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Constructing a Preference-oriented Index of Environmental Quality

-A welfare theoretical generalization of the concept of environmental indices-

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1 Introduction

In the literature on environmental indices these measures are typically seen as informational tools for the communication between environmental experts, politicians and the public at large. To this end environmental indices are presumed to make complex and detailed information on the state of the environment simpler and more lucid. They may serve as a means of resource allocation, of judging and comparing the quality of different locations, of measuring the success of environmental policy or of informing the public on the development of environmental quality in a country or in certain geographic regions. This multipurpose character of environmental indices implies the well-known dilemma inherent in this concept: on the one hand environmental indices should be easy to understand and to interpret also for laymen and on the other hand the information they convey should not be trivial or too superficial. Their construction implies a reduction of complex multidimensional environmental specifics to a single number which obviously goes along with a considerable loss of information as compared to the original data set underlying the respective indices. The reason why one is willing to accept this loss of information is the hope that more people will be interested in such a condensed informational tool than in the complex data set on which it is based. Clearly, the dilemma between comprehensibility and scientific profoundness is not easy to resolve. Looking at the main environmental indices used today one might get the impression that the intention to find the middle ground between these two claims has led to constructions that are neither much noticed in the public nor very instructive from a scientific point of view. So, today there is not much left of the euphoria of the early days. In spite of the fact that most countries and also supranational institutions like the OECD (cf. OECD 2001) have implemented systems of environmental indicators to monitor and illustrate the success of their environmental policy these indicators are largely unknown to most people as well as to most politicians (see also Wiggering & Müller 2004).

Since environmental indices are supposed to inform scientists, politicians and the public of changes in the state of the environment they are regarded as a yardmanstick for the success of environmental policy as a whole and en detail. As long as environmental indices reflect the knowledge and opinion of experts only as it is typical of most indices today, they cannot be expected to attract much attention: on the one hand the scientific information they contain is too highly aggregated and, therefore, too superficial to be of interest to the scientific community and on the other hand common people do not find in these indices what they are interested in since the informational content is not oriented by people's preferences. This latter point might also be responsible for the indifference of most politicians to environmental indices since they are mainly interested in the perception of their environmental policy efforts by their voters and not in the objective results of this policy, as is well-known from public choice theory.

Against this political background we suggest to construct a class of indices which are grounded on household preferences instead of expert opinion. In particular, we propose to use household preferences as an aggregator for the valuation of environmental changes (air quality, water quality, climate, traffic, radiation etc.) when constructing an overall environmental index. Since such an index reflects people's attitudes towards environmental changes as well as the perception and valuation of these changes by the people it may represent a significant element of communication between politicians and their voters regarding the success of environmental policy. It should be noted that, of course, such a "People's Index of Environmental Quality" cannot substitute completely for traditional expert indices but it can complement them.

The fundamental dilemma of environmental indices, i. e. how to convey exact expert information and attract public attention at the same time, can be solved by separating these tasks. If pure expert indices are freed from the burden of being popular they may contain more detailed and more exact information and, therefore, they might turn out to be more satisfactory for the scientific community[1] while preference-oriented indices on the other hand might develop to be attractive instruments of information among politicians, the media and the people. It is well-known that environmental policy can be successful only if it is accepted and supported by the people and if it becomes part of the social norms guiding people when they have to make non-economic decisions. Therefore, a preference-based index of environmental policy as proposed here might provide an attractive link between policy makers on the one hand and "the people" on the other. A regular (e. g. annual) publication of such an index would keep politicians as well as the public at large informed about developments in the main sectors of our natural environment filtered through the preferences of the citizens concerned by these developments.

The paper is organized as follows: section 2 contains a short overview of the most important existing environmental indices and of their main characteristics. In section 3 we discuss the construction and the main features of descriptive environmental indices and indicators. In section 4 we propose the construction of a preference-based environmental index and discuss the possibilities for its empirical assessment and practical implementation. The last section contains some concluding remarks.

2 Environmental indices in practice

Before we propose a preference-oriented environmental index we want to give a short overview over the most important environmental indices which are used now in the practice of environmental monitoring. While we will focus on descriptive indices of environmental states, we will include two normative indices, as well. There exists a variety of different indices in the literature, therefore, this selection doesn't claim to be comprehensive. However, the examples were chosen so as to reflect the main developments up to date.

2.1 Descriptive environmental indices

The most popular descriptive indices are the Environmental Quality Index (EQI) for Canada (cf. Inhaber 1974), the Hope & Parker Index (HPI) for the UK, France and Italy (Hope & Parker 1990 and 1995), the Mirror of Cleanliness (MoC) for the Netherlands (den Butter 1992) and the Korean Composite Environmental Index (CEI) described in Kang (2002). A

[1] Within the scientific community the so-called pressure-state-response framework (PSR) for environmental indicators has become very popular and has also been adopted as official framework by EUROSTAT. For a detailed presentation of this concept and practical issues see Markandya & Dale (2001).

conceptually slightly different variety has been developed by Ten Brink et al. (1991) known as the Ecological Dow Jones (EDJ) which found its applications also mainly in the Netherlands. The construction of all mentioned descriptive indices follows a two-step procedure. In a first step, suitable indicators representative for an environmental issue are selected or created from underlying data. Subsequently, the set of these indicators is aggregated to an overall index number using an appropriate aggregator function.

Within the first group of indices it can be observed that the importance of the respective index as an information tool for the public increases over time. The Canadian EQI was designed as a pure index of the state of the environment that was to serve as an information tool for the administration and national statistics. This is reflected by the fact that the first step of the index construction procedure, the creation of the set of indicators from environmental data, strictly follows the criteria of environmental experts, while the second step follows a purely arbitrary aggregation procedure in which an equal importance of the single indicators is assumed. As a consequence, the set of indicators reflects very specific and well weighted information and could serve as an informational basis for policy making in the respective environmental issues. The final index number of the EQI , however, seems to contain little information as the assumption of equal importance of environmental issues is highly doubtful. A conceptually similar approach has been taken for the MoC whereas the level of environmental data is not as detailed as in the EQI. On the contrary, the computation of a pollution index was meant to be particularly simplified by the use of selected environmental quantities that were found to be representative, i.e. indicative, of some pollution theme. Still no solution could be proposed as to the determination of the relative importance of the pollution themes in an objective way.

In contrast to the Canadian EQI and the MoC, the Hope & Parker Index shifts the focus of the environmental index away from the pure expert index to an index that on the one hand takes people’s perceptions of the different environmental issues into account and on the other hand aims at creating an information tool specifically for the broader public (cf. Hope & Parker 1990 and 1995). While the selection and creation of the set of indicators is based on expert knowledge the (additive) aggregation to the final index number of the HPI considers people’s preferences for the determination of the aggregation weights. To this end the weights for the indicators are determined by public opinion surveys concerning people’s state of worry with respect to the various environmental issues. The index is meant to be published on a monthly basis.

A refinement of the HPI can be found in the Korean CEI (cf. Kang 2002). This index makes use of the respective core indicators for “environmental themes” recommended by the OECD (cf. OECD 2001). Furthermore, the determination of the final aggregation weights follows a strict hierarchical process in which the respondent to a public survey will produce a priority list of the various environmental themes and will also state the degree of seriousness concerning each theme. Consequently, the CEI reflects the public’s trade-offs between the various environmental themes in a more consistent way.

Finally, an index that does not make use of any measured environmental data but is simply based on changes of abundances of indicator species in representative ecosystems is the so-called “Ecological Dow Jones” described in Ten Brink et al. (1991). As such, this index is a pure expert index and completely ignores public preferences toward the various species or ecosystems.

2.2 Normative indices

A different type of environmental indices are normative indices which combine the measurement of certain indicator values with a normative statement. One form of normative indices are achievement indices that are designed to measure and visualize the extent to which a specific environmental goal, i. e. the normative statement, has already been attained. Another form can be seen in the comparison of a state index with a normative statement of sustainability. Examples of these two forms are given in the following.

The first example is the German Environmental Index (DUX) which was developed in the year 1999 for the specific purpose of conveying information about the effectiveness of national environmental policy to the general public. The degree of target achievement of six theme-related sub-indices is computed separately and subsequently added up to form an overall score of achievement of German environmental policy. While no weighting according to public preferences is included in the index, its computational simplicity and close connection to policy making are characteristics that could in principle lead to considerable perception in the broader public. The second example for an achievement index recently found in the literature, the Health-related Environmental Index (HEI) proposed by Wheeler (2004), refrains from the calculation of an overall index number and stops at the level of a set of four health-related indicators which he, however, calls “indices”. The aim of this set of indicators is to inform policy makers and the public about spatial inequity with respect to environmental (living) conditions in order to identify those regions within a country that should be given a high priority for environmental improvements. The construction of these indicators is based on the relation of measured environmental data, e.g. ambient pollutant concentration in a certain region, to a threshold value (i.e. the target) considered acceptable from a health-related point of view. As such, this set of indicators is purely based on expert knowledge.

The so-called Ecological Footprint (EF) as an example of a sustainability index represents a normative index in the sense that it allows the direct comparison to a normative measure of sustainability (cf. Rees 1992 and 2000, Chambers et al. 2000). However, in contrast to the simplicity of the DUX its conceptual approaches of “carrying capacity” and “bioproductive areas” of a country is highly problematic from a scientific as well as from a computational point of view. While aggregate index numbers are without doubt very appealing for policy making and for the information of the public the EF has certainly reached a limit of validity.

Of all the described indices the DUX had the best chances of becoming an influential index for German environmental policy due to its clear and simple message of target achievement and to its embedding into the German environmental administration. However, the DUX has failed to prove operational mainly because of delays in data collection and inconsistent data categories among the various administrative bodies.

3 The general structure of environmental indices

In the literature the terms "environmental index" and "environmental indicator" are not always used in a consistent way. In our presentation we follow Ott (1978, p. 8) in defining an environmental indicator as a function of environmental data and an environmental index as a function of environmental indicators.

While an environmental index describes the condition of "the environment" as a whole environmental indicators are more specific. It is common practice that each indicator characterizes a particular aspect of the environment like the classical environmental media water, soil or air quality. In the more recent literature these media have been extended by the so-called environmental themes climate, landscape, radiation, noise etc. For simplicity's sake in what follows we shall treat the traditional environmental media (water, air, soil etc.) as a subset of the more comprehensive category of "environmental themes" since all arguments relevant for this paper hold for "media" as well as for "themes".

3.1 Environmental indicators

The first step of constructing an environmental index consists in the collection of data pertaining to the various environmental themes mentioned above. Then these data are aggregated to theme related indicators (water, air, soil, climate …) where each indicator is a mathematical function defined on the variables characterizing the respective medium or theme. These indicators serve as arguments of a mathematical function that describes the overall state of the environment by a single number, the environmental index. Therefore, indicators are often also referred to as sub-indices. The relation between environmental data, indicators and indices is illustrated in fig. 1.

Fig. 1 illustrates that at each stage of this aggregation process information is lost on the one hand while simplicity and intelligibility of the environmental "message" is gained on the other. Obviously, there is no single "correct" way of aggregating e. g. air pollution data (nitrogen oxides, sulphur dioxide, carbon dioxide etc.) to form an air quality indicator. There is always a certain degree of arbitrariness inherent in the choice of an aggregation function

$$I^j = i^j\left(z_1^j, z_2^j, \ldots\right) \qquad (j = A, W, S, \ldots). \tag{1}$$

If more than one variable is to be included in an indicator I^j it is common practice to normalize these values (i. e. by dividing them by some reference or base value $\bar{z}_k^j$) so that I^j as well as z_k^j become dimensionless numbers where k = 1, 2, …, K denotes the various data or variables characterizing the environmental medium or theme j = A, W, S, … (air, water, soil …)[2]. If $(\partial I^j / \partial z_k^j) > 0$ and variables z_k^j represent pollutants the indicator I^j is a pollution indicator, while it is an environmental quality indicator if z_k^j stands for something positive for the environment (like e. g. the number of species per acre of land).

[2] Normalization is, of course, only possible and meaningful for ratio-scale measurable variables, like e.g. masses or pollutant loads (cf. Ebert & Welsch 2004). For interval-scale measurable variables, like e.g. most commonly used temperature units, normalization yields meaningless numbers unless transformed to their origin unit (e.g. Kelvin in this case).

<u>Environmental Variables:</u> **(data)**	**<u>Environmental Indicators:</u>** **(sub-indices)**	**<u>Environmental Index:</u>**
z_1^W, z_2^W, ...	***<u>Water:</u>*** $I^W = i^W(z_1^W, z_2^W, ...)$	
z_1^A, z_2^A, ...	***<u>Air:</u>*** $I^A = i^A(z_1^A, z_2^A, ...)$	$X = f(I^W, I^A, I^S, ...)$
z_1^S, z_2^S, ...	***<u>Soil:</u>*** $I^S = i^S(z_1^S, z_2^S, ...)$	

<u>where e. g.:</u> z_1^W = phosphate conc., z_2^W = nitrate conc.,
z_1^A = sulfur content, z_2^A = nitrous oxide conc.,
z_1^S = pesticide conc., z_2^S = landscape

Figure 1

An aggregator function for environmental indicators that is very popular in practice is the weighted sum of the measured data (see e. g. the German DUX, the Ecological Dow Jones Index or the indices proposed by Hope & Parker 1990 or ten Brink et al. 1991):

$$I^j = \sum_{k=1}^{K} a_k \cdot z_k^j \quad . \tag{2}$$

Such a linear aggregation implies that the influence of the different variables on the value of the indicator is constant no matter how high the concentration of the respective pollutant is. Things are different if instead of such a mechanical aggregation form a so-called functional aggregator like a CES function[3] with the general form

$$I^j = \left(\sum_{k=1}^{K} a_k \cdot \left(z_k^j \right)^{\rho} \right)^{1/\rho} \tag{3}$$

is used. Here the absolute weight of a pollutant within an indicator changes as its quantity changes. For $\rho > 1$ the relative weight of a pollutant $\frac{\partial I^j / \partial z_k^j}{\partial I^j / \partial z_n^j}$ increases c. p. with its quantity while for $\rho < 1$ it is just the other way round. Of course, there are many other possibilities of aggregating environmental variables which have different implications with

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[3] CES stands for "Constant Elasticity of Substitution"

respect to the relative weights of the various pollutants (for a thorough treatment of these problems cf. e. g. Ott 1978) but for practical environmental indicators mostly either a weighted sum or a CES function is used as an aggregator.

The question which kind of aggregator should be used cannot be answered in general. It depends on the environmental theme or medium to be described by the indicator and on the kind of variables z_k^j. At least in cases where the variables z_k^j describe more or less technical data whose consequences for the environment as a whole cannot be comprehended by laymen, aggregation should be based on the advice of natural scientists or environmental experts.

3.2 Environmental indices

Another aggregation process is needed to obtain an overall environmental index X based on the various theme- or media-related environmental indicators, i. e.

$$X = X(\pi) \quad \text{where} \quad \pi = [I^A, I^W, I^S, \ldots]. \tag{4}$$

Here the vector π represents the environmental profile to be valued by the index X. This profile consists of the theme-related indicators or sub-indices for air, water, soil etc. Again, we have the choice between a multitude of different aggregation functions. Also at this stage the most popular and most wide-spread aggregation form is the weighted sum of the indicators so that

$$X = \sum_{j=A,W,S,\ldots} b_j \cdot I^j \tag{5}$$

This implies that the absolute weights of the different environmental media or themes in the overall index are constant no matter what their actual state is:

$$\frac{\partial X}{\partial I^j} = b_j = const. \tag{6}$$

Accordingly, the weight relation between two different indicators, i. e. their marginal rate of substitution

$$\text{MRS}_{r,j} = -\left.\frac{dI^j}{dI^r}\right|_{dX=0} = \frac{\partial X / \partial I^r}{\partial X / \partial I^j} = \frac{b_r}{b_j} \qquad (\text{r, j} = \text{A, W, S}, \ldots) \tag{7}$$

is also constant along the index level curves (i. e. for X = const.). The marginal rate of substitution between e. g. water and air $\text{MRS}_{W,A}$ indicates by how much the indicator for water quality I^W must increase if the indicator for air I^A decreases by an infinitesimally small unit and the value of the overall index X is to be constant. It denotes how large an increase in water quality is necessary in order to compensate for a marginal deterioration of air quality so that the overall index is constant. This can be illustrated graphically in a ($I^W \times I^A$) - diagram like fig. 2 where the MRS between water and air quality equals the slope of the level curves for different values X_1, X_2 and X_3 of the index X. Such a level curve is the locus of all $(I^W - I^A)$ - combinations that generate the same value of the index function $X\left(I^A, I^W, I^S, ...\right)$. For the linear aggregator (5), which is quite popular in practice, these level curves are straight lines with a negative slope equal to $(-b_r / b_j)$ as shown in fig. 2. It follows that this aggregation form implies a constant compensation scheme even in extreme cases where one of the media under consideration is nearly destroyed (like "air" in point B in fig. 2). Even then a further loss of quality of this medium can be compensated by the same improvement of another medium like water in fig. 2 as in a situation where the quality of all media is well-balanced like in point A in fig. 2.

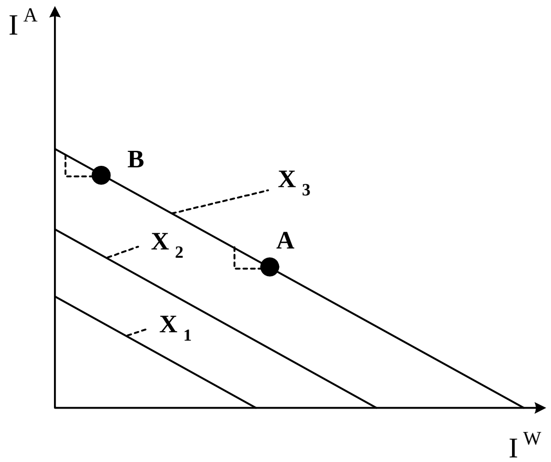

Figure 2

The question arises if the marginal trade-off between e. g. water and air quality is really independent of the actual condition of the two media. Would it not be more plausible to assume that the relative importance of an environmental medium like air quality or an environmental theme like traffic or noise increases as its general condition deteriorates? This would definitely be more in accordance with what most people feel. Nevertheless, the linear aggregation form (5) is rather common in practice. It is used e. g. for one of the most important German environmental indices, the so-called DUX ("Deutscher Umwelt Index"), which is published monthly by the Umweltbundesamt. Choosing the weighted sum of media and theme related indicators as an overall environmental index is also proposed e. g. by Hope & Parker (1990 and 1995) for the U.K.. They recommend to consider people's preferences when fixing the weights of the different themes in the overall sum (the b_j in (5) above). Though this is an improvement compared to the determination of these weights by expert opinion only we are still left with the problem of constant compensation rates between sub-indices.

As an alternative aggregator the already mentioned CES function is also quite popular in practice (see e. g. Inhaber 1974, den Butter 1992 or den Butter & van der Eyden 1998). Applied to our aggregation problem here it assumes the general form

$$X = \left(\sum_{j=W,A,S,...} b_j \cdot \left(I^j \right)^{\rho} \right)^{1/\rho} \tag{8}$$

Here, the influence of the different media on the index value varies with the value of the respective indicator

$$\frac{\partial X}{\partial I^j} = b_j \cdot \left(I^j \right)^{\rho - 1} \cdot \left(\sum_r b_r \cdot \left(I^r \right)^{\rho} \right)^{\frac{1-\rho}{\rho}} \tag{9}$$

and the marginal rate of substitution between the values of two different indicators

$$MRS_{j,r} = - \frac{d I^j}{d I^r} \bigg|_{dX=0} = \frac{b_r}{b_j} \cdot \left(\frac{I^r}{I^j} \right)^{\rho - 1} \tag{10}$$

varies with the environmental quality mix expressed by the ratio (I^r / I^j):

$$\frac{\partial MRS_{j,r}}{\partial I^r} = \frac{\left(\rho - 1 \right) \cdot b_r \left(I^r \right)^{\rho - 2}}{b_j \left(I^j \right)^{\rho - 1}} \tag{11}$$

as can be seen from fig. 3. In fig. 3 the standard case of a CES-based environmental quality index is shown where the value of X increases as the values of the media related environmental quality indicators I^j increase, i. e. $X_1 < X_2 < X_3$. For an environmental quality index the parameter ρ is typically chosen smaller than one in the aggregator function (8) which leads to convex level curves as shown in fig. 3.

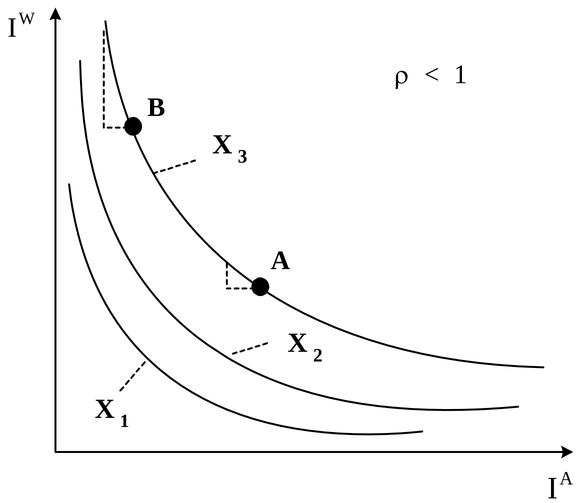

Figure 3

The trade-off between different media depicted there seems to be quite plausible from an empirical point of view. The relative weights of the different media change along a level curve of the index X, i. e. for a changing mix of air and water quality with X being constant (e. g. at a level $X = X_3$). In an extreme situation like in point B where air quality is low compared to water quality it takes a much higher increase in water quality to compensate for a further loss in air quality than in a more balanced environmental situation like point A. Such a flexible compensation scheme where the relative importance of an environmental medium increases as its quality decreases seems to be more in accordance with our everyday experience than the rigid compensation type of the linear aggregator (5).

Nevertheless, in the literature on environmental indices it is often suggested to use the additive aggregation form (5) for the computation of environmental indices from media- or theme-related sub-indices. In most contributions it is recommended to choose the coefficients of the different media in this aggregation process according to the suggestions of environmental experts. Other authors propose to choose these aggregation weights in accordance with people's preferences which are to be assessed in opinion surveys. This proposal was made e. g. by Hope & Parker (1990 and 1995) for an environmental index for the U.K. Using a CES aggregator as proposed e. g. by Inhaber (1974), den Butter (1992) or den Butter & van der Eyden (1998) is even closer to human preferences towards environmental themes as we think. As will be explained below we propose to go even one step further and base the whole construction of an environmental index on people's preferences and not only on the choice of single coefficients. Such a preference-oriented environmental index might represent a most useful complement to traditional natural science-oriented environmental indices.

3.3 The role of time

Until now we have ignored the significance of time in our discussion of environmental indices. But environmental indices have, of course, to be located precisely in time because environmental quality is not constant but changes in time. In this context we have to make a difference between environmental state indices and environmental change indices.

3.3.1 Environmental state indices

A descriptive environmental index like (4) describes the state of environmental quality at a certain point in time. To make this clear we rewrite (4) as

$$X^t = X(\pi^t) \tag{12}$$

where the vector π^t is the environmental profile at time t

$$\pi^t = [I_t^A, I_t^W, I_t^S, \ldots] \tag{13}$$

that describes the various facets of environmental quality at that point. Depicting the state of the environment alone is useful only if some reference state of the environment exists to which the actual state can be compared at least implicitly. If we know e. g. that a value of "2" or less of the index means that environmental quality is hazardous to human health we implicitly compare the actual value of the index to this reference value, i. e. if the index takes on a value of "8" we know that everything is fine. Without knowing that a value of "2" means danger to man we would not know how to interpret the actual value of "8". Therefore, even if an environmental index is defined as a state index, i. e. in terms of an absolute value, it is implicitly interpreted in relation to some reference level of the index which signifies danger or bliss or a "typical" or average state of the environment. If we want to make this comparison explicit we define an environmental change index rather than an environmental state index.

3.3.2 Environmental change indices

An environmental change index typically compares two different states of the environment. Therefore, change indices are often based directly on state indices like X^t discussed above. If r and t denote two different states of the environment we can, therefore, define:

$$CX^{r,t} = CX\left(\pi^r, \pi^t\right) = \frac{X\left(\pi^t\right)}{X\left(\pi^r\right)} = \frac{X^t}{X^r} \tag{14}$$

The index X^r for the reference state r of the environment to which the actual state t is compared might stand for some hypothetical threshold or critical value of environmental quality. It could also represent a historical value of the index like the value it assumed in the preceding time period ("last year") or at the starting point of a time series. In this case the change index describes the development of environmental quality over time. This is, of course, the most interesting use of change indices.

From a formal point of view descriptive environmental change indices like CX in (14) are "classical" index measures like e. g. price or quantity indices and can, therefore, be characterized by the so-called Identity Axiom and the Monotonicity Axiom going back to Irving Fisher (1927):

Identity Axiom for descriptive indices: (15)

$$CX^{t,t} = CX\left(\pi^t, \pi^t\right) \equiv 1$$

Monotonicity Axiom for descriptive indices: (16)

$$\pi^r > \pi^s \Rightarrow CX\left(\pi^t, \pi^r\right) > CX\left(\pi^t, \pi^s\right)$$

$$\pi^r > \pi^s \Rightarrow CX\left(\pi^r, \pi^t\right) < CX\left(\pi^r, \pi^s\right)$$

where $\pi^r > \pi^s$ means that at least one element of the environmental profile π^r is greater than the respective element of π^s and no element of π^r is smaller than the respective element of π^s.

If we want to illustrate the change of environmental quality over several successive time periods using a descriptive environmental index it is desirable that the mathematical structure of this index allows to link the different indices characterizing single time periods together. The resulting "chain index" describes the overall change of environmental quality from the starting period to the actual period correctly. This refers to be the so-called Circularity Condition going back to Irving Fisher (1927):

Circularity Condition: (17)

$$CX\left(\pi^{t-1}, \pi^{t}\right) \cdot CX\left(\pi^{t}, \pi^{t+1}\right) = CX\left(\pi^{t-1}, \pi^{t+1}\right)$$

The Circularity Condition makes it possible to link an arbitrary number of successive environmental change indices starting from some base year t = 0 in order to judge the change of environmental quality over the whole time horizon covered by these period indices, This leads to an environmental "chain index" according to

$$CX^{0,t} = CX^{0,1} \cdot CX^{1,2} \cdot \ldots \cdot CX^{t-1,t} = \prod_{\tau=1}^{t} CX\left(\pi^{\tau-1}, \pi^{\tau}\right) \quad (18)$$

Such an index can be interpreted in direct analogy to the common price and quantity indices known from statistics. One can observe how it changes from one year to the next and one can compare this index for several years to see how environmental quality changes over the whole time span of observation. Circularity according to (17) guarantees intertemporal consistency of the index.

The axioms and time-related consistency conditions discussed in this section were defined for descriptive environmental index measures. Such indices aggregate theme-related environmental indicators or sub-indices in a purely mechanical way, mostly as a weighted sum.

In the next section we propose a different kind of environmental index that values an environmental profile in accordance with people's preferences. Such a preference-oriented index reflects how people feel about the changes of environmental quality to be valued. Therefore, the aggregation of the environmental sub-indices has to be based on the principles of welfare theory in this case. That means that for preference-based indices there exists a theoretical foundation for the aggregation of the theme-related sub-indices. In the next section we shall propose such a preference-oriented index and we shall scrutinize its theoretical properties in the light of the axioms and consistency conditions considered here. Further, we shall discuss the possibilities for its empirical assessment.

4 A preference-based environmental index

4.1 Theoretical concept

The most important complication of constructing a preference-oriented environmental index is that such an index cannot be based on measurable facts alone like $X(\pi)$ but has to rely on people's perceptions of environmental quality and on their stated preferences with respect to this quality. The objective is to build an index describing the state of the environment filtered through people's preferences. At this point we have to refer to microeconomic household theory where preferences are typically described by a consumer's direct utility function

$$U_h = u_h\left(y_h, \pi\right) . \quad (19)$$

Here U_h is the utility level an individual h realizes with a vector y_h of market consumption goods and an environmental profile π (which is the same for all households).

If we want to construct an index valuing environmental quality according to people's preferences we have to rely on interviews in order to obtain a comprehensive valuation of the environment.[4] The problem is that it is quite difficult for people to state the absolute value or utility they obtain from a specific environmental situation.[5] Instead one usually needs a reference situation against which one can value the actual situation. If we want to assess e. g. the value of a bottle of wine we implicitly compare the situation where we drink this bottle to a situation without it. But what would be a situation without environment? Apparently, such a reference situation does not make much sense.

The obvious choice of a suitable reference situation for the (relative) valuation of the actual state of the environment would be some previous state of the environment which people have experienced personally and which is close enough in time so that they can still remember it. For example, one could assess an environmental index on an annual basis so that people compare the actual environmental situation as characterized by the actual environmental profile π^t to last year's environmental profile π^{t-1}.

It is clear that a preference-based environmental index has to be defined on an individual basis, i. e. it has to consider individual preferences. In a second step one has to think about aggregating the individual environmental indices to a representative social or overall environmental index which is compatible with the descriptive natural science-based environmental indices.

For a preference-based index it obviously does not make sense to postulate the monotonicity axiom (15) directly. Since we now regard the environment through the filter of people's preferences we rather have to make sure first of all that these preferences are truly mirrored by the index. We expect a preference-based individual environmental change index $PCX_h\left(\pi^{t-1}, \pi^t\right)$ to indicate reliably if the individual prefers the actual situation to the previous one or not. We call this the

Indicator Condition: (20)

$$u_h\left(y_h, \pi^t\right) \begin{matrix} > \\ = \\ < \end{matrix} u_h\left(y_h, \pi^{t-1}\right) \quad \Leftrightarrow \quad PCX_h\left(\pi^{t-1}, \pi^t\right) \begin{matrix} > \\ = \\ < \end{matrix} 1$$

In the case of strict monotonicity of the preference ordering the Indicator Condition implies the fulfilment of the Monotonicity Axiom but it is important to note that for preference-based indices monotonicity is only a derived property and not a postulate. Preference-based indices are linked directly to a consumer's preferences but only indirectly to

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[4] It is well-known that valuation methods which do without interviewing people (the so-called indirect valuation methods) can assess only the use value of environmental goods which represents only a small part of their total value (see e. g. Ahlheim 2003, p. 29 ff.).

[5] Of course, one could make them value their satisfaction with the environment on a Likert scale but this is much too imprecise to be useful for the construction of an environmental index.

the environmental profile. So, what we want is a measure for the utility change induced by changes in environmental quality.

4.2 Empirical aspects

Since a consumer's utility function is not empirically observable we propose to construct an index which is based on the household's money-metric utility function

$$M_h = m_h\left(p, \pi, U_h \right) \qquad (21)$$

which measures utility in monetary terms. This function expresses the utility level U_h realized by a household h as the minimum amount of money the household would have to spend in order to attain this utility level when market prices are given by the price vector p and environmental quality is given by the environmental profile π. The money-metric utility function m_h provides a description of an individual's well-being which is equivalent to the corresponding direct utility function.

The money-metric utility function m_h is strictly monotonically increasing in the utility level U_h, i. e.

$$\frac{\partial m_h}{\partial U_h}\left(p, \pi, U_h \right) > 0 . \qquad (22)$$

It can also be shown (see e. g. Ahlheim 1993, p. 41 ff.) that the money-metric utility function is strictly monotonically decreasing in environmental quality π:

$$\frac{\partial m_h}{\partial \pi_j}\left(p, \pi, U_h \right) < 0 \qquad (j = A, W, S, \ldots) \qquad (23)$$

This is plausible if we consider that higher environmental quality with all other things being equal means a higher level of utility so that it needs less market consumption (and, therefore, less expenditures) to maintain the same utility level as before. For other properties of the money-metric utility function see e. g. Ahlheim (1993, p. 39 ff.) or Ahlheim (1998, p.492 ff.).

Since the money-metric utility function is strictly monotonic in utility we can now specify our preference-based index of environmental change from a time period t - 1 (e. g. "last year") to period t ("this year") as

$$PCX_h^{t-1,t} = \frac{m_h\left(p^{t-1}, \pi^{t-1}, U_h^t \right)}{m_h\left(p^{t-1}, \pi^{t-1}, U_h^{t-1} \right)} \qquad (24)$$

where p^{t-1} is the market price vector of last year and π^{t-1} is last year's environmental quality. Analogously, U_h^{t-1} is the utility level that the consumer realized last year while U_h^t is his actual utility level. In principle, this index is based on the quantity indices and welfare indices put forward e. g. by Allen (1975), Pollak (1978) or Deaton & Muellbauer (1980). It reflects the change in people's well-being or utility from a time period t - 1 to the following period t in index form. With additional assumptions we must now focus this index on environmental changes only.

From the strict monotonicity of the money-metric utility function in utility it follows that this index is a true welfare indicator in the sense of the indicator condition (20), i. e.

$$PCX_h^{t-1,t} \underset{<}{\overset{>}{=}} 1 \quad \Leftrightarrow \quad U_h^t \underset{<}{\overset{>}{=}} U_h^{t-1} \tag{25}$$

The index PCX according to (24) compares two expenditure amounts: former real expenditures $m_h\left(p^{t-1}, \pi^{t-1}, U_h^{t-1}\right)$ on the one hand and the hypothetical expenditures $m_h\left(p^{t-1}, \pi^{t-1}, U_h^t\right)$ on the other where the latter describes the minimum amount of money the household would have to spend in order to realize the actual utility level U_h^t with former market good prices p^{t-1} and the former environmental profile π^{t-1}. If we denote former expenditures by E_h^{t-1} and actual expenditures by E_h^t we can write

$$m_h\left(p^{t-1}, \pi^{t-1}, U_h^{t-1}\right) = E_h^{t-1} \quad \text{and} \quad m_h\left(p^t, \pi^t, U_h^t\right) = E_h^t \quad . \tag{26}$$

Both terms can easily be assessed empirically since they represent expenditures that have actually been made.

Things are different with hypothetical expenditures $m_h\left(p^{t-1}, \pi^{t-1}, U_h^t\right)$ which cannot be observed directly so that we have to assess them indirectly. We can reformulate this term according to

$$\begin{aligned} m_h\left(p^{t-1}, \pi^{t-1}, U_h^t\right) = {} & m_h\left(p^{t-1}, \pi^{t-1}, U_h^t\right) - m_h\left(p^t, \pi^{t-1}, U_h^t\right) \\ & + m_h\left(p^t, \pi^{t-1}, U_h^t\right) - m_h\left(p^t, \pi^t, U_h^t\right) \\ & + m_h\left(p^t, \pi^t, U_h^t\right) \; . \end{aligned} \tag{27}$$

Since our index focuses on changes in environmental quality we treat market prices as constant according to $p^{t-1} = p^t$, so that the first difference on the right-hand side of (27) become equal to zero. The second difference in (27) is equal to the Hicksian Equivalent Variation for a change in environmental quality

$$EV\pi_h^{t-1,t} = EV\pi_h\left(\pi^{t-1}, \pi^t\right) = m_h\left(p^t, \pi^{t-1}, U_h^t \right) - m_h\left(p^t, \pi^t, U_h^t \right). \quad (28)$$

From property (23) of the money-metric utility function it follows that EVπ is positive for increases in environmental quality and negative for environmental deteriorations. It is important to find a suitable and plausible economic interpretation of this measure since we have to assess it through households interviews, i. e. we have to be able to explain it to ordinary people.

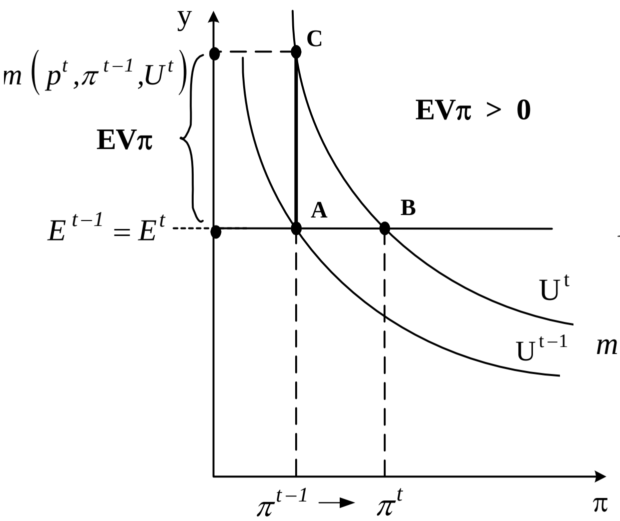

Figure 4

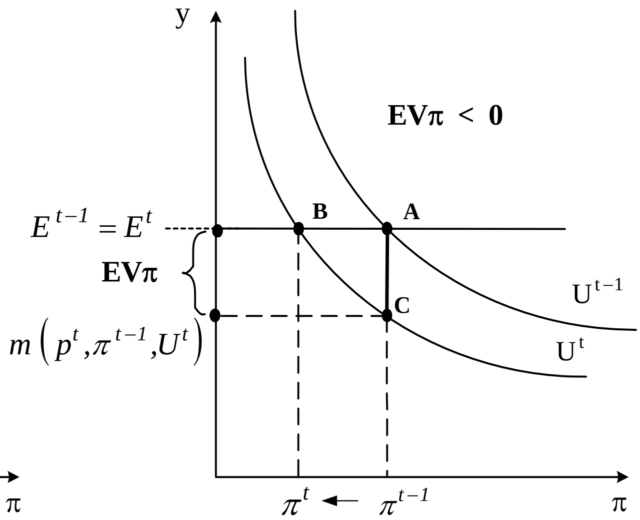

Figure 5

From fig. 4 and 5 it can be seen that EVπ equals the amount of a hypothetical money transfer suitable to bring a consumer in the environmental situation $\pi_h^{t-1,t}$ of the former period t – 1 to his actual utility level U_h^t. If environmental quality has improved during the last year (i. e. if $\pi^t > \pi^{t-1}$) this money transfer is positive and equals the minimum sum the consumer would accept as compensation if environmental quality were reduced now to last year's level. If environmental quality has decreased during the last year (i. e. if $\pi^t < \pi^{t-1}$) this money transfer is negative and equals the maximum amount the consumer would be willing to pay to make a restoration of last year's (higher) level of environmental quality possible. In the first case EVπ (> 0) equals his willingness to accept compensation (WTA) for a (hypothetical) reduction of actual environmental quality to its former level, while in the second case EVπ (< 0) equals his willingness to pay (WTP) for a return to the former level of environmental quality. So, EVπ can be interpreted as the money equivalent of the utility gain or loss the consumer has experienced through the change in environmental quality from period t - 1 to period t.

Considering (26) and (28) in (24) our preference-based environmental change index becomes

$$PCX_h^{t-1,t} = \frac{E_h^t + EV\pi_h^{t-1,t}}{E_h^{t-1}} \quad (29)$$

In this version all terms determining the index PCX can be assessed empirically: The two expenditure terms E_h^{t-1} and E_h^t are obvious and the empirical assessment of $EV\pi$ will be discussed in the next section. Since we are interested in the valuation of environmental changes only we can treat the household's expenditures for market goods as constant so that $E_h^{t-1} = E_h^t$ and our index becomes

$$PCX_h^{t-1,t} = \frac{E_h^t + EV\pi_h^{t-1,t}}{E_h^t} \quad . \tag{30}$$

From (30) it becomes apparent that PCX is a pure environmental change index. It compares the utility in monetary terms E_h^t a consumer obtains from his market consumption only to the utility he receives from market consumption plus environmental quality change, i. e. $E_h^t + EV\pi_h^{t-1,t}$.

4.3 Properties

As a consequence of the monotonicity properties (22) and (23) of the money-metric utility function the preference-based index (30) fulfils simultaneously the Identity Axiom (15) and the Monotonicity Axiom (16) on the one hand and the Indicator Condition (20) on the other. That means that PCX meets the consistency requirements for a descriptive index measure as well as the condition for a reliable welfare measure.

It is shown in the appendix that $EV\pi$ (and, consequently, the environmental index PCX according to (30)) is strictly concave in environmental quality. Since the environmental profile π is a vector this implies that the level curves of our PCX are convex, i. e. they resemble the level curves shown in fig. 3. That means that we have decreasing marginal rates of substitution between the various theme-related sub-indices I^A, I^W, I^S etc. In other words: the relative importance of a sub-index like e. g. the water quality index I^W decreases as water quality increases relative to the quality of other environmental media like air or soil. This seems plausible from a psychological as well as from a natural science point of view as was explained in section 3.

If we assume that household preference orderings are homothetic, as is common in most empirical studies of household behavior, PCX fulfils also the circularity condition (17), so that the overall improvement (or deterioration) of environmental quality since some base period 0 until today can be documented by linking the PCX together for all time periods between 0 and the actual period t:

$$PCX_h^{0,t} = PCX_h^{0,1} \cdot PCX_h^{1,2} \cdot \ldots \cdot PCX_h^{t-1,t} \tag{31}$$

This is possible since for homothetic preferences the money-metric utility function is strictly separable in p and π on the one hand and utility U on the other:

$$m_h\left(p, \pi, U_h\right) = \hat{m}_h(p, \pi) \cdot \overline{m}_h\left(U_h\right) \tag{32}$$

This reduces PCX from (24) to

$$\overline{PCX}_h^{t-1,t} = \frac{\overline{m}_h(U_h^t)}{\overline{m}_h(U_h^{t-1})} \tag{33}$$

and implies fulfilment of the circularity condition. As mentioned above the empirical assessment of the utility people derive from environmental changes depends on stated preferences, i. e. on people's judgments regarding these changes. If the base period 0 lies back 10 years from today people cannot reasonably be expected to remember exactly what environmental quality was like in those days as compared to today. For the empirical assessment of PCX the only sensible reference point is environmental quality of last year. That means in such interviews we can only assess $\mathrm{PCX}_h^{t-1,t}$ and if we want to compare the development of the overall-index over the years, i. e. $\mathrm{PCX}_h^{0,1}$, $\mathrm{PCX}_h^{0,2}$, …, $\mathrm{PCX}_h^{0,t}$ we have to link together the successive period indices $\mathrm{PCX}_h^{t-1,t}$.

Until now we have discussed the individual environmental index PCX_h. Aggregation of the individual indices to a preference-based social change index PSCX is analogous to the common practice in applied cost-benefit analysis. The individual Hicksian Equivalent Variations EVI_h as well as the individual incomes are added up over all households so that we obtain the social environmental quality index as

$$PSCX^{t-1,t} = \frac{\sum_h E_h^t + \sum_h EV\pi_h^{t-1,t}}{\sum_h E_h^t} = \frac{\sum_h \left(E_h^t + EV\pi_h^{t-1,t}\right)}{\sum_h E_h^t} . \tag{34}$$

It follows that

$$PSCX^{t-1,t} \begin{matrix} > \\ = \\ < \end{matrix} 1 \quad \Leftrightarrow \quad \sum_h EV\pi_h^{t-1,t} \begin{matrix} > \\ = \\ < \end{matrix} 0 . \tag{35}$$

The sum of the individual EVπs is positive if and only if the sum of the positive EVπs (i. e. the sum of the individual $\mathrm{EV}\pi_h^{t-1,t}$ of those, whose utility has increased as a consequence of the underlying change in environmental quality) is greater than the sum of the negative $\mathrm{EV}\pi_h^{t-1,t}$ of those, whose utility has decreased and who would prefer to go back to the former state of the environment π^{t-1}. So, $\sum_h \mathrm{EV}\pi_h^{t-1,t}$ can be interpreted as the monetary value of net social utility or welfare gain or loss caused by the change in environmental quality that took place during the time period to be valued (e. g. during the last year). The greater the value of the index the higher is the social welfare gain accomplished through environmental improvements. So, the preference-based social environmental change index PSCX is an indicator of social satisfaction with the development of environmental quality during the period under review. In an anthropocentric world, where environmental policy is justified mainly by the preferences of man for an intact environment, such an index could be a significant measure for the success of environmental policy and for the satisfaction of people with their politicians. Therefore, it could be a useful instrument of environmental policy monitoring and a valuable complement to the existing descriptive environmental indices.

4.4 Practical assessment

Our preference-oriented social index of environmental change PSCX is based on the individual expenditures for market consumption and on the households' Equivalent Variations for the change in environmental quality. While data on household expenditures for market commodities E_h^t are directly available the Equivalent Variations $EV\pi_h$ of households for environmental changes have to be assessed through personal interviews, as explained above. Such interviews can be conducted as face-to-face interviews or as mail surveys, which is less reliable but cheaper.

As explained above the environmental Equivalent Variation $EV\pi$ can be interpreted as the monetary equivalent of the utility change induced by the change in environmental quality that took place during the period under review. If a consumer feels that environmental quality has improved during the last year his $EV\pi$ equals the minimum amount of money (WTA) that could compensate him for a return to the original state of the environment of one year ago. If environmental quality has deteriorated $EV\pi$ equals the maximum amount of money the consumer would be willing to pay (WTP) to return to the original (better) state of the environment. There are well-established techniques for the elicitation of the WTP or WTA of people for environmental changes following environmental projects or environmental accidents. The most popular assessment technique is the contingent valuation method (CVM) which is based on the construction of hypothetical markets where people reveal their preferences for environmental goods through their market behavior (for details see e. g. Ahlheim 2003).

CVM surveys are typically conducted on a household basis. For the computation of the social index PSCX one would first draw a representative household sample for which the individual household $EV\pi$s would be assessed through CVM interviews. Then an average $EV\pi$ could be calculated for this sample. Multiplication of this average $EV\pi$ by the number of all households of a country yields an empirical approximation of the social Equivalent Variation $\sum_h EV\pi_h^{t-1,t}$. Household expenditures for market goods can also be asked during these interviews, but, of course, these data are available from household statistics as well.

For the elicitation of the $EV\pi$ one would first ask a respondent, e. g. the head of the household, if from the perspective of his household environmental quality has improved or deteriorated during the last year (one could also focus on specific aspects of environmental quality or on certain "environmental themes") . In the case of a perceived improvement one would ask e. g.: "In times like these it is very difficult to sustain the actual level of environmental quality. Imagine that we drop back to the level of environmental quality we had one year ago. What would be the minimum amount of money you would accept as a compensation for this deterioration of environmental quality so that altogether you would not feel worse off than today?". In CVM surveys it often shows that people have difficulties to think of an "adequate" value of environmental quality. Therefore, instead of this open-ended question format one often chooses a closed-ended format so that the question would be for example: "Would you agree to this deterioration if government paid you 100 Euro to compensate you for this loss of environmental quality?" With this elicitation format several sub-samples of households are built and for each sample a different payment proposal (e. g. 100 €, 150 €, 200 € etc.) is made. From these data the average EVπ can be calculated. For households who state that environmental quality has dropped during the last year the analogous elicitation questions would be: "Imagine government would restore the environmental quality we had one year ago. Since this would be rather costly a surcharge on the …tax would be necessary to finance this environmental program. What would be the maximum amount of this surcharge you would accept to regain last year's state of the environment?" The analogous closed-ended elicitation question would be: "Would you agree to this environmental program if you had to pay a surcharge of 100 € for its realization?"

In order to keep the cost of the practical assessment of a preference-based environmental index like PSCX low one could add the respective EVπ-questions e. g. to the questionnaire that has to be filled in anyway by the household sample chosen for the assessment of household panel data, in Germany the "Socio-Economic Panel" (SOEP) or the Microcensus. Published on an annual basis such an index could provide a good impression of the public perception of environmental changes like e. g. a "business climate index" does for the perception of economic policy by private firms.

5 Concluding remarks

In this paper we propose the construction and practical implementation of a preference-based environmental index as a complement to the existing descriptive environmental indices. The idea is that such an index should inform politicians as well as the public about the perception of environmental policy and the resulting change in environmental quality by common citizens. The role of such an index in society could be analogous to the role a business climate indices, like e. g. the "ifo business climate index" or the “ZEW indicator of economic sentiment”, play in the world of business.[6] Business climate indices inform politicians and the media on the performance of the economy as seen by private firms (i. e. by managers and shareholders) and they are taken very seriously as indicators of the actual economic situation of a country in spite of the fact that they are not based on "hard facts" but on personal judgments and expectations of private managers. Analogously, our PSCX could serve as an indicator of the degree to which people agree with the actual environmental policy and development.

The PSCX could be assessed annually. Like business climate indices it could be based on personal interviews with a representative random sample of private households. In order to obtain useful results it is advisable to keep the sample of households constant over time as it is common for the assessment of household panel data for household statistics like e. g. the

[6] The ifo business climate index (published monthly by the ifo-Institut) is formed by private business managers’ assessments of their current business situations as well as their expectations of their business performances within the subsequent six months. In contrast, the ZEW indicator of economic sentiments (published monthly by the Centre for European Economic Research (ZEW)) rests on financial analysts’ expectations concerning the performance of the whole economy.

Socio-Economic Panel (SOEP) or the Microcensus in Germany. Adding the questions that provide the data from which the PSCX is constructed to the standard questionnaire that is sent to the households participating in a country's official panel survey would help to save costs. Therefore, the practical implementation of such an index would pose no substantial financial or organizational problems.

Summing up, a preference-based social index of environmental quality could be a valuable complement to the traditional descriptive environmental indices which are mainly based on expert knowledge. Like in other areas of public policy we experience also in the field of environmental policy a significant gap between expert opinion and the feelings of common people. This gap which should not be ignored in a democratic country could be filled by a preference-based index like the PSCX proposed in this paper.

Appendix: The concavity of the PCX

It is well-known that the money-metric utility function is strictly convex in environmental quality (see e. g. Ahlheim 1993, p. 44 f.). From the definition of convexity it follows then that for two different environmental profiles π^r and π^s

$$m_h\left(p, (1-\alpha)\cdot\pi^r + \alpha\cdot\pi^s, U_h\right) < (1-\alpha)\cdot m_h\left(p, \pi^r, U_h\right) + \alpha\cdot m_h\left(p, \pi^s, U_h\right)$$

for any $\alpha > 0$. This implies that for a given initial environmental profile π^{t-1} (as a starting point) it holds that

$$m_h\left(p, \pi^{t-1}, U_h\right) - m_h\left(p, (1-\alpha)\cdot\pi^r + \alpha\cdot\pi^s, U_h\right) > m_h\left(p, \pi^{t-1}, U_h\right) - (1-\alpha)\cdot m_h\left(p, \pi^r, U_h\right) - \alpha\cdot m_h\left(p, \pi^s, U_h\right)$$

or

$$m_h\left(p, \pi^{t-1}, U_h\right) - m_h\left(p, (1-\alpha)\cdot\pi^r + \alpha\cdot\pi^s, U_h\right) > (1-\alpha)\cdot\left(m_h\left(p, \pi^{t-1}, U_h\right) - m_h\left(p, \pi^r, U_h\right)\right) + \alpha\cdot\left(m_h\left(p, \pi^{t-1}, U_h\right) - m_h\left(p, \pi^s, U_h\right)\right)$$

This implies the strict concavity of $EV\pi$ (as defined in (28)) in the actual environmental profile π^t which is valued by $EV\pi$ (following some given initial profile π^{t-1}), i. e.

$$EV\pi_h\left(\pi^{t-1}, (1-\alpha)\cdot\pi^r + \alpha\cdot\pi^s\right) > (1-\alpha)\cdot EV\pi_h\left(\pi^{t-1}, \pi^r\right) + \alpha\cdot EV\pi_h\left(\pi^{t-1}, \pi^s\right)$$

q. e. d.

For given market expenditure E_h^t our index PCX according to (29) is linear in $EV\pi$ so that the PCX is also strictly concave in the actual environmental profile to be valued.

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