	7.32
19	14.15	4.31	4.19	7.71	12.70	2.12	10.00	9.66	35.34	6.81	7.16
20	14.58	4.38	4.12	7.81	12.60	2.17	9.91	9.87	37.63	6.68	6.99

T	INDSQA	FV	INDWL	POP	MIG	INDTH	AM	DIS	INDINC	EMP	INDWDF
1	9.97	9.00	10.00	10.02	.02	10.00	6.11	4.57	10.01	4.55	.89
2	9.70	9.18	10.72	10.38	.35	10.00	6.26	4.74	10.54	4.94	1.06
3	9.53	9.36	11.41	10.58	.20	10.00	6.41	4.74	10.93	5.08	.90
4	9.38	9.55	12.09	10.71	.13	10.00	6.55	4.69	11.17	5.18	.72
5	9.24	9.74	12.76	10.83	.12	10.00	6.69	4.65	11.39	5.28	.53
6	9.09	9.94	13.40	10.96	.13	10.00	6.83	4.62	11.63	5.37	.34
7	8.94	10.14	14.03	11.09	.13	10.00	6.97	4.59	11.87	5.47	.15
8	8.79	10.34	14.64	10.69	-.40	10.00	7.10	4.40	11.50	4.81	-2.45
9	8.65	10.54	15.24	10.66	-.03	10.00	7.23	4.31	11.46	4.77	-2.98
10	8.50	10.76	15.82	10.79	.13	10.00	7.36	4.28	11.71	4.85	-3.26
11	8.35	10.97	16.39	10.93	.15	10.00	7.49	4.27	12.00	4.94	-3.50
12	8.19	11.19	16.94	11.07	.14	10.00	7.61	4.26	12.27	5.04	-3.74
13	8.03	11.41	17.48	11.22	.14	10.00	7.73	4.26	12.54	5.14	-3.98
14	7.87	11.64	18.00	11.36	.14	10.00	7.85	4.26	12.82	5.24	-4.22
15	7.71	11.88	18.51	11.51	.15	10.00	7.97	4.27	13.10	5.35	-4.46
16	7.55	12.11	19.01	11.66	.15	10.00	8.09	4.29	13.39	5.45	-4.71
17	7.38	12.36	19.49	11.81	.16	10.00	8.20	4.32	13.69	5.56	-4.96
18	7.22	12.60	19.96	11.97	.16	10.00	8.31	4.35	13.99	5.67	-5.22
19	7.05	12.85	20.42	12.14	.16	10.00	8.42	4.38	14.31	5.78	-5.48
20	6.88	13.11	20.86	12.30	.17	10.00	8.53	4.42	14.63	5.90	-5.74

SCENARIO 8

T	ARQM	EARQM	ARDM	EARDM	ARQSM	EARQSM	ARDSM	EARDSM	ARP	OLN	OLD	EOPD
1	1.10	1.12	10.00	10.15	.55	.56	20.00	20.30	22.00	23.65	.35	.36
2	1.12	1.13	10.15	10.30	.56	.57	20.30	20.60	22.66	24.00	.36	.36
3	1.13	1.15	10.30	10.46	.57	.58	20.60	20.91	23.35	24.36	.36	.37
4	1.15	1.17	10.46	10.61	.58	.58	20.91	21.23	24.06	24.73	.37	.37
5	1.17	1.19	10.61	10.77	.58	.59	21.23	21.55	24.78	25.10	.37	.38
6	1.19	1.20	10.77	10.93	.59	.60	21.55	21.87	25.53	25.48	.38	.38
7	1.20	1.22	10.93	11.10	.60	.61	21.87	22.20	26.30	25.86	.38	.39
8	1.22	1.24	11.10	11.26	.61	.62	22.20	22.53	27.10	26.25	.39	.39
9	1.24	1.26	11.26	11.43	.62	.63	22.53	22.87	27.92	26.64	.39	.40
10	1.26	1.28	11.43	11.61	.63	.64	22.87	23.21	28.76	27.04	.40	.41
11	1.28	1.30	11.61	11.78	.64	.65	23.21	23.56	29.63	27.45	.41	.41
12	1.30	1.32	11.78	11.96	.65	.66	23.56	23.91	30.53	27.86	.41	.42
13	1.32	1.33	11.96	12.14	.66	.67	23.91	24.27	31.45	28.28	.42	.42
14	1.33	1.35	12.14	12.32	.67	.68	24.27	24.64	32.40	28.70	.42	.43
15	1.35	1.38	12.32	12.50	.68	.69	24.64	25.00	33.38	29.13	.43	.44
16	1.38	1.40	12.50	12.69	.69	.70	25.00	25.38	34.39	29.57	.44	.44
17	1.40	1.42	12.69	12.88	.70	.71	25.38	25.76	35.43	30.01	.44	.45
18	1.42	1.44	12.88	13.07	.71	.72	25.76	26.15	36.50	30.46	.45	.46
19	1.44	1.46	13.07	13.27	.72	.73	26.15	26.54	37.60	30.92	.46	.46
20	1.46	1.48	13.27	13.47	.73	.74	26.54	26.94	38.74	31.38	.46	.47

T	OLP	CB	WS	IND	REC	C	INDRQ	WD	INDF	INDFM	INDSQM
1	8.28	3.30	5.49	5.07	30.27	1.50	10.13	4.81	10.31	9.80	9.98
2	8.53	3.35	5.49	5.91	33.99	1.51	10.30	4.49	10.80	9.60	9.87
3	8.79	3.40	5.49	6.16	34.68	1.64	9.79	4.59	11.28	9.41	9.79
4	9.05	3.45	5.49	6.29	34.94	1.67	9.61	4.71	11.82	9.22	9.71
5	9.32	3.50	5.49	6.39	35.12	1.70	9.58	4.84	12.47	9.04	9.63
6	9.61	3.56	5.49	6.49	35.29	1.73	9.56	4.98	13.23	8.86	9.55
7	9.90	3.61	5.49	6.59	35.45	1.76	9.54	5.12	14.10	8.68	9.47
8	10.20	3.66	5.49	6.69	35.60	1.80	9.50	5.27	15.07	8.51	9.39
9	10.50	3.72	5.49	6.79	35.75	1.84	9.47	5.43	16.15	8.34	9.31
10	10.82	3.77	5.49	6.89	35.89	1.88	9.43	5.59	17.32	8.17	9.23
11	11.15	3.83	5.49	6.99	36.02	1.92	9.39	5.76	18.58	8.01	9.14
12	11.49	3.89	5.49	7.09	36.15	1.96	9.35	5.93	19.94	7.85	9.06
13	11.83	3.95	5.49	7.19	36.27	2.00	9.30	6.10	21.39	7.69	8.97
14	12.19	4.00	5.49	7.29	36.39	2.04	9.25	6.29	22.92	7.54	8.89
15	12.56	4.06	5.49	7.39	36.51	2.08	9.20	6.48	24.53	7.39	8.80
16	12.94	4.13	5.49	7.48	36.62	2.13	9.15	6.67	26.22	7.24	8.71
17	13.33	4.19	5.49	7.58	36.72	2.17	9.09	6.87	27.99	7.09	8.62
18	13.73	4.25	5.49	7.68	36.82	2.22	9.03	7.08	29.83	6.95	8.53
19	14.15	4.31	5.49	7.78	36.92	2.27	8.97	7.29	31.74	6.81	8.44
20	14.58	4.38	5.49	7.88	37.01	2.32	8.90	7.51	33.72	6.68	8.35

T	INDSQA	FV	INDWL	POP	MIG	INDTH	AM	DIS	INDINC	EMP	INDWDF
1	9.98	9.00	10.00	10.02	.02	10.00	6.11	4.57	10.01	4.55	.68
2	9.87	9.18	10.72	10.38	.35	10.00	6.26	4.74	10.54	4.94	1.00
3	9.78	9.36	11.41	10.58	.20	10.00	6.41	4.74	10.93	5.08	.90
4	9.70	9.55	12.09	10.71	.13	10.00	6.55	4.69	11.17	5.18	.78
5	9.62	9.74	12.76	10.83	.12	10.00	6.69	4.65	11.39	5.28	.65
6	9.53	9.94	13.40	10.96	.13	10.00	6.83	4.62	11.63	5.37	.51
7	9.45	10.14	14.03	11.09	.13	10.00	6.97	4.59	11.87	5.47	.37
8	9.36	10.34	14.64	11.22	.13	10.00	7.10	4.57	12.12	5.56	.22
9	9.28	10.54	15.24	11.36	.14	10.00	7.23	4.56	12.38	5.66	.06
10	9.19	10.76	15.82	11.50	.14	10.00	7.36	4.56	12.64	5.77	-.10
11	9.10	10.97	16.39	11.64	.14	10.00	7.49	4.56	12.90	5.87	-.26
12	9.01	11.19	16.94	11.78	.14	10.00	7.61	4.57	13.18	5.97	-.43
13	8.92	11.41	17.48	11.93	.15	10.00	7.73	4.59	13.45	6.08	-.61
14	8.83	11.64	18.00	12.08	.15	10.00	7.85	4.61	13.74	6.19	-.79
15	8.74	11.88	18.51	12.23	.15	10.00	7.97	4.64	14.03	6.30	-.98
16	8.65	12.11	19.01	12.39	.16	10.00	8.09	4.68	14.33	6.41	-1.18
17	8.55	12.36	19.49	12.55	.16	10.00	8.20	4.72	14.63	6.53	-1.38
18	8.46	12.60	19.96	12.72	.16	10.00	8.31	4.76	14.94	6.65	-1.58
19	8.36	12.85	20.42	12.88	.17	10.00	8.42	4.82	15.26	6.77	-1.80
20	8.26	13.11	20.86	13.06	.17	10.00	8.53	4.88	15.59	6.89	-2.02

SCENARIO 9

T	ARQM	EARQM	ARDM	EARDM	ARQSM	EARQSM	ARDSM	EARDSM	ARP	OLN	OLD	EOPD
1	1.10	1.13	10.00	10.25	.55	.56	20.00	20.50	22.00	23.65	.35	.36
2	1.13	1.16	10.25	10.51	.56	.58	20.50	21.01	23.11	24.24	.36	.37
3	1.16	1.18	10.51	10.77	.58	.59	21.01	21.54	24.28	24.85	.37	.38
4	1.18	1.21	10.77	11.04	.59	.61	21.54	22.08	25.51	25.47	.38	.39
5	1.21	1.24	11.04	11.31	.61	.62	22.08	22.63	26.80	26.11	.39	.40
6	1.24	1.28	11.31	11.60	.62	.64	22.63	23.19	28.16	26.76	.40	.41
7	1.28	1.31	11.60	11.89	.64	.65	23.19	23.77	29.59	27.43	.41	.42
8	1.31	1.34	11.89	12.18	.65	.67	23.77	24.37	31.09	28.11	.42	.43
9	1.34	1.37	12.18	12.49	.67	.69	24.37	24.98	32.66	28.82	.43	.44
10	1.37	1.41	12.49	12.80	.69	.70	24.98	25.60	34.31	29.54	.44	.45
11	1.41	1.44	12.80	13.12	.70	.72	25.60	26.24	36.05	30.27	.45	.46
12	1.44	1.48	13.12	13.45	.72	.74	26.24	26.90	37.87	31.03	.46	.47
13	1.48	1.52	13.45	13.79	.74	.76	26.90	27.57	39.79	31.81	.47	.48
14	1.52	1.55	13.79	14.13	.76	.78	27.57	28.26	41.81	32.60	.48	.49
15	1.55	1.59	14.13	14.48	.78	.80	28.26	28.97	43.92	33.42	.49	.51
16	1.59	1.63	14.48	14.85	.80	.82	28.97	29.69	46.15	34.25	.51	.52
17	1.63	1.67	14.85	15.22	.82	.84	29.69	30.43	48.48	35.11	.52	.53
18	1.67	1.72	15.22	15.60	.84	.86	30.43	31.19	50.94	35.99	.53	.55
19	1.72	1.76	15.60	15.99	.86	.88	31.19	31.97	53.52	36.89	.55	.56
20	1.76	1.80	15.99	16.39	.88	.90	31.97	32.77	56.22	37.81	.56	.57

T	OLP	CB	WS	IND	REC	C	INDRQ	WD	INDF	INDFM	INDSQM
1	8.28	3.30	5.49	5.07	30.27	1.50	10.13	4.81	10.31	10.20	9.98
2	8.70	3.38	5.49	5.30	30.05	1.51	9.86	5.11	10.42	10.40	9.86
3	9.14	3.47	5.49	5.45	29.72	1.58	9.27	5.43	10.22	10.61	9.75
4	9.60	3.55	5.49	5.60	29.36	1.64	8.66	5.77	9.69	10.82	9.63
5	10.09	3.64	5.49	5.74	28.98	1.69	8.07	6.12	8.82	11.04	9.51
6	10.60	3.73	5.49	5.88	28.57	1.75	7.47	6.48	7.59	11.26	9.39
7	11.13	3.83	5.49	6.02	28.13	1.81	6.87	6.86	5.97	11.49	9.27
8	11.70	3.92	5.49	6.16	27.65	1.87	6.27	7.26	3.94	11.72	9.14
9	12.29	4.02	5.49	6.30	27.13	1.93	5.66	7.68	1.47	11.95	9.01
10	12.91	4.12	5.49	6.44	26.56	2.00	5.05	8.12	-1.48	12.19	8.88
11	13.56	4.22	5.49	6.58	25.93	2.07	4.43	8.59	-4.97	12.43	8.75
12	14.25	4.33	5.49	6.72	25.23	2.14	3.81	9.09	-9.05	12.68	8.61
13	14.97	4.44	5.49	6.86	24.44	2.21	3.18	9.61	-13.81	12.94	8.47
14	15.73	4.55	5.49	7.00	23.54	2.29	1.75	10.18	-20.46	13.19	8.33
15	16.53	4.66	5.49	7.14	22.48	2.37	1.10	10.79	-28.63	13.46	8.19
16	17.36	4.78	5.49	7.28	21.22	2.45	.45	11.45	-39.55	13.73	8.04
17	18.24	4.90	5.49	7.42	19.64	2.54	-.20	12.19	-48.34	14.00	7.89
18	19.17	5.02	5.49	7.56	17.54	2.62	-.84	13.04	-57.30	14.28	7.73
19	20.14	5.15	5.49	7.70	14.22	2.71	-1.47	14.12	-66.44	14.57	7.57
20	21.15	5.28	5.49	7.84	1.50	2.79	-2.08	16.87	-75.76	14.86	7.41

T	INDSQA	FV	INDWL	POP	MIG	INDTH	AM	DIS	INDINC	EMP	INDWDF
1	9.98	9.00	10.00	10.02	.02	10.00	6.11	4.57	10.01	4.55	.68
2	9.86	8.10	9.41	10.20	.18	10.00	5.80	4.56	10.33	4.69	.39
3	9.73	7.29	8.80	10.39	.19	10.00	5.49	4.54	10.70	4.81	.06
4	9.61	6.56	8.18	10.58	.19	10.00	5.18	4.52	11.07	4.94	-.27
5	9.48	5.90	7.55	10.77	.19	10.00	4.86	4.52	11.44	5.06	-.62
6	9.35	5.31	6.90	10.97	.20	10.00	4.54	4.52	11.83	5.20	-.98
7	9.22	4.78	6.24	11.18	.21	10.00	4.22	4.54	12.24	5.34	-1.37
8	9.08	4.30	5.57	11.39	.21	10.00	3.90	4.56	12.65	5.48	-1.77
9	8.94	3.87	4.89	11.61	.22	10.00	3.58	4.59	13.09	5.62	-2.19
10	8.80	3.49	4.19	11.84	.23	10.00	3.25	4.63	13.54	5.77	-2.63
11	8.66	3.14	3.47	12.08	.24	10.00	2.92	4.69	14.01	5.93	-3.10
12	8.51	2.82	2.74	12.33	.25	10.00	2.59	4.75	14.49	6.09	-3.59
13	8.36	2.54	1.99	12.58	.26	10.00	2.26	4.82	15.00	6.25	-4.12
14	8.21	2.29	1.23	12.85	.26	10.00	1.92	4.89	15.52	6.42	-4.68
15	8.05	2.06	.46	13.12	.27	10.00	1.58	4.98	16.06	6.59	-5.29
16	7.89	1.85	-.34	13.40	.28	10.00	1.24	5.08	16.62	6.76	-5.96
17	7.72	1.67	-1.15	13.68	.28	10.00	.90	5.18	17.19	6.92	-6.70
18	7.56	1.49	-1.98	13.96	.28	10.00	.54	5.29	17.77	7.08	-7.54
19	7.39	1.27	-2.82	14.22	.26	10.00	.08	5.39	18.34	7.19	-8.63
20	7.21	1.00	-3.68	14.23	.01	10.00	-.55	5.42	18.61	6.94	-11.37

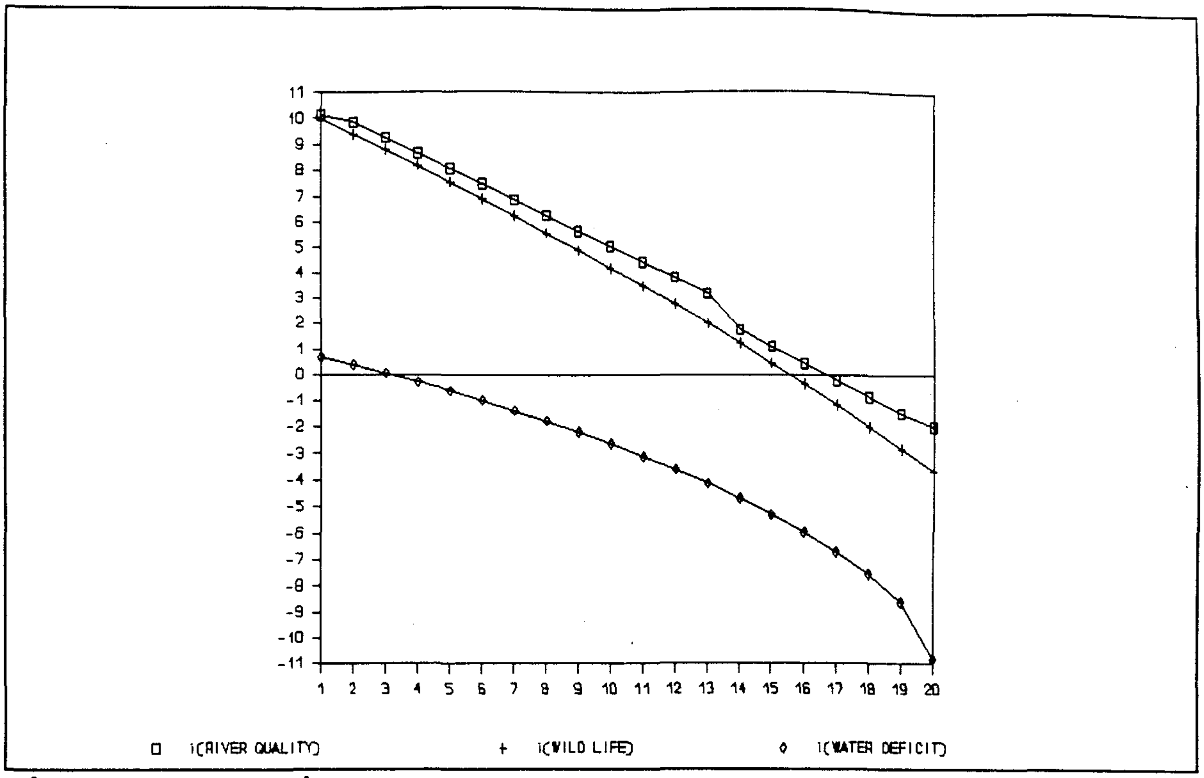

Figure 1:scenario 1

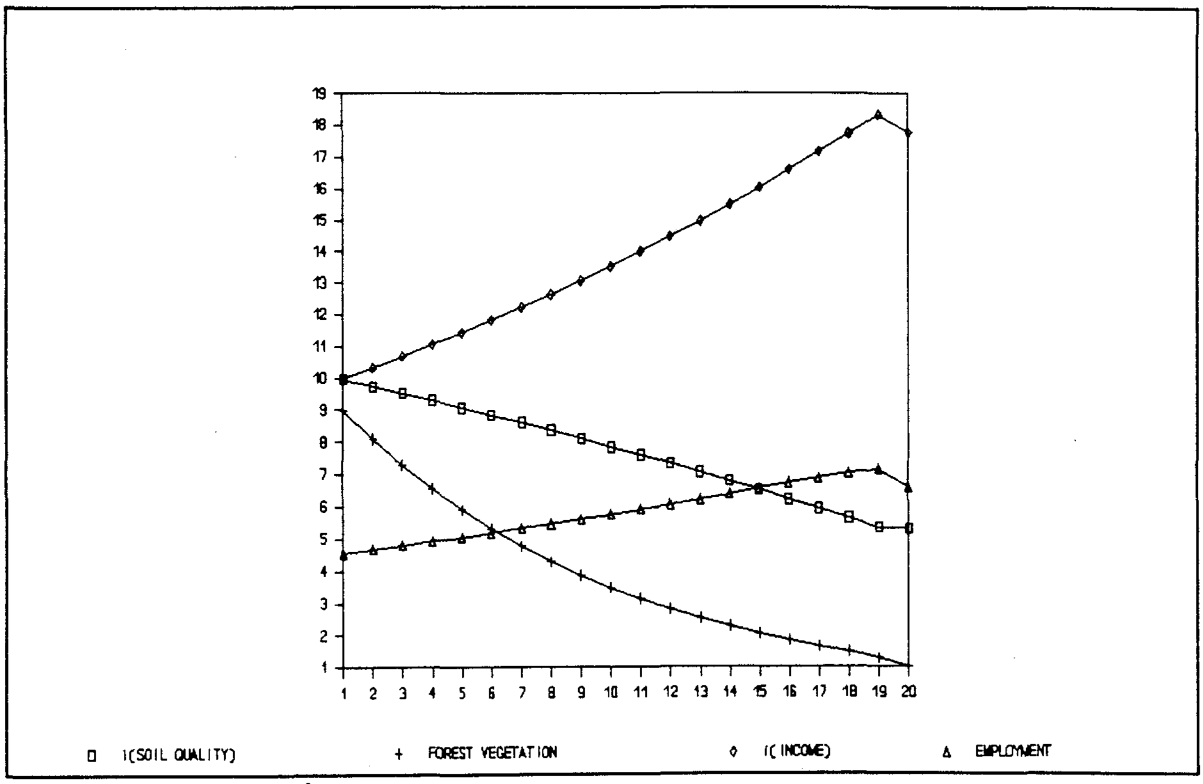

Figure 2:scenario 1

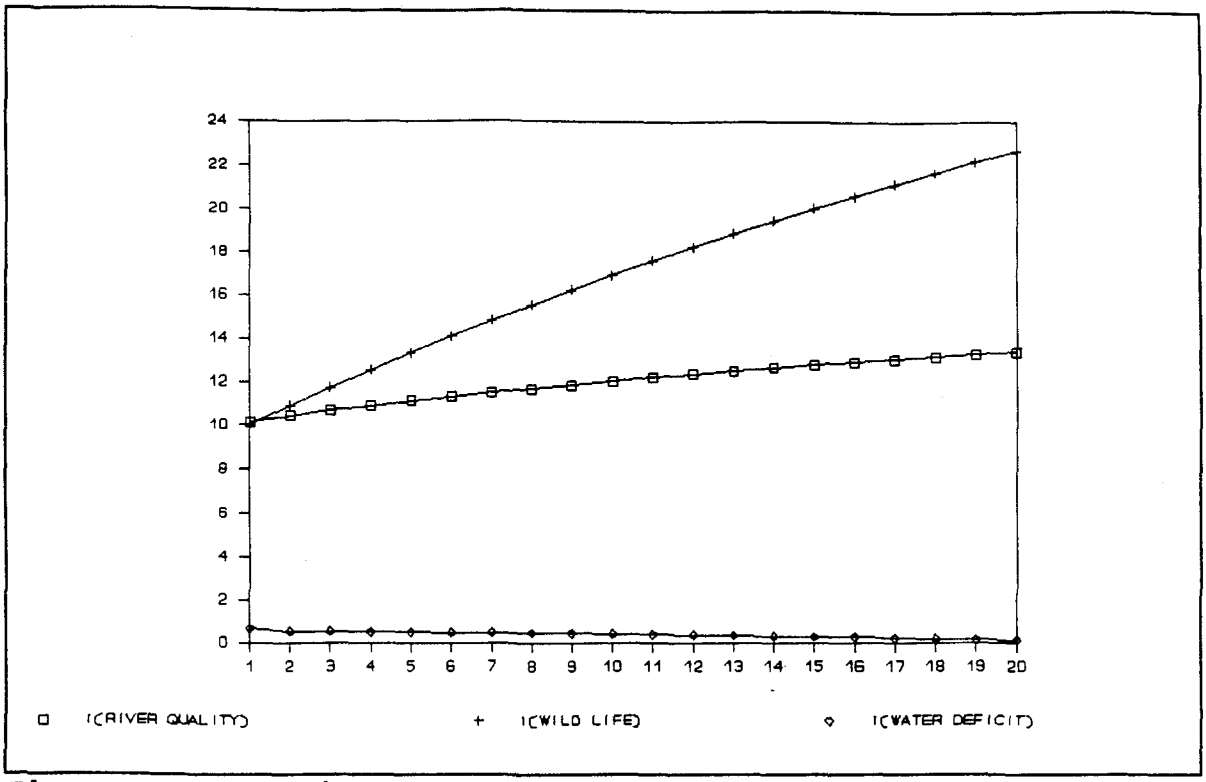

Figure 3: scenario 2

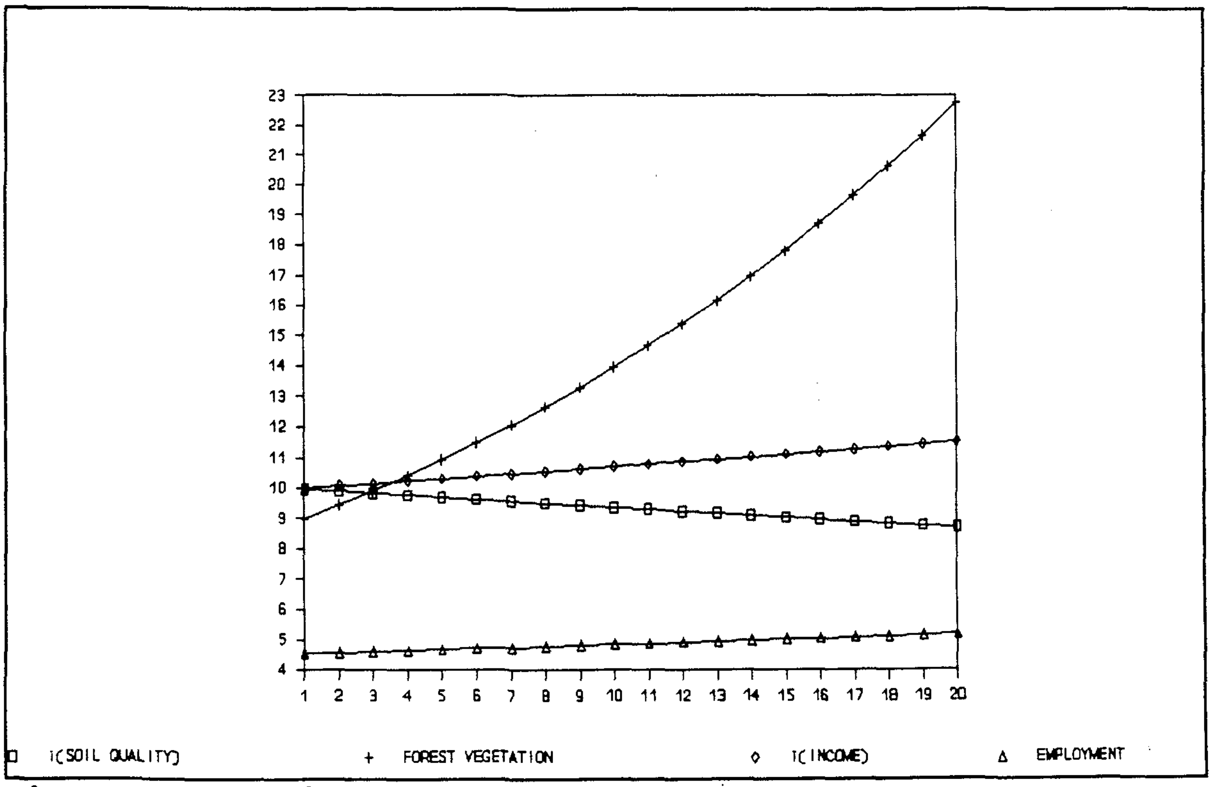

Figure 4:scenario 2

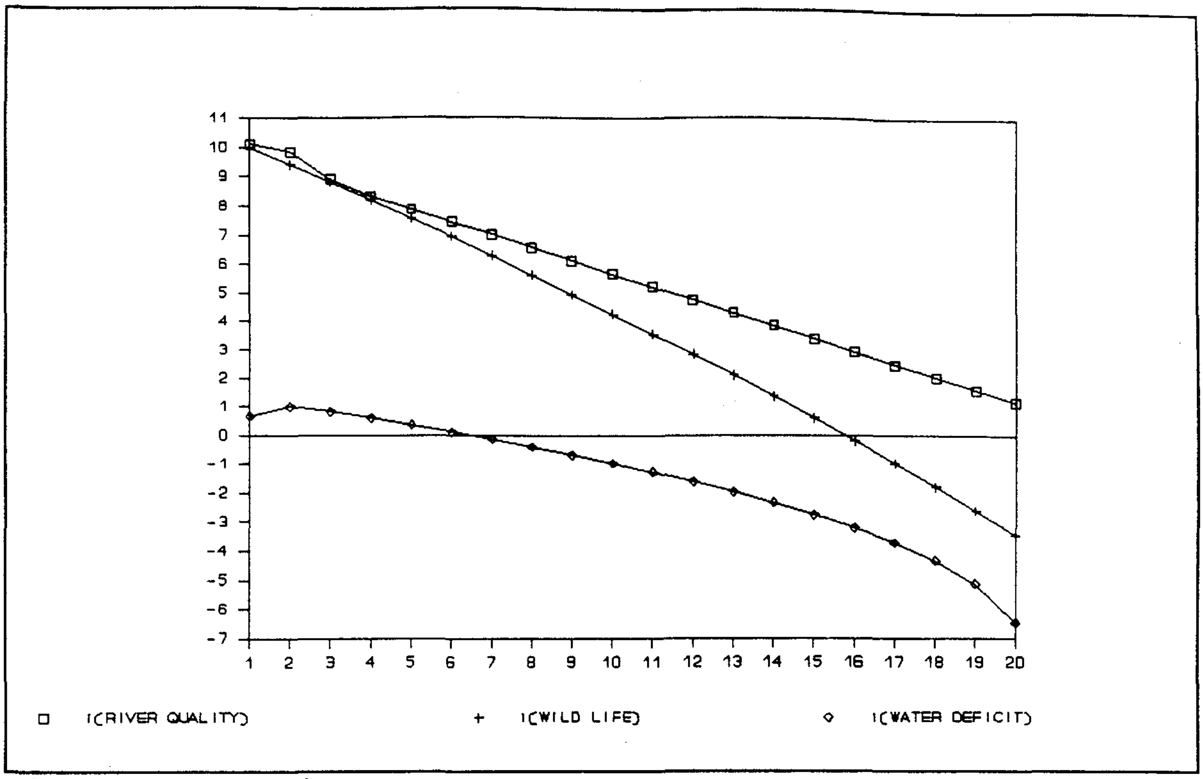

Figure 5:scenario 3

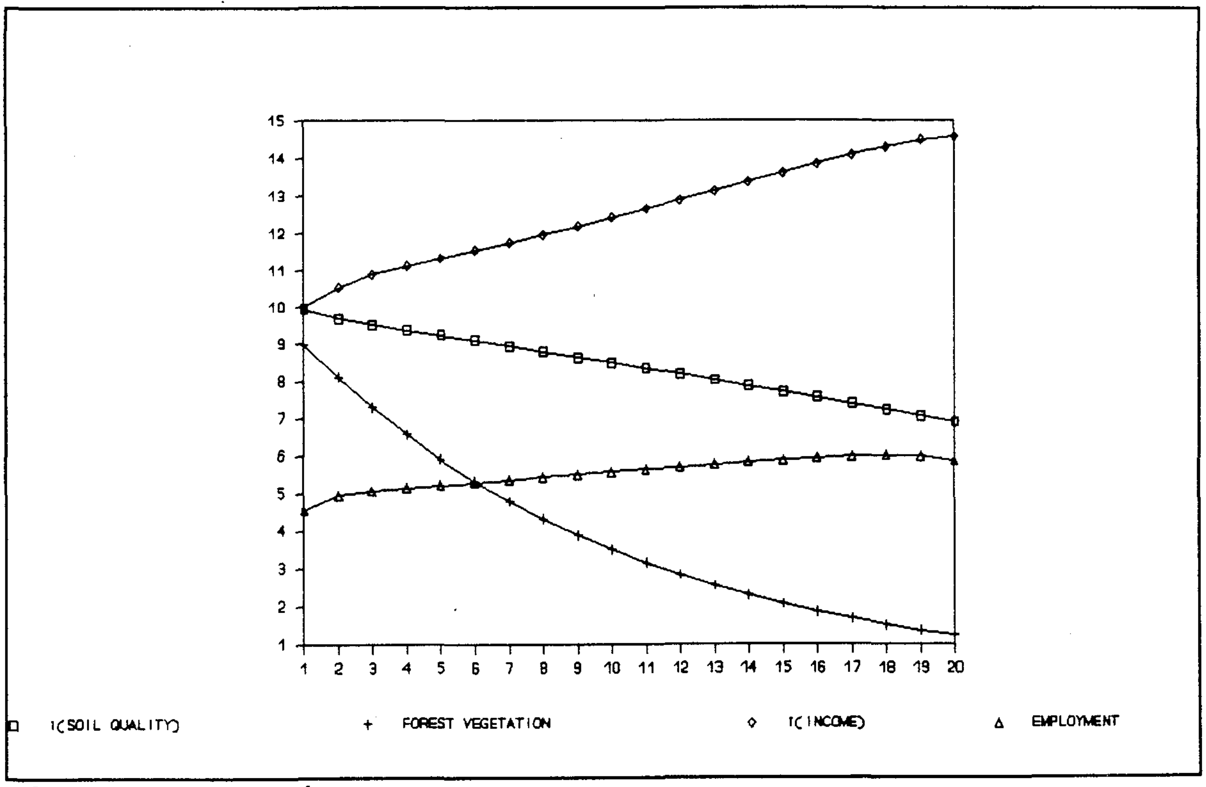

Figure 6:scenario 3

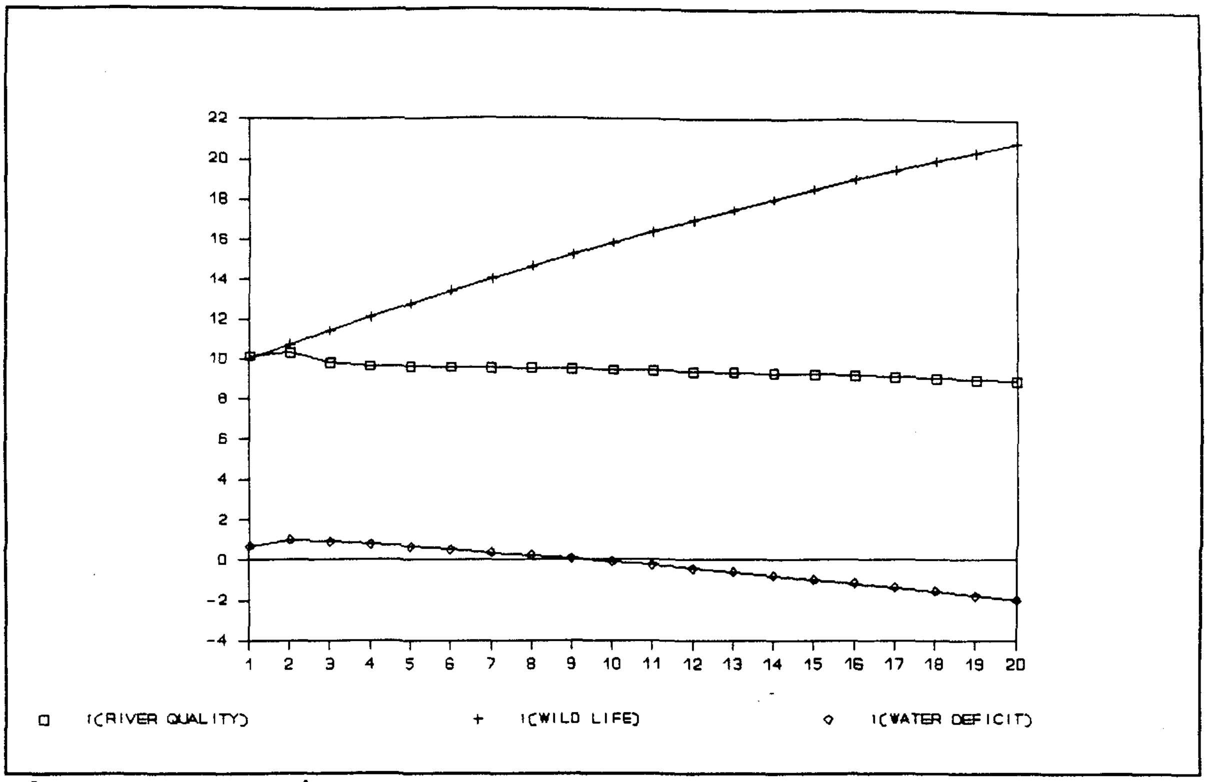

Figure 7:scenario 4

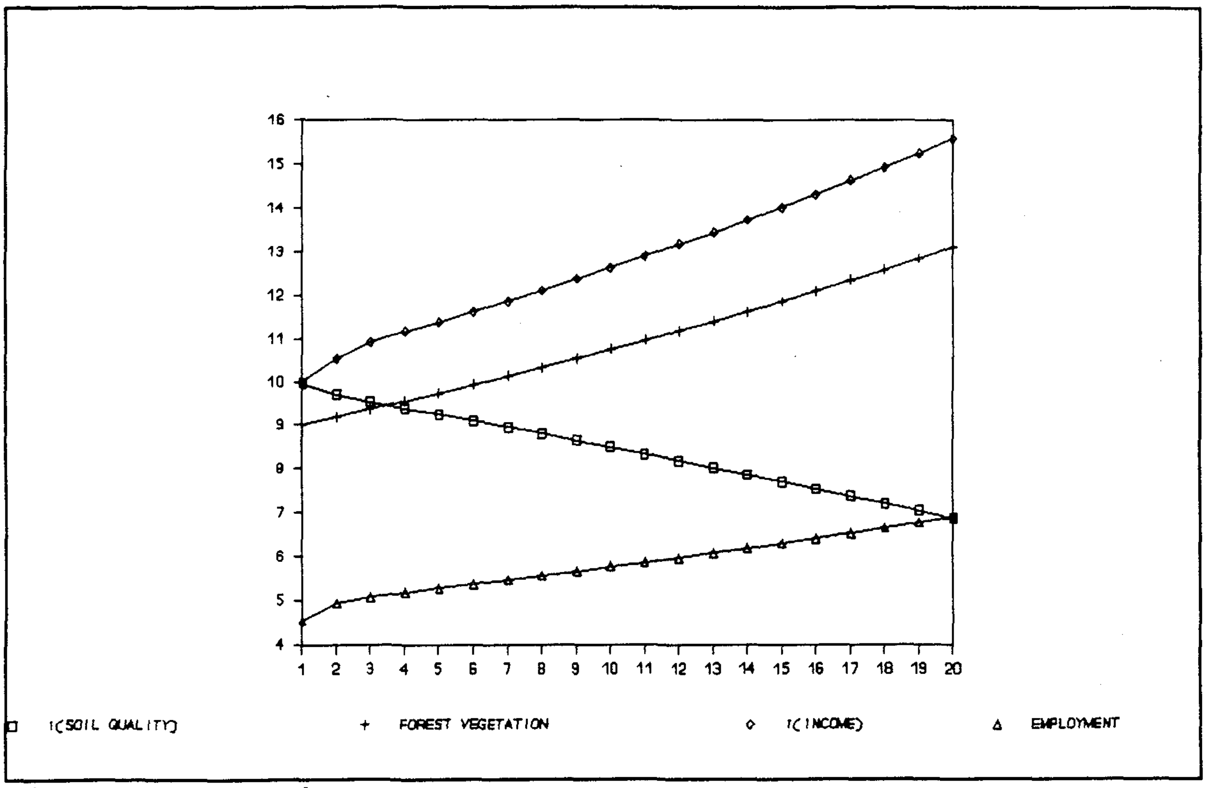

Figure 8:scenario 4

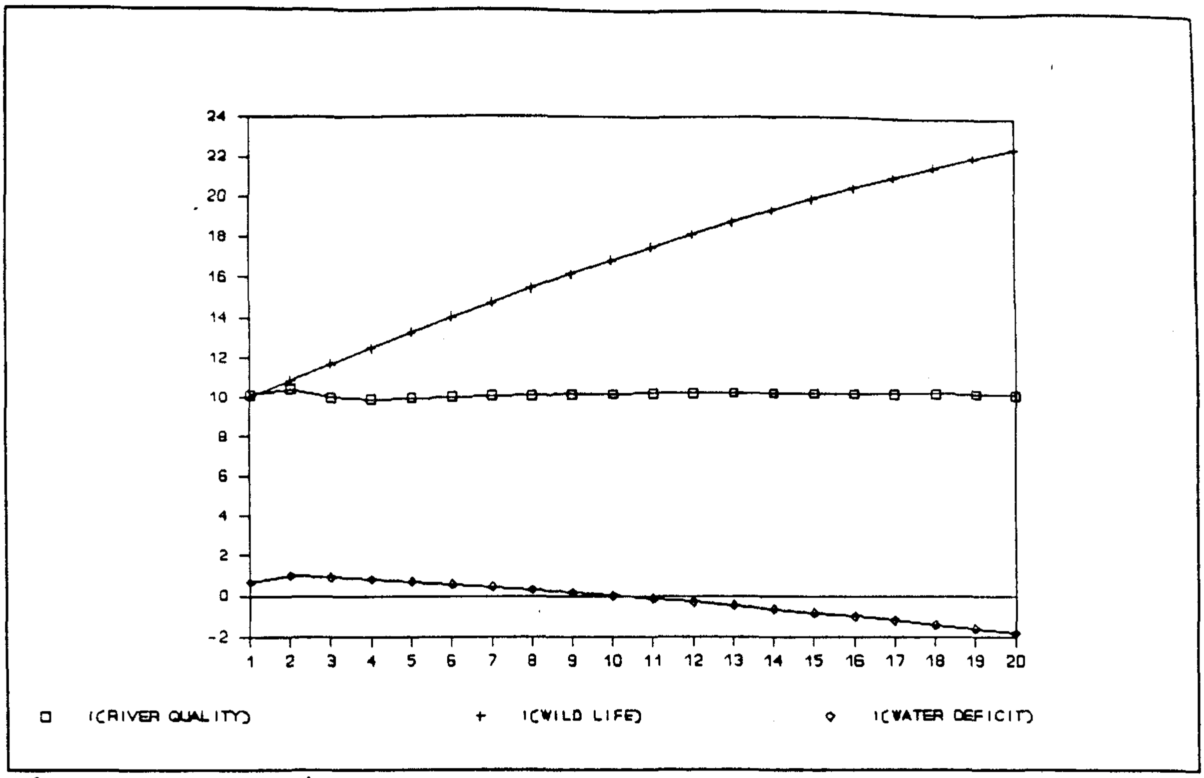

Figure 9:scenario 5

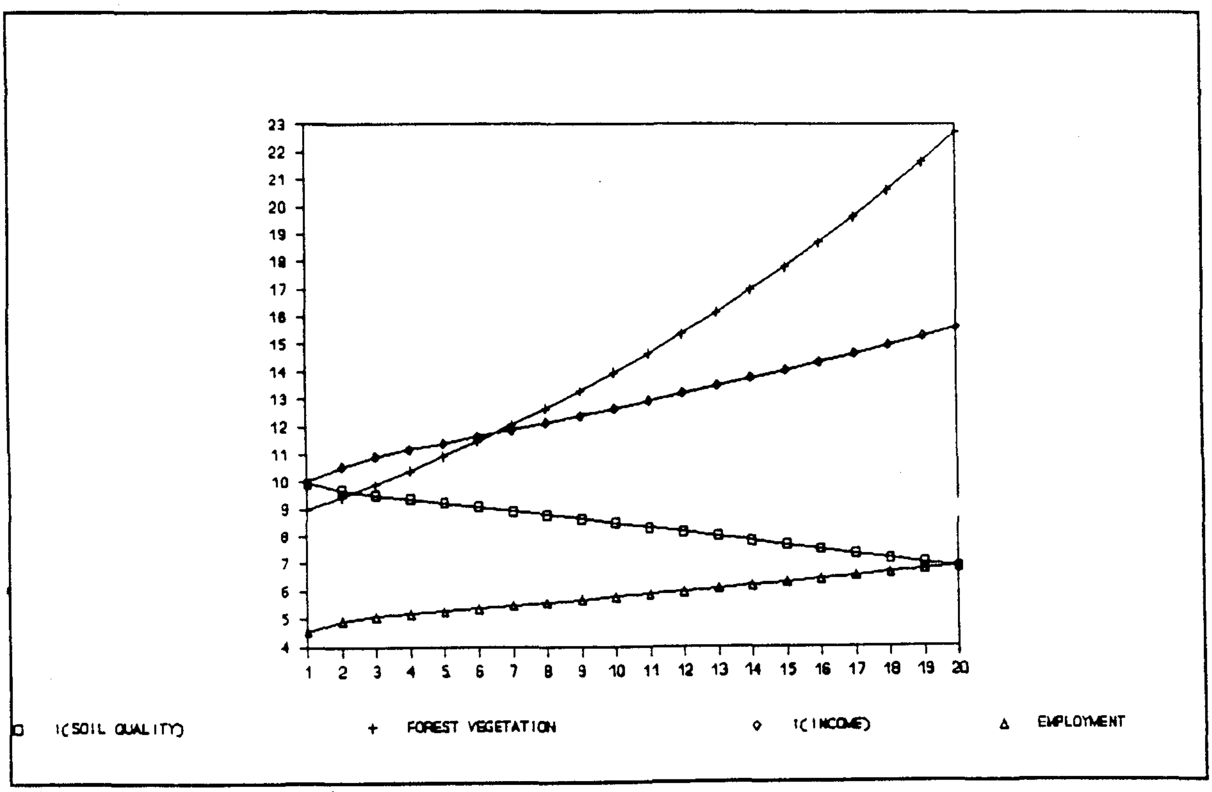

Figure 10:scenario 5

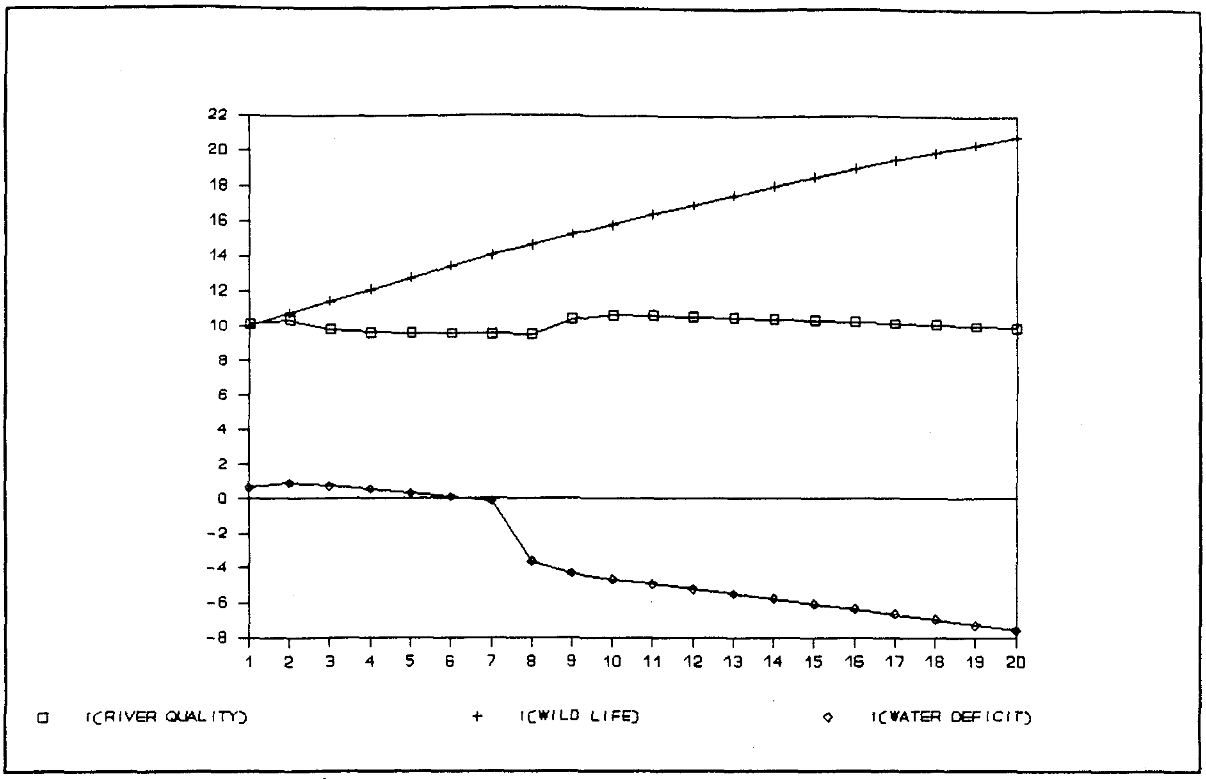

Figure 11:scenario 6

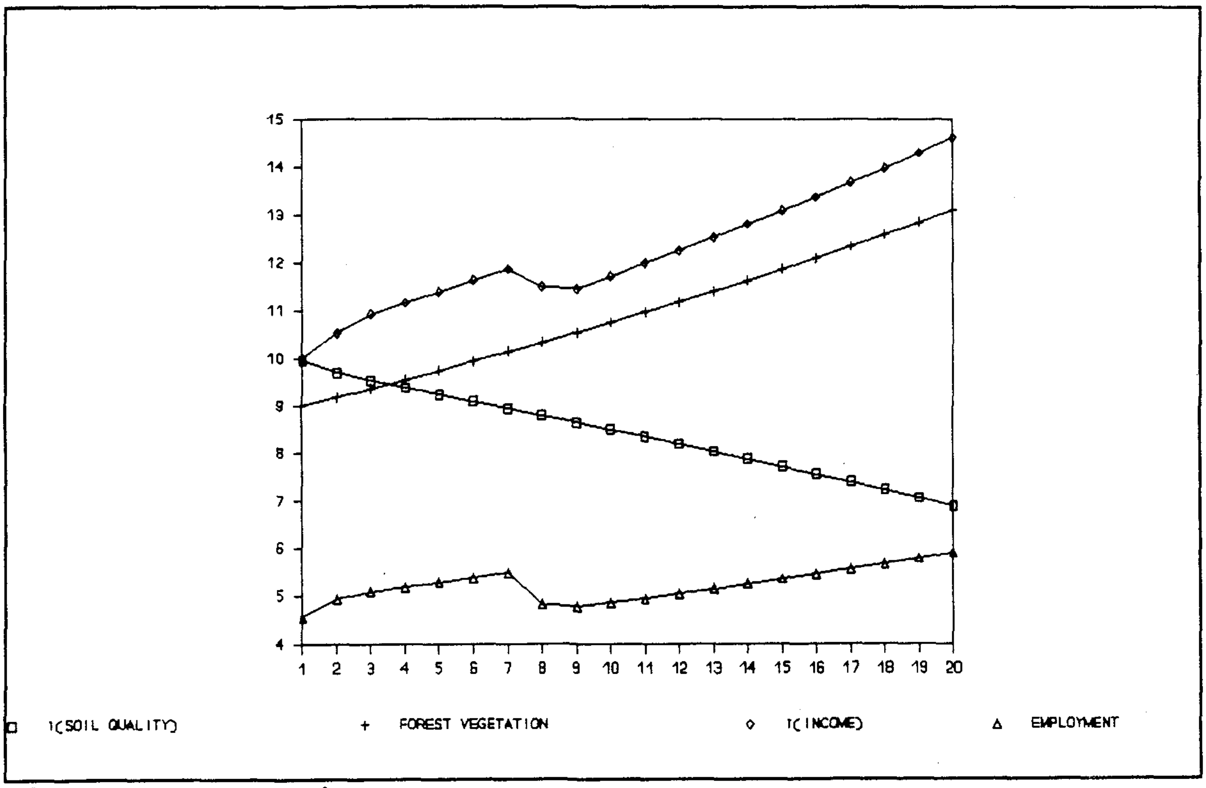

Figure 12:scenario 6

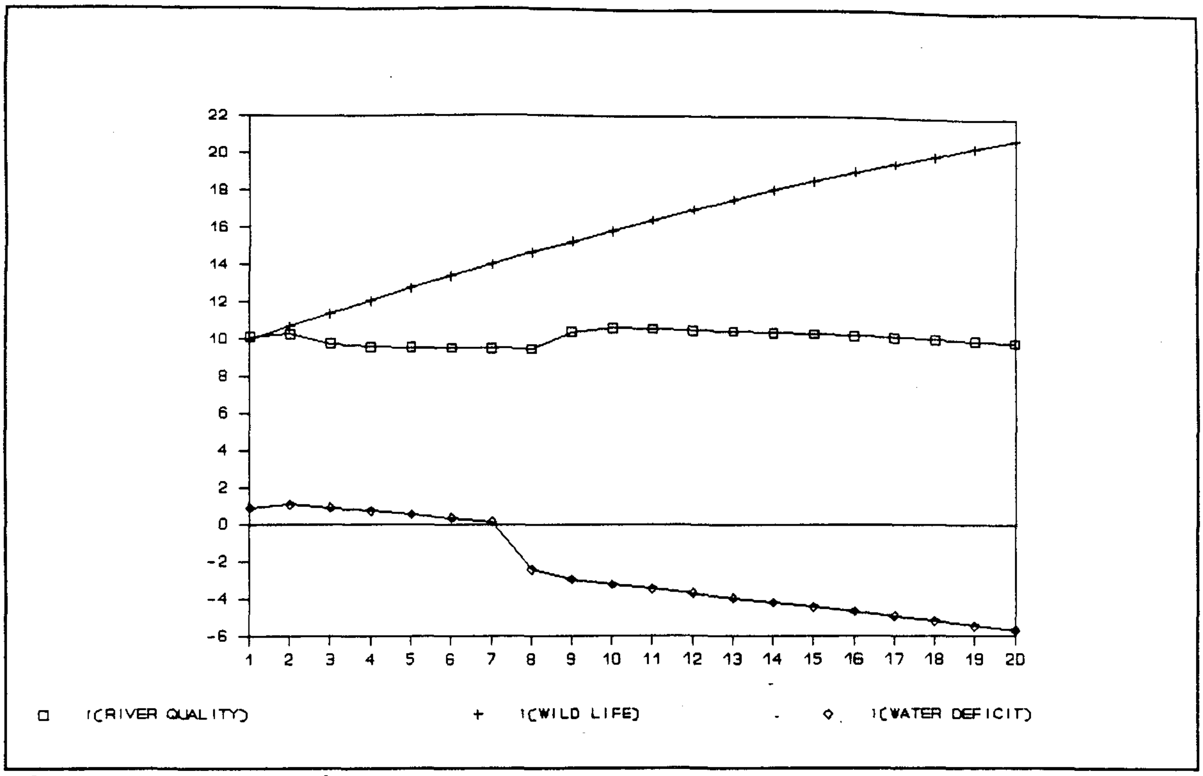

Figure 13:scenario 7

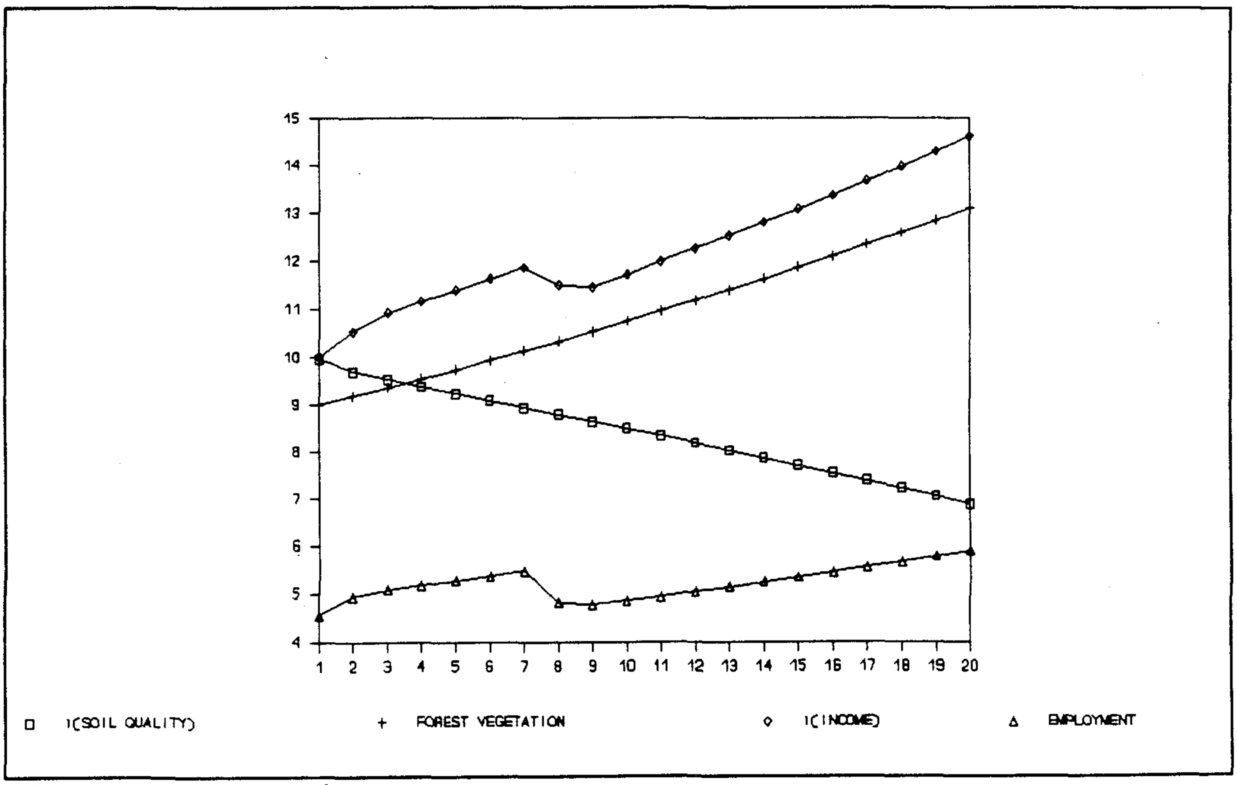

Figure 14:scenario 7

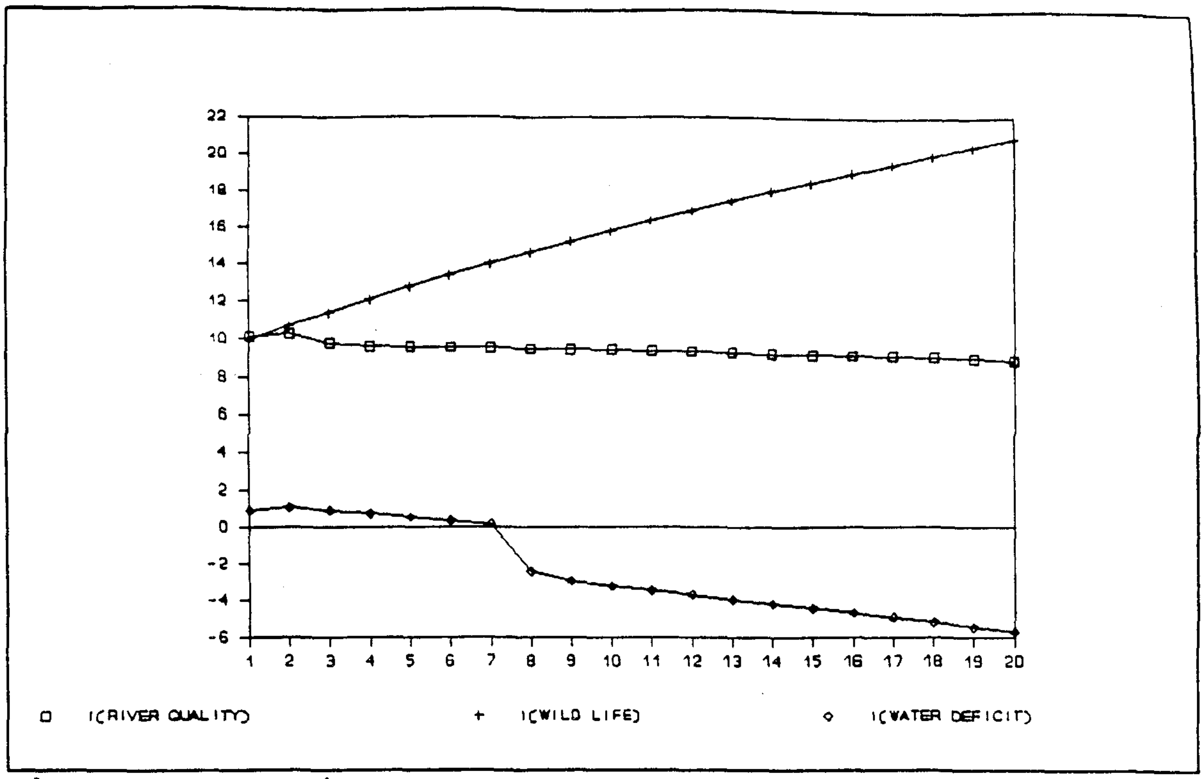

Figure 15:scenario 8

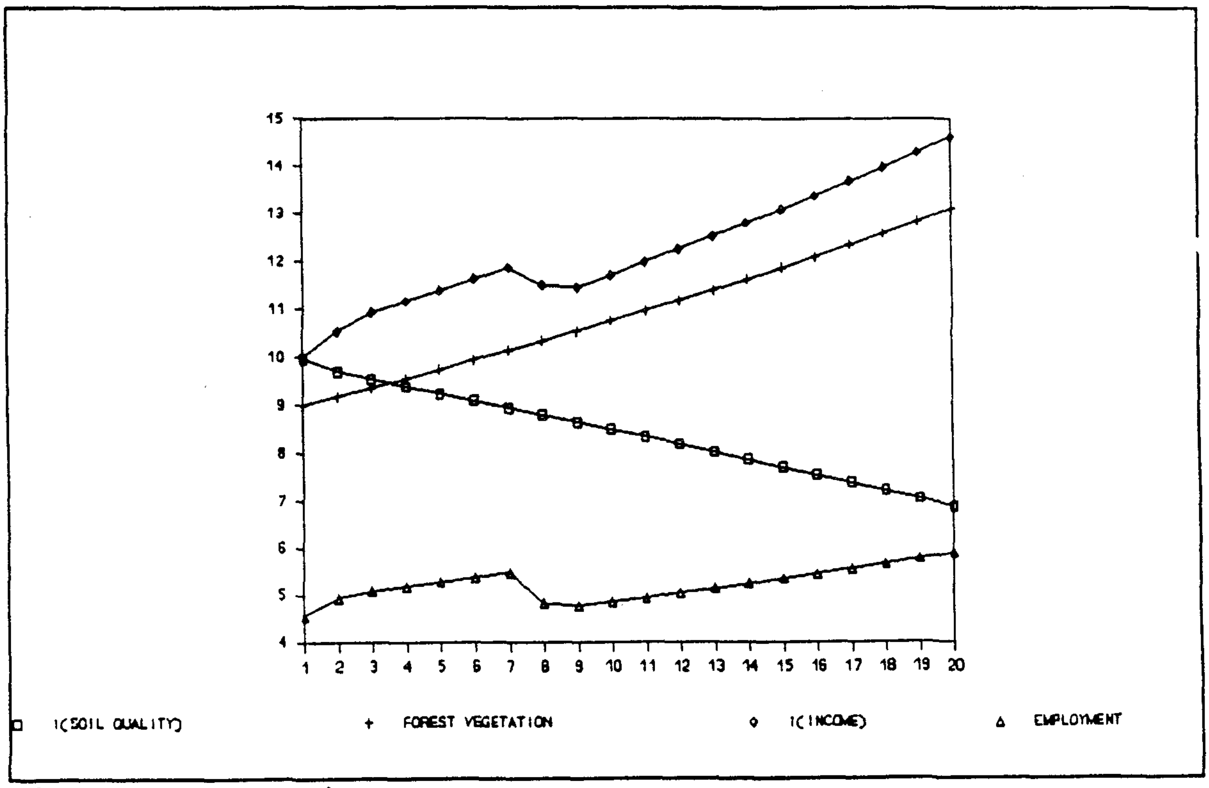

Figure 16:scenario 8

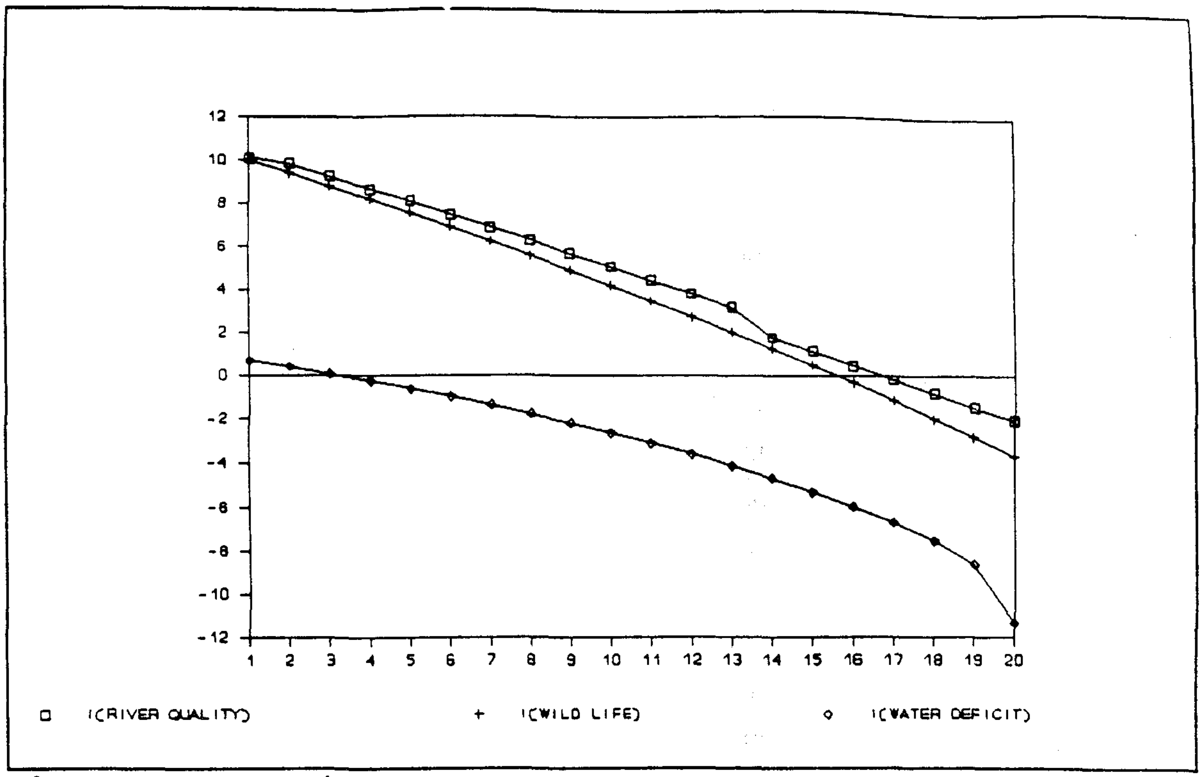

Figure 17:scenario 9

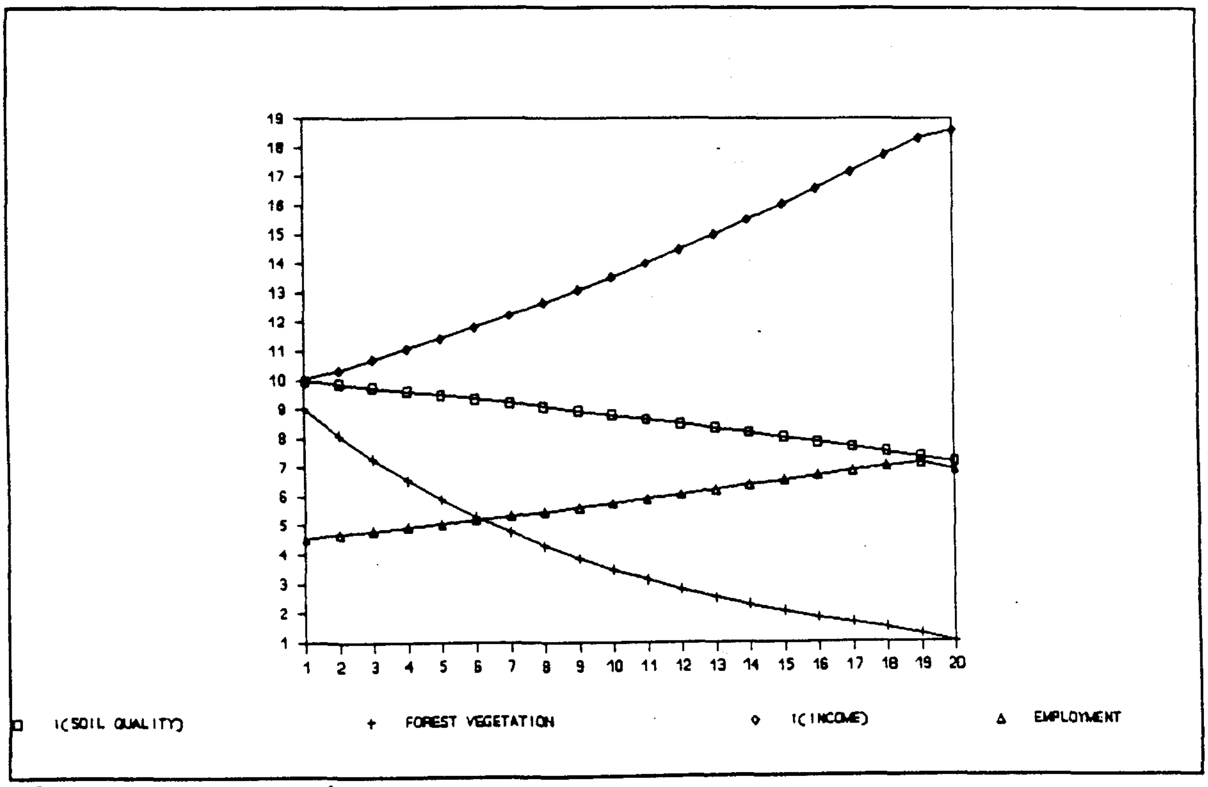

Figure 18:scenario 9

Appendix 3

The variables of the model(s) are interpreted as follows:

IndFM: Fishing index. The unit is 100*($Fisherman_t$ / $Fisherman_{t=0}$)
IndRq: Index of river water quality. The unit is 100*(Rq_t / $Rq_{t=0}$)
IndWl: Index of wildlife. The unit is 100*($Wildlife_t$ / $Wildlife_{t=0}$)
Hm: The number of huntsman
Olp: Olives production. The unit is the kgr of oil
Arp: The production of the arable cultivatios. The unit is in kgr
El: The activities of the Electricity generating unit. The index takes values from [0 100]
Wsup: An index that depicts the water supply
Wd: An index that gives the demand for water. It takes values from [0 100]
IndWdf: Index of water deficit. It takes any value
Ws: Index that presents the water stock. It takes values from [0 100]
R: The annual participation, its value is in mm of rainfalls
Rws: River water stock. An index taking values from [0 100]
Cb: Cattle breeding. The unit is the number of the animals
ECb: Exogenous variable presenting the target-assumption for the cattle breeding
C: Activities of the construction sector. Its unit is the number of the new buildings
Hw: House wastes. The unit is 100*(Hw_t / $Hw_{t=0}$)
Nois: The level of noise in the dig communities. The unit is 100*[$Nois_t$ / $Nois_{t=0}$)
Ind: The number of employees in the industrial sector, it is measured in real number.
EInd: An exogenous variable depicting the target-assumption for the number of the employees of the industrial sector
Wq: The water quality. It is an index taking values from [0 100]
Oln: The number of olives trees
EOln: Exogenous variable giving the target-assumption for the number of olives trees
Old: The productivity of olives cultivations
EOld: Exogenous variable depicting the target-assumption for the evolution of Old
Ardsm: The productivity of the arable cultivations in the semi-mountainous area
EArdsm: Exogenous variable depicting the target-assumption for the evolution of Ardsm
Ardm: The productivity of arable cultivations in the mountainous area
EArdm: Exogenous variable depicting the target-assumption for the evolution of Ardm
Arqsm: The magnitude of arable cultivations in the semi-mountainous area
EArqsm: Exogenous variable depicting the target-assumption for the evolution of the Ardsm
Arqm: The magnitude of arable cultivations in the mountainous area
EArqm: Exogenous variable depicting the target-assumption for the evolution of Arqm
Indsqsm: An index of the soil quality in the semi-mountainous area. The unit is 100*(soil quality_t / $\text{soil quality}_{t=0}$)
Indsqm: The same with the previous index for the mountainous area
IndF: An index depicting the quality and the quantity of the fishes. Its unit is 100*($Fish_t$ / $Fish_{t=0}$)
IndFM: An exogenous variable depicting the number of fisherman, its unit is 100*($Fisherman_t$ / $Fisherman_{t=0}$)
Rq: River water quality taking values from [0 100]

Dis: Dissamenities taking values [0 100]

Carw: Professional cars, its unit is in real number of vehicles

Carp: Cars, its unit is in real number of vehicles

Am: Natural amenities taking values from [0 100]

Mig: Migration measured in number of peoples

IndTH: Index for the state of Temple and Heritage. Its unit is $100*(TH_t / TH_{t=0})$

PTH: Protection policy against the Temple and Heritage. Its unit is $100*(\text{protection policy}_t / \text{protection policy}_{t=0})$

Pop: Population, the unit is number of people

FV: The magnitude of forests and natural vegetation

Emp: Employment measured in number of employees

Sew: Sewage, the unit is $100*(\text{sewage}_t / \text{sewage}_{t=0})$

IndInc: Index of income level, its unit is $100*(\text{income}_t / \text{income}_{t=0})$

Rec: The level of the activities in the recreational sector. Its unit is the number of accommodation days

ERec: Exogenous variables depicting the target-assumption for the evolution of Rec

TH: The state of the Table and of the Heritage. It takes values from [0 120]

EPILOGUE

In the concluding part of this study we will just concentrate in brief on the conclusions concerning the relevant research issues that have already been drown in the preceding chapters.

The investigation of the scientific implication of the political term of Ecologically Sustainable Economic Development stems down to two conditions. First, it is the good functioning of the biosphere system as well as of the human system's biological characteristic's that should be preserved; they form together the prime-condition of ESED, called "biological sustainability". Second, the supply of the economic production with natural inputs (matter and energy) should be ensured for the long run; this is the second-order condition of ESED.

There is a kind of difference between the first and the second-order conditions of ESED. It consists in the existence of a clear-cut criterion-rule for the achievement of the first-order condition, while such a criterion-rule cannot be prescribed for the second-order condition. Moreover, the first order condition regards the benefit of all individuals, which is valid for all generations, while the second order condition brings the seed of a competition between generations. Next, the solution to the current environmental problems, which emerge in the framework of the comprehensive theory of the traditional Environmental Economic, do not fulfill the criteria-rules of the prime-condition. Therefore, these solutions, do not lead to "biological sustainability" and hence to ESED, which means that a strategy is required imposing explicitly the criteria of "biological sustainability".

As far as the second-order is concerned, the supply of the economic production with natural inputs in the long run does not result in a clear-cut criterion. For the condition involves the presence of certain crucial uncertainties. Namely, the issues of technological evolution, of new discoveries of natural resources, of future population magnitude etc. are present when examining the second order condition. As a result the only feasible action of the mankind today is "to minimize future regrets" (Georgescou-Roegen 1979).

That is to say, the utilization of non renewable resources should be "wise" the relevant recycling processes should be induced, the utilization of renewable resources should be confined suitably, so that their regeneration capacity would not be threatened the technological evolution should promote the production of durable and lean goods, the utilization of solar energy should be persuaded as much as possible etc.

Passing to the Part B of the present study, we deal with some application issues of ESED. Specifically, a modeling methodology is proposed; this methodology offers an alternative proposition for those cases where limited statistical data are available. This methodology may also be used for environmental impact assessment. The entire study aims at examining the scientific meaning of ESED especially in the economic science domain. On the other hand, there exist of course, a great number of research issues, raised by ESED within the economic science framework, which are not handled by the present study. However, the tools establishes by this study may help in the examination of these issues. First, it is the issue of ESED implications on the decision making methodologies that are based on the economic science. To give only some examples of questions that can be raised: what are the implications on cost-benefit analysis, on social appraisal of projects, on the multi-criteria decision framework etc? Second, what could be the role of the economic tools for the design of a strategy towards ESED? Specifically, what may be the role of the taxes and subsidies system in this strategy.

Finally, we close this study by mentioning one of the foundmental scientific targets that should be performed by ESED. This target underlines implicitly the whole orientation of the present study. Specifically, ESED should resolve the debate between conservatism and developism. Conservatism, in general, asserts that it protects environment against growhtmania and this is good for the present and future generations. Developism, on the other hand, asserts that economic development increases social and individuals' welfare and so the decayed environment will be compensated by the increased social benefits. However, both conservatism and developing are dogmatic doctrines, with all the restrained horizon that can this imply. ESED is called to resolve the particular characteristic relevant conflict; in order to accomplish this mission ESED should resort in some logical criteria. According to these criteria, the economic development will occur as far as it is rational. In other words, economic development will take place as far as it creates and assures the benefit of the relevant society without jeopardizing the existence and the well-being of the named society or its environment in the long run.

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