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Possibilities and Limitations of Economically Valuating Ecological Damages

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Possibilities and limitations of economically valuating ecological damages

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Abstract

Ecological damages have to be evaluated in monetary terms for implementation in an economic analysis. Economic theory is based upon individual preferences (methodological individualism): Ecological damages can only be socially evaluated when individual values are available. However, in sharp contrast to marketable goods and services, ecological damages generally are pure public goods and, thus, market prices as a lower value bound do not exist. Therefore, we have to use alternative evaluation methods to get economic values of ecological damages. In this paper, we concentrate on four main points of the evaluation of ecological damages in economic models: Firstly, we show the general economic approach to obtain values of non-marketable goods and services on a micro-economic level. Afterwards, we discuss the assumptions and shortcomings of the economic approach. Thirdly, we determine optimal social environmental levels from a macro-perspective which is followed by an analysis of the applicability of this approach. Some summarizing remarks close the paper.

1 Introductory Remarks

Analyzing ecological damages requires clear distinctions and definitions of its meaning within different research areas. From an economic point of view, we have to check in how far ecological damages can be analyzed within economic models. Generally, economic theory concentrates on (1) subjective well-being (micro-perspective) and (2) economy-wide welfare (macro-perspective). Thereby, economic theory assumes "super-rational" agents who act strictly according to well-known preferences ("Homo Oeconomicus"). Whenever a net increase in subjective well-being or economic welfare takes place by a specific action, this action has to be realized. Otherwise, not taking any actions is a rational choice and the overall individual or social situation compared to the status-quo does not change.

Environmental aspects have to be taken into account in almost all decisions. Generally, economic decisions decrease the environmental quality or, i.e., environmental damages have to be considered for. This is economically beneficial as long as a net increase in societal welfare exists, i.e. the positive economic effects overcompensate the negative ecological ones. To compare economic and environmental impacts with respect to welfare, we have to ensure that ecological damages can appropriately be measured in economic equivalents. Thus, applying economic theory demands for numerical evaluation of the natural environment. In

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the US, for example, economic evaluation of environmental damages is stipulated e.g. in CERCLA (Comprehensive Environmental Response Compensation and Liability Act) and the Oil Pollution Act, where polluters have to compensate the damages they cause in monetary terms. Thus, the application of these legislations demands comprehensive evaluations of damages.

Let us have a closer look at the role of "ecological damages" in the economic context. To exactly define the meaning of "ecological damages" we give two typical characterizations: (1) Damage assessment:[1] "The damage caused by pollution can take many different forms. It may impact on human health, on crops or materials or on the natural environment more generally. The assessment of damages in monetary terms is becoming increasingly important, especially in the US where the government can seek compensation for damages to the environment arising from spills and releases of hazardous waste. Damage assessment may be made through the impact pathway approach or through other methods such as the contingent valuation method, hedonic pricing and the travel cost method. The impact on health, crops and materials can be measured and a value attributed to the damage." Additionally, we want to define (2) costs of environmental damage:[2] "The economic and social costs of environmental damage are usually divided into three broad categories: Health costs (health consequences of environmental damage – sickness, premature death, and so on); productivity costs (reduced productivity of natural resources and human-made capital, disruption of environmental services such as the natural cleansing of water or the yield from fisheries, spending more time on cleaning and maintaining houses and other buildings); and the loss of environmental quality, or amenity costs (a loss of biodiversity, a clear view, a pristine lake, a mature forest, and clean and quiet neighbourhoods, and so on). The economic values of these costs can be estimated using valuation methods such as the contingent valuation method (CVM)." Once again, one can see that economists concentrate on measuring monetary values of ecological damages. This is due to the specific assumptions underlying economic models, where quantified monetary values have to be compared to each other. Just like all other goods and services, the environment has a specific value for human-beings. Variations of the environmental quality increase or decrease individual utility levels. Therefore, ecological damages have to be translated into economic monetary terms which is mostly done by estimating (economic) costs of environmental damages.

The paper is organized as follows: a survey of micro-economic valuation techniques is given in section 2. Section 3 discusses the application of the mentioned methods and their shortcomings from a micro-economic perspective. In section 4 we highlight the aggregation

[1] Markandya et al. (2001), p. 54.
[2] Markandya et al. (2001), p. 50.

of individual damage estimations and the calculation of “optimal” economic damage levels (“macro-economics”). Section 5 analyzes specific problems of the macro-economic analysis, before section 6 summarizes the most important statements.

2 Economic valuation methods to obtain monetary values of ecological damages

Economic theory distinguishes between different types of values of (economic) goods and services. Use-values exist whenever individuals directly use or are supposed to use specific goods and services in the future. Additionally, positive values are revealed although individuals do not want to use some of the goods and services which are to be valued. This kind of inherent or intrinsic values are so-called non-use-values. For example, the pure existence of the tropical rain forest and the high degree of biodiversity therein leads to positive non-use values (existence value). On the other hand, a kind of altruism towards subsequent generations (ones own children and grandchildren) leads to positive non-use-values, too: bequest values. An individual who is asked for the monetary value of a specific species does not want to use this kind of species directly, but he is not sure whether his own children will be able to use this kind of species. Therefore, to ensure the existence of specific species current living generations have positive non-use values for specific goods and services. Table 1 summarizes the different economic types of values:

I. use-values:
   a. direct use-values
   b. indirect use-values
   c. option values
   d. quasi-option values

II. non-use-values:
   a. existence values
   b. bequest values.

Table 1: Different types of economic values.

A total economic value (TEV) can be derived by adding all kinds of use- and non-use-values. We do not want to describe the different valuation methods for the different economic value-types in detail.[3] Let us only make some remarks: (1) The evaluation of some of the value-types is – at first glance – not difficult, e.g. direct use values. Economic agents show their preferences on markets when they buy specific goods at the market price. The market price is a perfect measure for the minimum value of the purchased good. However, the complete

[3] See for an introduction Cansier/Bayer (2003) or more detailed Cansier (1996), Marggraf/Streb (1997), and Markandya et al. (2002).

individual value cannot be measured via market prices due to the neglection of the consumer surplus. Therefore, even the total value of a bottle of wine cannot as easily be determined as it seems. (2) Even the lower value bound of marketable goods is missing when non-marketable goods (public goods, e.g. environmental goods or damages) have to be evaluated. Therefore, economic theory evaluates these types of goods using Hicks-compensating- or –equivalent variations. The following figure 1 depicts these evaluation techniques:

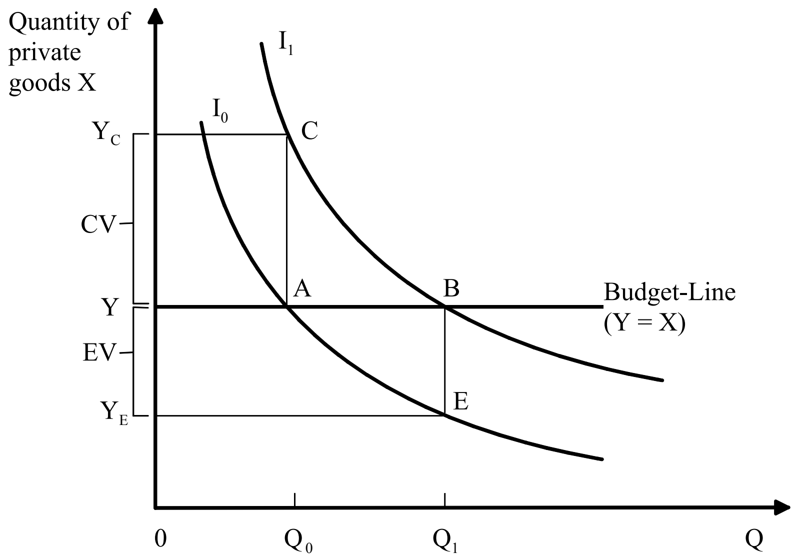

Figure 1: Hicks-compensating compensation (CV) and
Hicks-equivalent variation (EV) evaluating environmental damages.

The quantity of private goods X is depicted on the vertical axis where we set the price level to unity. The environmental quality Q, which is depicted on the horizontal axis, is a public good and completely independent of the quantity of private goods X. Therefore, the budget-line is a parallel to the Q-axis. The indifference curves I_0 and I_1 show two different utility levels which are available by combinations of the quantity of private goods and the environmental quality: The lower the environmental quality is given, the more private goods have to be consumed to maintain a predetermined utility level. The figure enables us to combine the environmental quality and the quantity of private goods to evaluate the environment as a non-market good. Let us assume an environmental quality loss say from Q_1 to Q_0. The initial situation is described by point B in figure 1, where the indifference curve I_1 intersects the budget-line. Environmental degradation leads to point A. Obviously, the environmental degradation (movement from B to A in figure 1) can be measured in two alternative ways: We can measure the line AC or the line BE. They differ in the assumption, which utility level after the environmental degradation is relevant: The previous one (i.e. without diminished environmental quality) or the new one where the environmental degradation has taken place.

Let us start with the first possibility (AC) where a compensation for environmental degradation will be derived: To maintain the same utility level which is represented by I_1, the reduction of the environmental quality from Q_1 to Q_0 can be compensated by the compensating variation CV. The individual maintains his predetermined utility level I_1: Decreasing environmental quality from B to A is substituted by more private goods (AC). The second possibility is to deduce a willingness to pay or an equivalent variation: Reference point is the utility level directly after the environmental degradation took place (E in figure 1). He is now asked how much he would be willing to pay to prevent decreasing environmental quality from B to A. The equivalent variation (EV) is the amount of public goods which an individual is willing to pay to maintain the environmental quality on the former level. The payment of the amount would increase his individual utility level from I_0 to I_1. He substitutes quantities of the private good X to increase the environmental quality. Thus, equivalent and compensating variations indicate a specific (1) willingness to pay for the prevention of environmental degradation or (2) willingness to accept environmental damages. Therefore, applied environmental valuation concentrates on the determination of monetary values based upon the theory of equivalent and compensating variation. Contingent valuation methods exactly ask for monetary values according to question (1) and (2) (see below).

In summary, economic theory derives a value for a pure public good (here the environmental quality) by assuming substitution processes between the public good and a private good. The derivation of an economic value is only possible when the private and the public goods are substitutable.

3 Application and shortcomings in the economical measuring of ecological damages

Let us next transfer these theoretical considerations to practical valuation processes. Deriving monetary values of ecological damages, all in table 2 mentioned methods can generally be applied. Whenever market-prices are available, the evaluation of ecological damages is relatively simple. However, in general market-prices do not exist, thus, we have to look for feasible proxies (direct and indirect ones). E.g., whenever ecological damages induce productivity losses, these values can directly be applied as an indicator for ecological damages. On the other hand, indirect proxies can be used to derive environmental damages as well: Hedonic Pricing combines an environmental quality component with observable market prices. E.g., an ecological damage can be derived when we compare identical flats in different environmental quality areas. The better the environmental quality is given, the higher will be the rentals and, thus, the rental difference can be used as a proxy for the value of the environmental quality. However, the most difficult and realistic case is the situation, where neither direct nor indirect proxies are available. In this situation, only contingent valuation methods are applicable to deduce values for ecological damages. A comprehensive overview of different valuation methods is given in table 2:

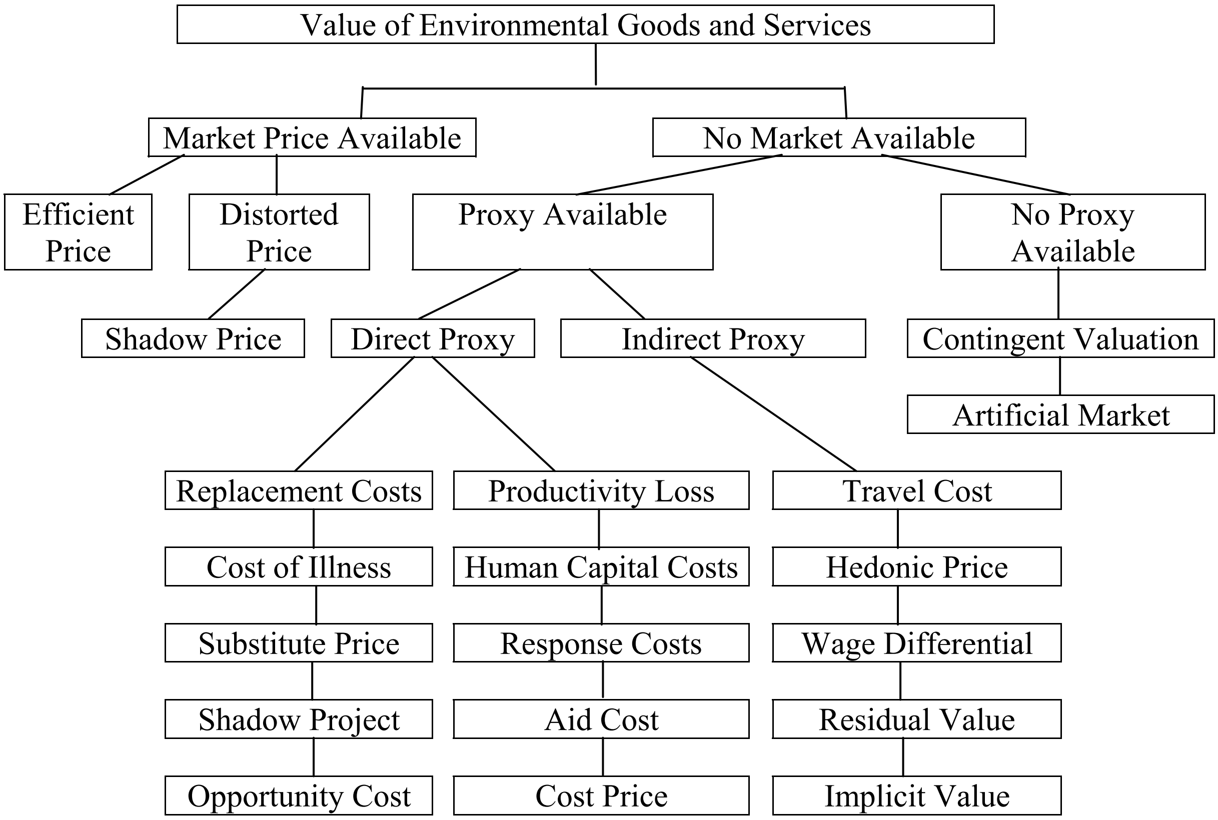

Table 2: A possible taxonomy of valuation techniques, in: Markandya et al. (2002), p. 309.

All economic measuring methods to value ecological damages are based upon some assumptions which are discussed in more detail.

1. One crucial problem of the application of all evaluation techniques is the uncertainty of environmental damages. The uncertainty is manifested threefold: Firstly, natural scientists can only provide incomplete information about environmental damages in the future. With respect to climate change, they know that there will be an increase in the average temperature on earth of 1°C to 3.5°C with a best guess of 1.5°C until the year 2100. However, the impacts are yet unknown in detail: Some regions will benefit while others must suffer severely. Thus, the more research natural scientists undertake (and the more results they supply), the better is the individual knowledge-basis where decisions can be based upon. Secondly, economic valuation is carried out by individuals and, thus, individual preferences influence the statements (see below for more details). Specific problems are the individual assimilation and acquisition of knowledge. Some individuals are not really interested in environmental degradation independent of scientific results: Although natural scientists predict significant

damage costs in the future, they only marginally value environmental protection measures.[4] Thus, even if scientific research sufficiently provides information, some individuals will not use them when they have to evaluate environmental degradation. Thirdly, some individuals are not able to fully understand the relationship between their own activities and resulting ecological damages.[5] The effects which are caused by driving a car (and emitting CO_2) are not interpreted responsible for climate change. Of course, this kind of informational deficiency can be cured by intensified information campaigns.

However, the first two problems cannot be adequately depicted in economic models: Scientific knowledge influences the restrictions of individual utility maximizing. The utility frontier generally becomes narrower with additional information about ecological damages. The second mentioned problem contradicts the assumption of the "Homo Oeconomicus": The economic man simply acts irrational whenever he does not use all available information.

2. Theoretically, an economic estimation of damages combines unobservable prices for the natural environment with observable prices of private market-goods, assuming that the respective utility of the evaluating individual remains constant. Thus, one crucial assumption of economic evaluation of ecological damages is substitutability between the (public) ecological and the (private) market good. Non-compensatory or lexicographical preferences – i.e. environmental goods and market goods are non-substitutable - with respect to the environmental and the market good impede an economic valuation of ecological damages. Ecologists question the substitutability of man-made and natural capital. Many contingent valuation inquiries show that individuals generally reject the substitutability assumption between the environment and conventional economic goods. This means that ecological damages cannot be economically evaluated.

3. Generally, one estimates expenditure functions subject to a given utility level (compensating and equivalent compensation). Individuals try to minimize their expenditures for buying marketable goods and services while their predetermined utility-level remains constant. Environmental degradation must be compensated by more private goods to maintain the ex-ante utility-level. However, these clearly theoretical concepts have to be applied to practical valuation. (1) To estimate the maximal willingness to pay (WTP) one asks for the amount of currency units which an individual is willing to pay for environmental improvements without being worse off (compared to the situation before the environmental quality has decreased). However, reference utility-level is the new utility-level after the environmental degradation has taken place. To compensate for the environmental degradation, individuals substitute environmental goods by conventional market goods. This

[4] Of course, ecologically interested individuals exist as well: They are willing to pay immense amounts of cash to prevent the environment without knowing possible damages.
[5] See Weimann (1995), pp. 199-204 for a comprehensive overview of emissions, diffusion and damages.

leads to the EV in figure 1. (2) The other possibility is to ask for the willingness to accept (WTA): In contrast to the EV-case, one assumes that the reference utility-case is given as the situation before the environmental quality has decreased. The environmental degradation has to be compensated for by additional units of private goods. Thus, individuals have to be asked for that amount of currency units which enables them to purchase more private goods to compensate their welfare losses caused by the environmental degradation. Principally, the WTA is higher than the WTP due to the higher reference utility level in the WTA case, which leads to the possibility of strategic biases of the evaluation results. Therefore, contingent valuation surveys have to clearly distinguish whether they ask for the WTP or the WTA. Otherwise the ecological damage will be over- or underestimated.

4. Economic valuation methods concentrate on the evaluation of marginal effects (marginal increases or decreases of existing stocks). Contingent valuation methods ask for these monetary amounts which individuals are willing to pay or accept for marginal improvements or diminishments of the natural environment. In this framework, the assumption of substitutability between natural and man-made capital can be useful. However, it does not make any sense at all to assume that the whole stock of biodiversity can be substituted by man-made capital: It is simply impossible to substitute clean breathable air by additional capital units. Nobody is generally interested to agree with his own death only because of additional income units.

5. Thus, targets preventing environmental damages cannot be completely derived by the application of the economic analysis. The employed assumptions of economic analyses do not cover all societal influences. Economic analysis might, therefore, give some impressions that specific targets induce high costs, the economic benefits for the society as a whole from the protection of the global environment is ambiguous and leads – if this is not mentioned, to distorting impressions in the political arena.[6] The values derived by economic valuation processes can be used as lower boundaries for complete societal values. However, whenever environmental targets are set (by politicians or other societal decision-processes), economic theory can be applied to reach these given targets at lowest possible costs: Cost-efficiency. Thus, economic considerations can excellently be applied whenever a social decision of the preferred level of ecological damages has already taken place.

6. The application of all economic valuation methods demands the assumption that each individual acts according to a "well-behaved" utility function. The individuals behave rationally in that way that they maximize their respective utility-level at each point of time by exchanging goods whenever the individual utility level can be enlarged. This assumption

[6] This statement is valid although the very prominent economic analysis undertaken by Costanza et al. (1997) estimates the value of biodiversity to 16 to 54 trillions US-$ per year. To derive this value, the authors had to set all economical assumptions which we have already criticized within this paper, and, therefore the immense value can easily be questioned.

requires that the rationality assumption is valid in all circumstances even for environmental considerations. However, besides the economic sphere human-beings act in many areas where the economic rationality assumption can be questioned, e.g. the choice of the nationality, the choice of the primary and sometimes even secondary education, the choice of drinking alcohol or smoking cigarettes etc. This theoretical shortcoming could be cured by using more realistic economic actors. The concept of the Homo Oeconomicus has to be completed. One should be able to take into account additional individual variables e.g. non-compensatory preferences or sympathy or antipathy, additional elements of the institutional context (especially the framework of the inquiry and its hypothetic character), and additional variables of the social and political context, e.g. whether human-beings generally take part in referenda etc.

7. Another shortcoming of economic valuation methods is biased and incomplete information. Researchers do not know exactly the impacts of climate change, biodiversity loss or the depletion of the ozone layer. Many ecosystematic interdependencies do exist which demand further research work. Thus, individuals who are asked for their monetary valuation of preventing the further depletion of the ozone layer cannot base their decision upon assured knowledge and, therefore, are influenced by latest news, the opinion and importance of friends and the family etc. However, these uncertainties do even exist with respect to quality properties of pure economic goods due to missing information on sales packages and are, therefore, not specific with respect to environmental evaluation. Nevertheless, incomplete information is a general problem when we want to determine a societal value of specific goods and services and leads to valuation biases which have to be taken serious. Probably, instruments of risk-management could be applied to prevent too strong influences of these static incomplete information effects.

8. More important, intertemporal uncertainties exist. Environmental damages are not only caused today by today's emissions, but also in the future (see table 3 for an example with respect to climate change) e.g. through accumulating-processes in the atmosphere. A full internalization of intertemporal external effects demands for the consideration of all effects throughout the whole lifetime of the emissions in question. Thus, estimations of environmental damages have to take into account these effects in the future. Besides static incomplete information a dynamic component of uncertainty comes into play: As can be seen in table 3, only vague knowledge is available about the lifetime of greenhouse gases. Additionally, biological, physical and chemical processes take place which enlarge or diminish their lifetime. The estimation of their specific damages per time-period is, therefore, a very difficult topic. From an economic viewpoint, natural scientists have to intensify their research work to provide robust data where economists can base upon their damage estimations. However, a specific economic problem exists whenever future and current effects

have to be considered: They have to be made comparable by discounting future effects to the point in time when the damage function is estimated. Mathematically, the damage present value can be calculated according to the following formula:

$$(1) \qquad PV(E) = \sum_{t=0}^{N} \frac{D_t}{\left(1+d_t\right)^t}.$$

One emissions unit today leads to damages in the current and subsequent periods (D_t). Thus, the present value of damages of one specific emissions unit can be calculated according to equation (1).

9. Apart from the difficulties of damage valuations for each point in time, the time-discounting procedure is of crucial impact on the damage present value. Which discount rate d_t should be used? Moreover, is the discount procedure well-defined when intergenerational effects have to be evaluated? Strategic usages for decisions-makers can be considered: In general, discounting implies that two identical damage levels in two different time-periods have two different present values. The further in the future a specific damage effect takes place, the less is its present value in today's decision-making process. Very high damages in the future can substantially be diminished by using high discount rates from today's perspective. Thus, damage present values can be biased in such a way that expensive abatement measures are inefficient from an economic point of view. Thus, calculating present values should be undertaken in the framework of Generation Adjusted Discounting (GAD).[7] Within this framework one has to distinguish discounting within oneselfs lifetime (individual discounting according to individual preferences, intragenerational discounting) and discounting effects after the death of these individuals (intergenerational discounting in a social decision-making framework). Intergenerationally, individual preferences do not play any role, thus, individual influences like myopia, short-sightedness and impatience cannot be applied to determine an intergenerational discount rate. The intergenerational discount rate for societal discounting is of lower value than the intragenerational one which leads to higher present values of damages in the future as in the case of "conventional" discounting according to economic theory.

Apart from time-discounting one might also consider "spatial discounting". This means that the spatial closeness of damages is important for individual damage estimations. The farer away specific damages occur, the more insignificant are these damages from an individual point of view. Societal spatial discounting can be considered for when it is useful but should be applied according to GAD.[8]

[7] See Bayer (2003) for fundamental work and Bayer/Kemfert (2003) for an application with respect to climate change and sustainable development.

[8] However, for global damage estimations spatial discounting leads to additional problems when the individual values have to be aggregated.

10. The design and the enforcement of the inquiries is always a critical point in the economic evaluation process. We will just give some impressions on the variety of specific problems.[9] (a) One has to distinguish between real inquiries (where the participants have to pay the called amount) or hypothetical inquiries. In the latter case, there is a danger of over- and underestimations of environmental values. (b) The payment vehicle is also of highest importance. If e.g. the WTP for environmental improvements has to be determined and the interrogators tell the respondents that their payments are passed on to the state authorities, they often interpret these payments as an additional tax. In that case, the WTPs are significantly lower than in the case, where the collected amount is passed on to environmental NGOs. (c) Sympathy for and antipathy against specific parts of the environment can strongly bias the estimation ("warm-glow-effect"). Respondents with fear of spiders will not value this part of the biodiversity like people who are not afraid of them. On the other hand sympathy for very nice birds or fish generally leads to overestimations. (d) Some respondents cannot strictly separate whether they are asked for one specific type of bird or all birds at all. They are asked to evaluate one specific sort of an animal, but they integrate all sorts of animals in their evaluation ("embedding-effect"). This leads to significantly higher values of specific species. However, cross-checking these results by asking for total values of all sorts of birds shows only marginal increases of WTP. (e) To get robust data, the respondents have to be informed of these effects which are to be valued. However, the information process itself can be strategically biased to induce either high or low values (depending on the objective of the evaluation study). Within contingent valuation studies – for example – very high willingnesses to pay and very low ones can be derived within the same sample of respondents depending on the provision of information. (f) Strategic behaviour also leads to biases in the valuation process. Persons with a high environmental awareness principally reveal higher values for the environment than others. In combination with the hypothetical argument (a), it is furthermore possible that respondents act as free-riders: One indicates only low values for an environmental good because one assumes that all others indicate high values. The aggregated value of the environmental good is assumed to be high enough to improve the environment (or prevent further degradation) and the respondents with high willingnesses to pay have to finance the lion's share of the environmental improvement.

Let us summarize the most important statements of this section: We discussed the most significant shortcomings of economic valuation measures in general. Some of them can be cured relatively easy (like the discounting problem). Others, like strategic behaviour or the provision of information, need improvements and further research. However, scientific research has substantially improved in the last two decades. Further research is necessary, but

[9] More detailed information with respect to biodiversity is given in Geisendorf (1998), pp. 228-250.

we are on a promising way. However, some shortcomings are not only a problem of the economic profession. To get more robust estimations, interdisciplinary research should be done enabling economists to implement the environment in their analyses as well as natural scientists to accept (some) economic arguments.

4 Macroeconomic considerations: Total Cost Minimization

When we have derived individual values for the natural environment, we are able to determine an optimal level of emissions (corresponding with an optimal level of damages) in our economy. Therefore, a macroeconomic damage cost function has to be derived by aggregating all individual damage estimations. In more detail, all respondents must have been asked for their individual damage estimates with respect to varying damage sources, generally emissions.

However, one should consider that individual estimations require specific questions concerning the damages which have to be evaluated. Nobody is able to give sensible values when he/she is asked for all environmental damages caused by e.g. CH_4. Therefore, our macroeconomic considerations only refer to specific problems e.g. climate change or biodiversity losses: Macroeconomic estimations necessarily concentrate on "sectoral" damage costs with respect to one specific environmental problem. This requires a link between the economic and the environmental sphere which is given by using emissions. Economic activities cause emissions and show positive as well as negative effects: Economically emissions are necessary to produce and consume goods and services. Thereby, they cause negative impacts on the natural environment as well. Considering varying emissions-levels leads to a macroeconomic damage cost function which relates damages in monetary values to different emissions-levels.[10] The higher the emissions-level is given, the higher damage costs will be. Mathematically, these considerations are given as follows:

(2) $D=D(E)$; $\mathrm{d}D/\mathrm{d}E>0$; $\mathrm{d}^2D/\mathrm{d}E^2>0$.

However, damages are only one side of the economic medal. Emissions are also economically beneficial in that way that they are connected with economic activities (production and/or consumption). Emissions abatement, therefore, causes welfare "costs" (opportunity costs of environmental control). For example, the reduction of emissions leads to additional unemployment (including some follow-up effects), lower tax payments, etc. The other kind of economic costs of emissions control are direct abatement costs due to emissions reductions measures: End-of-pipe-technologies to clean up pollution at the end of the production process or integrated environmental policy measures within the companies lead to direct abatement

[10] Another possibility is to set "environmental quality" as independent variable. In this case, the statements can analogically be interpreted: The better the environmental quality is given, the less damages have to be taken into account and vice versa.

costs. The two components have to be summed up to get the total abatement cost function. Mathematically, these costs can be described as follows:

(3) $AC = AC(E)$; $dAC/dE < 0$; $d^2AC/dE^2 < 0$.

An optimization approach combining both cost-functions aims at minimizing a total cost function which can be depicted as follows:

(4) $TC(E) = D(E) + AC(E) \rightarrow \min!$

Minimizing the total cost function leads to an optimal emissions level E^*. Using simple mathematics, the following first-order condition results:

(5) $dTC(E)/dE = dD(E)/dE + dAC(E)/dE = 0$

$\Leftrightarrow$ $dD(E)/dE = - dAC(E)/dE \Rightarrow E^*$

The optimal emissions level E^* is given where the marginal abatement cost curve equals the marginal damage cost curve, or - in other words – when the slope of the damage cost curve equals the slope of the abatement cost curve in absolute terms. Due to their different signs, they must be equal at a positive emissions level. The second-order condition has to be checked in each case as well. Generally, in most cases it is fulfilled, thus, the optimal emissions level guaranteeing minimum total costs is given in equation (4) by E^*. Graphically, the situation is given as follows:

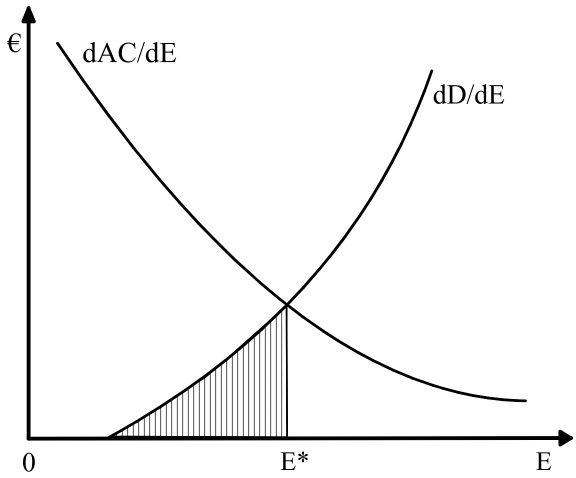

Figure 2: Cost-minimal emissions level and corresponding efficient damages.

Directly linked to the optimal emissions level E^* is an “optimal level of damages” (vertically hatched area in figure 2). Assuming that the economic analysis has taken into account all impacts in monetary terms, this economic damage level has to be evaluated from a social point of view, considering the preferences of all human-beings involved (as well as animals or plants). From an ecological point of view, for example, the emissions level and, therefore, the damage level may be unacceptably high because some species get lost. Thus, a social damage assessment has to follow up. In sharp contrast to the damage costs, questions concerning the abatement cost function are mainly economically motivated and, therefore, economic estimations show relatively good results.[11]

However, the economic approach can also be helpful to check whether politically determined emissions-standards are economically sensible. Looking at figure 2, one can see that all emissions-levels apart from E^* are economically inefficient. More restrictive emissions standards ($E < E^*$) as well as less sharper emissions standards ($E > E^*$) are not optimal. In both cases, economic costs can be reduced by emitting more or less than politically demanded. The situation changes when new knowledge is given, e.g. natural scientists might provide new knowledge about damages caused by climate change. This new knowledge (probably) changes the individual economic valuations. The valuation process on the micro-level has to be carried out once again as well as the aggregation and the determination of the macro-damage cost function. Let us assume that an upwards shift of the environmental damage curve exists. The new economically optimal emissions standard would be lower than the previous one.

5. Comprehensiveness of the macro-approach?

Is the economic approach to determine an optimal emissions-level able to capture all impacts of production- or consumption-induced emissions? What exactly is depicted in figure 2? Which damages caused by which emissions are taken into account?

Let us for the moment start with interpreting the damage cost function caused by increasing single emissions, i.e., one single emissions-type causes environmental damages (e.g. N_2O-emissions which cause climate change). Of course, this is only one emissions-type which causes ecological damages. Thus, a comprehensive analysis with respect to damages requires the aggregation of all single emissions which cause climate change.[12] Therefore, a sort of "sectoral" aggregation has, firstly, to be undertaken. Thereby, different emissions-types have to be made comparable to each other. With respect to climate change, for example, N_2O- and CH_4-emissions have to be summed up according to their specific "global warming potential", i.e. the specific impact of one emissions-unit to global warming.[13] A selection of the most important greenhouse gases and their relative global warming potential is given in table 3.

[11] Of course, minor discipline-specific economic problems exist when determining the abatement cost function, but they are not discussed here in more detail.

[12] See Cansier/Richter (1995) for more detailed analysis of aggregation methods.

[13] In figure 2, physical quantities of emissions are depicted on the horizontal axis. "Sectoral" aggregation – with respect to global warming, for example – demands that the specific impact of different emissions is taken into account. Methane (CH_4), for example, has a global warming potential for the 100 year time horizon of 24.5. This means that one unit of methane emissions is of equal impact as 24.5 units of CO_2-emissions. The comparison of these two emissions-types is carried out by searching for those emissions-quantities of the reference emission (CO_2) which induce the same effect as one unit of methane. After summing up all emissions that cause a specific environmental problem, we can derive a sectoral damage cost curve which has to be aggregated over all sectors to get the total damage cost curve.

Species	Lifetime Years	Global Warming Potential (Time Horizon)		
		20 years	100 years	500 years
Methane (CH_4)	14.5±2.5	62	24.5	7.5
Nitrous Oxide (N_2O)	120	290	320	180
CFC-11	50±5	5,000	4,000	1,400
HCFC-22	13.3	4,300	1,700	520
Sulphur hexafluoride (SF_6)	3,200	16,500	24,900	36,500

Table 3: Global Warming Potential of different greenhouse gases, source: Houghton et al. (1995), p. 33.

Secondly, emissions concerning different sectors (climate change, acid rain, depletion of the ozone layer, etc.) have to be brought together. Thereby, possible interactions have to be known and be taken into account: Do synergisms or antagonisms exist? In how far are single emissions independent of each other and their impact does not change whenever other pollutants have to be taken into account as well?[14] These analyses require comprehensive knowledge of all kinds of working mechanisms: Impacts on human beings have to be considered as well as impacts on animals and, at last, the complete biosphere.[15]

Thereafter, spatial and temporal effects have to be captured. Some emissions cause local or regional damages (e.g. NO_x or heavy metals like lead or mercury), thus, so-called hot-spots have to be considered when evaluating their damages. On the other hand, CO_2-emissions from all over the world cause global climate change. It is not useful to reduce CO_2-emissions in some regions of the world, while the increases of CO_2-emissions in unregulated regions overcompensate these reductions and an overall increase takes place. The consideration of the temporal dimension is also very difficult: Some emissions have only short-term direct impacts, others, like CO_2 or nuclear waste, will still cause damages in the far future.[16] Evaluating long-term impacts we have to compare future and current effects via discounting.[17]

Summarizing all mentioned aggregation steps, a comprehensive macro-approach where all single effects are taken into account is nearly impossible. We have to reduce the complexity of real phenomena to get economic relevant conclusions. Thus, proposals or conclusions with respect to comprehensive damage assessment always lack the theoretical completeness. However, these proposals are applicable in sharp contrast to more complex investigations. Of course, the shortcomings in the economical model framework have to be taken into account

[14] See Streffer et al. (2000), pp. 347-373.

[15] This is only at first glance contradicting the anthropocentric economic approach. Modifications of e.g. environmental quality leads to specific impacts on human-beings due to e.g. reduced assimilation capacities or decreased amenity values.

[16] It has to be stressed that short-term direct effects (e.g. acid rain from SO_2-emissions) possibly induces long-term damages due to environmental degradation: Lakes become more and more polluted. Exceeding critical pollution levels, animals and plants cannot survive in these lakes. Thus, environmental quality and diversity diminishes.

[17] See above (section 2), and Bayer (2003).

when proposals are made. Sensitivity analysis may help us to ensure our proposals but they never are fully verifiable. Thus, useful interpretations of figure 2 can only be undertaken within a sectoral analysis. Statements with respect to ecological damages in total – e.g. climate change, biodiversity losses, depletion of the ozone-layer etc. – are impossible.

Practically, environmental policy concentrates on some indicators. Some "lead-indicators" are chosen which are assumed to sufficiently describe environmental changes, i.e. improvement as well as degradation. In Germany, the Federal Statistical Bureau uses a basket of six indicators (so-called "Umweltbarometer") to estimate environmental changes:[18] (1) Climate (indicator for greenhouse gas emissions, depicted are CO_2-emissions per year), (2) Air (indicator for air burdens, depicted are SO_2, NO_x, NH_3 and VOC), (3) Soil (indicator for land utilization, depicted is the daily increase of settlement and traffic areas), (4) Water (indicator for water quality, depicted is the fraction of water of the chemical quality class II), (5) resources I (indicator for energy use, depicted is the energy productivity, i.e. relation of GDP and energy use), and (6) resources II (indicator for usage of raw materials, depicted is the raw material productivity, i.e. relation of GDP and usage of renewable energies). However, this approach is economically inefficient due to its simplifications. No specific damages which were caused by specific emissions are derived. Indicators and their mix necessarily are not as detailed as more disaggregated data. However, this approach is applicable. Marginal variations of one specific indicator can be interpreted as environmental improvement or worsening. Environmental policy can be adjusted in such a way that the measures become more restrictive (worsening case) or less restrictive (improvement case).

Let us summarize our statements: An economic approach must ensure the consideration of all effects of specific activities. Although emissions cause damages, they also increase individual and social welfare. On the other hand, reduced damages by lowering emissions diminish economic welfare. Costs and benefits have to be weighed up and an optimal emissions level can be derived on a macro-economic level. Relatively robust statements are possible when we have sectoral considerations, e.g. climate change, depletion of the ozone layer, etc. Spillovers with other environmental problems can be neglected and, thus, economic statements are useful for the political process within this certain "area".

6 Summary

The economic valuation of environmental damages is of highest importance to appropriately integrate environmental impacts into the economic analysis. For instance, their results can be used for an economic analysis of the usefulness of environmental targets. However, informational deficits as well as methodological problems on the micro- as well as on the

[18] See Beirat „Umweltökonomische Gesamtrechnungen“ (2002), pp. 97-99.

macro-level exist. This is subject to further research – especially within interdisciplinary research teams. Currently, not all environmental values can be derived and integrated into economic damage assessments. However, to check whether environmental protection is economically sensible or not it is better to have some lower bounds of potential costs than the lack of all information.

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