

# **The Methodology of Economics, its Relations to Natural Science, and Implications for Understanding Eco-Efficiency**

Håvard Solem

Department of Economics, Norwegian University of Science and  
Technology, N-7491 Trondheim, Norway

Draft: Not to be quoted

e-mail: [havards@svt.ntnu.no](mailto:havards@svt.ntnu.no)

Telephone: +47 7359 1935

Fax number: +47 7359 6954

## **1. Introduction**

Production of commodities and services yields profits on the supply side and increases utility for the consumers in form of consumer surplus on the demand side, thus creating welfare gains for the society as a whole. But it also creates externalities because the second law of thermodynamics implies that the amount of material and energy put in a production process must equal the amount coming out on the other side. The process creates energy loss and residuals leading to pollution and other forms of degradation of the environment when producing and consuming a commodity (Ayres and Kneese, 1969). Since the report of the World Commission on Environment and Development (WCED, 1987) sustainable development have become a reference for industrial production and for economic activity in general, which must be met in order to secure the welfare of the existing and future generations. However, there has not emerged a consensus on what a sustainable development really means or how it should be implemented. A new way of dealing with the problem was the industrial ecology approach, initiated in 1989 (Frosch and Gallopoulos, 1989). The idea is that the eco-systems seen in nature are the ideal for designing material and energy balance systems consistent with sustainable development to be implemented in industry.

To correct any inefficiency by policy action, improvements of market mechanisms or production technology, there is need for a measure of the effectiveness in the production and consumption of various commodities in a wide sense. Such measures have come to be a part of the industrial ecology approach, and are called eco-efficiency measures and express the relationship between economic, technological and ecological efficiency. This term has however not been seen to often in economic literature, where the focus has been more on Environmental Performance Indicators (EPI), and Sustainable Development Indicators (SDI), which is related to eco-efficiency (Tyteca, 1998).

The interpretation of different terms in scientific disciplines will often differ among scientists depending on their scientific heritage. So the essence of this essay is to look at how economics and natural science differ in the view of what eco-efficiency means depending on methodological aspects within the disciplines. In order to do this we will first discuss briefly how the main points in the debate of what is acknowledged as science and what is not, have influenced the way of thinking in economics and the natural sciences. Then we will discuss eco-efficiency in light of the previous sections by examining the relations between eco-efficiency and economic efficiency. Before we conclude we will relate the discussion to EPI and SDI.

## 2. Developments of economic methodology and its relations to natural science

Not only will the interpretation of terms used in science differ, but there will also exist a debate about what is to be called science. The arguments in this debate have in turn been used to verify the authority and autonomy of science. The discussion have been on rationalism versus relativism, Popper's falsification argument against Kuhn's theory of changing paradigms, and in the end Feyerabend's extreme point that anything goes. No consensus about a universal demarcation criterion has so far been reached. The criteria will in general differ between the disciplines and we will now offer a brief overview of developments of the methodology in economics and then compare it to the methodology of the natural sciences.

The methodology of the nineteenth-century British economists like Smith, Ricardo and Malthus focused attention on theory and was defensive about the validity of verification of economic predictions. The grounds for theory were introspection or casual observations constituting *apriori* truths, which were true *aposteriori* only in the absence of disturbing causes<sup>1</sup>. In this way the purpose of verifying implications was to determine the extent of applicability of economic theory and not to test its validity. There was hence no accepting of the symmetry thesis saying that explaining is equivalent with prediction. This means that economists of that time were verificationists rather than falsificationists because they took a defensive position in order to secure the young science against attacks. Economists following Ricardo took his writings as a basis for arguments for economics being a science, not because of its methods of investigation but because of the certainty of its results. Robbins sums up the economic methodology of the nineteenth century by stating that the validity of a theory is dependent on its logical derivation from the general assumptions, but its applicability to the real world is depending on whether it is encompassing the forces operating in that given real world situation (Blaug, 1980).

As a reaction to the economic methodology of the nineteenth century as a system of pure deductions from a set of postulates derived from introspection, which themselves are not open to external verification, Hutchison proposed a prescription that economic methodology should be confined to statements empirically testable. Machlup calls this ultraempiricism and argues that this implies a system based on observations, which is not applicable for a social science like economics. Unlike the natural sciences the data of observations are themselves interpretations of human actions by human actors (Machlup, 1978). Arguments along the same lines are found in Friedman (1953) in the defense of his irrelevance of assumptions thesis. He points to that theory is to be judged by its predictive power for the phenomena that

---

<sup>1</sup> This has led to the characterization of economic rules as tendency laws. In order to control for contradicting effects a tradition for applying *ceteris paribus* assumptions has been echoed in modern economics. It is widely believed that this assumption are much more rare in the natural sciences, which is not true (Blaug, 1980).

it is intending to explain. If predictions of a hypothesis have survived many opportunities for contradictions we will have great confidence to it, despite the lack of realism that we find in the assumptions of the theory. Friedman does not refer to Popper but his arguments are to a great extent similar when he finds that a desirable criterion of good theory is simplicity (which increases the possibilities for falsification) and hence isolates the economic mechanisms from disturbing effects. In this way we can pinpoint the motives of economic actors and that is what must characterize economics as science using theory only as instruments for making predictions (instrumentalism). Economics are later held to be a box of tools, and empirical testing is not so much a tool for rejecting or accepting a theory, but to see to which degree a theory is applicable in a given situation. Blaug (1980) characterizes the current mainstream methodology of economics as innocuous falsificationism because of its highly protective “rules of the game”: “...almost any model will do provided it is rigorously formulated, elegantly constructed, and promising of potential relevance of real-world situations.” (Blaug, 1980, p. 128).

Summing up the history of economic methodology the development from the classical economics originating from Adam Smith, via the marginalist approach in the late nineteenth century to the Keynesian revolution in the early twentieth century have by some been characterized as changes in paradigms (Hicks, 1976). Those defining paradigms in a more strict Kuhnian way argue that there has been only one dominating paradigm, namely the ideology of efficiency, but over the years we have seen some subparadigms emerge (Bromley, 1991)<sup>2</sup>. The main paradigm runs roughly from Adam Smiths “invisible hand” via the distinction between analytic and synthetic truths (and between positivist and normative economics) to the Pareto criterion for efficiency and Arrows view of the market as the only supplier of consistent choices that were not value-laden.

The emergence of economic methodology as we know it has also been influenced by the natural sciences, which by some is seen as the “most scientific” science. Since the success of Newton’s contributions to the development of natural science, the use of mathematical methods has become an ideal for other branches of natural science and a source for perceptions of the social sciences as inferior to the natural sciences because of the lack of formalization. Even before Newton’s *Principia*, as early as in the seventeenth century, there were a number of attempts of constructing social sciences on the principles of mathematics and the natural sciences because of the accomplishments of among others Descartes, Galileo, and Kepler. Neo-classic economists like Jevons, Pareto, and Fisher declared physics as a model for economics as a discipline in order to reach a goal of making economics a “true”

---

<sup>2</sup> The main subparadigms are the historicists of the nineteenth century and the American institutionalists in the early twentieth century (Gordon, 1965).

science (Cohen, 1994). It is later argued that economists “boldly copied the reigning physical theories.” because mathematical physics was the part of an exact science with the highest standing and would show that their subject shared the features of an exact science (Mirowski, 1989, p. 454). It is also argued that economics in the mid-nineteenth century proved to be well adapted to the application of mathematical techniques as can be seen in the theories constructed by economists like Edgeworth, Jevons, and Walras (Cohen, 1994).<sup>3</sup>

However, the adoption of, and the heavy reliance on mathematical methods has been proposed as the reason for making economic *less* scientific (Payson, 1997). It is argued that it is not sufficient to obtain and manipulate data, but one must also understand what the data actually means. Payson (1997) plead that the wide use of abstractions from reality is a sign of lack of scientific practice, and that this is the disciplines main problem. Developing advanced econometric methods can not mend the lack of using the appropriate data.<sup>4</sup> The same argument is put forward by Ravetz (1995, p. 174), which states that “Perhaps the economists were the victims of the doctrines they learned from the philosophy of science, which concentrated on abstract problems of validation of theories while ignoring the principles of measurement.” Arguing along the same lines are Keeports and Morier (1994), which labels methodology based on Friedman’s irrelevance of assumptions thesis pseudoscientific belief because even through sound reasoning a false hypotheses may lead to true predictions. According to these authors, the reason for economists having a different perspective on science is that the natural scientist is devoted to having a purely objective view of reality (including any assumptions), while the economist is only interested in the conformity of a hypotheses’ implication with empirical observations. An explanation for this is offered by Payson (1997) saying that economics is less interdisciplinary than science. Majors in economics have some mathematical education, but mathematics is not underlying economic behavior. Knowledge in other disciplines can lead economists to “assume things away” not because of convenience, but instead base the assumptions on the fact that the effect of certain factors are negligible.

While it can be argued that the logic and technique do not differ much, the division between the natural sciences and economics can be traced back to the difference in the objects that is studied. Machlup (1978) has labelled this difference as “silent nature, talking man” and are based on Schutz (1953) who argues that the facts, events, and data before the social scientist refers to and are founded in a context which he himself is an actor, while the observational field of the natural scientist does not mean anything to the objects themselves. This

---

<sup>3</sup> Whether the social science is suitable for application of a particular technique is depending on the state of development reached by the subject. It is also depending on the degree of development of the natural sciences and whether this permits application. An example of such an application is the use of comparative statics in economics.

<sup>4</sup> Payson (1996-97) offers examples of this from agricultural and welfare economics.

difference is an argument in favour of those that does not see the methodology of physics as the ideal and the standard for what is to be called science. In economics the scientist have the possibility of accessing data for inner experience that is unavailable for the natural scientist. Such introspection and communication with the actors on the social scene makes the source of information larger in the social sciences than in the natural sciences.

This difference in observations and data between the disciplines can however be seen as both an advantage and as a disadvantage. It can be argued that it is the personal experience that enables us to understand mechanisms within observations and hence formulate more accurate hypotheses about the scientific object. Theorizing *a priori* is necessary to understand and be able to interpret the observations made by the scientist. This is as important in explaining action as well as explaining intentional refraining from action. An example of the disadvantage of not having access to introspection is found in attempts to explain the mechanisms within the stock market only by observing the actors without knowing anything about the language or economic theory. The nature of difference is that the social sciences makes “subjective” or psychological inventions of hypotheses from objective occurrences as opposed to the natural sciences where they do not have first hand experience, but makes hypotheses from observations “without knowing what it is like to be a rapidly moving molecule.”(Nagel, 1961, p. 484). This first hand information can be misleading as well as helpful because the classes of social phenomena is poorly bounded compared to the more well-bounded class of physical phenomena, which creates differences in the possibilities for plausible generalizations. The chance of experiencing observations contradicting theories is larger when the observations are subject to interpretations by the object itself or by the scientist<sup>5</sup>. A question whether the observations in the social sciences are conscious or unconscious reactions must also be taken into account. These two elements have to be considered by the social scientist and can be a source of new knowledge, which can be valuable for modifying existing theories.

The inherent “meaning structure” of human action implies some degree of subjective interpretation. This means that not only one model of an individual mind would fit the observed facts. Different levels of specificity or generality may be adequate for explaining the same set of observations, so the social scientist has the same problem as the natural scientist of choosing between different hypotheses. Despite this subjectivity, Nagel questions “...whether such imputations involve the use of logical canons which are different from those employed in connection with the imputation of ‘objective’ traits to things in other areas of inquiry.” (Nagel, 1961, p. 481). The main difference is that the natural scientist does not

---

<sup>5</sup> Philosophers of science are however now fully agreed on that almost all disciplines includes a core of general propositions, independent of time and space, which can be applied to concrete situations or particular cases (Machlup, 1978).

communicate with the molecules, but if he had to, he too would have to deal with the help or hinder this would imply. So the impression is that the main difference between economics and natural science lies more in the objects of investigation than in the methodology and logic of the disciplines.

### **3. The different interpretations of eco-efficiency**

As mentioned in the introduction, eco-efficiency is a way of evaluating the environmental and economic efficiency in production and consumption of commodities or services in an industrial ecology perspective. There is by now not a general agreement on how to define eco-efficiency, or how it should be made operational, with respect to both criteria and indicators. But since eco-efficiency is a measure used in the industrial ecology tradition, we will first offer a brief summary of the emergence of this way of treating environmental problems.

Industrial ecology is connected to industrial metabolism, which is concerned about revealing inefficiencies by tracing the flow of energy and materials through various systems. This approach has its origins in the engineering disciplines and is focusing on systems analysis (Ayres, 1989). Extending this approach by using ecosystems found in nature as a model for industrial systems, the metaphor industrial ecology was used to label this kind of thinking about environmental issues in a pioneering article by Frosch and Gallopoulos (1989)<sup>6</sup>. The ideal was that no waste should leave the industrial system or in other ways impact the natural eco-systems in a negative way. The focus was on physical, chemical, and biological interactions and interrelationships between the industrial system and nature (Erkman, 1997). So when the field was, and still is, emerging, the knowledge used in research is clearly based in the natural sciences as the focus is very much on the potential of improving technology used in production processes. Industrial ecology is however meant to go beyond industrial metabolism stressing the functionality of the production to meet human needs. But since the distinction between the two in the literature often is not made clear, this has certainly affected the methodology in the field. This is reflected in the impression of little economic research on the subject relative to the research done by natural scientists and by the industry itself.

The need for a measure of the potential improvements in industrial performance, lead to the emergence of the term eco-efficiency. The concept of eco-efficiency was introduced in the beginning of the 1990's, but was more frequently used after the UN Conference on Environment and Development (UNCED) in Rio de Janeiro 1992 (Schaltegger and Sturm, 1990). Some of the most used definitions of eco-efficiency is given as:

---

<sup>6</sup> The concept of industrial ecology existed well before the expression, which appeared sporadically in the literature as early as the 1970's. See Erkman (1997) for a historical review of industrial ecology.

- Value added per unit of environmental impact (Schaltegger and Sturm, 1990)
- The optimal use of material, energy, human resources, and capital to supply innovative products to the market (Glausser and Müller, 1997)
- Pollution added relative to profit margin (Schaltegger, 1996)
- Environmental gain relative to costs (OECD, 1998)
- Value of products or service relative to the sum of environmental life cycle impacts (Schaltegger, 1997)

The above definitions are summed up in WBCSD's widely used definition of eco-efficiency, which also is adopted by the United Nations Environment Programme: "Eco-efficiency is reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality to life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity." (WBCSD, 1999)<sup>7</sup>. In contrast to this ambitious definition a review of the literature shows however that the bias towards technology and production is becoming more apparent when the definitions become more specific. The central role of natural sciences and the industry is reflected in WBCSD's seven criteria for eco-efficiency (WBCSD, 1999):

1. Reduce the material intensity of goods and services
2. Reduce the energy intensity of its goods and services
3. Reduce toxic dispersion
4. Enhance material recyclability
5. Maximize the use of renewable resources
6. Extend product durability
7. Increase the service intensity of goods and services

As we see, these criteria rely heavily on the materials of balance approach and are not considering what is the most efficient resource allocation for society. The focus is isolated on the product and on the firm. In itself this is not a bad thing, but economists will argue that there has to be some criteria on effective resource allocation in addition to the above listed criteria. For instance, it is evident that the (marginal) effect of pollution on human welfare differs depending on where the pollution is geographically located. This is the reason why we should also think about where we are able to get the most environmental gains, and hence we need some economical decision criteria. Since the purpose of producing goods and services is to meet human needs, it is essential in an industrial ecology approach to investigate the social

---

<sup>7</sup> WBCSD stands for World Business Council for Sustainable Development, a coalition of 125 companies drawn from more than 20 major industrial sectors from 35 countries.

benefits and costs of both production and consumption and not to look isolated on the physical quantities in one process alone.

Further, the idea behind eco-efficiency is to achieve increased welfare without increasing the environmental degradation. Since the elasticity of demand for environmental quality is believed to be larger than one, the de-coupling between environmental degradation and economic growth starts at a relatively high income level (for more on the Kuznets curve mechanism, see Barbier, 1997). This means that for actors in a society to be able to operate eco-efficient there has to be some degree of equity with respect to income distribution within the society as well as relative to other societies. There is therefore a need to diversify between environmental aspects, effects and implications for human society. In other words it is essential to focus on equity and futurity as well as the environmental aspects (Rikhardsson and Young, 1996; Welford, 1995).

Further, there are differences in the nature of material and energy flows and the flow of cash that has to be acknowledged because “Important flows in material terms are not always important economically and vice versa.” Pesonen (1999, p. 38)<sup>8</sup>. The principle that the amount of material and energy are constant at any flow or process in a system is known as the second law of thermodynamics. This does not, however, hold for cash flows. In a process there is some value added to a product generated by the utilization of the producer’s productive capacity, so the input amount of cash will not be the same as the output amount. The implications of this is that analyses focusing heavily on only the physical quantities (like material flow models) are interested not in the process itself, but on the input and output of materials and energy, thus neglecting the costs and benefits to society created within the different processes. From an economists point of view there exists an optimal level of damage, meaning that the goal is not to minimize the level of resource use or emissions *per se*, but to find the amount that leads to the highest level of welfare for society. Consequently, there is clearly a necessary relationship between economics and technological knowledge that must be present in order to achieve eco-efficiency. Because the effects on human welfare can not be estimated without insights about the flows of materials and energy or the production processes and its environmental impacts, the natural sciences can offer quantitative data that are necessary inputs in economic analysis.

The method most frequently used to measure the eco-efficiency of products or companies is Life Cycle Assessment (LCA). The method has its origins in the material flow models and is therefore influenced by the methodology of the natural sciences. This is seen by the focus of

---

<sup>8</sup> If the prices are right (that is, if the externalities are fully internalised) there should not be a divergent, and sometimes contradictory, difference between environmental and economical valuation.

the method being heavily biased towards the flow of materials and energy and the immediate effects on the environment. The method is criticized for treating the effects of material flow on the human society without a general and consistent theoretical basis, for the subjective setting of the systems border, and for neglecting that there may have been imposed corrective incentives elsewhere in the economy (Brekke and Vennemo, 1999). It has also been noted that LCA uses single and not continuous samples aggregated for different geographic locations, which affects the quality of the data (Schaltegger, 1997). This is essential because eco-efficiency is not static and must account for changes in variables over time (technology, preferences, etc.). An LCA may therefore be seen as an incomplete and inaccurate Cost-Benefit Analysis (CBA). The implication may be that LCA is inefficient compared to other methods of measuring eco-efficiency<sup>9</sup>. A further study of the effectiveness of the methods used to collect and analyze the data is likely to be a fruitful area for research.

As noted above, the eco-efficiency literature is dominated methodologically by LCA and other related methods. In economics the LCA-methodology has not gained very much popularity and the reason for this is that LCA is a well established method for identifying and quantifying environmental impacts associated with the life cycle of products and not so much when it comes to evaluating and weighting between sometimes conflicting objectives. Further, economists are accustomed to analyze problems also for the purpose of providing information to policy makers on how to realize overall economic efficiency. In order to do this, their analyses are performed at the firm or industry level and not so much on specific products because such detailed analysis (like LCA) will often be applicable for the specific product only. Economists have a more aggregated perspective and focuses on the source of the problem and not on a single actor in one market. The indicators used by economists to measure what can be interpreted as eco-efficiency, is called Environmental Performance Indicators (EPI), and must therefore from an economists point of view, allow comparisons between and within firms or industries (Tyteca, 1996). A proposed measure for efficiency allowing this is the non-parametric method known as Data Envelopment Analysis (DEA). Eco-efficiency at the firm level are however only a necessary, and not a sufficient condition for sustainable development. Using analysis on firm level is a bottom-up approach, while analysis also incorporating equity, futurity and indicators on nature's carrying capacity will serve as a top-down approach. The carrying capacity of the earth is bounded and there are thus some limitations to the size of the economy making the top-down approach necessary in order to achieve sustainable development. Indicators reflecting this are in the economic literature called Sustainable Development Indicators (SDI) (Tyteca, 1998).

---

<sup>9</sup> This is an important point to make, especially when the analysis is used by governments for regulating economic activity.

The optimality of applying LCA will depend on the scope of the analysis. It can be a highly appropriate method to use on the product level and from a firm's viewpoint, but when it comes to evaluating the society's overall efficiency and to design environmental policy, some other methods have to be applied. The LCA can nonetheless serve as a source for information on the specific processes applied by the actors in the various markets. It is hence possible to see that the economists' critique of LCA is, to an extent, a consequence of the disciplines' different definitions of terms and what it is intended to encompass. Whereas economics is a social science and hence first and foremost focus on human behavior, the natural sciences are dealing with physical quantities and the relationship between man-made production and the natural environment. This will in a number of fields lead to diverging definitions of terms used by different disciplines. One example is whether maximizing the economic surplus means the bottom line for a company or society's economic profit. Further, there is also disagreement about what is meant by efficiency and how to achieve it. In parts of the eco-efficiency literature there is made a distinction between efficiency and effectiveness and argued that "... getting the prices right are not sufficient. The *scale* of the production and activity should be taken into account, and in this perspective the distinction between the two terms seems legitimate..." (Røine et al., 1998)<sup>10</sup>. According to economic theory it is sufficient to get the prices right, that is, reflecting all the benefits and costs associated with the commodity, for an efficient allocation of resources for society to be realized<sup>11</sup>. The scale of the production will be regulated by the fluctuations in the price of the product and of the input factors depending on the amount of the resource, extraction costs, and the availability of substitutes. Underlying the different approaches is probably that the natural scientists are focusing on the flow of physical units like material and energy, while economists use price mechanisms in markets to reveal the humans' preferences, valuations, and appreciation of different commodities and services.

The economists' general proposal for solving environmental problems is to internalize the externalities by direct or indirect regulation in the form of individual transferable quotas (ITQs) or imposing (pigouvian) taxes. In this way the difference between private and social optimum (namely the externalities) is taken care of. The only problem is thus to pinpoint the true value of each service and commodity in the economy, and there exist a great amount of economic literature on how to handle this problem<sup>12</sup>. Further, students of economics are to a great extent taught that externalities are rare and special cases where the market has not been able to reflect the true value in the existing prices, which it usually are able to. It is nevertheless worthwhile to draw attention to the relevance of this approach and the

---

<sup>10</sup> Effectiveness is defined as causing or capable of causing a desired or decisive result, and efficiency is defined as the degree of effectiveness with which something is done (Webster's dictionary, 1992).

<sup>11</sup> This is of course a first-best solution, and this Pareto efficient solution does not say anything about equity.

<sup>12</sup> There is, however, not general agreement on how accurate and relevant these valuation methods are.

relationship between economics and the physical laws found in nature. As Ayres and Kneese (1969) argues, economists must face the fundamental laws of conservation of mass, which states that the earth can be seen as a spaceship with fixed amounts of mass (Boulding, 1966). An implication of this is that residuals from production and consumption processes are not anomalies, but an inherent and normal part of the activities, thus making externalities a normal part of economic activities. Because economists are focusing on services in the form of the value or utility, they are sometimes missing the point that the amount of mass put into a production process comes out as either a part of the product or as residuals. Hence, the ability of the environment to receive and assimilate the residuals is consequently an important natural resource, which value is increasing as the economic development, and necessarily the externalities, proceeds. As the scale of the externality is increasing the problem becomes one of pervasive externalities, that is the internalizing of it cannot be realized by the ordinary marginal instruments (Daly and Cobb, 1990). An example of this is the problem of accumulative CO<sub>2</sub> emissions. The message is therefore to improve the measures of externalities with regards to differing concentrations and duration of residuals. Further, there is a need for more systematic methods for forecasting the production of different externalities, the technical and economic trade-off between them, and the effects of recycling on environmental quality.

Regarding the relationship between eco-efficiency and social sciences other than economics, the latter can provide guidelines on the micro-level with respect to optimizing design of organizational structure towards environmental thinking and its connection to economic considerations. The last point is an important one to make because in competitive markets the actors are first and foremost focused on profit-maximization. So in order to survive in tough market situations, the industry will not act in line with eco-efficiency if the cost of being eco-efficient is considered to be too large relative to the gains. The challenge is hence to contribute to ways of organizing business so that the market structure encourages eco-efficient behavior.<sup>13</sup> On the macro-level some criteria concerning the political arena are often missing when eco-efficiency is analyzed. Since the optimal social and private resource allocation often is found to differ there is need for the authorities to correct any marketfailures, and therefore important to investigate how eco-efficiency thinking is handled in politics. Thus, neglecting the social aspect will negatively affect the possibilities for successful implementing of eco-efficiency in society.

#### **4. The relationship between eco-efficiency and economic efficiency**

As noted above, we find a variety of different definitions of eco-efficiency in the literature. The way the term is being used changes according to the purpose of the analysis at hand.

---

<sup>13</sup> One example of this kind is the formation of eco-parks.

Schaltegger (1996) gives an overview of three often used applications and Brattebø (1998) discuss the term eco-effectiveness, which is based on eco-efficiency. By evaluating these four definitions of eco-efficiency and some related definitions in light of economic terms, we hope to add some insight on the differences and similarities between the different ways to treat efficiency in an ecological-economic setting.

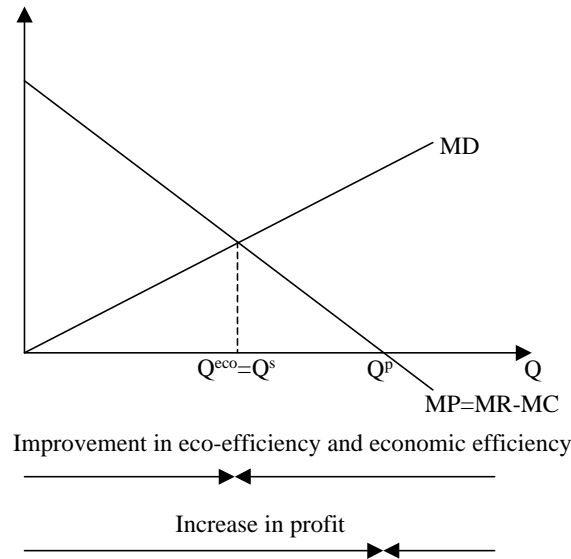
The explicit definitions of eco-efficiency covering most of the less exact definitions are:

1. Economic-Ecological Efficiency (Eco-efficiency) = Value added / Environmental impact added
2. Eco-efficiency = Value of products or service / Sum of environmental life cycle impacts
3. Ecological efficiency = Desired output of production or function / Environmental impact added
4. Eco-effectiveness = Eco-efficiency / Volume

I will go through the definitions of eco-efficiency and make clear how we understand the terms being used in them, and then compare them to the definition of efficiency used in economics.

***Definition no. 1: Economic-ecological efficiency (Eco-efficiency)***

Eco-efficiency defined by definition 1 is evaluated by the ratio between value added and environmental impact added. Value added is here interpreted as net profit for the producer of the product or service, while it could also be the shareholder value or the contribution margin, depending on the purpose of the analysis. Environmental impact added is understood as the total environmental damage throughout the life cycle of the product. I will not go into any details on how environmental impact is measured, but we can assume that the damage is revealed through a life cycle analysis. According to this definition the most eco-efficient product is thus the one where the difference between net profit for the producer and environmental damage is the largest. Given that the external costs for society are of environmental concern only, there will be no difference between an eco-efficient and an economically efficient production because the latter is characterized by a situation where marginal benefits less the producers marginal production costs equals society's external costs on the margin. This is illustrated in figure 1 where we see that the eco-efficient and economically efficient production level will be lower than the market solution, assuming linearly increasing environmental damage and production costs, both measured on the margin. In a non-regulated market there is therefor possible for a producer to increase profits by deciding on a production level above the level efficient for society. By direct or indirect regulation there is hence possible to increase the overall efficiency regardless of what efficiency measure is being used.



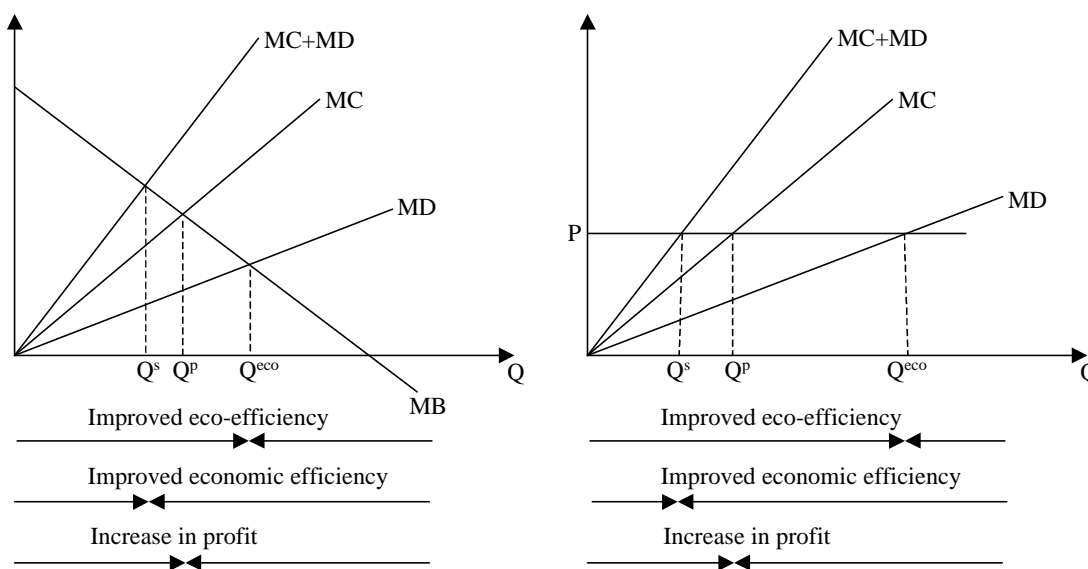
**Figure 1** Defining eco-efficiency by the ratio between value added (net profit) and environmental impact added is consistent with economic efficiency defined by equating net profit (MP) to marginal environmental damage (MD) on the margin. External costs are assumed to consist only of environmental damage.  $Q$  is production level,  $MR$  is marginal revenue,  $MC$  is marginal costs for the producers,  $Q^{eco}$ ,  $Q^s$ , and  $Q^p$  are efficient production levels defined by eco-efficiency, overall economic efficiency for society, and private profit maximization, respectively.

**Definition no. 2: Eco-efficiency**

Definition 2 means that eco-efficiency is measured by the fraction between the value of products or service and the sum of environmental life cycle impacts. The numerator is interpreted as total value to the consumer, that is, the area under the demand curve up to the quantum desired, while the denominator is understood as total environmental damage over the products life cycle. This is the same as to say that the most eco-efficient product when definition number 2 is used, is the product where the total utility for consumers is largest relative to environmental damage. We are hence not taking account of direct costs of producing the product, but are focusing only on the external costs for society concerning the environment. Clearly, we are not dealing with the same as economic efficiency for society. From an economists point of view it is crucial to take all costs into consideration when evaluating efficiency so that the value of the alternative use of the resources are accounted for. The result of leaving out the direct costs is that according to definition number 2 it is possible to raise eco-efficiency by increasing production to a level above the overall efficient level. Eco-efficiency is increasing even if the total costs of producing the product or service are larger than the benefits received by the consumers. In figure 2 we have illustrated this by

two situations with a falling and a completely elastic demand-curve, respectively. When marginal costs facing the producer is higher than the marginal environmental damage there is a possible increase in eco-efficiency by producing a higher level than what is efficient in a non-regulated market with profit-maximization as the decision rule.

The eco-efficiency definition in this section can however be used to evaluate the same product produced by different producers with regards to the extent of internalization of external costs<sup>14</sup>. If one of the producer spends money on abatement technology he will lower the marginal damage from production and raise his own marginal costs. Given that the sum of the internal and external costs on the margin is the same as for the other producer we can unambiguously conclude that there is a difference in eco-efficiency (by definition no. 2) as the degree of internalization of environmental effects differs. But for the overall economic efficiency to differ between the two there has to be a different weighting of internal and external costs relative to the initial situation.



**Figure 2** Eco-efficiency defined by the difference between the value of products or service and the sum of environmental impact added is equivalent to non-consistency between eco-efficiency and economic efficiency for society. This is illustrated both by situations with a falling demand curve denoted MB (marginal benefit for consumers), and a completely elastic demand curve, where P is the market price of the product or service. For definitions of the other symbols see figure 1.

**Definition no. 3: Ecological efficiency**

<sup>14</sup> For some further reading on issues concerning externalities, see Vatn and Bromley (1997) and Massarrat (1997).

From definition number 3 we have that eco-efficiency is given by desired output of production or service relative to environmental impact added. From an economists view desired output must be the same as the economically efficient level for society, that is where marginal benefit equals marginal total cost or where the producer maximizes profit (in the absence of externalities this will coincide). The most eco-efficient product is hence the one with the least environmental impact associated with the desired output level<sup>15</sup>. So by using ecological efficiency to range products with the same economic efficiency, consumers with a relative large emphasis on environmental damage can make a more informed choice.

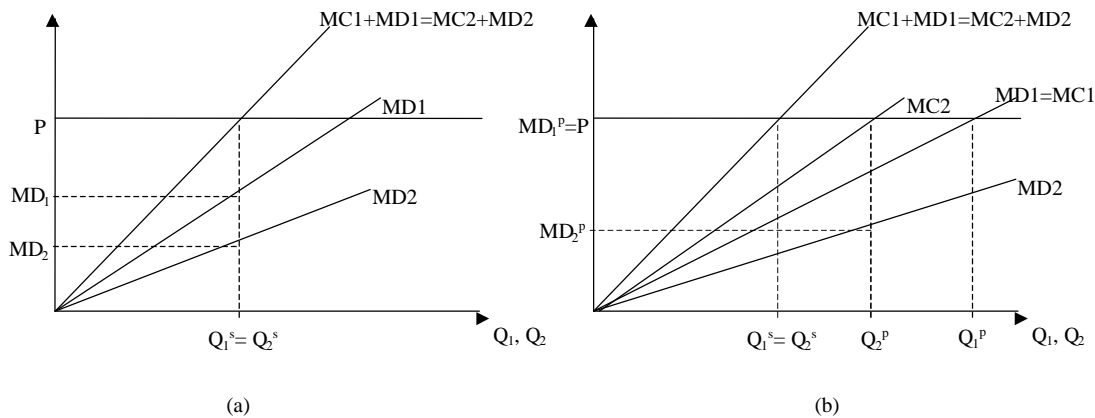
Two measures of ecological efficiency can be distinguished, namely ecological product efficiency and ecological function efficiency. The former measurement is defined as the fraction between product unit and environmental impact added, while the latter is defined by a fraction between served function and environmental impact added. Hence, the difference lies in whether we are interested in the ecological efficiency of the product itself or the function it is intended to serve. The ecological efficiency of a product can be improved to a substantial degree, but as long as a different product being more ecologically efficient offers the same function, the first product can not be the most ecological efficient product. The problem of this division of ecological efficiency is that products often fulfill several functions. A car and a bicycle is both a means for transportation, hence one can claim that a bicycle is the most ecological efficient of the two, but the car also have other attributes besides transporting one person. The car can transport you a longer distance in the same amount of time, it can transport a larger amount of mass, and are thus not directly comparable to a bicycle. Economists will argue that the difference in function will be reflected in the price of the product, that is the value of the product decided from the market. Even though the car is less eco-efficient as a means for transporting one person from point A to B than a bicycle, the car offers more than just this particular function, which is reflected in the market price. Hence, value should be used instead of function in eco-efficiency indicators. We will however modify this argument later when we discuss eco-efficiency indicators for systems.

Setting the problem of deciding the difference between output of product and function aside by assuming they will be the same, we can go on discussing eco-efficiency defined by definition number 3. As a first approximation we assume that the desired output level is based on maximizing overall economic efficiency, and that this level is the same for two producers of the same product. This is equivalent to saying that the efficiency of the two producers are equal in terms of overall economic efficiency. However, when it comes to eco-efficiency the same is not necessarily the case. This is shown in figure 3 (a) where we see that for the given level of output ( $Q_1^S = Q_2^S$ ) producer 2 is more eco-efficient compared to producer 1 as the

---

<sup>15</sup> Environmental impact is here understood as under the above definitions.

production process of the former leads to lower environmental damage. But also here, like in the discussion of definition 2, the overall efficiency is decreasing and the eco-efficiency is increasing as the production is raised above the desired level. Thus, there is not overall correspondence between eco-efficiency and economic efficiency because when evaluating the former, the private costs are left out of the efficiency criterion.



**Figure 3** Defining eco-efficiency as the relationship between desired output of production or service and environmental impact added means that the product associated with marginal damage as relatively low fraction of total marginal costs will be the most eco-efficient. Desired production is based on overall economic efficiency (a), and private profit maximization (b), respectively.  $MD_1$  and  $MD_2$  are marginal damage of production process 1 and 2, respectively, at the overall economic efficient production volume ( $Q_1^S$  and  $Q_2^S$ ).  $MD_1^P$  and  $MD_2^P$  are marginal damage of production process 1 and 2, respectively, at the profit maximization efficient production volume ( $Q_1^P$  and  $Q_2^P$ ). For definitions of other symbols see figure 1.

When the desired level of production is based on private profit maximization, we see from figure 3 (b) that the desired output level of production ( $Q_1^P$  and  $Q_2^P$ ) is found where private marginal costs ( $MC1$  and  $MC2$ ) equals the unit price of the product ( $P$ ). We are still assuming that the social marginal cost for the two production processes are the same, which means that the optimum social levels of production are identical. In an unregulated market we see that the most eco-efficient product by definition number 3 is  $Q_2$ , which also is associated with the lowest production volume because of the relatively high private marginal costs. The same conclusion will apply when we evaluate the overall economic efficiency of the market solution. Given that the social costs of the two producers are the same, the difference between the economic value and the total costs of the products will be larger as the production volume increases beyond the economically efficient level. Because the desired level of production in this special situation is lower for product 2 than 1, the latter product is the most inefficient.

As we noted in the section above the private costs of product 2 was larger on the margin than for product 1. The difference in private costs may be due to producer number 2 using a more expensive and less polluting capital stock than producer number 1. This can be interpreted as that producer number 2 has internalized some of the external cost associated with the production process. He is hence less profit maximizing than producer number 1, as he uses the cheaper capital and are making more money. But under a different market situation where producer 2 may be able to exploit the “greener profile” in order to sell more or to sell to a higher price than the competitors, he may not be less profit maximizing than producer 1 after all.

From this section we found that by evaluating the eco-efficiency of the two producers by definition 3 we can conclude that producer number two is the more eco-efficient, no matter how we define the desired level of production. But seen from the overall economic efficiency perspective the conclusion will be different. Because the total costs for society on the margin is the same for both producers, they are seen as equally efficient in the social optimum. Only for a different weighting of the private and environmental costs or where production is set according to the profit maximizing rule  $MR=MC$ , will there be a difference in economic efficiency between the producers.

***Definition no. 4: Eco-effectiveness***

This definition states that the most eco-effective product or service is the one with highest eco-efficiency controlled for production volume (Brattebø, 1998). The aim of this definition is to measure “total eco-efficiency” so that the overall burden laid on the natural environment is minimized. The idea is that an eco-efficient product produced in large numbers can degrade the environment in a greater extent than a less eco-efficient product produced in a smaller scale. How does this argument relate to economic efficiency measures of products?

We showed above that definition number 1 of eco-efficiency was in correspondence with economic efficiency measures. Because all costs, including the costs of scale, is assumed to be accounted for in finding value added, the production level at this optimum need not to be controlled for volume. A product is not necessarily inefficient just because it is produced in a relatively large volume. The benefits from the production of the product may be large enough to counterbalance environmental impacts and possible negative scale effects. So from an economist’s view using the measure of eco-effectiveness given in definition 4 can lead to unjustified discrimination against products produced in large numbers.

A large production volume can either be a result of low overall economic costs (increasing returns to scale), or a result from the functions associated with the product. A product with a functionality appreciated by the consumers that also is regarded as relatively low-priced will sell relatively more than a not so desirable product. And if the price of the product reflects the value added then the traded volume will be economically efficient, given that the true costs of producing and consuming the product are reflected in the price. So the result is that eco-effectiveness given by definition number 4 and economic efficiency is not consistent measures (given that eco-efficiency is defined according to definition number 1).

In theory, the costs associated with scale can be included in the cost function used in economic efficiency measures. However, one can certainly argue that this is not done to full extent in practice. The reason for this is the difficulty of having knowledge of all impacts from pollutants and other forms of environmental degradation especially concerning global effects stretching out also in the time dimension. Examples of this is CO<sub>2</sub>, ...and time lags (Kleijn, et al., 2000)...

So if the costs per unit is underestimated with regards to the environmental impacts, the misalignment between value added and environmental degradation adds up as the production volumes increases. Hence, it can be argued that one should control for volume when evaluating eco-efficiency so that the uncertainty about environmental effects is (to some extent) accounted for. On the other hand, if one knows how to correct costs for increasing production volumes, shouldn't we also be able to correct the costs of producing and consuming a product unit by unit? The answer is probably yes and hence, there is no difference between eco-effectiveness and economic efficiency so long as all costs are accounted for (not only the environmental).

#### ***4.1 Indicator for the firm or for an entire system?***

The design of the eco-efficiency indicator and the data requirements that follows from this depends on the scope of the study and on the chosen functional unit. Generally the scope can differ from studying a single product (like in an LCA) to one single firm, or an entire system in which the firm is only a part of. Limitations associated with LCA have been discussed above. As for going beyond the LCA but limiting the analysis to the impacts of the firm, or to the impacts that the firm has possibilities to control, may also lead to important effects being left out. On the other hand such an analysis is easier to handle for the firm and is easier to communicate to investors and other stakeholders. The problem with a more exhaustive analysis, like a CBA encompassing an entire system, is the need for extensive data, which can be costly. So in practice there exists a trade-off between expanding system borders and data requirements.

In the discussion of eco-efficiency definition number 3 we argued that the value of products should be used instead of function as argument in eco-efficiency indicators. However, when the eco-efficiency of entire systems is the focus of the analysis, then function should be considered as functional unit. The broader the aim, the higher the likelihood one should use function as unit instead of prices (or material throughput as in LCA). So, if the intention of the analysis is to evaluate the efficiency of a recycling system *per se*, one ton of recycled material can be used as functional unit. However, if it is the efficiency of recycling as a strategy to reduce the impacts from consumption and production of a commodity that is under investigation, then function is the relevant candidate for functional unit in the analysis. Such a function could for instance be one liter of milk consumed. In this way the analysis enables comparisons of recycling and alternative strategies like reuse or curbside systems, and even different ways of organizing waste treatment systems.

#### ***4.2 Measuring and valuing the environmental impacts.***

Above we have taken the measuring and valuing of the environmental impacts for given. But this is really a field with some major problems to be handled if eco-efficiency is to be measured. In order to not only get an overview over the full range of impacts, but also to set the right monetary value on them, there is need for extensive data.

To avoid some of the difficulties mentioned above an alternative strategy may be to express eco-efficiency in terms of value added per unit of a non-monetary measure such as CO<sub>2</sub> equivalent...

### **5. Concluding remarks**

There has been a tradition for the more non-formal analysis in the social sciences whereas economics is the social science whose methodology is closest to that of the natural sciences. This is reflected in economics by the habit of expressing models and results from analysis in mathematical terms, so the conclusion must be that the logic between economics and natural science is not so different, but it is the focus and objects of research that differs. The effect this has had on understanding eco-efficiency has more or less explicit been demonstrated in this paper. An example where this have been illustrated is in the difference in systems boundaries applied in LCA and CBA. Because of the difference in the nature of the objects, the natural sciences have to a greater extent a tradition for dealing with universal laws expressed in mathematical terms constraining the field of research appealing to the natural scientist relative to the social scientist. The problems that are focused on in the natural sciences are hence better bounded than those in the social sciences. The question one could put forward is whether the problems focused on in the natural sciences are bounded too narrowly or not.

We have seen that like industrial ecology, most definitions of eco-efficiency rely heavily on technical and engineering knowledge, but there are scientists claiming that the accomplishment of sustainability through eco-efficiency requires inputs from the social sciences because of the need for changes in the social patterns and in human behaviour. Where the natural scientists are focusing too much on physical quantities, it can be argued that economic methods are paying too much attention to the optimal allocation of resources between production of different commodities and services. The economist is therefore in danger of neglecting the importance of innovative processes and hence underestimating the possibilities for developing new production technologies and new ways of organising consumption patterns that will affect eco-efficiency in a significant way.

So, one would think that the co-operation between technology and economics and other social sciences would be sufficient to secure eco-efficiency. And this might be true, but there are voices arguing for a more deep cutting revolution. McDonough and Braungart (1998) states that eco-efficiency is not the solution to the environmental problems of the world because recycled materials will in the end lead to waste ending up in landfills and hence only reduce the environmental degradation. Consequently, there is a need for a restructure of the products and production processes more in line with nature itself. By making products with biodegradable input factors together with technical inputs where the latter can be reused in later production without a loss of quality, one will come closer to a sustainable solution to the problem. This is labelled eco-effectiveness and is an important part of what is expected to become the next industrial revolution.

## References

- Ayres, R. U. and Kneese, A. V. (1969): Production, Consumption, and Externalities. *American Economic Review*, June 1969. In Oates, W. E. (1992): *The Economics of the Environment*.
- Ayres, R. U. (1989): Industrial Metabolism. In Ausubel, J. H. and Sladovich, H. E. (eds): *Technology and Environment*. National Academy Press, Washington D.C., 23-49.
- Blaug, M. (1980): *The Methodology of Economics or how Economists Explain*. Cambridge University Press, London.
- Boulding, K. E. (1966): The Economics of the Coming Spaceship Earth. In Jarrett, H. (ed.): *Environmental Quality in a Growing Economy*, Baltimore, 3-14.
- Brattebø, H. (1998): *State of the art – P2005 Industriell økologi*, Industrial Ecology Programme, NTNU.
- Bromley, ? (1991):
- Cohen, I. B. (1994): *Interactions: Some Contacts Between the Natural Sciences and the Social Sciences*. The MIT Press. London.
- Daly, H. E. and Cobb, J. B. (1990): *For the Common Good*. Beacon Press, Baltimore.
- Erkman, S. (1997): Industrial Ecology: a Historical View. Preprint, to appear in *Journal of Cleaner Production*.
- Friedman, M. (1953): *Essays in Positive Economics*. University of Chicago Press, Chicago.
- Frosch, R. and Gallopoulos, N. (1989): Strategies for Manufacturing. *Scientific American*, 261, September, 144-152.
- Glausser, M. and Müller, P. (1997): Eco-efficiency: A prerequisite for future success, *Chimia*, 51, p. 201-206.
- Gordon, D. F. (1965): The Role of the History of Economic Thought in Understanding Modern Economic Theory. *American Economic Review*, 55 (2), p. 119-127.
- Hicks, J. R. (1976): Revolutions in Economics. In Latsis, S. J. (ed.): *Method and Appraisal in Economics*, Cambridge University Press, Cambridge.
- Keepports, D. and Morier, D. (1994): Teaching the Scientific Method. *Journal of College Science Teaching*, September-October, p. 45-50.
- Kleijn, R., Huele, R. and van der Voet, E. (2000): Dynamic substance flow analysis: the delaying mechanism of stocks, with the case of PVC in Sweden, *Ecological Economics*, 32, 241-254.

Machlup, F. (1978): *Methodology of Economics and other Social Sciences*. Academic Press, New York. pp. 345-367.

Massarrat, M. (1997): Sustainability through cost internalisation: Theoretical rudiments for the analysis and reform of global structures, *Ecological Economics*, 22, 29-39.

McDonough, W. and Braungart, M. (1998): The Next Industrial Revolution. *The Atlantic Monthly*, October, p. 82-92.

Mirowski, P. (1989): *More Heat than Light: Economics as a Social Physics, Physics as Nature's Economics*. Cambridge University Press, New York.

Nagel, E. (1961): *The Structure of Science*. Harcourt Brace, New York.

OECD (1998): *Eco-Efficiency*. OECD Publications, Paris.

Payson, S. (1997): Regardless of philosophy, economics will not be a science until it is based on science. *Journal of Post Keynesian Economics*. Vol. 19, No.2, Winter 1996-97, p. 257-274.

Ravetz, J. (1995): Economics as an Elite Science: The Suppression of Uncertainty. *Journal of Post Keynesian Economics*. Winter 1994-95, Vol. 17, No. 2, p. 165-184.

Schaltegger, S. (1996): *Corporate Environmental Accounting*, John Wiley & Sons, New York

Schaltegger, S. (1997): Economics of Life Cycle Assessment: Inefficiency of the Present Approach. *Business Strategy and the Environment*, Vol. 6, p. 1-8.

Schaltegger, S. and Sturm, A. (1990): *Eco-Efficiency by Eco-Controlling : on the Implementation of EMAS and ISO 14001*. Hochschulverlag, Zürich

Schutz, A. (1953): Common Sence and Scientific Interpretation of Human Action. In *Philosophy and Phenomenological Research*, Vol.XIV. Reprinted in Schutz, A. (1962): *Collected Papers*. Vol. I, Martinus Nijhof, The Hague.

Tyteca, D. (1996): On the Measurement of the Environmental Performance of Firms – A Literature Review and a Productive Efficiency Perspective. *Journal of Environmental Managment*, 46, 281-308.

Tyteca, D. (1998): Measuring Environmental Performance for Industry: from Legitimacy to Sustainability and Biodiversity? *International Journal of Development and World Ecology*, 5, 111-124.

Vatn, A. and Bromley, D. W. (1997): Externalities – A Market Model Failure, *Environmental and Resource Economics*, 9, 135-151.

WBCSD (1999): *Eco-Efficiency Indicators & Reporting*. Report April 6. 1999, <http://www.wbcd.ch>

WCED (1997): *World Commission on Environment and Development. Our common future*. New York.