ENVIRONMENTAL VALUATION AND SUSTAINABLE NATIONAL INCOME ACCORDING TO HUETING

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1. INTRODUCTORY OVERVIEW

The notion of what some now refer to as the sustainable national income according to Hueting (SNI, see Van Ierland et al (eds.), Verbruggen et al., Edward Elgar (2001)) has a relatively long history that goes back to the mid-1960s. Most of the work has appeared in print. In this chapter we therefore restrict ourselves to our main lines of argument, referring the reader back to earlier publications where appropriate. Such a procedure is necessary, experience has taught, for our treatment of SNI involves concepts and insights from diverse fields of research, and for a proper overall understanding there must be careful elaboration of each. What is *terra incognita* for one reader may be self-evident to another, however, and we have therefore structured this chapter in a way that allows us to concentrate on the key steps of our approach while retaining the quality of our argument, at the same time allowing the reader to decide which sections are relevant to him or her and which can be skipped over. To assist the reader, in this introduction we will therefore briefly summarize the basic principles and their consequences before substantiating them in subsequent sections. The most important principles are the formal concept of welfare and the concept of competing functions.

On the road to the SNI, a series of theoretical problems had to be solved, notably with regard to environmental valuation. The solutions found follow from the principles adopted, and are thus consequences thereof. Arranging the principles and their consequences in fact provides an overview of the chapter. This procedure has allowed us to restrict the scope of Section 8 (Conclusions) of this chapter to the status of the SNI according to Hueting within so-called general growth theory and the reasons for the pronounced differences between this SNI and estimates of other green national incomes, based on other principles and assumptions.

One further introductory note is in order. In Hueting (1974a) and later publications it is consistently argued that one problem is unresolvable: establishing shadow prices for environmental functions and, consequently, correct prices for goods produced and consumed at the expense of those functions. The strategy adopted to get round this problem in fact constitutes a crucial element in estimating an SNI as well as other green national incomes.

1.1 Principles

1. In our approach to SNI we are engaged in statistics, a science of the past, not in forecasting the future. Concerns about future generations, which are justifiable, are recognized as being an important element of the preferences of the current generation (see Section 2). In

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observing and measuring the past, it is relevant to take these preferences into account; doing so is obviously backcasting, not forecasting.

2. We remain within the traditional methods of the System of National Accounts (SNA), but provide another national income figure, the SNI, for use alongside the standard figure. Our figure is based on assumptions regarding preferences that differ from the assumptions implicitly made when standard national income (NI) figures are used as one of the indicators for welfare, namely that the current package of goods and the state of the environment perfectly reflect the preferences of the economic subjects, implying that the current path of the economy is optimal. The latter is questionable (see Principle 3, iv). Changes in the volume of NI are nonetheless still taken universally as the key indicator for economic success. The main purpose of the SNI research is to improve the statistical information about our economic success (increase in welfare).
3. Estimation of SNI rests on four pillars.
   i. The formal or indifferent concept of welfare, as introduced probably by Rosenstein-Rodan (1927) and elaborated further by Robbins ([1932] 1952) and particularly by Hennipman (1940, 1962, 1995), from which it follows immediately that if there exist strong preferences for the environment, conservation measures will lead to a decline in the NI and an increase in welfare (Hueting, 1974a; see Section 3). Thus, when strong preferences for sustainable use of the environment are assumed, as is the case when constructing the SNI, satisfying these preferences has a positive effect on welfare, borne of the knowledge that future generations will have freer disposal over the functions of their physical surroundings, which outweighs the negative effect on welfare due to the resultant decline in instantaneous consumption. As Hueting (1996) emphasizes, this assumption can be neither proved nor refuted on empirical grounds.
   ii. The concept of possible uses of our physical surroundings, referred to as environmental functions, or simply functions. Competing functions are economic goods (Hueting, 1969, 1970a, 1970b, 1974a; see Section 4).
   iii. The position that sustainability is an objective, scientific concept that must be clearly distinguished from whether or not there exist preferences for such. This implies that it is indeed possible to establish sustainability standards, even though these may sometimes be bracketed within high margins of uncertainty. Standards for sustainability must thus be sharply distinguished from subjective preferences for attaining such standards, or for not doing so.
   iv. The position that there exist certain ‘blockages’ (or ‘barriers’) as a result of which preferences for environmental conservation are *incapable* of being fully expressed through the market and budget mechanisms; see Section 5.2. This justifies making assumptions about preferences that differ from those underlying NI figures, when used as an indicator of economic success (see Principle 2 and Section 5.2).
4. For the valuation of environmental functions or losses of function (which amounts to the same thing) data are required on both preferences (demand) and costs (supply). Data on the costs of restoring and maintaining vital functions can, in principle, always be obtained. Preferences for such measures can be only very partially estimated, however, because of the existence of blockages (see Principle 3, iv). This is particularly true of preferences for maintaining vital environmental functions for the future, that is for sustainability. Making assumptions about preferences for the present and future availability of functions is therefore inescapable (see Section 5.2).

1.2 Consequences of the Principles

1. *The SNI according to Hueting is the maximum net income which can be sustained on a geological time scale, with future technological progress assumed only in the development of*

substitutes for non-renewable resources, where such substitution is indispensable for sustaining environmental functions, in turn essential for sustaining income. The modelling exercise to estimate the SNI can only be consistent if the vast majority of the subjects in the model are assumed to have an absolute preference for sustainability. This SNI concept is theoretically sound as well as operational, although it involves considerable statistical effort. Its theory is in line with so-called general growth theory (see Sections 5.3, 5.4 and 6).

2. When applying the concept of 'environmental function', the distinction between weak and strong sustainability cannot be made: nonrenewable resources must gradually be substituted by other elements of our physical surroundings, whereas substitution of a large class of renewable resources is impossible, particularly life support systems, including ecosystems. Economically speaking, we find no essential difference between renewables and non-renewables: the only thing that matters is that their functions must remain available (see Section 7).
3. The environment is defined as the non human-made elements of our physical surroundings, on which elements we are entirely dependent and which can be described as a collection of possible uses or functions. In accordance with standard theory, producing is defined as adding value by labour. Goods can be produced solely by using and changing the environment. This process has an exclusively positive effect on welfare, and consequently adds exclusively positive value to our surroundings, as long as functions are not rendered scarce in the same process. When functions start to compete, however, they become scarce and their price rises from zero to an ever-greater positive value, which constitutes an impoverishment, and consequently an increase in costs. On this view it follows that in moving from NI to SNI or some other green national income *only* negative corrections can be made, and no additions (see Section 5, up to 5.1).
4. Maintaining a record of the SNI leads to greater awareness of the effect of asymmetric bookkeeping of environmental functions on the NI (see Section 5, up to 5.1).
5. We seek the maximum net national income at which the environmental functions are sustained. This implies that the functions must be sustained above or at the approximated minimum levels that nature can support and that the sacrifices required to attain the associated sustainable development path are minimum. (An SNI calculated with future function levels chosen as high as possible will probably be zero; see Section 6.6.) The goal, consistently, is to ensure that possible (potential) future uses of the environment (that is functions) are not lost. Future generations then retain their freedom of action *vis-à-vis* these functions, although we explicitly assume that they exercise this freedom while remaining on a specific, namely sustainable production and consumption path.
6. Because the bulk of national income is generated by those production (and consumption) activities that are most burdensome to the environment, a shift from environmentally burdensome to less burdensome activities will have a negative effect on the volume of NI (Hueting, 1981; Hueting et al., 1992). Calculation of this effect is a three-step process: (1) capital goods are reallocated as part of the optimization embodied in effectuating the necessary shifts among production activities; (2) the production possibilities frontier is assumed to be curved 'around' the origin; (3) prices are used that arise after internalization of the costs of the required elimination measures (including the levies to induce direct shifts) when making the step from standard to sustainable national income; see Section 6.4. Shifts from meat to beans, say, or from car to bicycle or plane to train are the most essential solutions from the environmental angle and also the most plausible (see 'Three myths', Chapter 3, this volume). However, the sectoral subdivisions available at Statistics Netherlands (CBS) are not yet sufficiently detailed to simulate this effect in the model, so that the effect is not yet visible in the result (see Van Ierland et al (eds.), Verbruggen et al., Edward Elgar (2001)). We hope to improve the approximation at a later stage. For the time being, less essential and less plausible shifts have been incorporated.

7. The SNI according to Hueting is defined such that adjustment of the NI in the successive years of investigation is based on the technology of the year in question, including technology that is operational but not yet on the market. This precludes the risks of extrapolated technological progress subsequently proving unattainable (precautionary principle). An inevitable exception is substitution of non-renewables (see Section 7 and note 6). This position implies that SNI may be expected to increase over time.
8. The difference between NI and SNI is a monetary measure for the *distance* between the current and the sustainable development path.
9. Sustainability standards for environmental pressure are - in theory the levels of environmental pressure on the sustainable development path that is associated with the SNI and that includes both the economy and the environment. These standards reflect the regeneration capacity of the environment with respect to the various forms of environmental pressure and, with the exception of those relating to the consumption of non-renewables, are constant.
10. In practice it is and will probably remain unfeasible to compute the sustainability standards, the costs associated with attaining these standards and the SNI in a theoretically consistent manner, that is with a single, comprehensive, dynamic environmental-economic model. Instead, the standards are calculated with the aid of environmental models and the SNI according to Hueting with a general economic equilibrium model. This requires introduction of additional rules as well as several *ad hoc* choices. The principal rule is the assumption that sustainability is guaranteed if human activity and the resultant environmental pressure do not accelerate the extinction of biological species at the global level. Because of these rules, the practical sustainability standards for environmental pressure and the practical SNI are probably lower than their theoretical counterparts were they to be computable.
11. As a very rough estimate of sustainable world income Tinbergen and Hueting (1991) arrive at a figure of 50 per cent of current world income. The provisional results of the study on an SNI for the Netherlands are of similar magnitude (Verbruggen et al., 2001). This means that roughly half our present production and consumption depends on unsustainable use of the environment.
12. We are concerned here with a comparative, static exercise in which time plays no role. A transition to a lower, sustainable level of economic activity free of shock to the social fabric will require considerable time. The transition route to a sustainable level must itself also be sustainable, that is involve no irreparable damage to vital environmental functions (see Section 6). The quest for such a route would be the obvious sequel to the present SNI study. Assuming a preference for sustainability, welfare will increase by pursuing this route as rapidly as possible.

2. SOME ARGUMENTS FOR AN SNI

Economic growth, defined as increase of production as measured in the standard national income, enjoys top priority in the economic policies pursued by every country of the world. The economic success of government policy and even success *tout court* is measured primarily against the yardstick of production growth. In doing so, we are steering by the wrong compass, however, for production growth - that is to say, a decrease in the scarcity of man-made goods - is accompanied by an increase in the scarcity of environmental goods. This is not a new phenomenon. Hueting (l974a) provides a brief historical survey, which includes Plato (about 400 BC) on erosion, Juvenal (about AD 100) on noise nuisance in Rome and Erasmus (around 1500) on the unhygienic conditions prevailing in European cities, with their open sewers and waste-strewn streets. In earlier ages it was a local phenomenon, though, which proceeded slowly. The world still had only a small population, moreover, and space was abundant: if need be people could simply move on. According to Tinbergen, even in the 1930s the environment did not play any substantial role in the economy, and it was consequently ignored when the System of National Accounts was established (Hueting, 1974a; Tinbergen and Hueting, 1991). Since about the middle of the twentieth century environmental degradation has become a global phenomenon, with pressure on the natural environment increasing rapidly, together with production and population, the doubling rates of which have declined markedly, showing up as a veritable explosion on long-term time charts.

The twentieth century can be characterized by a phenomenon entirely new in the history of humankind. Humanity is capable of destroying its civilizations and perhaps even the human species as such. This may be through nuclear war and the ensuing nuclear winter, but it may also be by way of an insidious process that eats away at the very foundations of our existence: the vital functions of our physical surroundings. Over the past few decades, the latter possibility has been the subject of a wealth of literature that has signalled the very real risks being posed to future generations by our actions here and now. One of the first reports to review the issue was the Study of Critical Environmental Problems (SCEP) *Man's Impact on the Global Environment* carried out by the Massachusetts Institute of Technology (Wilson et al., 1970). As the main threats to life on earth the study identifies climate change and large-scale disturbance of natural ecosystems. According to Odum (1971) the impact of the extinction of biological species, particularly predators, on life on earth can only be established with certainty after the 'point of no return', that is after recovery of equilibrium is no longer possible. This whole process is occurring at breathtaking speed, when viewed on an evolutionary time scale. There is a high risk of irreversible effects occurring, and the further the process continues the more difficult and of longer duration recovery will be. According to *The Limits to Growth* (Meadows, 1972), if population and production continue to grow, catastrophes are probably inevitable. Hueting (l974a) provides a synopsis of these publications.

The principal justification for an SNI lies in the following: there are solid, rational grounds for being concerned about the conditions under which our children's children will have to live if we maintain current levels of production and consumption, because of the cumulative nature of many of the processes involved. In particular, a wide variety of poorly degradable toxins and greenhouse gases are accumulating in the environment and human encroachment on undeveloped land - the main cause of species extinction - continues apace. In the now decades-long debate on growth and the environment, there are two diametrically opposed opinions. Given continued gross economic growth, that is per capita production and consumption multiplied by population, some hold that the situation will improve, others that it will deteriorate. We ourselves hold the latter position (Tinbergen and Hueting, 1991; Hueting, 1996). Ultimately, though, the response of ecosystems, life support systems and other natural processes to human activity is unpredictable, and will always remain so, as will the potential - or otherwise - of future technologies to alleviate the environmental impact of an ever-growing volume of produced, material goods. We see the future as a race between environmental technology and production growth, the outcome of which cannot be predicted (Hueting, 1997).

In such discussions concerning what is possible and what is not possible in the future, the SNI appears to provide a welcome *statistical resting point.* The SNI is defined as the maximum attainable level of production and consumption, using the technology of the year under review, whereby the vital functions, that is possible uses, of the physical surroundings remain available forever. In this approach, sustainability is formulated as the maintenance of vital environmental functions *ad infinitum* (Hueting and Reijnders, 1996a, 1996b, 1998). The difference between the standard and the sustainable national income reflects the *distance,* expressed as costs, which must be bridged in order to attain sustainability; this is our debt to future generations. Any politics concerned with safeguarding the foundations of human existence should surely give first priority to bridging this gap, and then wait and see whether, and how much, production growth then results.

As elaborated in Section 4, from the perspective of preferences there exist as many shadow prices for environmental functions as there are possible assumptions about demand for uses of the environment, that is for environmental functions; *ergo,* there are also as many 'green' national incomes, but only one of them is the SNI.[1] Given the future perils stemming from our activities now, sustainability is viewed by many as the crux of the environmental problem (IUCN et al., 1980; World Commission on Environment and Development, 1987; IUCN et al., 1991). The SNI points the way for application of the so widely recommended precautionary principle. This principle asserts that, given the inherent unpredictability of the future and the real risk of human activity having unprecedented effects, that activity should be governed by avoidance of such effects. When informing people on the issue of environment and growth, economists, in particular, have a responsibility that is of a different order than that involved in informing them on any other issue, because the possible consequences of misjudgement are of an entirely different order.

Among other possible green national incomes the SNI consequently enjoys a special status. To this may be added that in some regions in the south the future already appears to have begun: many thousands have already lost their lives or livelihoods as a result of floods, droughts and poisoned water resources, the result of neglecting the importance of nature's functions for humanity. This is obviously not to say that calculation of one or more green national incomes alongside the SNI would not contribute substantially to the information flow.

In the SNI study the estimate for the Netherlands is seen as an indicator for what is occurring at the global level. The picture is growing clearer as an SNI is calculated for more nations. In the Dutch case, the extent of the measures required to achieve sustainability is determined by and proportional to the contribution of the Netherlands to global environmental pressure (or to regional pressure in the case of regional problems). With an import and export quote of around 50 per cent, the Netherlands is solidly interlinked with the rest of the world and the environmental degradation occurring there. Importation of tapioca livestock feed and tropical hardwood, to take but two examples, has serious environmental consequences in the respective countries of origin. The Netherlands is one of the most densely populated countries in the world and is among the nations with the highest per capita production. In the study *The Ecological Footprint* (Wackernagel and Rees, 1996) the Netherlands scores high: the 'ecological footprint' of the Netherlands is almost 15 times higher than its land mass warrants. Conversely, the Dutch are exporting their - or rather the world's - environmental resources for a price below sustainability costs, as the exporters of tapioca and hardwood are doing with their environment. As a worked example, the Netherlands does not seem such a bad choice.

Right from the start, it has been argued that an income corrected for the environment should be estimated alongside rather than instead of the standard national income (Hueting, 1967, 1974a, 1974b). The latter course would, in the first place, disrupt a key macroeconomic time series that is employed for a wide variety of other purposes besides estimating production growth. Second, a green national income derives its informative value precisely from establishing the *distance* from the standard national income, measured in terms of costs. As is familiar, a national income, standard or green, is itself a meaningless figure: only when a comparison is made over time, or with other incomes, does meaningful information arise (see, for example, Hueting et al. 1992).

[1] In calculating the SNI, often choices must be made because of existing scientific uncertainties (see Hueting and Reijnders, 1999). From both the preference side and the cost side, a whole spectrum of outcomes can result, from which a choice must be made for the purpose of presentation.

3. THE FORMAL OR INDIFFERENT CONCEPT OF WELFARE

The view now accepted by the mainstream of economic thought is that the phenomena arising from scarcity together form a logical entity, irrespective of the end for which the scarce means are employed. This is referred to as the formal or indifferent concept of welfare, a term probably introduced by Rosenstein-Rodan (1927). What he wrote can be summarized as follows. The subjective state of welfare or the total economic utility that people endeavour to achieve in their economic activities is a quantity determined purely formally. It encompasses all that has been striven after, to the extent that scarce goods have had to be used for achievement thereof, irrespective of (indifferent to) whether such pursuit springs from egoistic or altruistic, from ethical or unethical motives, from 'real' or 'imaginary' wants.

It was Robbins ([1932] 1952) and Hennipman (1940, 1943, 1962, 1995), among others, who elaborated the formal concept of welfare and formulated its consequences for economic theory. For these authors, the subject matter of economics is demarcated by the criterion of scarcity. According to Hennipman it is therefore logical and consistent to interpret welfare, the end and result of economic activity, as the overall satisfaction of wants pursued or obtained by means of economic goods or, more precisely as the balance of the positive utility over the negative utility caused by external effects or productive efforts. In Hennipman's view economic activity can serve all kinds of ends. The ends themselves are meta-economic and are not for economists to judge. They cannot be derived from economic theory, nor are they amenable to it, they must be taken as given, as data. In the same vein, Robbins writes: 'There are no economic ends as such; there are only economic problems involved in the achievement of ends'.

Maximizing or even just increasing the social product (NI) should therefore, in Hennipman's view, no longer be considered a necessary end that can lay claim to logical priority. All those objectives aspired to by economic subjects that conflict with that end belong logically and in their entirety to the domain of economic policy. If preference is given to those objectives, he writes, this does not mean a sacrifice of welfare on the strength of 'non economic' considerations, as it is still frequently represented, since economic goods are then being utilized in accordance with the wants of the subjects and thus to the benefit of their welfare.

Proceeding from the work of these authors, Hueting (l974a) posits the following. All economic activity is aimed at the satisfaction of wants, and consequently the term economic growth can mean nothing other than increase in welfare defined as the satisfaction of wants derived from our dealings with scarce goods. Welfare is not a quantity that can be measured directly 'from outside'; it is a category of individual experience. It is for this reason that the statistician focuses in practice on charting trends in factors that *can* be measured and that can plausibly be argued to have an influence on welfare. These factors will not generally be strictly proportional to welfare but must at any rate satisfy the condition that they tend consistently in the same direction as the welfare they are indicating, positive or negative. The following welfare-influencing factors can be distinguished: (1) the package of goods and services produced; (2) scarce environmental functions; (3) time, that is leisure time; (4) the distribution of scarce goods, that is income distribution; (5) the conditions under which scarce goods are acquired, that is labour conditions; (6) employment, or involuntary unemployment; and (7) future security, to the extent that this depends on our dealings with scarce goods, and specifically the vital functions of the environment.

These factors are often in conflict with one another, although this is not always the case. For scarce goods it holds by definition, however, that more of one is less of another, for a good is scarce when something else has to be sacrificed in order to obtain it (sacrificed alternative, opportunity cost). The days when environmental functions were free goods are gone. All other things remaining equal (including technological state of the art), more production therefore means less environment and vice versa. When, in the margin, for whatever motive, preference is given to the environment over production and a government proceeds to impose controls on production processes and consumption habits that lead to a smaller volume of goods and services produced, there will be an increase in the overall satisfaction of wants obtained by means of scarce goods. *A decrease in production will then lead to greater welfare.* It is therefore misleading to identify growth of national income with an increase in welfare, economic growth and economic success, as is still common practice even today. This terminology is fundamentally erroneous in its implications, to the detriment of the environment, and it should therefore be outlawed, in much the same way as discriminatory language against women.

4. THE CONCEPT OF ENVIRONMENTAL FUNCTION

The notion of possible human use of the environment or ‘environmental function’ was introduced by Hueting (1969, 1970a, 1970b). In all, 16 basic functions of nature for humanity are distinguished; these include oxygen production, waste removal, gene pool for improving and creating crops and livestock, supplier of medicines (vaccines, antitoxins), supplier of natural products (timber, fish, skins, ivory and so on), hydrological regulation, erosion prevention and maintenance of biological equilibrium. The economic value of these functions is determined in an approach comprising, *inter alia,* the following elements: (1) estimate of expenditures on replacing the function (replacement costs) when the latter falls short of existing wants due to overload (up to this point it was a free good with zero value); (2) estimate of expenditures on measures to compensate for loss of the function (compensation costs); (3) estimate of expenditures incurred in going ever further to enjoy nature, such as travel expenses. This approach underwent substantial modification between 1970 and 1974, as discussed in the next paragraph. We mention the approach adopted in 1969, since this came to lead a life of its own and is still being used today.

In Hueting (l974a, 1974b) a fundamentally different approach is taken, the principles of which have not changed since. Compared with the 1969 approach the differences are as follows.

First use is now made of a supply and a demand curve, because in any process of valuation preferences (demand) and costs (supply) are inseparably linked (see Section 5). The supply curve is made up of the (rising) costs of the at-source measures required to eliminate the environmental burden, leading to restoration of functions. These are termed the ‘elimination costs’. One of the reasons for this choice is that the functions (or services) provided by ecosystems, say, cannot in fact be replaced, or only temporarily so. Restoration of functions by means of elimination is always possible, however, as long as the functions have not been irreversibly damaged of course (as in the case of species extinction, for example). The demand curve is made up of the expenditures actually made as a result of loss of function(s). These can be seen as revealed preferences for the various environmental functions. In conventional demand analysis, the researcher hypothesizes a utility function and derives the demand function from maximizing utility subject to income. Unknown parameters then are estimated using econometric techniques. Here, however, revealed preferences are used directly. Perhaps a term ‘revealed demand curve’ would be more suitable. But for the sake of brevity we will continue to use the shorter term. Anyway, the revealed preferences include the following: expenditures on measures to compensate for loss of function, including, *inter alia,* the replacement costs of the 1969 approach; expenditures on restoring damage due to loss of function (floods due to forests losing their ‘hydrological regulation’ function, for example); and expenses incurred in travelling ever further to enjoy nature. To a limited extent, but specifically not for the most essential functions, willingness-to-pay and similar estimates are also taken on board as revealed preferences, thereby avoiding double-counting (Hueting, 1974a, 1989, 1992b, 1995).

Second, in discussions among the multidisciplinary team that one of us had meanwhile formed at Statistics Netherlands for setting up environmental statistics and for adjustment of the standard national income for environmental losses, it proved impossible to satisfactorily demarcate the concept of 'nature' for statistical purposes. This resulted in a definition of 'environment' as the non-human-made physical surroundings, or elements thereof, on which humanity is entirely dependent in all its doings, whether they be producing, consuming, breathing or recreating. These physical surroundings encompass water, soil, air, natural resources, including energy resources, and plant and animal species. It is true that our observable surroundings are largely human-built. However, houses, roads and farm crops are the result of two complementary factors: labour and elements of the physical surroundings as here intended. Our crops, for example, have been bred or manipulated from genetic material taken from natural ecosystems; this material was not created by human beings and sooner or later we shall most probably have to fall back on it. We therefore continue to be dependent on the functions of the physical surroundings as here intended, including the functions of 'gene pool' (or: 'gene reserve'), 'habitat for biological species', 'water as raw material for drinking water', 'air for the physiological functioning of human beings, animals and plants', 'soil for cultivating crops' and the many functions of non-renewable natural resources.

Producing is defined, in accordance with standard economic theory, as the adding of value. This value is added to the physical elements of our environment. In this process one good is transformed into another in order to satisfy wants. The values are added by labour, that is hands and brains, with the brains guiding the hands, so that we are concerned ultimately with two factors: labour (technology) and environment. Thus, both consumption goods and capital goods embody a combination of the physical elements of the environment, on the one hand, and labour, accumulated or otherwise, on the other. In this view, labour and environment are the two factors with which humanity has to make do in securing a desired level of consumption. If environmental functions are lost we are left literally empty-handed. Environment and labour are thus complementary. Annual production as measured in the standard national income is therefore accompanied by a *physical flow of goods.* Put differently, regardless of whether the products are actually physical, in production and consumption there will always be an interaction with the physical environment and consequently always a physical burden on that environment. This environmental pressure is, obviously, a form of environmental use.

All this may seem obvious, but apparently it is not so to everyone. In the first place, production is still frequently taken to mean material welfare, a confusing *contradictio in terminis,* and the environment, immaterial welfare. Second, in recent publications on environmental valuation the distinction is neglected between the *possibilities* offered by the environment for direct use (for example breathing), for production and for consumption on the one hand, and the addition(s) to the environment, that is production, on the other (de Groot, 1992; Costanza *et al.,* 1997; Nentjes, 1997; Opschoor, 1997). These authors establish the value of an environmental function such as 'water as a habitat for fish' on the basis of the market value of fish, for example, thereby ignoring the fact that economically speaking a fish swimming is not the same good as a fish caught. The difference is brought about by the value added by labour. The value added for catching fish (fishermen, making ships and nets) has nothing to do with the value of functions (determined by the labour required to safeguard the function and the preferences for that); see Section 5. If the fish would remain in ample supply at the current level of catch and the current pollution level and so on, the function 'water as habitat for fish species' would not be scarce and would have a value equal to zero, because no opportunity costs would have to be spent to safeguard the function. The fish, in contrast, would still realize its value added, its price, on the market. The market reflects only this value added and precisely *not* the value of the environmental function. By 'environmental services' these authors do not mean the *possibilities* of catching fish, cropping timber and so forth: the possible uses or functions which mayor may not get lost, and restoration and maintenance of which requires sacrifices (opportunity costs).

Rather, they take such 'services' to 'be the fish and timber themselves. How environmental functions are to be valued will be discussed in the following section.

When use of one function is at the expense of another or the same function, or this threatens to be so in the future, there is competition of functions. As an illustration, once certain water pollutant thresholds have been exceeded, use of the function 'dumping ground for waste' may come to compete with the function 'drinking water'. In the case of overfishing, similarly, the function 'habitat for (one or more) species or ecosystems' comes to compete with itself, because overfishing may lead to extinction of a number of species, and the function may consequently get lost; many species and ecosystems of which they were a part, in other words many functions, have indeed already been lost. The function 'soil for cultivating crops' may be damaged by unsustainable use of the function 'supplier of timber', leading to loss of the function 'hydrological regulator' and subsequent erosion; it may also be in conflict with itself, when unsustainable farming methods lead to erosion and salinization of the soil. The many functions of natural resources that threaten to get lost as a result of exhaustion of the resource are in competition with themselves.

Competing functions are *by definition* economic goods. If, at a given level of technology, use of function A is at the expense of use of function B, greater availability of function B will lead, one way or another, to reduced availability of function A; conversely, more of A will lead to less of B. An alternative will always have to be sacrificed (opportunity costs) and consequently both A and B are scarce - and consequently economic - goods. Here, 'use' obviously also includes passive use such as designation of an area as a nature reserve, which thereby excludes other uses, following recognition of the right of other species to exist; the sacrificed use, or sacrificed alternative, constitutes the opportunity cost. Competing environmental functions, defined as economic goods, form the theoretical backbone of the SNI and its estimation.

In this way the environment, and environmental losses, acquires a central place in economic theory, in contrast to an approach whereby these losses are viewed as external effects. The subject matter of economic theory can then be formulated as follows: the problem of choice with regard to the use of the scarce, alternatively applicable, dead and living matter of our physical surroundings for the satisfaction of classifiable wants. Or, very briefly: arranging the dead and living matter of the environment according to our preferences. This is argued in Hueting (1974a) and, more extensively, in Hueting (1992b, 1995). One of the arguments can be stated succinctly as follows. In the literature external effects are defined, briefly, as unintended side-effects outside the market affecting third persons, non-market parties; for a more extensive definition, see Hennipman (1968). However, when a road is built through a nature reserve, or a sewer to a river, estuary or sea, and all citizens make equal use of the road or sewer, the same citizens nonetheless lose important functions, in part or *in toto,* and such decisions are often made intentionally, in full awareness of the consequences.

The availability of environmental functions is the degree to which those functions can be used for a given end. This depends on two factors: one objective and measurable, the other subjective and not directly measurable. *On the one hand,* the availability of functions depends on the quality, quantity and spatial extent of environmental elements such as water and soil, which are largely amenable to measurement in physical units, and on the likewise measurable functioning of systems, including, specifically, ecosystems and life support systems, [2] or in other

[2] Life support systems are understood as the processes that maintain the conditions necessary for life on earth. This comes down to maintaining equilibria within narrow margins. The processes may be of a biological or physico-chemical nature, or a combination thereof. Examples of biological processes include the carbon and nutrient cycles, involving the extraction of such substances as carbon dioxide, water and minerals from the abiotic environment during biomass creation, and the return of these substances to the abiotic environment during biomass decomposition. Examples of physico-chemical processes include the

words on the state of the environment. Through (over-) use of a certain function the state of the environment may be altered, leading to reduced availability of other functions or of the same function: competition between functions. Whether this happens, and to what extent, depends on the preferences of the economic subjects. The availability of functions is thus also dependent, *on the other hand,* on subjective preferences, which are not directly measurable. In Hueting (1974a) this is expressed in a system of coordinates with on the horizontal axis the availability of functions expressed in terms of a physical variable (parameter) and on the vertical axis the preferences and costs associated with restoration and maintenance of functions (see Section 5). *In this way the relationship is established between subjectivist economic theory and the measurable physical environment, or ecology.*

Three categories of competition between functions are distinguished: spatial, quantitative and qualitative. Spatial competition occurs when the amount of space is inadequate to satisfy existing wants, or threatens to be so in the future. For example, in many residential areas there is inadequate space to allow transport systems to operate and at the same time children to play in the street. Use of space for a wide variety of purposes, be it roads, agriculture or urban development, is at the expense of the function 'space for the existence of natural ecosystems'. Spatial competition is probably the main cause of species extinction, through loss and fragmentation of habitats. Everything points to this process continuing in accelerated tempo unless drastic measures are taken. Conservation of natural species is a key criterion for estimating the SNI according to Hueting (see Section 7).

In the case of quantitative competition, it is the amount of matter that is deficient or threatens to be so in the future. We are here concerned with natural resources such as oil, copper and groundwater, which are exhaustible and non-renewable on a human time scale or which cannot increase in quantity, such as water.

With qualitative competition, it is always one and the same function, the function 'dumping ground for waste', or much more accurately: 'addition or withdrawal of species and matter' that is in conflict with other possible uses such as 'drinking water', 'physiological functioning' and 'habitat for species'. The introduction of agents into the environment (water, soil and air) or their withdrawal from it, in the course of a given activity, alters the quality of these environmental media, and as a result other uses of them may be disturbed or rendered impossible. Here, an 'agent' is defined as an abiotic or biotic element or amount of energy (in whatever form) introduced into or withdrawn from the environment that can cause loss of function. Thus, agents may be chemical substances, plants, animals, heat, ionizing radiation and so on.

Competition between functions is a manifestation of the finite nature of the environment, and to trace this competition in appropriate matrices is to expose the underlying conflicts. This has been done by Hueting (l974a). The conflict proves to lie almost entirely in the use of environmental functions for production and consumption, and growth thereof, in the here and now, at the expense of other desired uses and of future availability of environmental functions, including those functions necessary for production and consumption. In other words, the conflict boils down essentially to a question of sustainable versus unsustainable use of environmental functions. An elaboration for the use of the functions of a rainforest has been published by Hueting (1991).

For a proper understanding of the economic aspects of the environment it is instructive to compare the concepts outlined above with the concepts traditionally used in economic theory. This is no more than a metaphorical exercise, however, as the two categories of concepts are ultimately incompatible. Thus, some functions of the physical surroundings can be seen as consumption goods. Examples include: 'air for physiological functioning (breathing)', 'water as

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water cycle and regulation of the thickness of the stratospheric ozone layer. As the examples show, there is interaction between the processes, with the possibility of equilibrium being disturbed. The water cycle, for example, may be disturbed by large-scale deforestation.

raw material for drinking water' and 'swimming water'. Other functions can be viewed as production means, such as 'water for irrigating crops' and 'gene pool for breeding and modifying crops and livestock'. However, 'normal' consumption goods and production means have to be reproduced over and over again, while environmental functions remain, in principle, freely available. Only if they come to compete, with each other or with themselves, for example if certain thresholds are exceeded, does their continued availability require a sacrifice. Finally, what was termed 'the non-manmade physical surroundings' in Hueting (1974a) is now often referred to as 'natural capital'. This, too, is instructive, but once again there is an anomaly: 'normal' capital goods wear out, but natural (or environmental) capital does not, in principle. Below, we shall use the two terms synonymously, however.

These differences in terminology make no difference when it comes to the valuation method elaborated in Section 5. After all, capital goods derive their value from the value of the consumption goods they are used to produce, and thus ultimately from preferences for these goods. Similarly, environmental capital, or the physical surroundings, derives its value from the value of its possible uses, the environmental functions, and thus from preferences for these functions. The elimination measures are of course always aimed at conserving water, air, soil, ecosystems, and so on, and thus at natural capital as the vehicle of the functions.

5. DEMAND AND SUPPLY METHOD (DSM) FOR VALUATION OF ENVIRONMENTAL FUNCTIONS

In Hueting (1974a, 1992a, 1992b, 1995) and Hueting et al. (1992, 1998) the view is defended that there can in principle be only one method for the valuation of environmental functions and their loss. It is argued that what are presented as different valuation methods are in fact valuation techniques that form parts of this one method. The method may yield widely varying results, however, mainly because assumptions must generally be made regarding preferences (the demand side). If these assumptions are made explicit, environmental valuation can yield comprehensible and valuable information. If they are not, as is all too frequently the case, the widely varying results will probably not be taken seriously by serious people. On the cost (supply) side there may be differences too, but these are generally made 'automatically' explicit in the presentation of cost estimates; here, the degree of difference is less dramatic. This position has been further elaborated by Hueting and de Boer (2001), in a parable of a carpenter who measures the area of a room, using different methods, with results varying by a factor of 10, 50 and more, as is the case with the various methods currently in sway for valuing the environment. The reasoning can be summarized as follows.

Environmental functions start out as free goods, available in abundance with regard to existing wants and consequently of zero value. The emergence of competition between functions marks a juncture at which functions start to fall short of meeting existing wants. The availability of functions or, in the terms of the SNA, their volume, decreases from 'infinite' (abundant) to finite (shortfall). Use that was initially free comes to require the sacrifice of an alternative. As a result, the shadow price of environmental functions rises, and with it their value, defined as price times quantity, from zero to positive. A *new category of scarce goods* has come into being. As the availability of environmental functions declines further, their shadow price continues to rise. This real increase in price and value reflects an increase in scarcity and thus a rise in costs or in other words: a decrease in wealth. After all, a rise in real prices reflects an impoverishment or, in terms of the SNA, a decrease in volume. A decrease in real prices reflects an increase in wealth or, in terms of the SNA, an increase in volume. The concept of 'volume' has two aspects, quantity and quality; in the elucidation below, for the sake of brevity we shall consider only the former.

Increases in volume are the result of increases in labour productivity, due in turn to technological progress: a greater volume of goods can be produced per unit labour, and the real price per unit product consequently falls. Conversely, a decline in volume results from a decline in productivity, measured in terms of produced goods, which is what follows from internalizing the costs of the measures taken to restore unaccepted loss of environmental functions (see Section 5.1). From this it follows that, in the view presented here, any adjustment of national income for losses of function will comprise only subtractions, and no additions. This is for a simple reason: losses of function are not written off when they originate, so restoration (and compensation, and so on) may not therefore be written on. In other words, the availability of the functions has not changed in comparison with the original situation, neither has welfare (assuming constant preferences). Ignoring this observation would result in asymmetric entries, rendering inter-year comparison less reliable. Environmental functions fall outside the SNA (Tinbergen and Hueting, 1991). As long as these are free or virtually free goods (see above), neither can they indeed be entered in the accounts, because their shadow price is zero, or approximates zero. In the SNA, and in fact throughout the economy, it holds that the sum total of values (added to the physical surroundings; see Section 4) equals the sum total of revenues equals the sum total of costs. Evidently, this holds likewise for environmental functions. Because the environment falls outside the SNA, however, so too do losses of function (costs) as well as the restoration and maintenance thereof (revenues). The unrecorded losses of function (costs) can be incorporated in the national income by way of entering the opportunity costs required for restoring that part of the loss of function that is not accepted; what loss is deemed unacceptable depends on the preferences (see Section 5.1). In this way a 'green' national income comes into being alongside the standard national income. In accordance with the aforementioned basic rule, the revenues in the form of restoration of functions are equal to the costs of restoration, but remain invisible, because the environment remains outside the system. These *are* recorded in physical terms, however; see Figure 1 in Section 5.1. We shall return to this point in Section 6.4.

As long as one form of use of our physical surroundings is not hampering another, an insufficiency of labour (intellect) is the sole factor limiting sustained production growth. As soon as one use is at the expense of another, though, or threatens to be so in the future, a second limiting factor is introduced. Labour is then not only reducing scarcity, but is also creating new scarce goods: formerly free, or less scarce, environmental functions. Similarly, consumption is then not only satisfying wants, but is also cancelling out such satisfaction. Labour and consumption, besides having a positive effect on welfare (more produced goods), also have a negative effect (diminished environmental functions). These losses are not entered in the SNA, nor in the majority of cost-benefit analyses (CBA). Over and against the unentered costs stand the revenues (more produced goods), which *are* entered. The question arises: what is the result on balance?

In the view presented here, the answer is given in four steps, in which the calculation is gradually built up, without suggesting any sequence of calculation. The first two steps constitute a partial approach and are described essentially in Hueting (l974a). Additions introduced in later publications are included in the following brief review. The third step embodies a macroapproach based on environmental economic growth theory as developed by Stiglitz (1974), Hartwick (1977,1978) Dasgupta and Heal (1979) and others. Step four is the setting up of a system of reliable, and thus reasonably detailed, interlinked environmental economic models with which to carry out valuation based on the principles deduced in the previous steps. The third and fourth steps have been elaborated and discussed in a number of internal Statistics Netherlands papers, correspondence with colleagues and several publications (de Boer et al., 1994, 1995, 1998; Brouwer and O'Connor, 1997).

The basic point of departure is the same for all four steps. If there are no preferences for a good, its value is zero, irrespective of how important, or even indispensable, that good may be for humankind. If a good can be obtained without sacrificing an alternative, its value is likewise zero. In valuing environmental functions, both preferences and costs must be quantified. These are therefore two inseparably linked elements of the valuation of environmental functions and their loss. This is why the method is known as the demand and supply method, or DSM, a name adopted only late on in its development (in 1996). Valuations that are, ultimately, estimates of only preferences (demand) or costs (supply) are here viewed as techniques forming part of the single valuation method presented here.

With respect to the economics of the environment we are concerned almost always with the choice between produced goods and environmental functions. If valuation is to be of use in making such choices, the two categories of goods must be expressed in the same unit. For environmental functions this requires the construction of shadow prices comparable with the market prices in which produced goods are expressed, that is shadow prices without a consumer's surplus. To establish the total economic value of the two categories, given BCGR in Figure 1, which does include the consumer's surplus, requires very extensive survey campaigns, for both categories. Overall, the results of such an exercise are of dubious reliability. This holds particularly for the vital necessities of life such as food, drink and medical care, for the intramarginal utility of these goods includes the utility of the first slice of bread, the first sip of water and the saving of a life (Hueting, 1974a). It holds in equal measure for the vital environmental functions (Hueting, 1989, 1992b, 1995; Geurts et al., 1994; Hoevenagel, 1994a, 1 994b, 1994c). In practice, therefore, we consider it necessary to define value as (shadow) price (marginal utility) times quantity, determination of which requires data on both preferences and costs.

5.1 Valuation on the Basis of Revealed Preferences and Known Elimination Costs

As *a first step* in the chain of reasoning, the line is taken that all preferences for environmental functions can be expressed in the marketplace or, as a complement to this, be discovered by means of surveys. On a system of coordinates function availability is recorded on the horizontal axis, in physical units, with the preferences and annual costs of the measures to restore functions being plotted on the vertical axis (see Figure 1). Two cost curves are constructed. The figure shows that the reduction of the costs plotted on the one curve constitutes the benefits accruing from the increase of costs plotted on the other. The aim, now, is to find the minimum total cost, or in other words the point where the difference between benefits and costs is maximum.

The first of these two cost curves consists of the sum total (without double counting) of all expenditures, actually made or yet to be made, by whatever party, resulting from loss of environmental functions and of the expenditures that people state they are willing to make to regain these functions (willingness to pay and to accept surveys, that is contingent valuation). As stated in Hueting (1974a, 1989, 1992b, 1995), surveys prove to yield unreliable results for precisely the most
vital functions. The costs actually incurred fall into four categories: (1) expenditures on measures to compensate for loss of function, such as the raising of dykes as a result of disruption of various functions regulating hydrology and climate, or on preparing drinking water as a result of overuse of the function 'dumping ground for waste'. These are the compensation costs; (2) expenditures, actually made or yet to be made, relating to damage, such as housing damage and harvest losses caused by flooding due to loss of the function 'hydrological regulation' of forests and soil, and production losses and medical costs ensuing from, say, loss of the function 'air for physiological functioning'. This is the financial damage; (3) travel expenses incurred in going ever further to enjoy nature; (4) Ricardian rent paid via the price of raw materials.

All these amounts can be interpreted as expressing revealed preferences for the original functions, so that the negative first derivative of the cost curve built up from these amounts can be seen as a collective demand curve for environmental functions (see Figure 1): the first derivative lying in the fourth quadrant is reflected to the first quadrant [-(d/d*p*)(*C*+*D*) = + (*c*+*d*), where the symbol *p* represents purity]. For category (2) this is based, strictly speaking, on the assumption that those suffering damage through loss of a function are prepared to pay at least the amount required to restore that damage in order to achieve restoration and lasting availability of the function in question. The curve has the same shape as a normal demand curve. With decreasing availability of the function, progressively more compensation measures must be taken and progressively more financial damage occurs: the price (and thus the marginal utility) increases. The second cost curve is built up from expenditures on measures, to be taken by

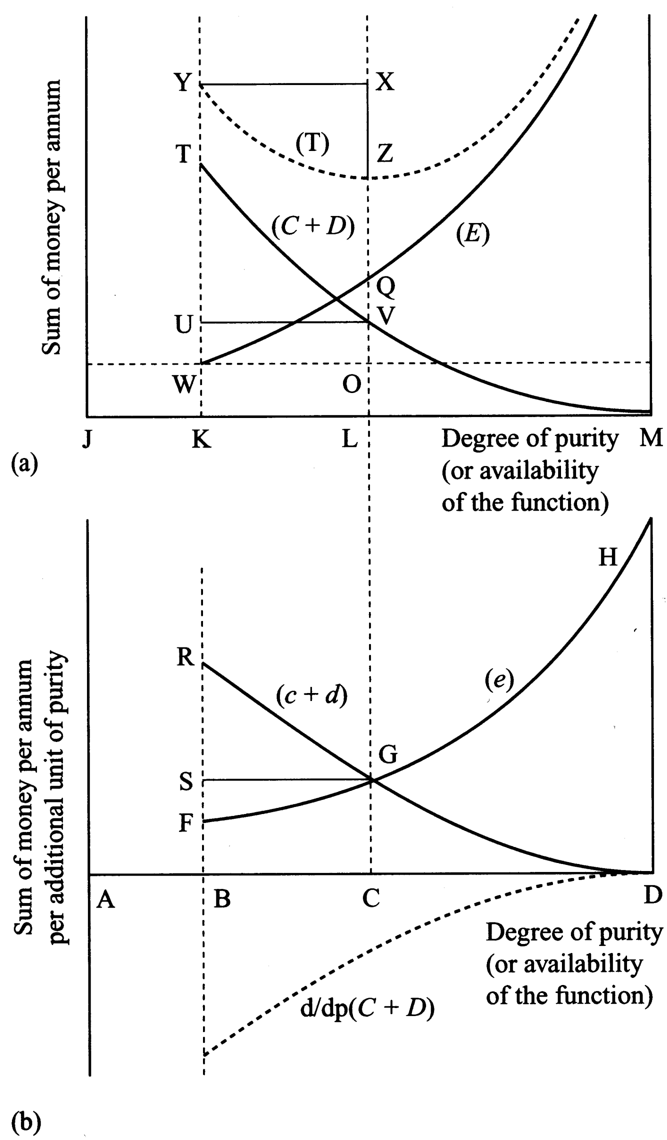

Figure 1 *Costs of elimination and revealed preferences for an environmental function: (a) total curves; (b) marginal curves. (E) = elimination costs, (C+D = compensation and (financial) damage costs, (e) = marginal elimination costs, (c+d) = marginal compensation and damage costs. Taken from Hueting (1974a)*

whatever party from the year of investigation onwards, which increase the availability of the original functions. This can only be achieved by eliminating the cause of loss of function and, where necessary and feasible, by neutralizing the accumulated impact of earlier environmental burdening *in situ.* For this reason this curve is referred to as the elimination cost curve (or abatement cost curve). The measures involved thus eliminate the source of the loss of function, that is the environmental burden, permitting partial or complete restoration of the function in question. They are, of course, arranged in order of increasing cost per unit of environmental burden eliminated. The measures consist of: (1) technical measures, including process re-engineering, redesign and developing and applying (renewable) substitutes for non-renewable resources (for example solar energy, glass fibre); (2) direct shifts from environmentally burdening to less burdening activities (reallocation); (3) a shrinkage of economic activity, with employment remaining unchanged (more leisure time); and (4) a decrease in the size of the population. No pronouncement is made as to the time frame within which these measures are to be implemented, as will be clear from their nature. Whether, and to what extent, they are indeed implemented depends on the preferences, in other words on the position of the demand curve. The cost curve to emerge from this procedure may be considered as a supply curve, because the measures act to make available, or supply, environmental functions. From how the curve is built up it follows that it is a collective supply curve. The sum of the elimination costs is equal to the sum of the prices of the production factors that must be withdrawn, by a variety of routes, from the production of consumption goods and budget goods in order for functions to be restored. The curve rises progressively from bottom left to top right. The further a function is to be restored, the more efficient the measures must be. This is generally accompanied by progressively rising (marginal) costs per unit avoided environmental burden.

As we move further up along the elimination cost curve, we automatically move further down the curve of compensation and other costs: as the original functions once again become more available, the necessity of such expenditure decreases. It is this reduction in compensation and other costs that constitutes the benefits accruing from the expenditures made on elimination measures. By summing the two curves a U-curve is obtained (see Figure 1). The minimum of this U-curve reflects the position of optimum function recovery, for here the total social costs are minimum while the difference between total benefits and costs is maximum. The minimum of the U-curve corresponds to the point of intersection of the first derivatives of the two curves, that is of the marginal supply and demand curve. This point of intersection would reflect the shadow price that we are seeking and that can be compared directly with the market prices, *provided* all preferences for environmental functions were reflected in the demand curve constructed as described above. The shadow price (CG in Figure 1) simultaneously determines the value of the environmental function as well as the costs of the unaccepted function loss. The residual function loss, recorded in physical terms, *is* accepted: the associated increase in production (which is entered in the national accounts) is valued more highly. Like any price, the shadow price of an environmental function is an indication of its marginal utility.

To value is to compare. In economics, there is no such thing as an absolute value; a good can only be worth more or worth less compared to another good. Because what is always at stake is a conflict between the environment and produced goods, as we have seen above, the value BCGS (or BCGF; see below) in Figure 1 gives us precisely what we need for making the inevitable choices involved in this conflict. At the same time, shadow prices that can be compared directly with market prices are also a necessary precondition for adjusting the standard national income for environmental losses. BCGS (or BCGF) comprises no consumer's surplus, for example, just like market values. Other conceptions of the valuation of environmental functions exist, however, and these will be discussed below.

Now consider Figure 1 again. The shadow price (partial, see above), directly comparable with the market price of a produced good, equals CG. The cost that must be incurred to achieve the optimum, and thus the value of the function, is given by BCGF, corresponding with the line OQ.

BCGF simultaneously indicates the value of the function, comparable with the market value of produced goods. As stated in Section 4, value should be shadow price times quantity, or in other words the area of BCGS. In Hueting (l974a), from which Figure 1 is taken, the producer's surplus was neglected. This is not essential, however (Hueting and de Boer, 2001). Now, the total value or benefits is equal to the increase in monetized total utility as one moves from B to C = BCGR = line section TU. *This thus includes BCGF as well as BCGS.*

FGR = monetized net increase of utility gained as the availability of a function increases from B to C = line section ZX. This net increase equals the total increase in utility BCGR minus the costs BCGF. This must always be a positive number, because there is a change from suboptimal to optimal.

Further on in the aforementioned exposition of Hueting (l974a) a second step is made: the demand curve (c + *d*) in Figure 1 moves to the right and is then termed (c + *d* + *x*)*; x* is not shown in Figure 1. If x is large (but unknown; *ergo x)* and (*c*+*d*) is situated far below (*c*+*d*+*x*)*,* then the bulk of FGR (after neglecting the producer's surplus) consists of what can be called the consumer's surplus, although we would rather refer to FGR as 'net benefit' or, because *x* represents an assumption about preferences for a function, as 'meeting an assumed demand'.

Erroneously, some authors (for example, Costanza et al., 1997; Opschoor, 1997) refer to FGR as 'the value'. Erroneously, because net increase in utility after reallocation (of resources and capital goods) and value are of course two entirely different things, while it is clearly 'value' that these authors are after. Certainly, comparison of FGR with costs may be a useful tool for deciding whether or not to go ahead with a given project - if a reliable demand curve is available, that is, for that is often not the case. But that 'value' is a very different concept can be readily understood with reference to a produced good with a very low consumer's surplus and a high price; few people will hold that surplus to be the value of the good.

5.2 Extension with Assumed Preferences for Environmental Functions

The *second step* in the reasoning behind our method is the following. It can be plausibly argued, for a variety of reasons, that preferences for environmental functions can be expressed only very partially through the market and the political process (mainly the budget mechanism) (see Section 1, principles 2 and 3, iv) and that questionnaire-type surveys cannot provide reliable answers when it comes to the most vital functions, that is those on which the lives of future generations are dependent (Hueting, 1974a, 1989, 1992b, 1995; Bateman and Turner, 1992; Geurts et al., 1994; Hoevenagel, 1994a, 1994b, 1994c; de Boer et al., 1995). As an example of compensation costs (as revealed preferences) there is no point in creating new forests or lakes so long as the process of acidification has not been halted by elimination measures, because without elimination at the source the process will acidify the newly created forests and lakes. Erosion-driven soil loss cannot be compensated. Much of the damage resulting from loss of functions will take place in the future; cases in point are damage due to disruption of climatic stability and to the loss of the functions of natural ecosystems such as rainforests and estuaries. No financial damage or compensation expenditures can therefore arise in the present. Choosing a discount rate, for instance the market interest, for calculating the net present value of future damage boils down to making an assumption about preferences for future environmental costs and benefits (Hueting, 1991). This does not, therefore, resolve the basic problem of preferences being unknown. We cannot base ourselves on observed individual behaviour, furthermore, given the working of the prisoners' dilemma. In practice, individuals do not switch to environmentally sound behaviour, because they doubt whether others will do the same, as a result of which the effect is thought to be negligible while the individual concerned causes him or herself detriment. The same holds at a meso- and macro-scale. If one company takes measures to protect the environment but others do not, it will price itself out of the market. If a given country adopts measures and others do not follow, that country will suffer damage, while the effect of those measures will be insubstantial.

Finally, there is a lack of information, for example about the complex nature of life support systems and the relation between safeguarding the environment, employment and growth (see Three myths, Chapter 3, this volume). *All these aforementioned factors, which make it impossible and very difficult respectively to fully express preferences for environmental functions, we shall call blockages (or barriers).* These blockages play an important role in Section 6.

The shadow prices we are seeking thus remain largely unknown. This has two consequences. First, the value (or relative scarcity or marginal utility or correct price) of the goods produced and consumed at the expense of scarce environmental functions remains likewise unknowable; this value differs from product to product, moreover (Hueting, 1974a). Second, we cannot escape from making *assumptions* about the urgency of the preferences for present and future availability of environmental functions (for example Hueting et al., 1992, 1995a, 1995b, 1998; Hueting and Bosch, 1994). This obviously holds in equal measure for cost-benefit analyses as well as for adjustments of national income for environmental loss. *When making such assumptions, the optimum described above is once again valid, as is the shadow price that is directly comparable with market prices, and this optimum is again located at the point of intersection of the supply and demand curves.*

In practice, an assumption regarding preferences can take the form of standards for the availability of environmental functions. We can imagine certain situations in which such is indeed the case. If there is some kind of 'survival minimum' for the function, the demand curve will become very steep near the minimum. It makes no difference, in principle, whether this minimum is below or above the current level of the function. If prices are high, however, the demand curve must bend towards the vertical axis, because it is impossible to sacrifice more income (goods) than is produced. The further to the right the urgently desired level lies, therefore, the shorter the vertical section of the curve will be. If it is plausible that the steep section of the curve will intersect the supply curve (marginal cost function), the demand curve can be replaced by a simple standard at the point of the urgently desired function level; this does not affect the outcome. Something similar holds if the demand curve is simply not well known but a reasonable assumption can be made about the position of the optimum and thus also of the optimal level of the function. That function level then becomes the standard. A special case arises if preferences for consumption and use of the environment in the future are far more urgent than those for consumption and use of the environment now (see the discussion of sustainability, below). In theory, the optimal function level is a characteristic of the sustainable path that can be found by optimizing a dynamic macroeconomic model; in practice, however, this is a calculation that is well nigh impossible to perform. Fortunately, the position of the optimum can be estimated (see third step in Section 5.3). From the above it follows that there are as many values for environmental functions as there are assumptions regarding preferences and, *ergo,* as many green national incomes, too. We understand 'green national income' to mean the national income in a situation in which preferences for environmental functions and produced goods are fulfilled as satisfactorily as possible. By this we mean that welfare is limited only by the technological state of the art in the year for which calculations are being made, and not by the aforementioned blockages; these are assumed to have been entirely overcome.[3] We thus base our calculation of an SNI on the assumption of preferences existing for the continued availability of vital environmental functions; an SNI is therefore a special case of a green national income. As long as the assumptions are made clear and explicit, the ensuing valuation exercise can yield valuable and comprehensible information.

[3] Another, frequently employed definition of green national income is the monetary welfare measure corresponding with the assumed preferences and is related to the green national income as we define it. We shall return to this point later.

5.3 Generalization in Dynamic Environmental Economic Theory

As a *third step,* the theory presented above is generalized in a macroeconomic sense by taking a systems approach. This step is necessary because the measures occurring in the calculation of green national income cause such a large change in the pressure on the environment that all variables change as a result, including the prices of market goods, budget goods and environmental functions. In other words, the *ceteris paribus* condition of the previous steps no longer pertains. The applied systems approach starts from the notion that all relevant interacting processes in society and the environment can, at least in principle, be modelled as mathematical relations between variables that can be combined in one comprehensive model. Meadows (1972), Solow (1974), Stiglitz (1974), Weitzman (1976), Hartwick (1978), Dasgupta and Heal (1979), Mäler (1991), Asheim (1994), Pezzey (1994) and Vellinga and Withagen (1996) are among those who have led the way in this approach.

This step leads to a generalized model of an economy consisting of a series of production activities and groups of consumers, each using both short-lived and long-lived (that is capital and durable) goods and services and each using the environment. These actor groups apply technical measures to reduce pressure on the environment and slow down or halt its deterioration. These measures require labour, capital goods, matter and energy flows. Outputs and consumption activities are dependent on all these inputs.

The assumption that (partly assumed) preferences are fulfilled in the best possible way, given the other data, relations and assumptions of the model, is often formalized in economics as the concept of all people maximizing their welfare. A person's welfare is not a physiological or psychological quantity amenable to direct measurement, but a theoretical internal model variable in which the products and environmental functions the person uses are weighted according to his or her (estimated or assumed) preferences. In calculating a person's welfare, allowance is made for the fact that the weight someone assigns to a product or function is influenced by the available quantities of all other goods and functions. The calculation of an individual's welfare from the quantities of products and environmental functions that he or she uses and wants to use in the future is described in a mathematical relation called the individual welfare 'functional'. It follows that individual welfare merely reflects the ranking of the combinations of products and functions considered in order of their desirability to the person in question. Consequently, all individuals are assumed to maximize their welfare.

We simplify matters and consider society as a whole, maximizing so-called social (or collective) welfare, or welfare in short, which reflects the ranking of the packages of products and functions that are used by the sum total of individuals in a society. Like individual welfare, social welfare is of course not directly measurable.[4] When the model is solved and the model variable called welfare is used as an outcome, it cannot therefore be anything but a welfare *indicator.*

As both present and future product flows and function levels are weighted in the welfare indicator, this is sometimes referred to as 'intertemporal welfare' as opposed to 'instantaneous welfare'. These terms may be confusing. 'Intertemporal' welfare at any given time may instantaneously rise (because people 'feel' instantaneously better) if a future risk is judged to have become smaller than it was. Here, 'instantaneous' denotes an aspect of 'intertemporal' welfare. From now on, however, we shall distinguish 'instantaneous welfare' in any given year

[4] From a systems theory point of view, personal or social welfare is 'observable' in most models, that is, it can be reconstructed from the model's input and output variables, like an individual's or society's actions, respectively. Therefore, 'observable' welfare can also be reconstructed from data on these variables. In reality, data are only available for actually measured (observed) environmental economic development and therefore only allow reconstruction of the small section of the welfare 'functional' in the neighbourhood of the data. The result of this 'functional' is still an ordinal quantity, reflecting the fact that it cannot be directly measured.

from welfare in the general sense in that year; this may be somewhat inelegant, but it is in accordance with the literature. Instantaneous welfare at a particular moment in time is the result of weighting all product flows and functions levels that are *used at that moment,* provided this weighting can be isolated from the intertemporal weighting. Welfare in the general sense is in that case the result of the weighting of the instantaneous welfare levels in the present and all future moments, that is intertemporal weighting.

Like welfare, production output is described as non-linearly dependent on inputs. Though it is questionable whether all non-linearities in the production functions hold in the long run, the general form is non-linear.

In general the model is dynamic, as it describes the effects of changes of economic and environmental stocks on other parts of the system. Economic stocks consist mainly of capital goods and durable consumption goods, while environmental stocks are quantities or concentrations of environmental resources and levels of pollutants, biota, available land and so on. The magnitudes of these stocks are so-called state variables and how they develop in time largely determines the solution of the model. The processes described by the model influence how these stocks vary, thereby producing patterns of inertia that are characteristic of the model. One result is that realistic model solutions as responses to sudden man-made changes are always gradual, and therefore always follow continuous *paths* in the space of the state variables (state space). Each set of assumptions concerning the representation of real processes in the model, parameter values and input data produces a path. Welfare is maximized by determining the ways in which controllable human actions depend on time and this process selects one optimal path for each set of assumptions, parameters and input data applied. For our purpose, it suffices to plot such a path in terms of certain characterizing variables, such as a welfare indicator, or benefits and costs, just as Figure 1 presents these variables for different static (that is time-independent) situations.

Several of the aforementioned authors have sought welfare indicators that can be related to national income. De Boer et al. (1995, 1998 and in preparation), Brouwer and O'Connor (1997) and Zeelenberg et al. (1997) have reviewed their efforts. We shall elaborate this subject in Section 6.

5.4 Practical Model System

In the previous section the calculation procedure is described in generalized terms, proceeding from standard economic theory. For such a calculation to be reliable, a large dynamic model is required that comprises all the relevant processes in both the economy and the environment. Welfare must be maximized within this complex model, yielding an optimal path, in our case a sustainable path. This appears to be an impossible task, given the capacities of standard computing hardware and software. We therefore opt for an approach using a set of interlinked models rather than one all-embracing model; this is our *fourth step.* The economic activities of production and consumption are represented in one model, and additional models constructed for each of the various environmental problem areas. Ideally, information should then be transferred back and forth between the models in a process of iterative exchange. To avoid tedious iterations with the total model set, we have reduced these interactions to one-way information flows, that is to one-time operation of each model for a given period. This means that the overall optimum, that is the optimal path, can be calculated only approximately, as opposed to the case with the theoretical comprehensive model. We have opted to achieve a reasonable approximation by assuming that the optimal function levels of the theoretical model (see Section 5.3) can be formulated in words and/or roughly quantified. It is further assumed that the levels of the state variables of the environment (quantities, qualities such as concentrations, space) corresponding to the assumed optimal function levels can be estimated, at least to within some range, on the basis of expert opinion or by using appropriate standards for the state of the environment. These standards are then entered as constraints in the model of each environmental problem, and standards for allowable environmental pressures (emissions and so on) are then derived by iteration. These pressure standards may be functions of time. However, the pressure levels associated with overall sustainability must be capable of being maintained forever and therefore these (constant) levels are independent of time (see Sections 6.5 and 6.6). The standards are then entered as constraints in the economic model. In this step it is decided which technical measures, which direct production shifts and which levels of production shrinkage and population reduction are to be taken to arrive at the standards and, subsequently, what national income results from these actions at the time of interest, that is the year of investigation.

6. INS AND OUTS OF A GREEN AND A SUSTAINABLE NATIONAL INCOME CALCULATION

Four main subjects are reviewed in this section. First, it is explained that each different set of assumptions regarding preferences for environmental functions and blockages preventing their expression forms a specific case, for which the model (or model set) computes an optimal development path of the economy and the environment. Second, we show that two significant *welfare indicators* and a *green national income* can be calculated for each path, and how they are related. Third, we argue why we opt for green national income as a practical welfare-related indicator. Finally, we focus on a special case: sustainable national income.

We work towards these goals by discussing a series of cases of increasing relevance to our problem: (1) preferences for environmental functions are unimportant because functions are abundant; (2) functions are scarce and preferences are such that the optimal path (computed by the model) approximates the actual path; (3) preferences for the environment are stronger than in the second case, but there are blockages preventing their full expression; (4) preferences are as strong as in the third case, but the blockages have been overcome; and (5) the special form of the last case in which preferences for sustainability are general and dominant. These cases are considered in Sections 6.1 to 6.5, respectively.

This step by step approach also enables several other issues to be explained: the difference between the welfare indicator on the actual and the optimal path; the difference in national income on the two paths, that is the opportunity costs; the part played by technical measures, production shifts and other measures in these costs; the prices to be used in calculating these costs; the nature of sustainability; and the existence of feasible transition paths to - for instance - sustainability. We shall discuss only the main features of these issues, referring for details to the literature as appropriate. De Boer et al. (forthcoming) gives a mathematical exposition of the argumentation.

6.1 Environmental Functions not Scarce

Consider an imaginary country (or a real country in the distant past) where people value the present and future availability of environment functions, but where these functions are abundant. The situation is then relatively simple. As explained in Section 5.3, a welfare indicator can in theory be calculated using a model of the economy including its interaction with the environment. This indicator, which we shall call v depends in this straightforward case only on present and future consumption of man-made goods and services. Welfare must, of necessity, be maximal in both the actual and the model economy. The actual and the model path consequently roughly coincide. If the model is ‘correct’, therefore, maximization of its welfare indicator will result in a model solution, or model path, that approximately reconstructs the actual development of the economy in this imaginary country. In particular, this means that the quantities of selected groups of man-made goods consumed in a series of historical years should be 'adequately' approximated by the model's consumption variables over these years. As a by-product, the welfare indicator is calculated in a fashion entirely consistent with the adopted assumptions on preferences.

In this case several convenient simplifications can be made. Calculation of the welfare indicator including the future (in the welfare 'functional') generally involves the use of different discount rates for different consumption goods. These rates may even depend on the length of the period between the future and the present year, that is on time. If *the same discount rate* is used for all consumption goods, the welfare indicator *on the optimal path,* in this case the current path of the economy, may be written as a sum of various kinds of terms. The consumption of produced goods (c) in the year of investigation is represented by the instantaneous welfare term, evaluated for that year. The consumption of products in the future is represented by the increases in the stocks of produced capital goods in the present year ($\mathrm{d}k/\mathrm{d}t$), each stock change weighted with its own 'welfare shadow price'. Additional terms occur if parts of the model are explicitly dependent on time, that is on time-dependent influences from outside the model ('exogenous' or input variables), such as a climate variable or a measure of technological progress. Some of these time dependencies can be avoided by making the influence an 'endogenous' variable, that is by extending the model such that the influence is the result of an internal process. The corresponding terms in the welfare indicator formula then disappear, being incorporated in other terms. Other time dependencies are often assumed away. We therefore concentrate on the terms due to immediate and future consumption, expressed in the consumption flows c and the rates of change of the capital stocks $\mathrm{d}k/\mathrm{d}t$, respectively.

A monetary welfare indicator proportional to the welfare indicator v can be computed by dividing the latter by the marginal welfare of some marketed product in the year of investigation. The outcome is entirely arbitrary, as it depends on the arbitrary reference level and units of the welfare indicator itself and the arbitrary choice of market good. Consequently, this result cannot be compared with national income. If there were a unique way of doing this, one would obtain the macroeconomic equivalent of such monetary welfare measures as the 'real economic value' and consumer's surplus of a good. We assume this to be impossible and follow the literature in that the term in c, the instantaneous welfare function, is linearized. Thus an approximate welfare indicator is obtained in which the flow of each consumption good and the change of the stock of each capital good is represented by a separate term. Replacing the marginal welfare coefficients in all the terms by the prices arising from the model exercise (which approximate the market prices) yields an approximate monetary welfare indicator or 'monetary welfare measure', which we denote as w. We call these prices shadow prices. It is important to note that, as a result of linearization and expression in market prices, the macro-equivalents of the consumer's surpluses have disappeared from both the immediate consumption terms and the stock change terms of the welfare measure. The respective terms of this measure still constitute the contributions of present and future consumption to welfare in a given year. These terms now sum to the macro-totals of *consumption* plus *net investments,* in other words to *net national product* (or income): y on the model's optimal path (Weitzman, 1976). As a formula: $w= p(c+\mathrm{d}k/\mathrm{d}t)=y$. This model-calculated national income is a good approximation of real standard national income as calculated in the national accounts, provided the model and its optimal path are fair approximations of the present economy and its development. This implies that the prices are 'real' prices, insofar as they are free of inflationary or deflationary tendencies.

6.2 Relatively Weak but Perfectly Expressed Preferences for the Environment

In a more realistic case than the last, the production and consumption of goods leads to direct or delayed damage to environmental functions, which consequently become scarce. Here, however, only moderate preferences for environmental functions are assumed, to such a degree that the model's optimal path *('business as usual', b* in Figure 2) is a fair approximation of the current economic and environmental path *('actual', a).* Although there are blockages preventing full expression of these preferences (see Section 5.2), these are assumed to have a negligible effect. The national income computed by the model under the assumed preferences is formally a green national income, but is in this case a good approximation of standard national income; see Figure 2.

If the same discount rate is taken for all consumption goods and all environmental functions in the welfare function, the welfare indicator *v* calculated for this optimal path may be broken down into terms, as indicated in Section 6.1. Some of these terms may be explicitly time-dependent (see above). Some of the latter may now also stem from environmental submodels. Both are again not discussed. Now the available quantities of both produced goods and environmental functions contribute to the welfare indicator. The available levels of consumption goods (*c*) and environmental functions (φ) in the year considered (the year of investigation) both contribute to the instantaneous welfare term.

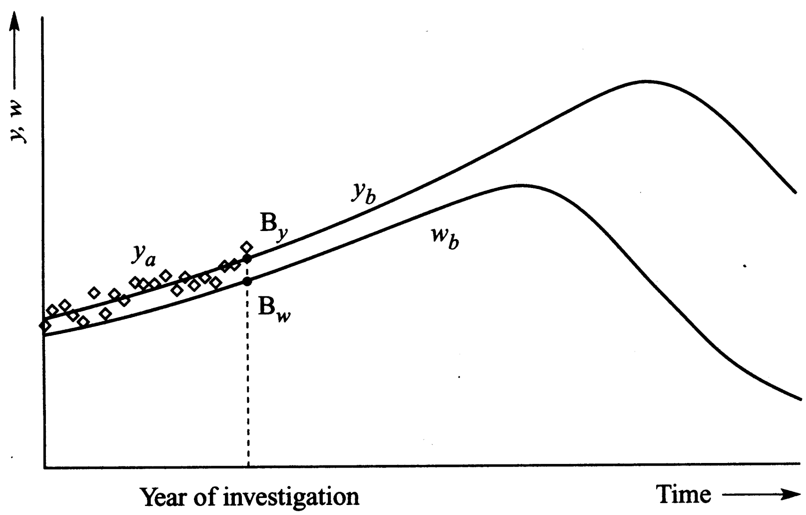

Figure 2. *Standard national income (y_a) as measured in the System of National Accounts and its approximation and extrapolation on a 'business as usual' path (y_b) as computed with an environmental economic model with relatively weak but assumed unblocked preferences for the environment, for a fictitious case; w_b is the welfare level on the 'business as usual' path. The collapse appears earlier in w_b than in y_b, because in w_b the future is taken into account, not in y_b. The points B_y and B_w indicate the levels of national income y and the welfare measure w in the year of investigation.*

The rates of change of the modelled stocks, namely of stocks of produced capital goods (d*k*/d*t*) and of levels of environmental functions (dφ /d*t*), appear in the welfare indicator as well. Each change rate is weighted with its own factor that can be expressed in terms of marginal welfare. These stock changes represent the safeguarding of the consumption of produced goods in the future and the deterioration of the future potential for using the environment, respectively.

Having linearized the instantaneous welfare term in the welfare indicator *v,* we can once again obtain an approximate monetary welfare measure *w,* following the procedure described in

Section 6.1. However, *w* now consists of the weighted sum of the available quantities of consumption goods *(c)* and environmental functions, and the rates of change of both the stocks of produced capital goods and the levels of the environmental functions; the weights are the *monetary shadow prices* (see Section 6.1). The expression for the welfare measure can be rearranged in such a way that the equality to net national income plus environmental terms becomes apparent. The latter are the contributions to welfare of available environmental function levels (φ), their rates of change (dφ/d*t*) and several cost terms (these costs do not cover all elimination, restoration and compensation costs and financial damage; for the sake of brevity we refer to de Boer et al. (forthcoming). The terms expressed in the function levels and the associated costs stand for the immediate use of environmental functions, as the term in *c* stands for the immediate consumption of products. Likewise, the terms in d*k*/d*t* and dφ/d*t* stand for the consumption of products in the future and the use of functions in the future, respectively. The latter term, consisting of the changes in environmental stocks, weighted with shadow prices, is analogous to the net investments term expressed in d*k*/d*t* and is therefore often referred to as the rate of change of 'natural capital'.

After these simplifications, the shadow prices of the produced goods *(c,k)* used in the indicator are the model's market prices of those goods. As the model's *business as usual* path *(b)* is an approximation of the actual development *(a),* the model's market prices are in this case approximately equal to the real market prices. Consequently, the model's national income approximates standard national income as provided by the national accounts. If net national income is increasing at the expense of the environment, the shadow prices of the declining environmental function levels φ are positive and increasing, because the functions are becoming scarcer. The derivatives of the function levels with respect to time, dφ/d*t*, are often negative because the functions are frequently on the decline, but their shadow prices are positive; see Section 5.3. This approach is proposed by Repetto et al. (1989, 1991), Mäler (1991), Landefeld and Carson (1994a, 1994b), Hamilton (1995) and probably several other authors.

It may well be realistic to assume relatively weak preferences for the environment and to accept the correspondingly small difference between the monetized welfare measure and national income, as has been done in this case. This choice means assuming that people are either not aware of the possibility of serious losses of environmental functions in the future, or do not care. From Section 5.2 it follows that stronger preferences for environmental functions are equally plausible. Cases built on this assumption are elaborated below.

6.3 Strong but Poorly Expressed Preferences for the Environment

In this case, people are assumed to have stronger preferences for environmental functions than appear from the actual development of the economy; yet the model is considered realistic. This discrepancy is explained by the existence of blockages in society that prevent people's preferences for environmental functions from being completely expressed in their actions, as discussed in Section 5.2 and referred to briefly in the introduction of Section 6. These blockages can be modelled as additional constraints on welfare optimization. The resulting optimal path is the '*business as usual'* path (*b*) that was also found as the optimal solution of the case presented in the former section, but which may now be referred to as the *'blocked path'*. Again, it approximates actual economic development and might be extrapolated into the future as an economic forecast (Figure 2). In this case, however, the national income associated with the path is *not* a green national income, because society's preferences for the environment are not expressed completely and immediately. We nonetheless prefer the procedure for calculating path *b* presented here (strong preferences, blocked expression thereof), because it allows us to keep the assumption on preferences the same, which allows this path to be compared with that from which our indicator is taken. This latter path is introduced in the next section.

6.4 Strong and Perfectly Expressed Preferences for the Environment; Absolute Optimum

The blockages preventing people from expressing their preferences for the environment in their actions can probably be overcome by a persistent, dedicated and broad policy, of which price instruments and awareness-raising are important constituent components. This may well be a lengthy process. Subsequently, social, production and consumption processes must be adapted to match the preferences. These adaptations will take the form of technical measures, production shifts, production shrinkage and measures to reduce population, as discussed in Section 5.1. Implementation of these measures will, again, take considerable time. Once the measures are in place the various pressures on the environment will be reduced. After delays that may again be substantial for some environmental processes, the state of the environment will return to more stable levels that under the assumed preferences form an optimal mix with the consumption and investment packages.

As the indicator we seek should be as transparent as possible, we make it independent of assumptions regarding the dynamics that determine the time lags in the adaptations just discussed. We assume - in a manner of speech - that these adaptations are started and completed all at once in the year of investigation. The result is an unfeasible 'leap' from the blocked path *b* to the unfeasible path s on which the assumed *strong preferences for the environment are perfectly and immediately expressed,* so welfare is absolutely maximum, given the technical possibilities at the present and as expected in the future (Figure 3). Despite the unfeasibility of the leap, this path is of great interest because it has a strong signal value, as a statistical orientation point or 'beacon' to head for when devising (environmental) economic policy, since it indicates the direction of perfect fulfilment of assumed preferences for the environment. The national incomes associated with the paths of this type are the *green national incomes* corresponding to the assumed (unblocked) preferences.

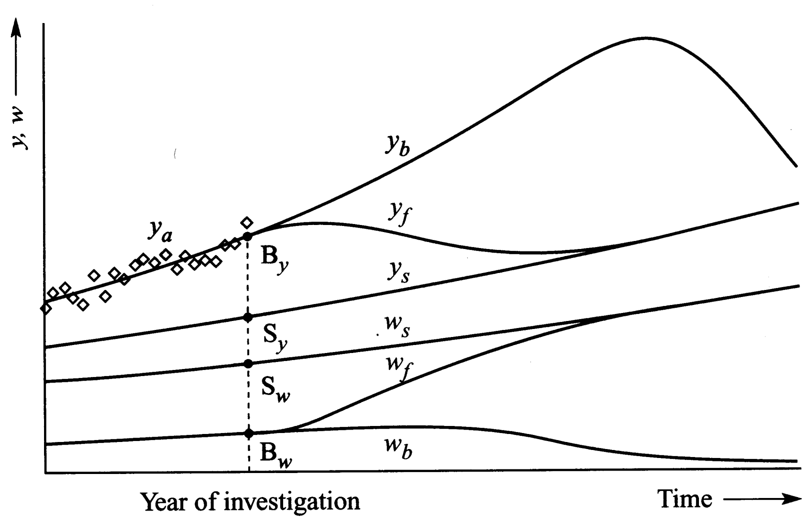

Figure 3 *Actual standard national income observations (y_a, fictitious example) compared with the net national income (y) and a welfare indicator (w) on three optimal paths, calculated with a dynamic environmental economic model. The blocked path (index b) approximates the actual path (index a) by assuming incomplete expression of preferences for the environment. These preferences are assumed to be completely expressed on the unfeasible unblocked path (index s) and the feasible unblocked path (index f). The points B_y and B_w indicate the levels of national income y and the welfare measure w on the blocked path b in the year of investigation; S_y and S_w are the corresponding points on the unfeasible unblocked path s.*

The stronger the assumed preferences for the environment, the lower the resulting green national income will be. It goes without saying that the green national incomes resulting from unblocked preferences are lower than the green national incomes resulting from blocked preferences. An example in which weak and blocked preferences for the environment are assumed is the analysis of Mäler (1991). The path of which 'our' SNI is a characteristic is one of the unblocked paths discussed here. This SNI path distinguishes itself from the other unblocked paths because adjustment of the standard national incomes in the successive years of investigation is based on the technology available in the respective year of investigation. This precludes the risk of extrapolated technological progress subsequently proving unattainable, with the attendant possibility of a collapse at some time in the future; see y_b in Figure 3. The SNI according to Hueting is lower than the other green and sustainable national incomes and the unfeasible 'leap' is therefore greater - and substantially so. This is because the path to which this SNI belongs does not involve cheaper solutions to environmental problems being anticipated in the future, as with the other *s*-paths, so that the opportunity costs are higher. Nonetheless, this path is not the lowest conceivable, for - entirely in line with the notion of sustainability - this path is concerned solely with maintaining vital environmental functions. Noise nuisance (function: 'silence as freedom from noise') is thus not included, for example, to the extent that it does not damage health, because noise does not accumulate and does not therefore undermine the living conditions of future generations. The situation is shown in Figure 6.

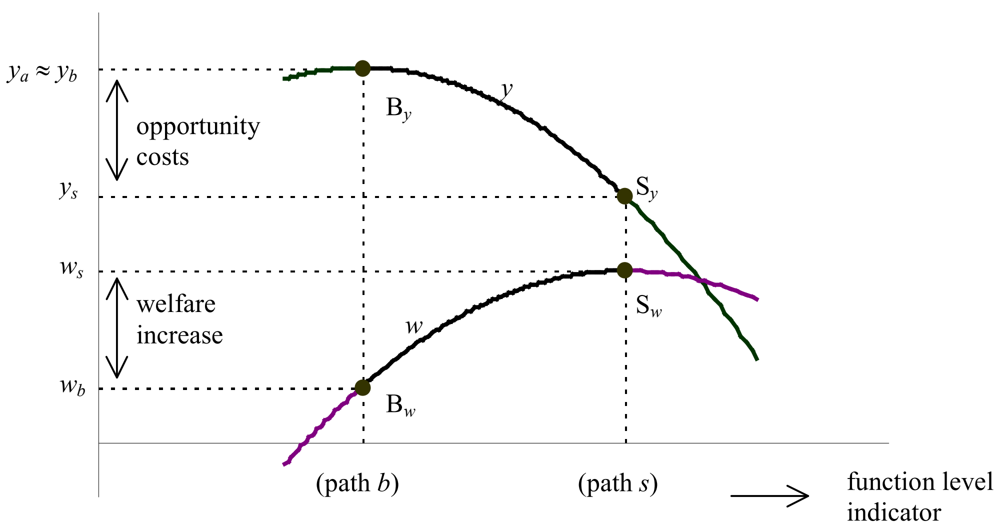

Figure 4 *Net national income (y) and the welfare indicator (w) in an (historical) year of investigation on the blocked optimal path (b) and the unfeasible unblocked path (s); y_a is the observed standard national income in that year. The points B_y, B_w, S_y and S_w correspond to those in Figure 3.*

The path *s* is found in theory by assuming that the blockages of the preferences have been overcome (that is have disappeared) and by optimizing the sizes of the modelled stocks in the year of investigation along with the measures that need to be taken in later years to maximize welfare. [5] The stocks in the modelled production, consumption and social processes consist of capital goods, durable consumer goods, employment allocation and population size. The differences between these stocks on the blocked path *b* and the unblocked path *s* in a given year are caused by the *measures available in that year,* required to reach *s* from *b* outright in that same year. The consequence of the assumption of blockages being overcome from the year of investigation onwards is that technology on path *s* in the year of investigation must be the same as on path *b* in that year.

In theory, the environmental stocks at each point on path *s* are the result of welfare maximization, as mentioned above. In practice, standards are derived or set for these stocks and related pressure standards are derived; the measures are selected on the basis of cost minimization; see Section 5.4.

As just stated, welfare on path *s* is greater than on any other path. Figure 4 illustrates this point. The welfare indicator v and its monetary approximation w have the properties discussed in Section .2. Under the simplifying assumptions discussed there, the monetary welfare measure *w* is again equal to national income on the path, plus terms due to the immediate use of environmental functions in the year of investigation, plus terms due to their use in the future. The environmental terms take the form of the modelled environmental stocks and their rates of change, respectively, both valued at the model's marginal prices, analogous to market prices, plus the costs of elimination and restoration measures, to the extent that these directly increase environmental function levels. The costs are a negative term of course. On the unblocked path *s,* the total term for future use of the environment, expressed in the rates of change of environmental stocks, is greater than on the blocked path *b,* while the total term for immediate use is probably of the same order of magnitude on both paths. Future use of the environment gains in importance if stronger preferences for the environment are assumed. On path *s,* the welfare indicators *v* and *w* are dominated by future use of the environment; this group of terms is related to the elimination costs. If these costs decrease with time, through technological progress, for example, *both* the welfare indicators *and* national income increase, and vice versa. Comparing paths in anyone year, however, for instance in the year of investigation, shows that national income decreases while welfare increases, and vice versa (Figure 4). This can be explained using the terms of the monetary welfare measure, as was done in Section 6.2.

Note that the time axis in Figure 3 might be a bit difficult to grasp. What is primarily relevant is the welfare evaluation by the current generation at the year of investigation. Here we see the jump increase in welfare (from point B to point S) when the infeasible leap to sustainability is made. The time axis shows a feasible evolution towards sustainability in the course of time, indicating a step-by-step decrease in national income accompanied by a step-by-step increase of welfare as the sustainable situation is approached. At each moment in time, welfare of course depends upon the complete 'future' development following that moment. The time axis of the graph is useful to show that the choice for the SNI is consistent over time. It may be repeated that some preference schemes could show a drop in welfare if the switch is made, but the assumed preferences underlying the SNI lead to a rise.

6.4.1 Welfare measure versus green national income

Unfortunately, the simplifying assumptions under which the welfare indicators behave so obligingly do not always apply. More important, the comprehensive dynamic environmental economic model required to perform a sufficiently realistic calculation is so complex that we are

[5] The unblocked path can be thought of as a rough approximation of the course economic development would have hypothetically taken if society had overcome its blocked preferences at the (likewise hypothetical) moment in the past when the environmental functions grew scarce, with technological development following the actual historical course, which is hypothetical indeed.

obliged to use a set of coordinated models instead of one comprehensive model, which, strictly speaking, makes welfare maximization impossible (see Section 5.4.) Consequently, standards for function levels cannot be obtained from the optimum but have to be approximated; see Section 5.4. Although it is, in principle, feasible to subsequently calculate the monetary welfare indicator w using the solution of this model system, this is still a complex task, while it probably cannot be checked whether the presented indicator really represents the maximum for the calculated path.

Another problem stems from our goal, which is to include the environment in national income in order to make this a more complete welfare indicator and one that can be compared with standard national income. This indicator consists of standard national income plus appropriate environmental terms. Comparing the values of this indicator on the blocked path b (w_b) and the unfeasible unblocked path s (w_s) is obviously not the same thing as comparing national income on both paths. Standard national income on the actual path a (y_a) or its modelled approximation on path b (y_b) can best be compared with national income on path s (y_s), that is with the green national income corresponding with the assumed preferences. Green national income y_s is lower than standard national income y_b, because of the opportunity costs of the required measures (see Figure 5). Welfare increases as a result of the 'leap' from path b to path s. Comparing the two paths b and s at any given time, a decrease in national income is found to be accompanied by an increase in the welfare indicator. The comparison shows the gap between the two paths in terms of the opportunity costs; this is a very important measure in practice, which is relatively easy to explain. This discrepancy (decrease versus increase) does not exist on the optimal path, because there the mix of environmental functions and produced goods is optimal. These considerations lead us to the conclusion that the calculation of a green national income as proposed by Hueting (1974a) and Hueting et al. (1992, 1995a, 1995b) is the best practicable approach for our present purpose.

6.4.2 Prices with and without measures

The theory discussed above makes clear that the welfare indicators v and w for path b or s at a given instant in time are expressed in shadow prices valid for the same path and the same instant (see Section 6.1). In other words, v_s and w_s on the 'indicator path' s are expressed in the shadow prices arising *after* implementation of what were referred to in Section 5.1 as elimination and compensation measures and subsumed under the headings technical, shift, shrink and population. Above, however, the welfare indicators v_s and w_s were abandoned in favour of green national income, that is national income on the unfeasible unblocked path s (y_s), In comparing (approximated standard) national income on the blocked path b (y_b) and (green) national income on path s (y_s) in the year of investigation, the comparison must be between points Band S in Figure 5.

Bearing in mind the close relation between the welfare indicator and national income, there are now grounds for concluding that this comparison of real income should be done on the basis of the prices arising *after* implementation of the measures (point S in Figure 5). The prices resulting after internalization of the costs of the measures (including levies) reflect the relative importance of the environmental functions better than the prices in the actual situation on path b: the 'new' price ratios are those on the sustainable path s. Shifts to more environmentally friendly production, particularly, are weighted more appropriately in this way, provided the model used computes all relevant production shifts.

This point can be elucidated as follows. It follows from Hueting (1981) and Hueting et al. (1992) that the bulk of national income growth is generated by industries that cause the greatest losses of environmental functions, both in production and in consumption. The increase in productivity in these

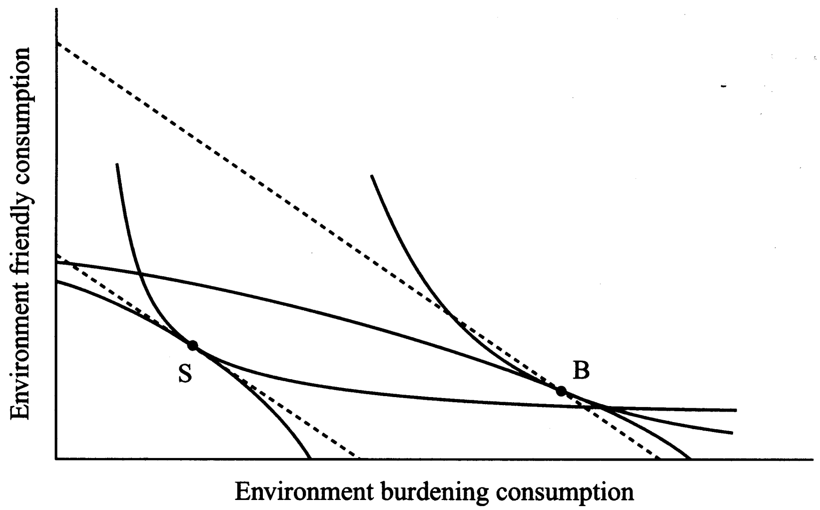

Figure 5. *The optima B and S discussed in the text as calculated by an environmental economic model under the assumptions made on preferences and blockages. In point B, approximating the actual situation in the study year, blockages prevent key preferences for the environment from being expressed. In S, these blockages are overcome. The (convex) indifference curves through these optima reflect the different forms of the welfare functional under the respective conditions. Each optimum lies on a different boundary of production possibilities (concave lines), determined by the availability levels of environmental functions. The dashed lines indicate the levels of consumption at both optima, using the prices at the optimum with blockages overcome (point S); these levels represent the standard national income (through point B) and the green or sustainable national income (through point S). Lines of constant income through both optima using prices of the optimum with blockages in effect (point B) are not drawn.*

industries, measured in terms of goods produced, is much greater than elsewhere in the economy, so the real prices of these products decrease strongly (see Section 2.5) and, with them, the price ratio between environmentally burdening and less burdening products. As a result, any shift to environmentally friendly products has a negative impact on the volume of national income (Hueting et al. 1992). This impact can be approximated by weighting using the (new) prices on path *s*, in which the costs of function restoration are internalized; as a result, the real prices of environmentally burdening products increase, as does the price ratio between environmentally burdening and friendly products. The latter price ratios reflect the situation on the sustainable path better than the price ratios on the actual path. This clarifies and improves the original concept of calculation of cost involved in production shifts.

6.5 Strong and Perfectly Expressed Preferences for the Environment; Feasible Optimum.

As indicated in Section 6.4, adaptation of the modelled stocks in production, consumption, social and environmental processes to ‘removal’ of the blockages may take a long time. From this perspective, large instantaneous changes in these stocks are unfeasible. If this restriction is respected, welfare maximization results in a feasible unblocked path *f*, which starts in the actual situation as observed in the year of investigation. In that year the stock variables in the environmental and the production and consumption parts of the model have the same values on path *f* as on the blocked path *b,* and consequently approximately the same values as in reality.

The first part of the feasible unblocked path *f* is a *transition* phase, in which measures are being implemented, environmental functions are recovering, national income is falling and welfare is rising. This transition is followed by a more stable phase in which these variables are more or less consolidated; in this phase the path comes to approximate the unfeasible path *s,* which obviously becomes feasible by that time. In Figure 3, path *f* is assumed to approach path *s* asymptotically.

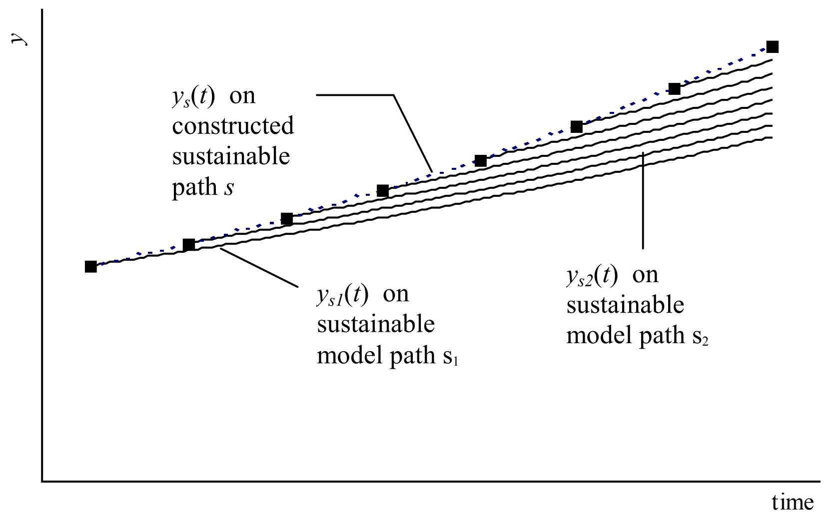

Figure 6. *Construction of the unfeasible sustainable path s and the corresponding sustainable national income y_s. In the calculation of the sustainable national income according to Hueting, technological progress is ex ante assumed zero on each model path. Consequently national income on these paths ($y_{s1}(t)$, $y_{s2}(t)$ et cetera) are constant and their graphs are horizontal lines. National income on the ex post constructed sustainable path s, however, may still rise due to technological progress*

The feasible unblocked path is included in Figure 3 for clarification because it is a vital element of understanding the indicator, especially when the indicator is presented to the public. Calculation of the feasible unblocked path is obviously not part of our research effort. Nonetheless, an indication of how such a path can be constructed is given in de Boer (1999) for the case of global warming. The standard is illustrated by comparing it with a feasible unblocked emission path. A dynamic model of the factors blocking preferences is not available, and so these blockages are assumed to be overcome outright in the year of investigation. The storage of carbon and heat in the oceans enables the feasible greenhouse gases emission path to lag centuries behind without causing losses of function that would otherwise prevent the long-term, optimal, stable emission value from being reached.

6.6 Strong and Perfectly Expressed Preferences for Sustainability; Absolute Optimum; SNI

This is a special case of that discussed in Section 6.4. Thus, we again assume that the blockages on preferences are overcome outright and that the measures required to reach the preferred path *s* are all implemented at once in the year of investigation, in an unfeasible 'leap', so to speak. In this case, though, we assume absolute preferences for sustainability, which we define loosely as the minimum availability of *vital environmental functions* that can be sustained forever in the future, either at a *constant* or at an *ever-increasing* level. In theory 'the future' is infinite, but in practice we limit it to the time span in which the influence of geophysical processes on the environment is unlikely to exceed human influence, say several millennia or longer. Moreover, we proceed from the special form of the definition that is limited to minimum *constant* levels of environmental functions; these represent our 'sustainable levels'. By 'absolute preferences for sustainability' we mean that people's preferences for the sustained availability of environmental functions far exceed their preferences for the availability of consumption goods or environmental functions in the year of investigation, or in any other isolated year.

The theory discussed in the previous sections can be applied to the problem of sustainability. See, among others, Stiglitz (1974), Dasgupta and Heal (1974, 1979), Hartwick (1977, 1978), Pezzey (1994) and Gerlagh (1999); Zeelenberg et al. (1997) provide a short overview. This theory indicates that an absolute preference for sustained availability of environmental functions implies sustained availability of consumption goods. The reverse statement, that an absolute preference for sustained availability of consumption goods implies sustained availability of functions, can probably be proven, because production is impossible in the absence of environmental functions. Although these two statements look very similar, they reflect the fact that sustainability can be defined in several ways, leading in turn to differences in the ensuing paths *s*. In every definition of sustainability, a distinct group of variables directly influencing welfare or directly related to welfare is kept constant forever: the welfare indicators *v* or *w,* environmental function levels, levels of actual use of the environment, flows of consumption goods, aggregate consumption, or net national income. Sustaining one of these variables at a maximally attainable level is at the expense of the other variables, although these are sustained as well. This trade-off also occurs if a group of variables, such as function levels, use levels or consumption flows, are sustained at maximally attainable levels. This requires multi-objective optimization, leading to a set of possible outcomes (paths). However, welfare maximization under assumed absolute preferences for sustained instantaneous welfare, or for sustained aggregate consumption, or for sustained national income, leads to a unique and different result each time, namely a maximum feasible sustainable level of, respectively, instantaneous welfare, aggregate consumption, or national income. The model solution is a different *sustainable path (s* again) for each of these cases. The function levels remain constant on each sustainable path, despite the fact that this was not explicitly assumed as the goal of the preferences, but these levels are in general different for each sustainable path. All model variables on such a sustainable path remain constant, it should be added, with the notable exception of stocks and extractions of non-renewable resources. Their function levels are sustained as well, however; see Section 7.

Sustainable function levels can therefore be found in theory; they follow from the process of welfare maximization in a comprehensive environmental economic model, under the assumption of strong preferences for sustainability. By adopting a specific definition of sustainability, we arrive at unique function levels. We define sustainability as the solution (path) of the environmental-economic model in which national income is maximal and is sustained at that level forever, under constant technology, employment and population. This national income is the SNI as defined in Section 1.2, point 1 under 'Consequences of the Principles'. The model then should indeed show that the functions are sustained above or at the minimal levels that nature can support (see Section 1.2, point 5 under 'Consequences of the Principles'). The goal, consistently, is to ensure that *possible* (potential) future uses of the environment are not lost. Future generations can then decide for themselves whether they wish to step up their level of usage. This approach thus involves minimum sacrifice (in terms of income, that is consumed goods) for the present generation.

In practice, as explained in Section 5.4, the comprehensive environmental-economic model required to compute maximum welfare and the corresponding sustainable function levels is far too complex to perform such optimization, even more so because a sustainable optimal path is not only an optimum but a limit case as well. Studies using simple environmental economic models that do allow for such optimization (Pezzey, 1994; Gerlagh, 1999) give us the following grounds for a simpler - and therefore feasible - one-way computation procedure. First, the sustainable levels of use of environmental functions may be interpreted as the regeneration capacities of nature for these types of use. Second, in theory these sustainable levels constitute the sustainability standards to be applied in the practical calculation using linked models (Section 5.4). Third, no attempt has yet been made to derive realistic standards from simple environmental economic models, but if one were to do so, these standards would probably turn out to allow higher activity levels (and therefore a higher SNI) than the standards we establish in our practical approach. The difference is due to the use of optimization in the simple models on the one hand and the application of the precautionary principle, some additional plausible assumptions and the more detailed environmental models of the practical approach, on the other. This approach is explained in Section 7.

Within the theory discussed up to now, it appears to be possible to find a sustainable path at a low enough but still positive rate of technological progress: vital environmental functions are maintained and (real) production and consumption increase without ever collapsing. Generally, technology on the sustainable path *s* progresses more slowly than on the blocked path *b.* For each year of investigation an optimal sustainable path is found ($s_1, s_2, \ldots, s_n$), starting in that year with technology equal to that on the unblocked path *b,* but with diverging technology in all later years. Only the level of y_s at the starting point of each path is taken as 'SNI' for the respective year of investigation. For later years of investigation, new sustainable paths with ever-higher levels of y_s at their starting points will most probably be found, as a result of technological progress. Connecting the starting points of the sustainable paths *ex post* yields the realized development of the sustainable national income or 'SNI' (as well as the realized developments of the other model variables under sustainability). This process is elucidated in Figure 6.

This procedure may be theoretically sufficient to arrive at a sustainable income, but it involves the risk of the theory proving erroneous, in that the projected technological progress needed to preserve the environmental functions may in the long run not be realized and a collapse may occur at some time in the future. Compare y_b with y_s in Figure 3. While some of the authors mentioned in this section accept this risk or just acknowledge it without taking the consequences, others, like the present authors, deem the risk too high. We therefore consider it appropriate to calculate the sustainable national income for each year of investigation (*n*) under the assumption that technological progress on the corresponding sustainable path (s_n) is *zero* (except for non-renewable resources; see Section 7). As before, connecting the starting points of the sustainable paths s_n *ex post* yields the realized development of sustainable national income y_s as we advocate it (SNI according to Hueting). It may rise in the course of time, as a result of actually realized technological progress, not anticipated in the model paths $s_1, s_2, \ldots, s_n$.

6.7 Basic Assumptions for Practical Calculation of SNI

Hueting et al. (1992) give a number of basic assumptions required for practical estimation of a country's SNI. See also Van Ierland et al (eds.), Verbruggen et al., Edward Elgar (2001). We mention the most important of these here; some have already been discussed.

- The transition to sustainable activities is made in every country in the world simultaneously and in the same way. This prevents the transfer of burdening activities from one country to another. In the model (Van Ierland et al (eds.), Verbruggen et al., Edward Elgar (2001)), an approach is taken in which the sustainability costs of import and export turn out to be approximately equal, thus meeting a proposal of ours.

- Sustainability standards for environmental pressures are set for the region in which they affect functions, that is national, regional or global. A given country's contribution to meeting a regional or global standard is proportional to its contribution to regional or global pressure.
- Transition costs are not taken into account. The SNI is associated with the calculated sustainable path, which runs at a certain distance from the current path and does therefore not involve any *transition* to the sustainable path. Therefore the costs of destruction of existing capital goods and the formation of new capital goods, for instance, are not included in the SNI. However, the costs of eliminating effects that have accumulated in a long period, such as soil pollution, *are* included as costs, likewise distributed over a long sanitation period.
- The employment rate is kept constant. Normally environmentally friendly producing and consuming requires more labour, because attaining a given end, for example raising crops or bridging a distance, requires with environmental protection much more labour than without (see 'Three myths', Chapter 3, this volume). However, just now we keep constant all variables that are not relevant for the main Issue.
- Technology is kept constant, except where technological progress is necessary to sustain environmental functions, that is in the development of substitutes for non-renewable resources (see Sections 6.6 and 7).

7 SUSTAINABILITY STANDARDS

As we saw in Section 5.4 as well as Section 6.6, assumptions regarding preferences for the availability of environmental functions allow for a one-way approach involving the application of standards. Similarly, assumed absolute preferences for sustained availability of functions can take the form of sustainability standards for these functions. The demand curve of Figure 1 is then replaced by a vertical line; see Figure 7.

Under such preferences for sustainability, the optimal function levels are sustained forever and the green national income to be calculated is turned into the (maximally attainable, *ad infinitum)* sustainable national income. As it is difficult to estimate or even quantify these levels, it is assumed that their existence is guaranteed by two slightly more practical conditions, which must both be satisfied in the present and in the future. The first is that the extinction of biological species at the global level may not be accelerated by human influence; see below. This condition puts certain demands on the state (quality) of the environment. The second condition is that any changes in the state of the environment may have only a minor, acceptable impact on human health. Health is generally described in the modern literature as a state of well-being extending beyond the mere absence of illness. Nonetheless, most 'maximum acceptable risk' levels in force for environmental state variables are construed with the aim of preventing illness. Be this as it may, both the species condition and the human health condition impose bounds on the acceptable variation in the state of the environment, however imprecise. Generally, the limits set for different environmental problems have to be tuned to each other in order to avoid combinatorial (synergetic) effects, leading to negligible risk levels instead of maximum acceptable risk levels (Beek, 1995). From these limit values, *sustainability standards* for the various forms of environmental pressure can then be derived as discussed above, that is with the aid of environmental models, and subsequently the sustainable national income can be calculated by imposing these standards on the economic activity model (see Section 5). Figure 8 presents an overview of the practical calculation procedure used at present.

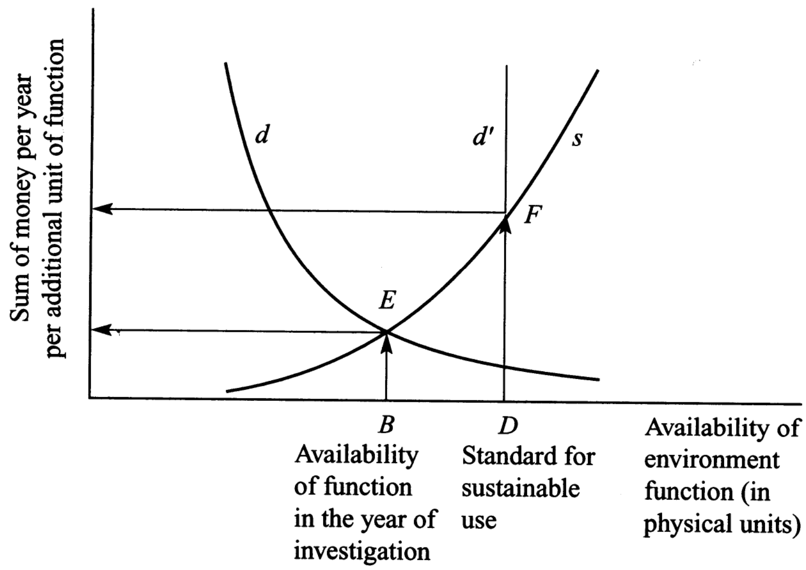

Figure 7. *Translation of costs in physical units into costs in monetary units: s = supply curve or marginal elimination cost curve; d = incomplete demand curve or marginal benefit curve based on individual preferences (revealed from expenditures on compensation of functions, and so on); d' = 'demand curve' based on assumed preferences for sustainability; BD = distance that must be bridged in order to arrive at sustainable use of environmental functions; area BEFD = total costs of the loss functions, expressed in money; the arrows indicate the way via which the loss of environmental functions recorded in physical units is translated into monetary units. The availability of the function (B) does not need to coincide with the level following from intersection point (E)*

We hold that sustainability standards can be scientifically established. See Hueting et al. (1992) and Hueting and Reijnders (1998) for several, examples and Bosch (1994), de Boer and Bosch (1995) and Dellink and Van der Woerd (1997) for a number of quantified standards. Thus sustainability, defined as the situation in which vital environmental functions remain available *ad infinitum,* is an objective concept, to the extent that the natural sciences can be deemed objective (Hueting and Reijnders, 1998). As Costanza and Patten (1995) and Hueting and Reijnders (1998) have argued, in the context of the interaction between human activity (loosely referred to as 'the economy') and the environment, criteria for sustainability are to be regarded as assumptions. Scientifically, therefore, it can only be established *ex post* whether the measures taken to fulfil these criteria, or standards, were indeed adequate.

As argued earlier, the availability of environmental functions depends on the quality, quantity and spatial capacity of the environment (or physical surroundings or environmental capital), which is after all the vehicle or carrier of these functions. Environmental functions remain available for as long as this environmental capital (in a broad sense, see par. 6.4) remains intact. Sustainability standards can thus relate to the qualitative, quantitative and spatial aspects of the physical surroundings, and environmental models then used to translate these standards into standards for human activities:

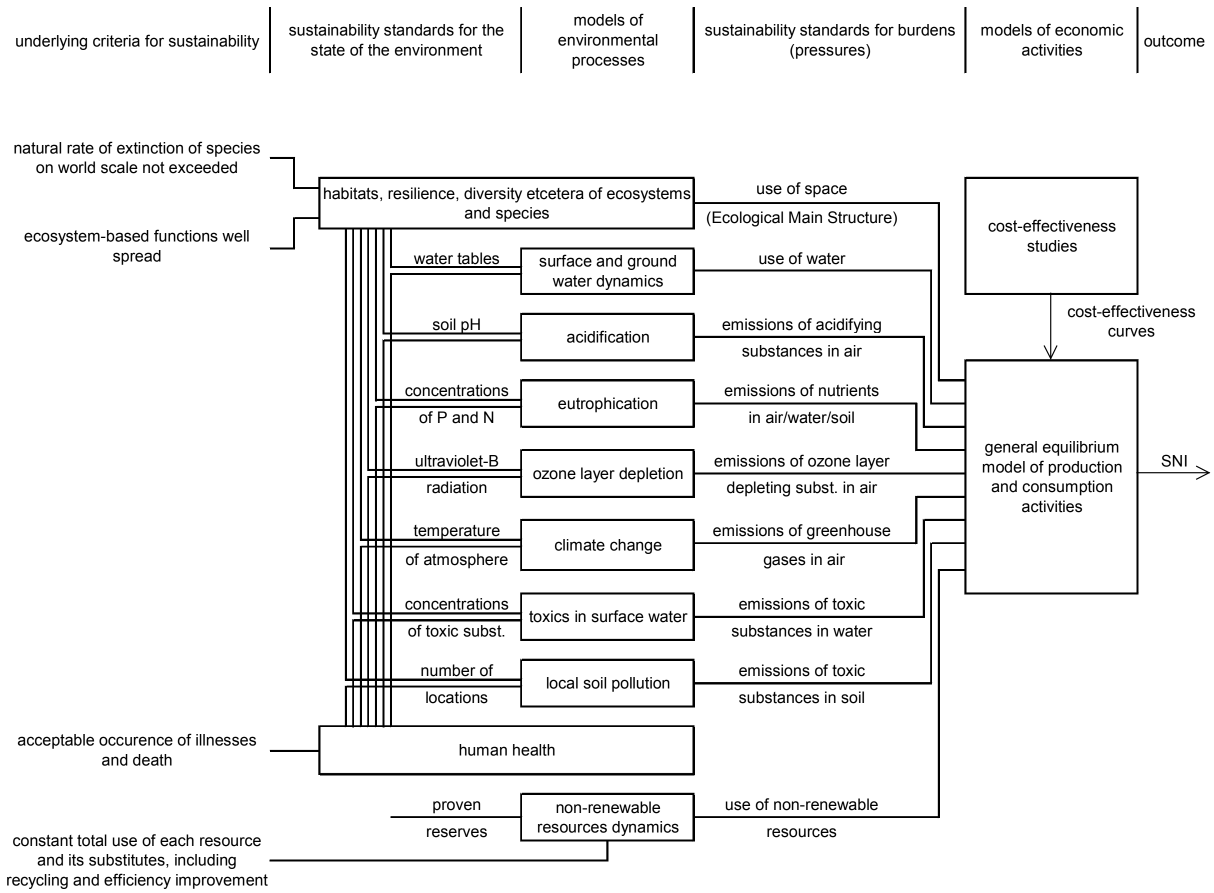

Figure 8. *Main steps in the calculation of the SNI (simplified). Blocks represent models of (sets of) processes, lines represent (sets of) variables. Calculation order is from left to right, unless arrows indicate otherwise. Crossover effects between environmental problem areas (themes) are not shown.*

emission or withdrawal of substances, heat, species, and so on into or from the environment (see Section 4), for example, or land use, or use of raw materials such as crude oil or copper. State variables are related to pressure variables using environmental models. The elimination measures mentioned in Section 5.1 reduce the pressure variables to the permitted or sustainable level of environmental burdening. In doing so, a distinction is made between renewable and essentially non-renewable (that is very slowly forming) resources.

Sustainability aims to maintain the functions of environmental capital provided by nature (in a broad sense, see par 6.4). As rightly pointed out by Goodland, this definition of sustainability goes beyond ‘sustainable yield’, a notion that is current in fishery and forestry circles. Sustainability applies to aggregate natural capital, not just to a few species of fish or timber trees (Goodland, 1995). In the case of forestry, for instance, it includes biodiversity, ecosystem integrity, water source and water moderation values and contributions to geochemical cycles (including the carbon cycle) and climate. Apart from this, a level can be established above which a (plant or animal) species can be harvested sustainability (see below). Thus there is obviously a level, defined as a number of individuals of a species, below which the species is threatened with extinction; arriving below that level is unsustainable, remaining above that level is sustainable. Together with the condition that harvesting a species should not disrupt the ecosystem of which it forms a part (see Odum, 1971), this yields the sustainability standard for the species.

In establishing sustainability standards, we have taken as the basic point of departure the natural regeneration capacity of the environment: as long as this remains intact, environmental functions will remain available. The following examples illustrate how this quantity and the acceptable, that is sustainable burden can be established. It can, for instance, be established that the rate of erosion of topsoil may not exceed the rate of formation of such soil due to weathering. Similar consumption standards can be set for other natural resources. With respect to how sustainability relates to species, then, the standard holds that the rate of human-induced extinction should not exceed the rate at which new species come into existence. This boils down to preserving all the species still alive today, for it is assumed that during the past several thousand years conditions have been such that, leaving aside drastic human intervention for the moment, the number of new species must certainly have at least equalled the number of species lost to extinction (Raup, 1986; Hawksworth, 1995). However, in contrast to the situation prior to human intervention, the rate at which natural species are becoming extinct is today at least a factor 10000 higher than the rate at which new species are evolving (Raup, 1986). In the absence of drastic human intervention, the quantity and quality of renewable natural resources such as groundwater or biomass (including wood) generally show a substantial degree of constancy. In the absence of human intervention, environmental capital is thus characterized by a substantial degree of constancy or even increase.

With regard to pollution, too, criteria can be established. Acid precipitation, for example, should not exceed the neutralizing capacity of the soil. Likewise, there should be no exportation of risks to future generations through pollution of groundwater that is to serve as a source of drinking water for those generations. In many cases, the accompanying environmental burden can be determined with great accuracy. There is a wealth of data on the rate at which new fertile soil is naturally formed and on the neutralizing capacity of natural soils, and these data enable a precise indication to be given of the admissible environmental burden due to erosion and acid rain (Reijnders, 1996). In other cases we have insufficient knowledge to make firm pronouncements. For example, at present we can do no more than give a rough indication of the conditions under which plant and animal species are able to survive (Hawksworth, 1995; de Boer, 1979). On the basis of the best available global circulation models it can be calculated that worldwide emissions of carbon dioxide must be reduced drastically to achieve stabilization of the global warming process, but an exact percentage cannot be given (de Boer, 1996). Similarly, shortcomings in our toxicological knowledge mean that we cannot fully analyse the risks associated with polluted groundwater. However, this does not detract from the fact that improved scientific knowledge can lead to a more precise establishment of standards for sustainability.

All in all, it is feasible to establish scientifically the environmental burden that is ‘admissible’ on the basis of the objective of sustainability. Hueting and Reijnders (1999) describe how the precautionary principle can be employed if there are uncertainties and inadequate knowledge in the context of sustainability.

In the case of very slowly forming natural resources such as crude oil and copper, which are to all intents and purposes non-renewable, ‘regeneration’ can take three forms: efficiency improvements, recycling and, over the longer term, substitution of one form of environmental capital by another that can provide the same functions. Familiar examples of substitution include solar power and glass fibre for crude oil and copper wire, respectively.

This can be expressed as follows in a numerical value. Sustainability of non-renewable natural resources means that in a given period only as much may be withdrawn from the stock as substitutes for the resource are expected to be developed in the long run as well as new potential for recycling and conserving the resource (improvement of efficiency). In this way the functions of a resource available in the year of investigation are maintained at the same levels in the future. In practice this can be worked out by, for instance, taking from a period in the past the quantity of possible uses (for example heating, transportation, and so on expressed in effective energy) that has become available through efficiency improvement, substitution and recycling and then assuming that the relative rates of efficiency improvement, substitution and recycling will be the same in the future. [6] There follows from this a maximum permissible annual rate of extraction that can be used as a sustainability standard. In a formula: $e(t_0) \leq r(t_0).S(t_0)$, in which $e(t_0)$ is the extraction rate in year t_0, $r(t_0)$ the relative rate (or rate coefficient) of reduction of consumption of the resource (resulting from substitution, and so on) at *a constant level of activities,* and $S(t_0)$ the stock in year t_0 (Tinbergen, 1990).

This formula is applied at the global level. Standards for individual countries can be subsequently derived by applying the general rule, given in Section 6, that a country's share in meeting the global standard should be equal to its share in total extraction.

In practice, the factor $r(t_0)$ is determined mainly by efficiency improvements, as substitution and recycling have still made only a very minor contribution in recent years. The aforementioned assumption that the line recording use of the resource in the past can be continued into the future with, basically, a constant annual rate of efficiency improvement, implies that as time progresses the same material output can be achieved at a fraction of current resource use. In a study on the development of energy efficiency, Tinbergen (1990) found a practical value of 1.67 per cent for this improvement rate. From this it follows that in 60 years' time the *present level of production* can be achieved with 37 per cent and in 315 years' time with 0.5 per cent of current fossil fuel consumption: $S(315) = (1-0.0167)^{315} \times S(0) = 0.005 \times S(0)$. Such enormous efficiency improvements (63 per cent and 99.5 per cent, respectively) seem rather unlikely. In the context of sustainability, 315 years is a very short time. The probability that humankind will sooner or later have to manage without the functions of the non-renewable natural resources, if no substitutes are found, is comparable to the certainty that humankind will sooner or later have to manage without the functions of the soil in those areas where the degree of erosion is higher than the rate of soil formation.

Because efficiency improvements alone are thus inadequate to achieve sustainability, it has been proposed that, in the calculation of SNI, additional measures must be taken for the development of substitutes (Tinbergen and Hueting, 1991). We here adopt this proposal, applying the following procedure. For each resource, statistical data are used to establish the rate at which substitution (the ultimate solution) has taken place over the past 10 to 20 years and the annual cost this has entailed. It is then calculated how long it would take, at this rate, to completely replace the resource (1). Next, it is calculated how long it will take for the resource to be depleted, at the *current* level of production (2). Then (1) divided by (2) yields a rough approximation of the required 'acceleration factor' for the development of substitutes in time for them to replace the functions of the resource when it is depleted. This factor multiplied by the statistically established annual cost of substitute development yields the sum that needs to be reserved for this purpose.

The figures thus found can be no more than rough estimates, of course. In the context of non-renewable natural resources, though, this is an approach that does justice to the principle of sustainability, which is the point of departure of our estimates. Our approach would be comparable with that of Solow (1974), Hartwick (1977, 1978) and others, if the latter were to exclude unfeasible substitution of renewable resources by other resources and by capital (see below), that is if they were to abandon their faith in the extreme areas of formal production functions.

When using the concept of environmental function, the only thing that matters in the context

[6] This involves an assumption about technological progress in the fields of substitutes and recycling. This exception to the point of departure that the estimation should be based on the technology that is operational in the year of investigation, or shortly thereafter, is the only way to arrive at a sustainability standard for non-renewable resources. The only other option, to pass on stocks untouched to future generations, is unfeasible and also makes no sense, because this would then have to be carried through *ad infinitum.*

of sustainability is that vital functions remain available. What does the conservation of vital functions imply for the distinction between renewable and non-renewable resources and for the distinction between strong and weak sustainability?

As for renewable resources, functions remain available as long as their regenerative capacity remains intact. Regeneration in relation to current use of 'non-renewable' resources such as crude oil and copper that are formed by slow geological processes is close to zero. 'Regeneration' then takes the form of efficiency improvement, recycling and, in the final instance, developing substitutes. The possibilities for this are hopeful (Reijnders, 1996; Brown et al., 1998). So, economically speaking, there seems to be no essential difference between the two types of resource: sustainability is attained if their functions remain available.

Advocates of 'weak sustainability' take the line that all elements of the environment can ultimately be substituted by man-made alternatives, implying that restoration of lost elements can be postponed in anticipation of cheaper substitutes provided by future technologies. However, the life support systems (see note 2) of our planet, on which a number of vital functions depend, are not substitutable at all (Lovelock, 1979; Roberts, 1988; Reijnders, 1996). The same holds for most of the functions of natural ecosystems, especially in the long term (see, for example, the remark on the function of 'gene pool' in Section 4). Consequently, there can be no such thing as 'weak sustainability' for the functions of these systems.

Advocates of 'strong sustainability' hold it to be impossible for humanity to substitute many of the elements of the natural environment. In its strictest form, however, this implies that stocks of non-renewable resources should remain fully intact, an unrealistic aim, as already discussed. Consequently, strong sustainability for non-renewable resources seems to be impossible.

In conclusion, there seems to be only one kind of sustainability, whereby non-renewable resources must gradually be substituted by other elements of our physical surroundings in order to guarantee the availability of functions, and substitution of a large class of renewable resources is impossible, particularly life support systems, including ecosystems.

The question is often asked whether sustainability standards should be applied locally or globally. This depends on the scale at which the functions in question should be substituted. For instance, preservation of the function 'soil for growing crops' requires local application of the standard for erosion (the erosion rate may not exceed the soil formation rate; see above), because exceeding the standard at one place cannot be compensated by remaining under this standard elsewhere. Crude oil, on the other hand, is a global resource, so in this case the sustainability standard, effectuated through efficiency improvement and substitute development, should be applied worldwide.

8 CONCLUSIONS

1. The SNI according to Hueting is the maximum net income which can be sustained on a geological time scale, with future technological progress assumed only in the development of substitutes for non-renewable resources, where such substitution is indispensable for sustaining environmental functions, in turn essential for sustaining income. This can only be realized if a vast majority of the subjects have an absolute preference for sustainability. The concept is theoretically sound as well as operational, although it involves considerable statistical effort. Its theory is in line with so-called general growth theory.
2. The pronounced quantitative differences between the SNI according to Hueting and other green national incomes can be traced back largely to different views *vis-à-vis* the position of the optimal path of the economy and thus to different assumptions regarding the

strength of preferences for the environment and the associated question of recognition, or otherwise, of the blockages referred to in Section 5.2. Authors such as Repetto et al. (1989, 1991) and Mäler (1991) assume that preferences for the environment are fully expressed in actual expenditures on compensation for and elimination of loss of function and in the financial damages incurred as a result of such loss. According to these authors, then, society is on the optimal path and there are no blockages on preferences for the environment. The standard national income is then corrected for the aforementioned costs, to the extent that these are actually incurred by government and private households. By applying this correction, a better measure is obtained of changes in the volume of scarce goods, being one of the factors influencing welfare. Others, such as Stiglitz (1974), Hartwick (1977, 1978), Asheim (1994), Pezzey (1994) and Pezzey and Withagen (1995) recognize that the optimal path is a sustainable path if strong preferences for sustainability are assumed. Comparison of the sustainable national income associated with this path with the standard national income associated with the actual path is hampered by the fact that the paths are calculated using different welfare functions, however. We therefore consider it more logical to consistently assume preferences for the environment to be strong enough for the optimal path to be sustainable. In our perspective, the existence of the suboptimal path in the real world is explained by the blockages preventing these preferences from being expressed; this in contrast with the sustainable path, where these blockages have been overcome. The pronounced differences in outcome are thus explained mainly by major differences in assumptions regarding preferences for the environment, with other theorists either denying the existence of blockages or, if blockages are indeed recognized, assuming far weaker preferences for the environment than we do. In our interpretation, the latter holds *inter alia* for El Serafy (1989, 1995). Under the assumption of strong preferences for sustainability, application of the theory of such authors as Stiglitz, Hartwick, Pezzey, Asheim and Withagen will yield an SNI of similar magnitude as the SNI according to Hueting.

3. If the underlying assumptions are rendered explicit, environmental valuation and green accounting can yield valuable and comprehensible information. If they are left undeclared, these disciplines will become discredited because of the incomprehensibly wide range of quantitative outcomes they yield.

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