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* Département des Études Économiques d'Ensemble - Timbre G201 - 15, bd Gabriel Péri - BP 100 - 92244 MALAKOFF CEDEX

** Observatoire Français des Conjonctures Economiques, 69 quai d'Orsay, 75340 PARIS CEDEX 07.

Département des Études Économiques d'Ensemble - Timbre G201 - 15, bd Gabriel Péri - BP 100 - 92244 MALAKOFF CEDEX - France - Tél. : 33 (1) 41 17 60 68 - Fax : 33 (1) 41 17 60 45 - CEDEX - E-mail : d3e-dg@insee.fr - Site Web INSEE : http://www.insee.fr

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Abstract

The Stiglitz report on the measurement of economic performance and social progress has been recently released. Part of this report is devoted to the issue of measuring sustainability. One of the sustainability indexes it considers is the concept of adjusted net savings (ANS). Compared to other indexes, it has the advantage of being truly concentrated on measuring sustainability *stricto sensu*, avoiding a frequent confusion between the measurement of sustainability and the measurement of *current* well-being. It also relies on an explicit accounting framework, and it includes all potential dimensions of global sustainability: physical and human capital accumulation, as well as changes in quantities or quality of environmental assets. But the major stumbling block is the definition of prices that are needed for valuing these different groups of assets. In a context of notoriously imperfect markets, these prices cannot be observed. They have to be imputed. This paper recalls what are the theoretical requirements for this imputation, and that they are quite strong: what is needed is no less than a full model projecting long term interactions between the economy and the environment. We use this observation as a point of departure for explaining why consensus on sustainability measurement is so difficult to reach, and how this argues in favor of more eclectic approaches mixing the ANS with some complementary indicators focusing on environmental issues.

Keywords: sustainability, adjusted net savings, imputed prices

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Épargne nette ajustée et autres indicateurs de soutenabilité : quelques repères théoriques

Résumé

Le rapport Stiglitz sur la mesure de la performance économique et du progrès social a été récemment rendu public. Une partie de ce rapport a été dédiée à la mesure de la soutenabilité. L'un des indices de soutenabilité qu'il considère est le concept d'épargne nette ajustée (ENA). Comparée à d'autres indices, elle a l'avantage d'être complètement focalisée sur la soutenabilité au sens strict, évitant une confusion fréquente entre soutenabilité et mesure du bien-être courant. Elle bénéficie également d'un cadre comptable explicite et elle inclut l'ensemble des déterminants potentiels de la soutenabilité : l'accumulation de capital physique et humain, aussi bien que l'évolution de la quantité ou de la qualité des actifs environnementaux. Mais le problème majeur qu'elle soulève est celui des prix à utiliser pour valoriser ces différents types d'actifs. En présence de marchés notoirement inefficients, ces prix ne peuvent être observés. Ils doivent être imputés. Ce texte rappelle quelles sont les exigences théoriques de cette imputation. Elles sont considérables puisqu'il ne faut pas moins qu'un modèle de projection complet des interactions à long terme entre l'économie et l'environnement. Nous nous appuyons sur ce constat pour expliquer la difficulté à trouver un consensus sur la mesure de la soutenabilité et nous examinons comment ceci plaide en faveur d'une approche éclectique combinant l'ENA et un ensemble d'indicateurs complémentaires focalisés sur les aspects environnementaux

Mots-clés : soutenabilité, épargne nette ajustée, prix imputés

Classification JEL : E01, Q01, Q56

Sommaire

Introduction

Among the many existing approaches to sustainability measurement, Adjusted Net Savings (ANS) is the one that is the most frequently favored by economists (e.g. Arrow et al., 2004 or, in French, d'Autume and Schubert, 2008). It consists in computing an extended notion of national savings that combines net capital accumulation in the usual meaning of the term with various kinds of dissavings such as consumption of non-renewable fossil resources, degradations of the environment or, on the positive side, the accumulation of knowledge or human capital. This index can also be understood as the net variation of an encompassing concept of global or "inclusive" wealth combining all the different assets that matter for production and quality of life. This index of net adjusted savings can also be amended to incorporate consequences of purely exogenous technical progress or of population change. Technical progress can help sustaining growth or well-being even when the global capital stock is declining. Concerning population change, the usual practice is to consider that sustainability requires maintaining inclusive wealth per capita, meaning that a positive population growth rate must be compensated by larger savings.

Such a way of quantifying sustainability has several arguments in its favor:

- Compared to the eclectic approaches of large sustainability dashboards[1], it has the advantage of summarizing the problem with a single number. This undoubtedly means a huge loss of information, but one may argue that this is the price to pay for being able to sum-up sustainability issues in a way that can compete with the simple one-dimensional message of standard GDP.

- Compared to a-theoretical composite indexes, it has the advantage of being built on a relatively well-defined notion of what sustainability is. The underlying conception of sustainability is that development is durable if we leave enough resources to warrant for next generations opportunities at least equal to the ones that we have had. Other synthetic indexes generally do not have such a clear underlying conceptual basis

- The ANS approach is also better suited for sustainability measurement than the concept of "green" Net National Product. What green NNP intends to measure is production net of natural resources depreciation. Contrary to a frequent belief, green NNP is not a direct measure of sustainability. It is not possible define a threshold of green NNP below or above which an economy can be considered as sustainable or not. What is required to assess sustainability is not a concept of production, gross or net. What is required is a comparison between a level of true production and a level of consumption, i.e. a savings index. This is exactly what the ANS approach tries to do.

This ANS approach to sustainability remains however challenged and criticized on many grounds. Quite a large amount of literature has been devoted to its discussion (e.g. Dietz and Neumayer, 2004; Pezzey and Burke, 2008) and the main criticisms can be regrouped under three headings.

One first point is that merging variations of very different assets into a single monetary figure requires putting money values on each of them, i.e. a system of relative prices, and such prices are difficult to compute in an adequate way. For some assets, prices are directly observable on the market. But we have no guarantee at all that these prices convey the right information on the long-term collective value of these assets. This is especially the case for the few environmental assets for which markets exist: such markets are very probably working in very inefficient ways, due in particular to large externalities. And there are also many assets for which there are no markets at

[1] For a more systematic review of these alternative approaches to sustainability, see the CMEPSP report itself (Stiglitz, 2009).

all, hence no observable price. This generally leads to simply excluding them from computations -a very unsatisfactory solution indeed.

A second difficulty is the so-called strong/weak sustainability debate. Taken literally, the additive nature of the ANS suggests that any level of natural capital depreciation can potentially be offset by a sufficiently high rate of physical or human capital accumulation. In other words, the index assumes that there always exists a possibility to substitute produced capital goods to natural ones, even when stocks for the latter become very low. Such a vision does not fit with the idea that minimal critical stocks of natural resources are necessary for the simple maintenance of human life, *a fortiori* for the maintenance of a certain level of well-being. Because it fails to incorporate this constraint, the ANS criterion is said to provide only a necessary condition for sustainability, not a sufficient one. It is in that sense that it is generally understood as a *weak* sustainability criterion.

The third main difficulty appears when ANS estimates are compared across countries. The World Bank has started some years ago a program of systematic computations of ANS indicators for all countries, with the recurrent conclusion that problems of unsustainability essentially arise in developing countries. Admittedly, there can be some elements of truth in such a conclusion: at least until recently, economic growth indeed appeared as more fragile or unstable in many less developed countries than in already developed ones. But, if we focus on environmental issues, the idea that there is no sustainability problem in developed countries is strongly at odds with the idea that they are the major contributors to environmental problems such as global warming.

All this leads to push forward other indicators that do not seem to raise the same difficulties. The most popular of them is the “ecological footprint” (EF) that compares each country’s direct or indirect pressure on natural resources either to its own resources or to the average of resources available per head at the worldwide level (Wackernagel and Rees, 1995). A variant of this ecological footprint is the “Carbon Footprint” concentrating on national levels of Green House Gas (GHG) emissions. One can also compute some other physical indicators measuring national contributions to variations of stocks of natural resources. When they are truly physical[2], such physical indicators generally avoid the pricing problem. By construction, they are consistent with the strong view of sustainability, i.e. the idea that sustainability requires a separate preservation of all environmental assets, whatever the accumulation of other produced assets. Last, concerning the international division of responsibilities in global unsustainability, these indicators generally convey messages more in line with the idea that developed countries’ modes of consumption bear a large responsibility in the degradation of the world’s ecosystem.

But promoters of the ANS approach remain in turn unsatisfied with such answers. They argue that even if substitution possibilities between produced and non-produced assets are not infinite, they are real, and that indicators that neglect them give an overly pessimistic view of future eco-environmental prospects. One can also point out that indicators that focus on natural resources are no more sufficient than the ANS for sustainability. For instance, an economy that has a very parsimonious use of its natural resources but that stops investing in physical capital or in education is on a path that is no more sustainable than an economy that does exactly the opposite. Indicators such as the EF miss this aspect of sustainability, because they only focus on the environmental dimension. It is precisely one of the attractive aspects of the ANS approach to try to combine both environmental and non-environmental dimensions of development. In this respect, it appears quite well in the spirit of the so-called three pillar approach to sustainability that has gained popularity since the Brundtland report, combining the economic, social and environmental aspects of durability.

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[2] This is not really the case with the EF. Here again, then reader is referred to the full report for details.

To sum up, we are facing antinomic views on durability, and this situation is a source of trouble for statisticians. On which indicator should they concentrate their quantification efforts? Should they definitely choose one at the expense of the others, or is there some rationale for a simultaneous use of more than one of them? What are their true limits and their true advantages?

The aim of this paper is not to fully answer these questions, *a fortiori* not to propose a reconciliation of these opposite views on sustainability. But it will try to give a better picture of what these indicators also have in common, and try to identify more exactly the true nature of their divergences. Such clarifications can foster a better dialogue between the competing approaches, and may suggest ways to better articulate the messages delivered by the two classes of indicators.

This will be done in three steps.

The first two steps will temporarily abstract from the international dimension of the problem. The question will be to measure sustainability in a closed eco-environmental system.

Step one will consist in clarifying the basic properties of the ANS under its most ideal version. Such a detour may seem excessively abstract and theoretical, but it is necessary if we want to avoid confusion between intrinsic limits of the approach and limits that characterize one or another of its implementations. We shall show in particular that the ANS approach does not intrinsically require an optimal functioning of the economy for delivering relevant messages, contrary to a frequent claim. Neither is it unable to deal with problems such as imperfect substitutability between natural and non-natural assets. This will suggest that the weak/strong sustainability opposition does not exactly coincide with the opposition between the ANS and physical indicators. Section 1 will illustrate all these ideas by simulating the behavior of the ANS and alternative indicators under perfectly controlled settings. These settings will be highly stylized but they will be sufficient to illustrate the main qualitative properties of the various indicators.

But, this will not mean at all that we can place all our hopes in a progressive convergence toward this "ideal" version of the ANS. Quite the contrary. This theoretical detour can instead be used to show how difficult such a convergence can be. We shall emphasize two main stumbling blocks:

- First, our theoretical detour puts in crude light how far the notion of sustainability is relative. It supposes a prior agreement on what we wish to sustain, i.e., in technical terms, a choice of the social utility function.

- The second one is that even if there was perfect agreement on what we want to sustain, there remains an extremely high level of uncertainty on the technological conditions under which future eco-environmental developments will take place. This dimension of uncertainty is regularly put forward in environmental debates, for instance on the consequences of climatic change. There is no reason why indexes of sustainability could have remained immune to this problem of uncertainty.

Section 2 will illustrate these two points, using once again stylized settings. We shall try to show how these two factors can speak in favor of hybrid approaches combining the different indicators, not in opposition to each other, but as complementary versions of a common basic framework, each of these versions corresponding to different views of either what should be sustained or on how it can be sustained.

Section 3 will then reintroduce the international dimension. This dimension raises new problems. Uncertainty in this field still plays a role, of course. But an additional problem is the fact that two perspectives can be adopted when moving to such a multinational setting. We can either choose to measure separately the sustainability of each economy, or choose to measure the contribution of each economy to overall sustainability. This opposition does not necessarily coincide with the opposition between the ANS and physical indicators. We shall see that the ANS can and should probably be computed according to both views, but practical difficulties are, here also, quite numerous.

In short, this paper deals more with the difficulties of building adequate sustainability indexes than draws definitive conclusions on which indexes should be built. But we hope that it will at least help clarifying the options and the major issues on which efforts could concentrate. The conclusion tries to suggest a few avenues for such a future work.

I - The “ideal” ANS: theoretical views and illustrative simulations

Adjusted Net Savings is another word for the older concept of “genuine savings” that has been coined and used during the 1990s (e.g. Pearce and Atkinson, 1993; Hamilton and Clemens, 1999). Several commentators had received this terminology negatively, for reasons that are understandable. This index was admittedly a strong improvement over standard measures of savings limited to physical or financial capital, but its limits remained quite numerous, so that the term of “genuine” was clearly premature. This generally led to move back to the less ambitious terminology of “adjusted net savings”. This retrenchment clearly suggests that the adjustments that are made to the standard savings concept, albeit significant, may remain highly incomplete.

We shall stick here to this softer term of adjusted net savings. Yet the term of “genuine savings” still points to a relevant question. Abstracting from measurement problems that occur in the real world, what would be the “ideal” definition of a true savings concept that would confidently warn us that current economic growth or living standards are not sustainable? To put it another way, and playing on words, what would be the definition of the indicator of “genuinely adjusted net savings»?

Several contributions to the sustainability literature have progressively allowed shaping the contours of what this “ideal” concept of savings should look like. We shall essentially base ourselves on Dasgupta (2001), Heal and Kriström (2003), Arrow, Dasgupta and Mäler (2003) or Mäler, Aniyar and Jansson (2008) who provide many more comments or illustrations to which the reader is referred. We shall first expose this concept in very general terms, and then present the more detailed specification that will be used for illustrating the properties of such an index, compared to those of alternative indicators.

I.1 A weighted average of changes in stocks of assets

From a very general point of view, measuring sustainability consists in measuring whether we pass on to following generations stocks of resources that will be *sufficient* to offer to all of them a level of well-being at least as high as ours. The current level of consumption or well-being is indeed said to be sustainable if it can be maintained or eventually improved forever. It is said to be unsustainable if at least one future generation will be obliged to be less well-off than the current ones.

The list of these resources that we have to transmit to ensure sustainability is necessarily a very large one, including buildings and machineries, as well as general knowledge or skills, social networks or other institutions, and the various kinds of natural resources that are necessary for production or contribute to the quality of human life. Economists often use the generic term of “capital” to characterize all these various elements. This terminology is one first possible source of misunderstanding with non-economists because of the highly connoted character of the term “capital”: many people are reluctant to see individuals and skills (“human capital”) or the environment treated in the same register as financial or physical capital. This is the reason why, in the following, we will use the terms of “assets”, “wealth” or “resources” along with the one of capital. Yet all these terms must be understood as synonyms in what follows.

This preliminary being made, the problem is to know what “sufficient” means. If we want to express this with numbers, quantifications must occur at all levels of the analysis. The basic element of quantification is to measure changes in quantities or qualities of these different assets or resources. Measurement problems are considerable, but we must assume that we are able to pass this stage if we want to arrive at some tangible results: we shall therefore assume that we are able to say by how much the quantities or qualities of all these resources vary between time t and time t+1.

Let therefore be $S_i(t)$ be the stock of resource i at time t, and let's assume that we know the variation $\Delta S_i(t)$ of this stock between time t and t+1. At a given point in time, we accumulate some of these resources, and this should contribute positively to future well-being. We deplete or deteriorate some other ones, and this contributes negatively to future well-being. The question is by how much exactly? If we impose to ourselves the constraint of answering this question with only one number -and such is the challenge- then we must find a way for aggregating all these physical variations.

For assets or resources that are traded in markets, one way to value their contributions to future well-being could be to use prices $p_i(t)$ currently observed on markets. If such markets existed for all resources, then the formula for the ANS would be simply:

$$ANS = \sum_i p_i(t)\Delta S_i(t) \quad (1)$$

But they are many reasons why such an approach is problematic. The first one is that, even when prices exist, there is a risk that they misrepresent the true long term contributions of corresponding assets to well-being because of their incapacity to fully incorporate all the externalities -positive or negative- that can be associated to the accumulation of these assets. Even if they were able to do so on the average, there is the additional problem that such prices also reflect myopic or irrational behaviors of investors, often leading to erratic changes around fundamentals. For instance, one just has to think of the huge variations that have been observed for financial assets or oil prices over the recent years. Such variations in these prices lead to huge changes in the value of the ANS computed according to (1), with little long-run economic significance.

Anyway, even if we were ready to believe in the validity of market prices when they exist, there remains the problem of assets that are not traded at all on any market, for which no p_i's are observable. Excluding them from computations is clearly an unsatisfactory answer. For these environmental assets, an alternative solution is to use estimates of costs of avoidance or abatement, for instance the cost of installations that would fully avoid the emission of such or such pollutant in the atmosphere. But this solution also remains unsatisfactory. It can be adequate for indexes such as green NNP, because, as underlined in the introduction, green NNP does not pretend to be a measure of sustainability. Green NNP only measures what we can be able to consume without deteriorating the environment: in such a perspective, it can be a good strategy to subtract from standard NNP the potential cost that we would have to support in order to maintain the environment in its current state.

But what sustainability indexes want to measure is something else: we want them to tell us whether the actual damages that are currently made to the environment are going to drive the well-being of future generations below the one that we currently enjoy. It is only under strong conditions that there can be equivalence between this long run impact and the current marginal cost of pollution abatement. This equivalence occurs only if we currently optimize between the present costs of these abatements and the benefits that will result from them in the future. It is excessively restrictive to assume that such is the case.

This means that a true measure of sustainability requires a direct imputation of what these future damages will be.

How can this imputation be done? The advantage of starting from a purely theoretical point of view is that it allows us to fully define how we should ideally proceed for such an imputation. Intuitively, knowing how a given change in $S_i(t)$ today will affect future well-being requires two elements:

- we need to know how this change will affect the future path of the eco-environmental system.

- we need to know these changing paths will translate in terms of global future well-being

Let's start with the first requirement. A rather general way to describe the evolution of n stock variables is to have an identical number of n flow variables $C_i(t)$ describing net consumptions of these different capital goods at time t (with negative values in case of savings). To remain as general as possible, we consider that the consumption of each good at time t can potentially depend on *all* variables describing the current state of the economy, i.e. all the $S_i(t)$'s, plus eventually a pure effect of time t. This writes down:

$$C_i = M_i\,(S_1(t),\ldots,S_n(t),t) \qquad (2)$$

In the same way, to be once again as general as possible, we shall assume that the net variation of stock S_i at time t depends not only on the direct consumption of resource i, but also on consumptions and/or stocks for all other resources. This allows accounting for spillovers, for instance if the accumulation of physical capital leads to a deterioration of the environment. It also allows incorporating the fact that rates of renewal for these different goods depend on their own stocks or eventually on stocks of other resources. For instance, in the case of a halieutic resource, the growth rate is generally assumed to depend upon catches, and on a natural growth rate that has an inverted U relationship with the global stock: natural growth rates tend to zero when the population is either too sparse or too dense. But this rate of natural growth can also depend on the biomass of nutrients used by this population of fishes, which has itself its own dynamics. In that case, the global dynamics of the ecosystem will involve an interaction between catches and two stock variables.

The general formulation for this renewal of capital good i, will then be:

$$\mathrm{d}S_i/\mathrm{d}t = R_i\,(S_1(t),\ldots,S_n(t),C_1(t),\ldots,C_n(t),t) \qquad (3)$$

or, in a slightly less general but natural fashion:

$$\mathrm{d}S_i/\mathrm{d}t = R_i\,(S_1(t),\ldots,S_n(t),C_1(t),\ldots,C_{i-1}(t),C_{i+1}(t)\ldots,C_n(t),t) - C_i(t) \qquad (4)$$

Let's turn to well-being. Here again, we try to remain as general as possible by considering that *current* well-being U potentially depends on all current flows (with consumption being *a priori* the major component) but also on all current stocks. For instance if we consider that natural or social capital have amenity values -the satisfaction of breathing a safe air in a pleasant landscape, or of enjoying positive human relationships-, then the corresponding S_i's must enter into the social utility function.

Adding time discounting at rate ρ, this leads to a general form for *intertemporal* well-being which is:

$$V(t) = \int_t^{\infty} e^{-\rho(u-t)} U(S_1(u),\ldots,S_n(u),C_1(u),\ldots C_n(u),u)\,du \qquad (5)$$

Concerning time discounting, we recall that the discount factor ρ must only correspond to the so-called "pure" rate of time preference, i.e. in principle a much lower value than market interest rates or the concept of social rate of time preference. The latter incorporates an additional discounting of the future stemming from general economic growth: all else equal, we have less reason to care about costs incurred to future generations if we believe that general economic growth will make them much more affluent than we are today. But this will come directly in (5) from the projected path of the C_i's. It does not have to be counted again in ρ[3].

Given that (2) and (4) provide a complete system of equations determining the future path of the eco-environmental system from initial conditions $S_i(t)$[4], $V(t)$ can be rewritten as a pure function of all values $S_i(t)$, and eventually of t, i.e.:

$$V(t) = V(S_1(t),\dots S_n(t), t) \tag{6}$$

With these notational conventions, defining sustainability becomes relatively straightforward. Sustainability refers to the path of current well-being U. It consists in having $U(s)\geq U(t)$ for all $s>t$. It can be shown that a necessary condition for this is to have dV/dt higher than zero. The reason is that if $V(t+dt)<V(t)$, then the comparison of the two integrals will show that at least one of the future $U(s)$'s will have to be lower than $U(t)$.

How can such a decline be avoided? This means transferring to t+dt a combination of $S_i(t+dt)$ that implies $V(S_1(t+dt),\dots S_n(t+dt), t+dt) \geq V(S_1(t),\dots S_n(t), t)$. Intuitively, this can be translated into a condition of non-negative ANS using partial derivatives, i.e.:

$$\frac{dV(t)}{dt} = \sum_i \frac{\partial V(t)}{\partial S_i(t)} dS_i(t) + \frac{\partial V(t)}{\partial t} \tag{7}$$

This exactly lead us to an ANS formula, where accounting prices for all assets appear to be equal to partial derivatives of $V(t)$ with respect to the asset that is considered, and with an additional drift term $\partial V/\partial t$ that captures the autonomous movement in $V(t)$, i.e. the fact that it can increase (or eventually decrease) over time even when stocks of resources are held perfectly constant.

Three remarks are to be made before proceeding further.

First remark, the ANS approach has been often criticized for implicitly assuming an efficient functioning of the economy and it is true that many early presentations of the method referred to this specific case. If the scope of the method were actually restricted to such situations, its interest would indeed be very limited. Eco-environmental interactions are precisely one of the domains where the allocation of resources is notoriously unlikely to hold and as noted by Fleurbaey (2009), any characterization of sustainability that could not apply to such inefficient situations would be of very little practical interest. Such is fortunately not the case in the general presentation provided here. The allocation mechanism described by (2) and (4) has been formulated in a very general way, and the case of an efficient economy that would permanently maximize $V(t)$ is only one possible specification of this allocation mechanism, in principle not the most interesting to explore.

Second remark, the only restrictive element in the specification retained here is the choice of an additively separable intertemporal utility function with a constant discount rate. Although this choice could be disputed, we shall consider that this form is already flexible enough to capture the most important points of the sustainability issue.

Third remark, all this framework is also well-suited for clarifying longstanding debates about what should be the proper treatment of so-called "defensive" expenditures in national accounting, and in particular those defensive expenditures that are devoted to repair damages to the environment resulting either from human activity or from nature

[3] Detailed expositions of this argument and its implication for environmental decision-making can be found in Guesnerie (2005), Heal (2008) and Sterner and Persson (2008).

[4] Arrow et al. (2003) use the term "allocation mechanism" to characterize this system of equations that entirely describe the future path of flows and stocks starting from initial conditions on S_i's.

itself. As it is well known, a bias of GDP is that it counts positively expenditures devoted to such repairs, suggesting for instance that a natural catastrophe may be a blessing for the society's standard of living. But such a shocking conclusion only comes from the fact that we use GDP for measuring something else than what it has been made for. GDP is a measure of economic activity. It is not wrong to say that a catastrophe may force a society to an increase in activity. But this does not mean at all that its well-being has improved. The approach combining measurement of current utility with the ANS has the advantage of clarifying things, at least conceptually. A natural catastrophe will be registered as a negative shock on wealth, expenditures incurred to repair the resulting damages will not appear in current utility, but will partially or completely offset the negative impact of the catastrophe on the ANS.

Now, to illustrate the properties of this "ideal" ANS index, we must shift to particular cases. The next section will present such a particular case, keeping the assumption of an inefficient accumulation path, but restricting the list of assets to only two, and specifying more precisely the laws of motion for these two assets. It is this stylized framework that will then be used all along the rest of the paper.

I.2 A stylized setting with only two assets

At this stage, we have a very general definition of the ANS. But the way it works as an advanced indicator of sustainability will be easier to understand if we restrict ourselves to a stylized example with a limited number of assets. The framework that we will use considers only two "capital" goods: produced physical capital in the usual sense of the term, denoted $K(t)$, and a stock of a natural resource available at time t in quantity $S(t)$. We warn right now that some of the scenarios we are going to build from this framework will be deliberately extreme ones, where clearly inefficient ways of managing natural resources will ultimately lead to an ecological catastrophe. This expresses no position on what will or could happen in the real world: this choice only results from our will to test the behaviour of indicators in the most extreme of cases.

Let's first consider the role of produced capital. We assume that global production $Y(t)$ depends on $K(t)$ according to a Cobb-Douglas function, i.e.:

$$Y(t)=K(t)^{\alpha} \tag{8}$$

with the production factor $K(t)$ being accumulated according to the standard net investment equation:

$$\dot{K}(t)=Y(t)-C(t)-\delta K(t)=\sigma Y(t)-\delta K(t) \tag{9}$$

where $C(t)$ is consumption of the produced good at t and where σ and δ are respectively the savings rate and the depreciation rate. We know that such a pattern of evolution for K implies an equilibrium capital stock K^* whose value is obtained by equalizing (9) to zero. We get:

$$K^{*}=(\sigma/\delta)^{1/(1-\alpha)} \tag{10}$$

From the pure point of view of K and Y, an economy that starts from a capital stock lower that the K^* resulting from σ and δ will be on an ascending path. If it conversely starts from $K(t)>K^*$, this means that it saves too little to maintain its production. This can for instance occur if it has inherited a large capital stock due to high savings by previous generations, and suddenly moves to a less frugal behaviour with lower savings, or if it is confronted with an increasing rate of obsolescence for its capital. In both cases, we can suspect that the current well-being of the population will not be sustainable.

Let's now turn to natural resources. We could have introduced them as an additional input for producing $Y(t)$. This would have meant an explicit modelling of their rate of extraction. We have chosen here a more compact modelling that consists in assuming that productive activity has a negative externality on S, and that this negative effect directly affects well-being by introducing $S(t)$ is the utility function.

The negative externality of production $S(t)$ is not supposed to come into play for low levels of output: even if some of this resource is consumed or damaged in the process, we assume that its spontaneous rate of regeneration is sufficient to keep its stock constant. But, once a certain value Y^* of Y is reached, this natural resource starts depreciating irremediably, at an increasingly higher rate when we move away from this threshold Y^*. We thus write:

$$\dot{S}(t) = -\lambda(Y(t)).S(t) \tag{10}$$

where $\lambda(.)$ is zero before Y^*, increases from 0 to λ_{max} between Y^* and a second threshold of Y^{**}, after which $\lambda(.)$ remains at λ_{max}.

The last step is to define current utility as a function of $C(t)$ and $S(t)$. Here again the specification is Cobb-Douglas, i.e. $U(t)= C(t)^{\mu} S(t)^{\nu}$. With this definition of current utility and a discount rate of ρ, intertemporal utility finally writes down:

$$V(t) = \int_{u=t}^{\infty} e^{\rho(u-t)} C(u)^{\mu} S(u)^{\nu} du \tag{11}$$

Given this definition of $V(t)$ and the laws of motion for all parameters of the economy, it is possible to compute at each period an ANS index with accounting prices imputed according to (7). For numerical illustrations, this ANS index will be expressed as a fraction of total current well-being, consistent with the fact that accounting prices in (7) are expressed in utility units. We will have therefore:

$$ANS(t) \; = \; \left[p_K(t)\dot{K}(t) \; + \; p_S(t)\dot{S}(t) \right] / U(t) \tag{12}$$

and we shall benchmark this indicator against two physico-environmental indicators. The first one will simply consist in the net relative variation of $S(t)$, that will be denoted dS/S. The second one tries to proxy the concept of ecological footprint or more precisely the ecological surplus. To this end, we use that fact that the threshold value Y^* can be interpreted as an environmental carrying capacity, i.e. the maximum level of production that we can have without degrading our resources in an irreversible way. The ecological surplus at time t will be relative difference between Y^* and $Y(t)$, i.e.:

$$ES(t) = 1 - EF(t) = 1 - Y(t)/Y^* \tag{13}$$

This *ES* will be negative if the economy produces more than what is compatible with the maintenance of its natural assets, and positive in the opposite situation. All the three indicators *ANS*, *dS/S* and *ES* are to be interpreted in the same qualitative way, with negative values announcing that current well-being is unsustainable either in the short run or the long run. Since all these indicators are expressed in relative terms, their order of magnitudes will roughly fall into comparable brackets, and this will make graphical illustrations easier. *ANS* and *ES* have the additional property that they can also be positive, while *dS/S* cannot be higher than zero. But positive values of *ANS* and *ES* will have different origins. For the *ANS* it will necessarily result from a positive accumulation of produced capital, while for the *ES*, this will simply mean that the economy lives below the carrying capacity of its environment.

I.3 First illustration: non-binding environmental constraints

Table 1 gives numerical values for the scenarios that are going to be used in this section. We start with two scenarios 1a and 1b where negative consequences of production on the environment never come into play, because the threshold level of environmental degradation is fixed at a sufficiently high level.

Table 1: Scenarios

	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b
Capital elasticity of production (α)	0.33			
Depreciation of produced capital (δ)	0.05			
Savings rate (σ)	0.2	0.1	0.2	
Initial capital stock ($K(0)$)	1	10	1	
Environmental threshold (Y^*)	2	5	1.5	
Maximum depreciation rate for $S(t)$ (λ_{max})	0.25			
Value of Y where this maximum rate is attained (Y^{**})	2.Y*			
Initial stock of environmental capital ($S(0)$)	1			
Coefficient for consumption in current utility (μ)	0.5			
Coefficient for the environmental good in current utility (ν)	0.5			
Pure rate of time preference (ρ)	0.01			0.05

Figure 1: A scenario of economic growth with no environmental constraint (scenario 1a)

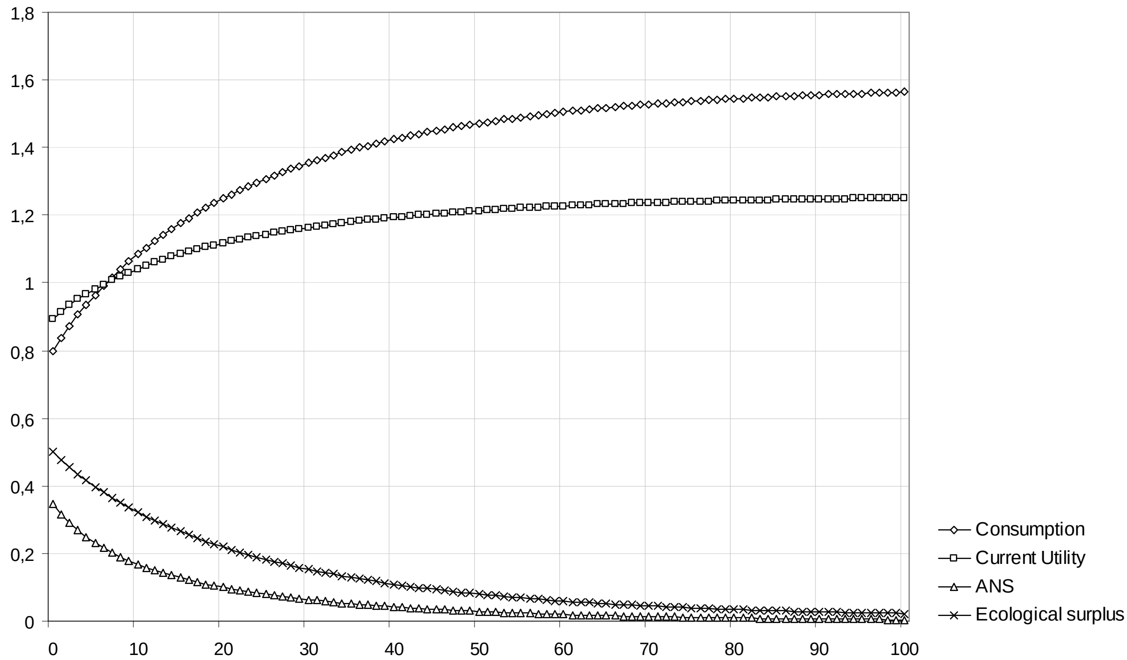


Figure 2: A scenario of economic decline with no environmental constraint (scenario 1 b)

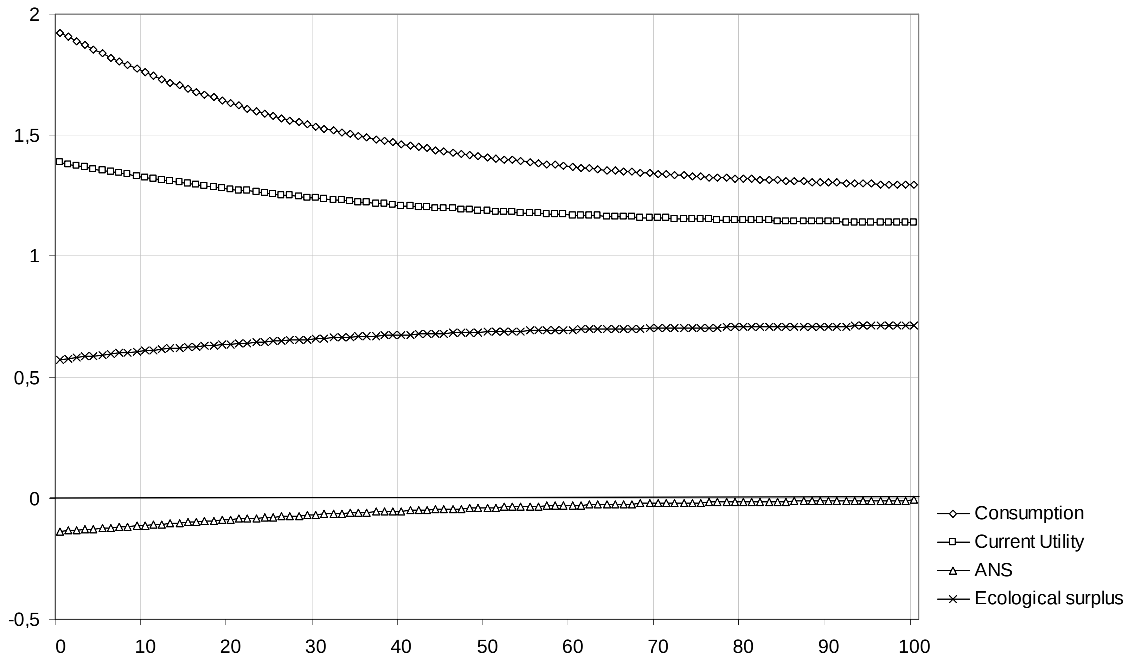
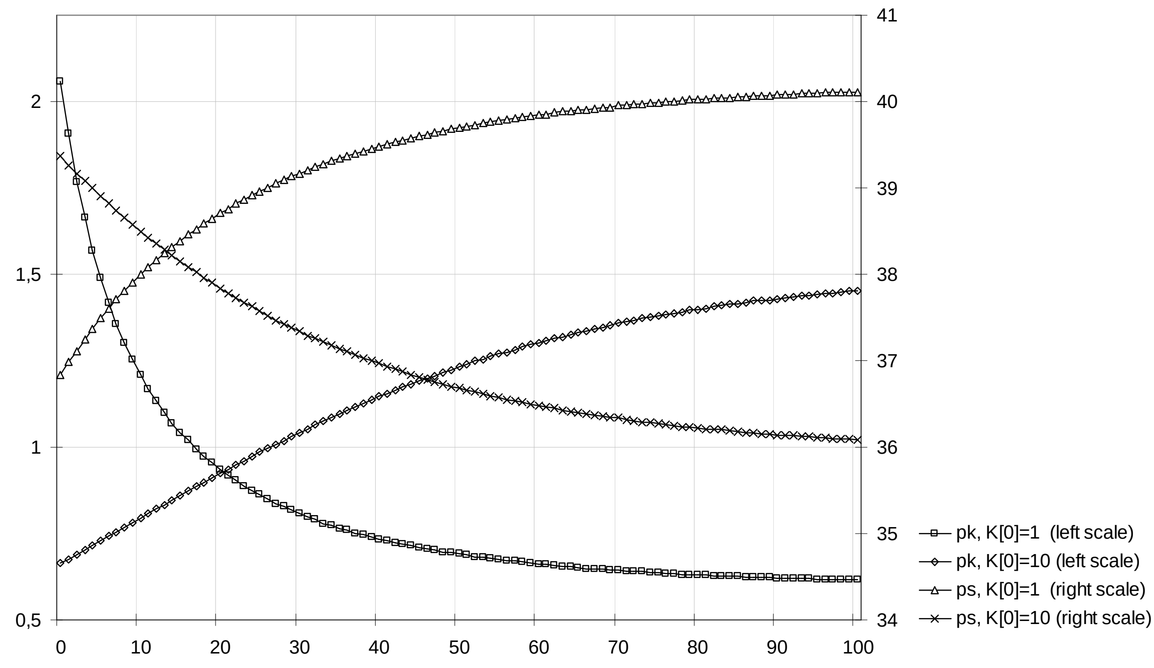


Figure 3: Accounting prices for scenarios 1a and 1b.



Scenario 1a is the standard scenario of catching up of the Solow growth model. We assume a saving rate of 0.2, a depreciation rate of 0.05, and a capital coefficient α=1/3. The resulting equilibrium level for K is 8, leading to Y=2 and C=1.6. But we assume that the economy starts from a much lower level of capital, K(0)=1. We have therefore a long period of expansion, that progressively slows down. All over this period, the stock of produced capital increases but there is no degradation of the environment. None of our three sustainability indicators points at non-sustainability, consistently with the effective path of the economy. But this is their only common property. By assumption, indicator *dS*/*S* is constantly equal to zero (and not reported on figure 1 for this reason). It does not send any message about the fact that we are on path of economic growth -but this is not what it aims at-. The message of the *ES* indicator is that we are more than just sustainable, since it is always positive, but increasing less so as *Y*(*t*) becomes nearer to *Y**: *ES* decreases from 50% in *t*=0 to almost zero after 100 years of expansion. The *ANS* also has such a declining profile, but for reasons that are quite different. The evolution of the *ANS* captures changes in the net savings rate, which is always positive but tending toward zero as *K* approaches *K**.

The importance of appropriately capturing changes in the net savings rate appears in cruder light with scenario 1b, where a savings rate reduced to σ=0.1 is unable to maintain the high initial capital stock of *K*(0)=10. Such an economy is on a declining path, until the capital stock stabilizes at its lower equilibrium value, equal to about 2.8. The decline in *C*(*t*) and *U*(*t*) is depicted on figure 2. The *ANS* adequately captures this form of unsustainability. It starts from a value of -0.2, and remains negative all over the simulation period, but progressively approaches zero. Not very surprisingly, the *ES* does not send any such message of non-sustainability. It is always positive, and even in a slightly increasing way because declining production pushes us further away from the threshold beyond which the environment would start to deteriorate. And, as in scenario 1a, *dS*/*S* is zero all along the projection.

To be complete, it is not uninteresting to look at accounting prices that are used for computing the ANS in these two scenarios. In a situation where *dS*/*S* is identically equal to zero, the environmental good plays no role in the *ANS*. But this does not mean that we assume it has no value. Values for p_S and p_K are represented on figure 3 and both are positive all along the projection period, for both scenarios. Concerning *K,* this results from its positive impact on *C.* Concerning *S*, this is the result of its direct contribution to *U*. A marginal variation in the initial stock of *S* will produce a gain in current utility and in utility at all future periods, and it is the discounted value of this gain that will be reflected in p_S. Prices are not constant however. They move in the opposite directions to relative scarcities of these two capital goods: p_K decreases over time in scenario 1a, from more than 2 to about .6, while p_S increases, from 34.5 to nearly 38. Changes are symmetrical in scenario 1b, with p_K doubling from 0.7 to nearly 1.5, capital becoming less and less abundant, while the price of the natural resource slightly decreases from more than 39 to about 36.

To sum up, we are therefore in two situations where it is the *ANS* that better tracks future developments of the economy. This is not very surprising, given that we are in a context where it is only net investment that matters for sustainability. There was no doubt that the ANS is the only indicator that is able to capture this element, and we were expecting it to do it quite well. The real question is to know how indicators perform when the environmental constraint comes into play.

I.4 Ecological catastrophes: scenarios with binding environmental constraints

How are these results changed when environmental constraints become binding? Does the *ANS* keep its value as leading indicator of growth or decline? To explore this question, we now consider two scenarios that are identical to scenario 1a except for the crucial difference that *Y** now has a much lower value of 1.5. This means that productive activity will start damaging the environment, in an irreversible way, well before the maximum values of *K* and *Y* are reached. In sub-scenario 2a, the ANS is computed keeping the same value of ρ as the one used for simulations 1a and 1b, i.e. ρ=0.01. Sub-scenario 2b is a variant where this rate of pure time preference is increased to 0.05. Results for *C*(*t*), *U*(*t*) and the various sustainability indicators are given on Figure 4, including the two variants of the *ANS*.

Figure 4: A scenario where economic growth generates an irreversible decline in natural resources (variants 2a and b: *ANS* imputed with ρ=1% and 5%, respectively)

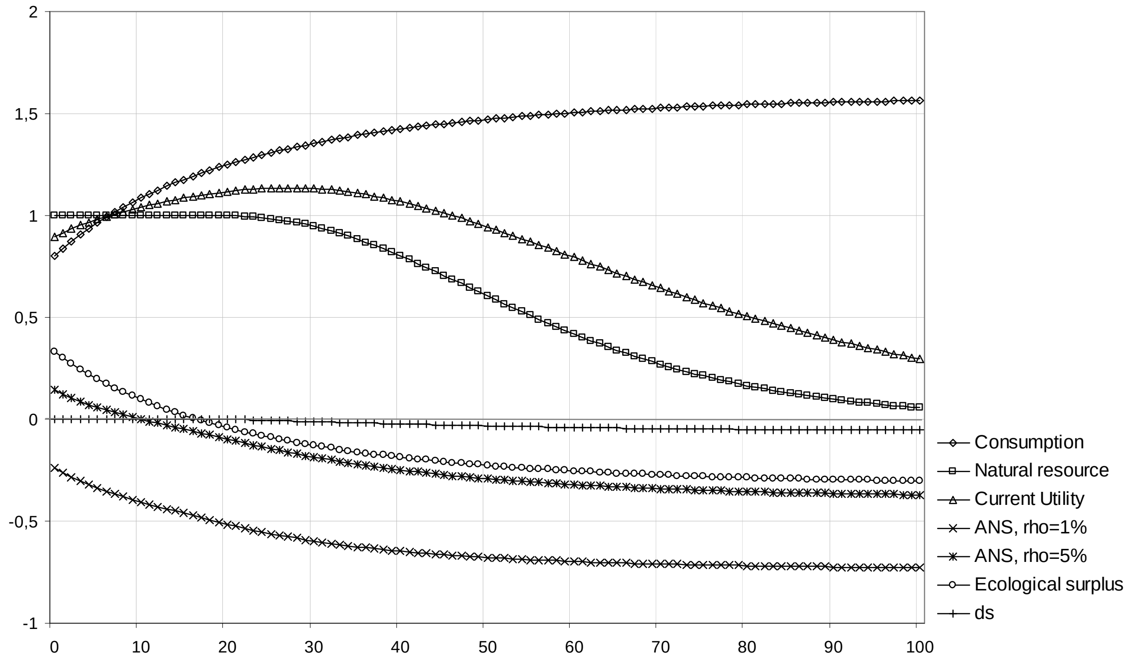
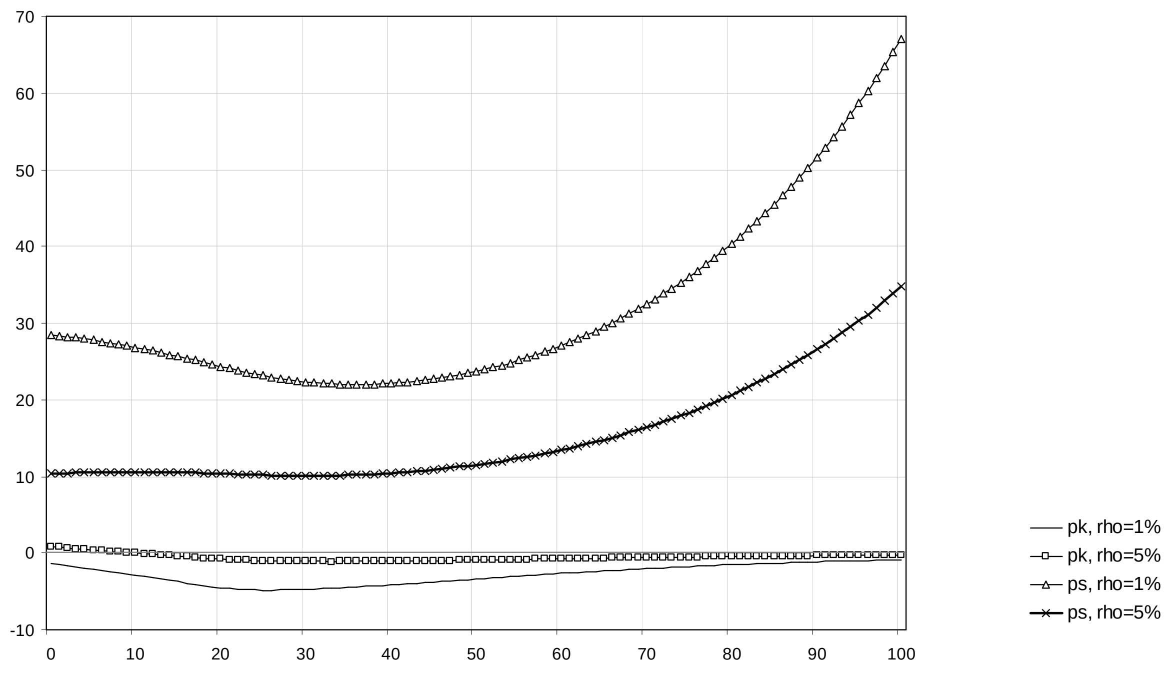


Figure 5: Accounting prices for variants a and b of scenario 2



The three upper lines on Figure 4 show what this scenario implies for production and well-being. The evolution of $Y(t)$ remains positive all along the projection. Until $t\approx25$, this implies an increasing level of current utility, because the stock of natural capital remains unaffected or only marginally affected by economic growth. But the situation dramatically reverses between t=30 and t=40. The rate of decline for $S(t)$ becomes rapid and dominates the positive impact of a still increasing $C(t)$. Both $S(t)$ and $U(t)$ asymptotically decline toward zero.

How do the different indicators anticipate such a final collapse? All of them warn about future unsustainability, but with degrees of anticipation that differ. In fact, under the specification retained here, the *ES* and dS/S do not anticipate that much the collapse. They start becoming negative about 10 to 15 years before well-being starts to decline. In this example, the *ANS* is the first to anticipate the downturn, but in a way that depends on the choice of ρ. Quite naturally, a higher value of ρ makes the indicator more myopic, in the sense that it gives a higher relative value to the initial period when U is still expanding. In fact, the *ANS* with ρ=0.05 is positive at the beginning of the projection. It is only for ρ=0.01 that the *ANS* constantly warns us that we are not on a path of sustained growth.

Here again, it is instructive to look at the values of accounting prices that explain this behaviour of the *ANS*. They are reported on Figure 5 for the two values of ρ. In the long run, the message on unsustainability essentially comes from the rapid increase of p_S. As $S(t)$ becomes increasingly scarce, its accounting price levels-off dramatically. But this cannot explain the early signal of unsustainability that we get with ρ=0.01. As long as $S(t)$ is non-declining, the *ANS* only reflect changes in $K(t)$, and this change is positive. If the *ANS* is negative, it therefore comes necessarily from a negative value of p_K, and this is exactly what is observed on Figure 5. The value of p_K is negative from the start with ρ=0.01, and starts becoming negative around t=10 for ρ=0.05. These negative values directly result from the mechanics of imputation. Even if a marginal increase in the initial value of K has an immediate positive impact on U, the computation of p_k as $\partial V/\partial K$ takes into account the fact that this will more rapidly lead to a decline in S and U: this negative effect immediately outweighs the positive short-run effect with ρ=0.01, and about 10 years later with ρ=0.05.

To sum up, here again, the *ANS* comes out as having interesting properties, and even the potential for dominating all other indicators. In particular, a proper evaluation of accounting prices is able, *in theory*, to fully anticipate the consequences of severe environmental stress or of strong environmental externalities of economic growth. In that sense, its use is not confined *a priori* to the assessment of situations of weak sustainability where capital accumulation is always able to offset consequences of a deteriorating environment. It substitutability between K and S is limited, then this will be reflected in a strongly increasing value for the relative price of S. Responding to the decline of S by accumulating still more capital will intensify this divergence between p_S and p_K, and this will prevent the *ANS* from becoming positive again. And if the deterioration of the environment is itself spurred by this process of capital accumulation, this externality must, in principle, be reflected in the accounting price of this capital good, eventually pushing it toward negative values.

But it would be obviously too rapid to infer from these theoretical results that we have at hand the ideal index able to deal empirically with all situations of potential unsustainability, because there is a long way from these theoretical properties to a trustable real world implementation.

II - Sustainability in practice: the difficulties of implementing the ideal ANS

As announced in the introduction, results from section 1 can be used in two ways: either as illustrating the ideal indicator in the direction of which all our future efforts should now concentrate, or as showing to which point conditions requested for implementing this indicator are unrealistic, urging us to look for alternative second best solutions.

It is indeed quite easy to re-read all the previous section with such a skeptical state of mind. It is only under scenarios such as 1a and 1b that implementation difficulties look minor. Such scenarios describe a world where produced capital is the main factor of development and where well-being is a simple monotonic function of production. In that case, measurement problems can indeed be considered as marginal: one can consider that standard measures of physical capital accumulation valued at market or close-to-market prices will constitute a good proxy of the ideal indicator.

But requirements are much beyond that in scenarios 2a and 2b. The predictive performance of the *ANS* in this alternative context relies on two strong assumptions. One is a perfect prediction of future eco-environmental developments; the second one is a perfect knowledge of how these developments are going to affect well-being.

These two assumptions are clearly very far away from our real world situation. Debates on eco-environmental perspectives are dominated by high levels of ignorance or uncertainty concerning future interactions between the two spheres, and by lack of consensus upon the definition of the objective function itself. This latter debate is not only about the relative valuation of the immediate and remote future, i.e. the value of ρ. It can be also about the definition of U itself.

In fact, one can say that the “ideal” ANS presented in section 1 gives an answer to the sustainability issue only if we assume that these two major problems have been solved. One can argue that this strongly limits its interest. If these two problems were solved, this would mean that we fully know in advance the prospective path for U. In such a case, a simple inspection of this projected path would be sufficient to know whether $U(s)$ becomes lower than $U(t)$ at some future point and there would be no need for a sophisticated summary indicator, except maybe for a rapid unidimensional classification of different countries according to their degree of sustainability -but section 3 will show other problems in that case.

Anyway, we are not such a world of perfect normative consensus or of perfect knowledge, and this section will develop rapidly the consequences of this for the relevance or the feasibility of the indicator.

II.1 Issue 1: sustainability of what?

From what we have seen, it appears that there can be as many indexes of sustainability as there are definitions of what we want to sustain, and this poses one first limit to the practical choice of a single headline indicator. This remark may seem trivial, but it is paradoxically not that frequent in the literature on sustainability indexes. It deserves a few comments. In standard National Accounting practice, the normative issues of defining preferences is generally avoided through the assumption that observed prices reveal the true preferences of people. No normative choice is therefore to be made by the statistician -and such is not its job, anyway.

But as soon as we consider that market prices cannot be trusted, imputed prices must be computed, and it is one of the main contributions of the theoretical presentation made in section 1 to have shown that this crucially depends on some knowledge or prior definition of what well-being is or should be. Just to illustrate this point, Figures 6 and 7 show alternative evaluations of the *ANS* and corresponding evolutions of *U*(*t*) with four different specifications of this function *U*. In all cases, the eco-environmental scenario is the same: it is the one used for scenarios 2a and 2b. We also fix the value of ρ to 0.01. This means that differences only reflect different values that are attached to *C*(*t*) and *S*(*t*) in *U*(.,.). The two extreme cases are those of the pure productivist that only values *C* and of the deep ecologist that only values *S*. The third case is the intermediate case that was used in the preceding section where *U* is equally sensitive to variations of *S* and *C*. The second case is an intermediate case where we assume some sensitivity to *S*, but less constraining in that a zero value for *S* remains compatible with a positive level of utility: the specification for the utility function is here $U(C,S)=C^{0.5}(S+0.5)^{0.5}$.

Figure 6: ANS for scenario 2 and various assumptions on current utility

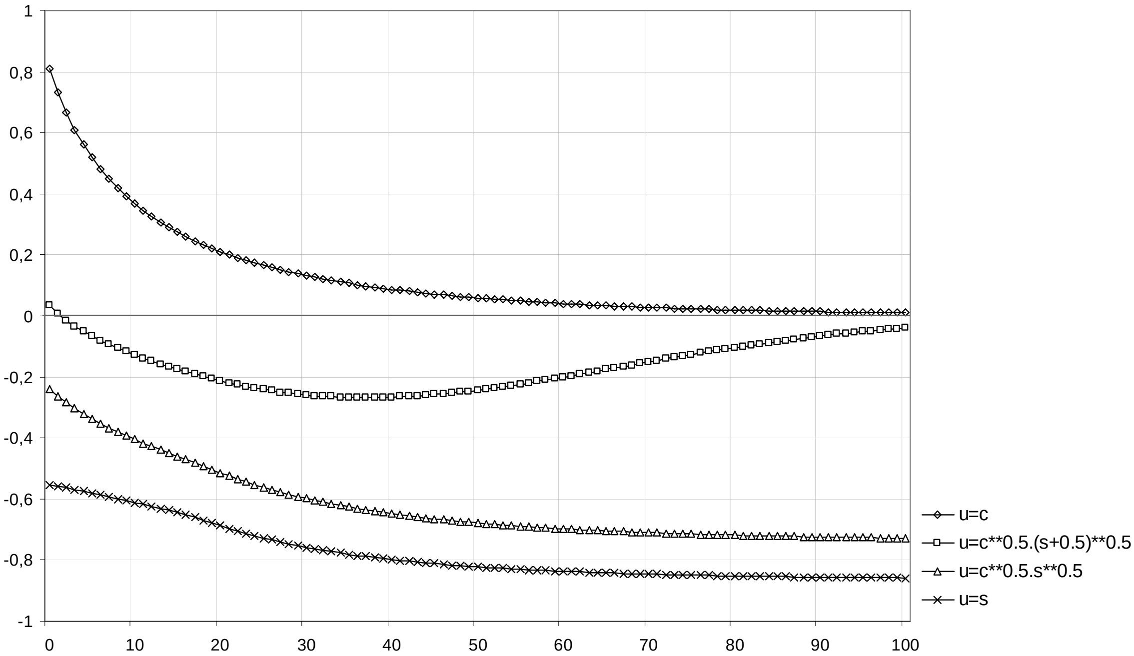
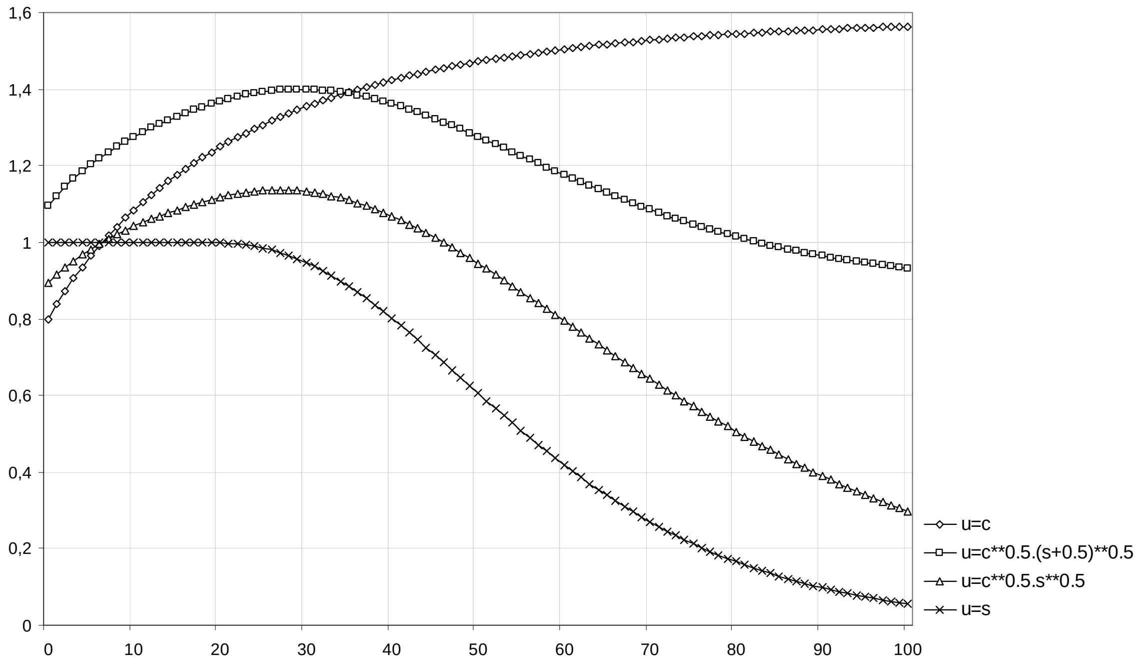


Figure 7: Levels of current utility corresponding to the different scenarios



The comparison of the different scenarios is instructive. The *U*=*C* hypothesis leads to results that are in fact exactly similar to the ones of scenario 1a: as soon as the environment plays no role in production and is not valued *per se*, everything works as if there was no change in *S*(*t*), and this was precisely the assumption of scenario 1a. On the opposite, the *U*=*S* scenario reinforces the negative message of scenario 2a. The profile for *U*(*t*) mechanically reproduces the sigmoid profile for *S*(*t*) and the *ANS* is immediately strongly negative. One point deserves particular mention here. One could have expected in such an extreme case a perfect equivalence between the *ANS* and the physical indicator *dS*/*S*: if it is only *S* that matters for well-being, *dS*/*S* should be the best predictor of unsustainability. This is not the case here: the *ANS* is negative from the start, while *dS*/*S* remains non-negative until t≈25. The reason is the more prospective nature of the “ideal” *ANS*: even if there are no immediate changes in *S*, the indicator anticipates that the expected process of capital accumulation *K* will ultimately deteriorate *S* and immediately attributes a negative value to *dK*, more strongly negative than it was the case in 2a given the fact that *dK* has no immediate positive impact on well-being anymore.

The third scenario exactly reproduces curves already given on Figures 4 and 5: it is noteworthy that, although it puts some positive value on *C*, it is qualitatively not that different from the *U*=*S* scenario. The fact that a positive *S* is necessary for a positive well-being is common to both scenarios and dominates all other aspects in the long run, explaining this qualitative similarity.

The scenario with $U(C,S)=C^{0.5}(S+0.5)^{0.5}$, in the end, gives us an intermediate case where environmental degradations would undoubtedly harm well-being, but in a temporary way, before stabilization and here again the *ANS* gives an adequate warning message on this temporary non sustainability. It starts being negative well before the peak of current utility, that takes place around *t*=30, then remain negative during most of the projection period but progressively returning to zero when *U*(*t*) starts converging to its long run stationary value.

These few examples are very artificial but they clearly emphasize the fact that the *ANS* indicator is completely dependant on the choice made for function *U* and this is clearly not a minor problem. One could try to solve this problem empirically, trying to infer the form of *U* from current observations of how people value environmental factors compared to economic ones. Since this cannot be done from observed prices, we must rely on other means, such as contingent valuations, or direct measures of the impact of environmental amenities on indexes of subjective well-being such as those considered in subgroup 3. But the limits remain numerous. In particular, can contingent evaluations or subjective measures established today in a certain eco-environmental setting be used to predict what will be the valuations of future generations in eco-environmental settings that may have become very different? The good properties of the ANS depend on the capacity of function U to capture the relative valuation of environmental and non-environmental goods over the full range of variation of their relative quantities.

Such a global profile may prove quite hard to infer simply from current observations in a narrow interval of variation of eco-environmental variables. Some may argue that our descendants may become very sensitive to the relative scarcity of some environmental goods to which we pay little attention today because they are still relatively abundant, and that the precaution principle should therefore command immediately putting a high value on these items just because we think that our descendants may wish to do so. On the other hand, some anti-environmentalists may argue on the opposite that these future generations may be completely indifferent to the disappearance of some environmental amenities that we currently value only because we are used to do so. This brings into the debate the additional complexity that can stem from changes in U over time, changes that may be themselves path dependent. For instance, and just to be provocative, a strict Easterlinian believing that people permanently adapt their aspirations to their realisations could argue that $U(t)$ is nothing else than a constant and, under such an assumption, any growth or de-growth path is a path of sustained well-being. Such is of course not the position we wish to defend, but it puts in crude light how relative the definition of sustainability can be.

To give another aspect of this normative problem, one can also mention the importance of knowing how U aggregates individual preferences, i.e. the distributive dimensions of current well-being. If for instance one considers that a headline indicator of current well-being must be the total disposable income of the bottom 80% of the population, or of the bottom 50%, rather than global disposable income, then indicators of sustainability must be adapted to such an objective function. In a world with natural tendencies to increasing inequalities within countries, messages concerning sustainability will differ depending on the goal that we fix to ourselves. A specific attention to distributional issues may even suggest enlarging the list of "capital" goods to be taken into account the aim of sustainability: the "sustainability" of well-being for the bottom x% of the population can imply some specific investment in institutions that help protecting efficiently this population from poverty. In principle, the theoretical framework of section 1 tells us how we could ideally put some value on such "institutional" investment. Arrow et al. (2003) actually mention institutions as some of the assets that should be ideally included in a really comprehensive measure of wealth. But needless to say that the perspective of being able to do so is still more remote than for other assets.

In short, all this question of properly predefining U is one first argument in favor of multiple sustainability indexes, corresponding to different definitions of what we are trying to sustain.

II.2 Issue 2: uncertainty in future eco-environmental developments

Second, whatever the solution given to this first problem of choosing $U(t)$ and $V(t)$, there remains the other limit resulting from the intrinsic uncertainty about future eco-environmental changes. The future is fundamentally uncertain. This means that indicators can be at best interpreted in probabilistic terms: they can give no more than a likelihood that we are or not on an unsustainable path, with the two symmetric risks of warning us unnecessarily of a future unsustainability that will not materialize, or on the other hand to let us believe that we are on sustainable path while we are not.

Let's give a suggestive illustration of these two opposite risks. We have re-run the same model as in previous sections, introducing some additional unexpected drift in parameters governing economic and environmental changes. More precisely, we simulate an economy whose initial characteristics are those of scenarios 1a or 2a and b, with the two differences that the initial capital stock is immediately fixed at the equilibrium K^* that results from σ=0,2 and δ=0,05, and that Y^* is initially fixed to 2, just equal to the equilibrium production level corresponding to K^*. These two initial conditions imply that, without any further change, the economy would stay forever in a stationary steady state with no change neither in K nor S, and sustainability indicators all permanently equal to zero. But we add the feature that this *status quo* is disturbed at each period by random changes in the depreciation rates of the two assets. Parameter δ is assumed to follow a random walk in the [0; 0.15] band and Y^* is assumed to follow another random walk in a band [0;4] (with a parallel change in Y^{**}). At each period, the *ES* or the *ANS* are estimated on the basis of currently observed values. In other words, we place ourselves in the case where the index-builder can rely on some correct information of current eco-environmental parameters, already an optimistic assumption, but ignores future developments of these parameters.

A simple check of the capacity of the two indicators to predict sustainability in this stochastic framework is to study the dependency between these simulated *ANS*'s and *ES*'s at the different periods t and the *ex post* changes in U measured in t and some distant date $t+n$. This has been done for 20 runs of 100 periods each, with n=30 and results are given on figures 8 and 9. Points located in the north-west quadrant correspond to cases where the indicator properly tells us that there are no threats on the growth of well-being, at least at the 30 years horizon -that one may consider as rather short. Points located in the southeast quadrant correspond to cases where the indicator adequately warns us of an unsustainable situation. Points in the two other quadrants correspond to the two opposite cases of mistaken diagnostics mentioned above.

On the whole, we have the reassuring property that both indicators have the positive correlation that one could expect with future changes in U. But misleading messages are frequent in both cases. Interestingly enough, we find that, in this setting, the *ES* indicator almost never predict unsustainability while the economy is in fact sustainable: there are very few points in the north-east quadrant of figure 9. But, on the other hand, cases are relatively frequent where the indicator predicts sustainability while the economy is not sustainable, and this is due of course to its ignorance of the risk of *economic* unsustainability: it misses all the cases where unsustainability comes from a value of δ that becomes higher than what it used to be, implying a decline in $K(t)$. Because it weighs more evenly the economic and environmental pillars of sustainability, the *ANS* indicator does not have such a bias. But this does not necessarily make it more precise: there are equally large numbers of cases of overoptimism and overpessimism of this *ANS* indicator, corresponding to point in the northeast and southwest quadrants of Figure 8.

In the real world, the simple forms of uncertainties that we have introduced in these simulations are of course amplified: uncertainty applies to a much larger set of parameters than the two simple ones that we have considered, and not only to their future values, but even to their present value. In fact uncertainty applies not only to the parameters of the model that governs these eco-environmental interactions, it applies to the structure of the model itself. It applies also to the measurement of current stocks, and even to the list of these natural assets whose stocks and future evolutions have to be taken into account. This leaves room for many different implementations of the basic framework of section 1a, depending on *a priori* beliefs concerning the model that best describes, or also different sensibilities to the risk of using a mistaken model, with some preferring models that are highly conservative on the environmental side, while other will accept the risk of underestimating these environmental risks. It has been recognized for long that most of the debates concerning long term environmental changes are not necessarily ideological ones -such as the opposition between different versions of the objective function U described in the previous subsection- but as reflecting different beliefs on probability distributions of future eco-environmental scenarios. There was no reason why we could have escaped such a difficulty. And this is clearly a difficulty that brings us well beyond the problems usually faced by statisticians whose ordinary job essentially consists in measuring the current state of the world. As far as this current state of is concerned, there can be measurement problems and/or divergences upon the way to aggregate the different characteristics of this state of the world in summary indexes. These problems are already large, but there is in principle no room for heterogeneity of beliefs or expectations. Trying to quantify sustainability adds this dimension of assessing the future, and heterogeneity of beliefs concerning this future come into play as an additional source of complexity. Here again, such a problem can push us to opt for a set of indicators able to reflect such a panel of beliefs, rather that favoring only one.

Figure 8:
Simulated relationship between *ANS*(*t*) and the relative change in *U* between *t* and *t*+30

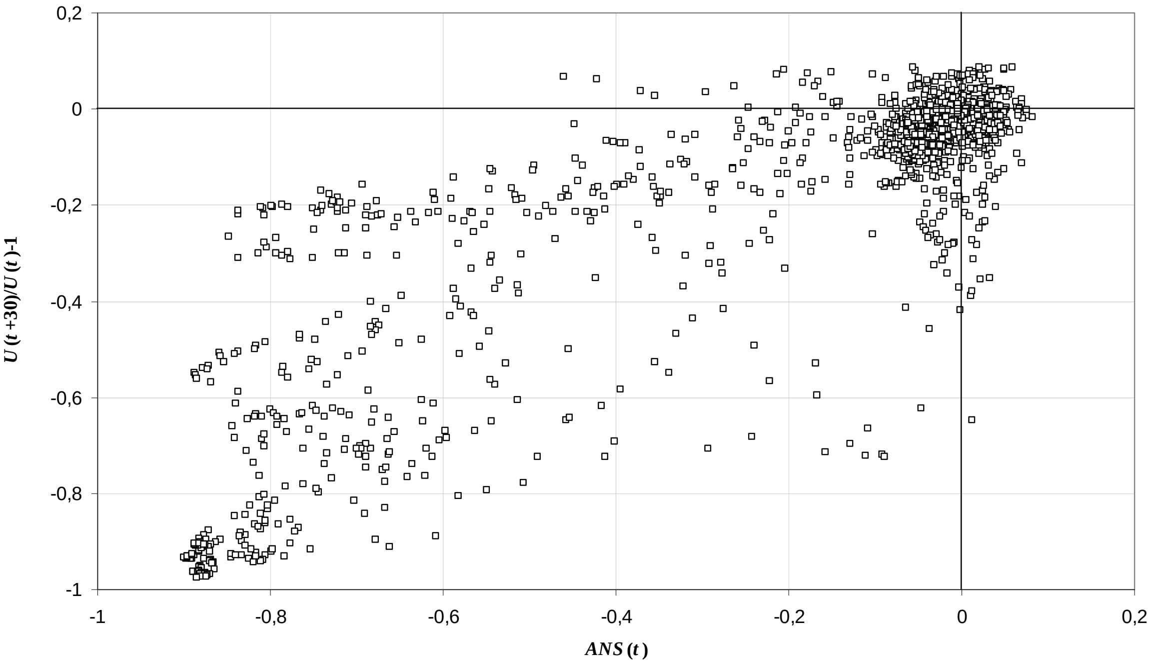
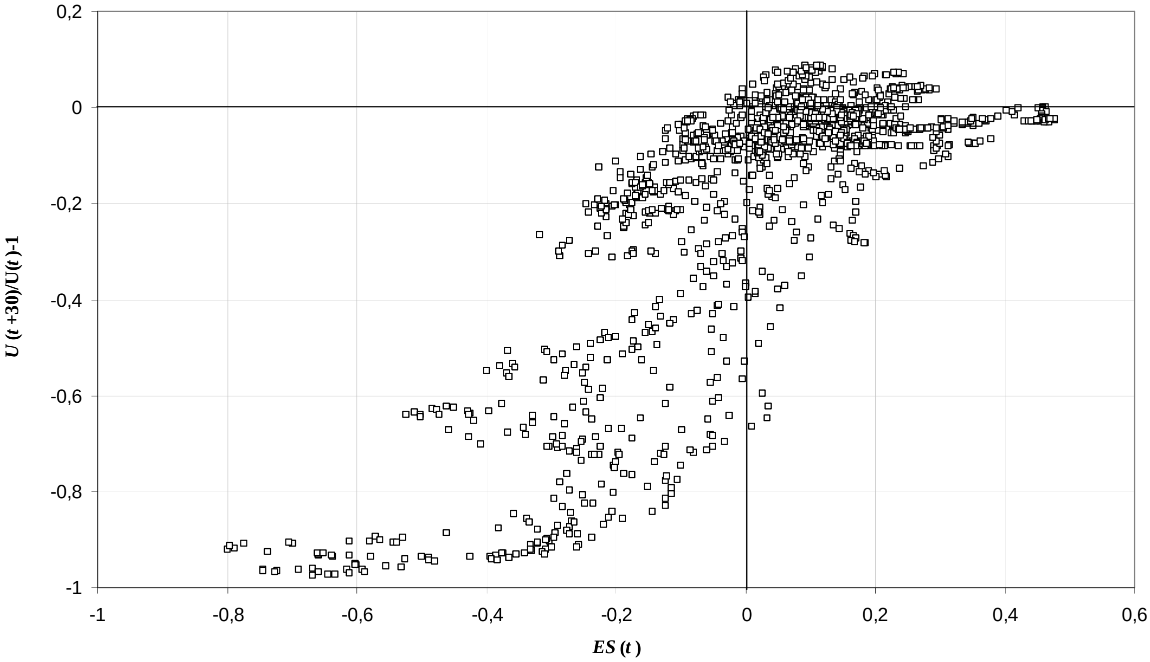


Figure 9:
Simulated relationship between *ES*(*t*) and the relative change in *U* between *t* and *t*+30



III - An additional problem: the cross-national dimension of unsustainability

Let's move on to the properties of indicators in a multinational context. As mentioned in the introduction, messages on this dimension of sustainability are another source of major cleavage between the ANS and many other approaches to sustainability. According to the index chosen, it is the least developed or the most developed countries that are the most severely concerned by unsustainability, the first ones because of underinvestment in physical and natural capital and/or because of a poor management of their natural resources, the second one because of their high standard of living that puts a lot of pressure on the world's ecosystem or natural assets.

Advocates of the ANS defend the first view by arguing that, if markets work properly, the pressure that developed countries exert on other countries' resources is already reflected in the prices that they pay for importing these resources. If, despite this cost of their imports, they are still able to have a positive ANS, this means that they invest enough to compensate for their consumption of natural resources. It is then the responsibility of exporting countries to reinvest the income from their exports in sufficient quantities if they want to be also on a sustainable path.

According to a basic version of the so-called "Hartwick rule" (Hartwick, 1977), it is all this rent that these countries would have to reinvest for sustainability: a country that sells a non renewable asset necessarily gets poorer if it does not convert all the resulting income in another asset. It is when they make such a choice of not reinvesting all their rent that many producers of natural resources are not on a sustainable path.

In reality, this Hartwick rule needs some qualification. If we take into account the fact that the price of an exhaustible resources must be on an ascending trend (the Hotelling rule), then the value of a given stock of this resource is expected to increase autonomously over time, and this allows a country to be sustainable even if it does not reinvest the entirety of the income currently derived from this resource. But, once this correction is made, ANS computations should be theoretically correct.

Yet they are so only if an additional assumption is supposed to be valid, the assumption of efficient markets. If markets are not efficient and if the natural resource is underpriced, then the importing countries benefit from an implicit subsidy and the exporting ones are taxed. This means that effective sustainability of the former is overestimated, while the sustainability of the latter is underestimated. And this problem will be all the more crucial when there are no markets at all, or in the presence of strong externalities.

As we have constantly done along this text, we cannot admit sticking to an approach that would not address such difficulties due to externalities or an inefficient functioning of markets. We must look for ways to tackle that dimension of sustainability. This is however not easy. We shall restrict ourselves to give a few hints of ways this good be done, relying once again on the kind of stylized example that was used in the previous sections.

The setting that we shall consider is a very simple two-country setting, derived from the single-country model of sections 1 and 2, but further stylized to allow concentration on the core of the problem. We neglect physical capital, production takes place with labour as the only input, but with external effects on the stock of a natural resource that is now a global public good with free access and available in quantity $S(t)$ at time t. We also neglect the spontaneous regeneration of this good. It is therefore treated as an exhaustible resource.

We assume that the two countries produce and consume at each period in quantity $C_1(t)=C_2(t)=1$, but with different technologies. Country 2 uses a clean technology that has no impact on $S(t)$, while country 1 uses a “dirty” one, that leads to a depreciation of $C(t)$ by an amount proportional to C_1(t), i.e. $S(t+1)=S(t)-\pi C_1(t)$.

Last, we push further the asymmetry by assuming that it is only country 2 that is affected by this loss in S(t), with an instantaneous utility function of the same form as before, i.e. $U_2(C_2,S)=C_2^{\mu}S^{1-\mu}$. Country 1 is completely indifferent to the level of $S(t)$, for instance because its geographical characteristics fully protects it from consequences of a declining $S(t)$. Its instantaneous utility function is simply $U_1(C_1,S)=C_1$. With such a setting it is natural to redefine countries 1 and 2 as being respectively “the polluter” and “the polluted”.

What can be the transcription of the general rules presented in section 1.a. to this two-country setting. One possibility suggested by Arrow, Dasgupta and Mäler (2003a) consists in computing country-specific accounting prices for $S(t)$, this difference reflecting he fact that the two countries suffer differently from variations in $S(t)$[5]. If V_1 and V_2 are the intertemporal utilities for the two countries, we therefore define $p_1=\partial V_1/\partial S$ and $p_2=\partial V_2/\partial S$. Next, given that the depreciation of $S(t)$ is global, it is the overall variation of $S(t)$ over time that must be deducted from each country's *ANS* weighted with the country-specific accounting prices. We get therefore:

$$ANS_1(t)=p_1(t)dS(t)= -p_1(t)\pi C_1(t) \tag{14}$$

and

$$ANS_2(t)= p_2(t)dS(t)= -p_2(t)\pi C_1(t) \tag{15}$$

It is easy to guess that $p_1(t)$ will be identically equal to zero: the polluter is not impacted by changes in $S(t)$, hence it gives no value to this asset. On the other hand, the polluted will give a positive value $p_2(t)>0$ to this asset. Figure 10 gives the result of a simulation of this system with an initial value of 1 for $S(t)$, with $\mu=0.5$ and $\pi=0.02$. We took an intertemporal discount rate of 1% per year. The results are as expected. Country 1 has an *ANS* always equal to zero, consistent with the fact that it maintains its current level of well-being all over the projection. Country 2 has a negative *ANS*, consistent with the fact that its well-being continuously declines over time. From a certain point of view, these results make sense. It is true that the polluter is on a sustainable path while the polluted is not. But from another point of view, the message to policy makers is misleading. Country 1 can do nothing to restore its sustainability. It is only a change in the polluter's technology that can help restore sustainability for the polluted country.

The solution to this paradox is not necessarily to throw away indicators (14) and (15) - the information they convey is not meaningless- but rather to combine them with another twin information whose purpose would not be to assess each-country's own sustainability, but rather contributions of the different countries to global unsustainability.

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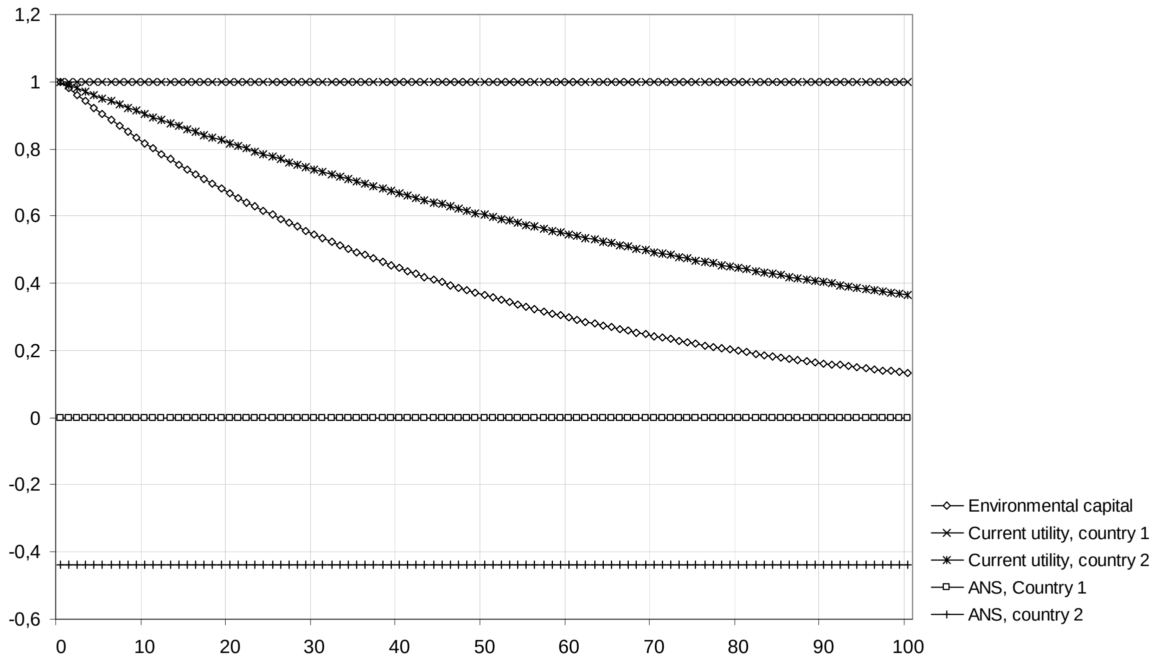
[5] They even mention the fact that a given change in $S(t)$ might be a good for some countries and a bad for other ones, hence accounting prices of opposite signs.

Figure 10: Natural capital, ANS and current utility levels in a two country setting



This is possible at least in the simple example proposed here. If we rewrite more generally dS_1 and dS_2 the contributions by each country to the deterioration of the global stock (with dS_2=0 in our particular example), (14) and (15) are rewritten as:

$$ANS_1(t) = p_1(t)[dS_1(t)+ dS_2(t)] \quad (16)$$

and

$$ANS_2(t) = p_2(t)[dS_1(t)+ dS_2(t)] \quad (17)$$

and we see immediately that the elements of these two equations can be rearranged as well as:

$$ANS_1'(t) = [p_1(t)+p_2(t)]\, dS_1(t) \quad (18)$$

and

$$ANS_2'(t) = [p_1(t)+p_2(t)]\, dS_2(t) \quad (19)$$

In this alternative formulation, the global accounting price $p(t)=p_1(t)+p_2(t)$ can be interpreted as a global impact of a given change in the global stock dS on an aggregate index of intertemporal well-being $S=S_1+S_2$, and contributions by each country to global sustainability or unsustainability is equal to its own contribution to dS, weighted by this implicit price. This is for instance the line that is followed when one estimates contributions of countries to climatic change using their respective levels of GHG emissions, valued at a common price supposed to reflect global worldwide damages from the marginal ton of CO_2.

The double accounting system of equations (16-17) and (18-19) clearly illustrates that unsustainability and contributions to global unsustainability are two different things that can both deserve measurement. A country with a highly negative dS_i and p_i=0 can be sustainable while strongly contributing to global unsustainability, and the reverse can be true as well.

Now, one cannot hide that all this requires, in turn, many disputable assumptions. There are for instance two additivity assumptions, that are respectively the additivity of the dS_i's and the idea that $V=V_1+V_2$ has some sense as a global well-being index, i.e. that national well-beings can be aggregated in an utilitarian way. And this answer to the multidimensional aspect of sustainability still raises the main general problem that we have met all along this paper, i.e. our ability to fully project long term consequences of changes in S, now in a simultaneous way for all countries in the world. But it is along these lines that we can hope reconciling still very divergent views on what sustainability means in an interdependent world.

Some conclusions

What are the main messages to retain from this rapid exploration of various properties of sustainability indicators, and which perspectives does it suggest concerning future work?

It seems at first necessary to re-emphasize two points that make the topic quite different from other examples of index-building activity.

The first point is the importance taken by normative issues. Defining sustainability needs a prior choice of what we wish to sustain, and there can be a large variety of choices in this respect: do we simply want to sustain standard GDP per capita, or any other notion of well-being that remains to define? Do we want to focus specifically on the maintenance of such or such element of the environment? Many divergent views on how to assess sustainability simply reflect such divergent views about what must be the focus of sustainability. Making choices in this respect goes far beyond the normal job or normal responsibility of statisticians: they can help clarify the options or help implementing correctly the index once the choices have been made, but they can in no way fully assume the definition of objectives. In addition to this, the last section has shown that normative issues also arise from the international dimension of the problem. Environmental issues are typically issues where "everyone for oneself" strategies cannot or should not apply. The question of measuring who is sustainable from its own point of view is interesting. But, when sustainability for the ones is at the expense of sustainability for the others, we must move to another point of view that imposes aggregating well-being across countries, i.e. one more potential source of normative debates.

The second point also brings us strongly beyond standard statistical practice. Statistics is about measuring what currently happens or what has happened in the more or less remote past. It is about facts. Measuring sustainability is about measuring what will or could happen in the future, it is about predictions. One could of course argue that, in a world of perfect capital markets, all the information on this future path of the economy ought to be already included in the current valuation of assets by capital markets. Such is the implicit view of some existing implementations of the ANS index. But this is a purely theoretical view. Recent events have shown up to what point well-established capital markets can be mistaken in their implicit predictions of future economic developments. This is all the more true in domains where markets are notoriously underdeveloped or inexistent, and such is the case in environmental domains.

We have seen at length what theoretical answer we have to this lack of price information. It is to assume that the statistician is endowed with the model of perfect long term foresight that would allow him telling what are going to be, tomorrow, the relative social utilities or relative scarcities of all kind of environmental and non-environmental goods. This solution is fully theoretical. Incidentally, in such a world of perfect foresight, building sustainability indexes would not be an issue anymore: the person interested in the relative well-being of future cohorts would just have to read in the crystal ball of the previsionist. Anyway, we are not in such a perfect world, and everybody should have in mind the difficulties that this implies. This explains why progress in the direction of these indexes is so slow: if the exercise were an easy one, it would have been already done quite long ago.

But we cannot respond to these difficulties by simply dismissing the problem. We need to suggest solutions. We shall very tentatively suggest three options, by increasing order of preference.

The first option would be to consider that, despite its many requirements and the difficulty to implement it, the ANS indicator remains the one that has the largest potential, because it mixes all the components of sustainability -economic, social and environmental-, because it mixes them in a way that is analytically founded, and because it is perfectly able to integrate the very strong constraints that environmental limits can put on socio-economic development. In that case, all efforts could be concentrated on making this indicator more operational and more accurate.

The main problem with this first approach is that it may defer to a very distant future the production of regular indexes, because it means parallel progress on many things: convergence on the underlying index of current well-being that has to be sustained, elaboration of projection models of eco-environmental interactions on which reasonable consensus could be reached… And the risk, in the meanwhile, is to have to fall back on a very imperfect second-best solution such as an ANS essentially based on observed market prices, with the risk of conveying unduly optimistic messages.

Table 2 : Three scenarios for articulating indexes

	Domains that need to be covered			
	Economic	Social	Exhaustible resources	Other environmental assets
Scenario 1	ANS			
Scenario 2	ANS+components			
Scenario 3	ANS restricted to socio-economic dimensions (index of socio-economic sustainability)			Index(es) of environmental sustainability

The second option is to limit this risk by temporarily complementing the ANS with a series of physical measures specifically focusing on the environmental dimensions that are not well covered by this ANS. The risk in this strategy is to have the ANS attracting excessive attention compared to its companion indicators. In particular, the fact of having the ANS incorporating some environmental elements may create the feeling that it already does a good part of the job of weighting against each other the environmental and socio-economic pillars of durability. The risk is to suggest that other information of this small dashboard are only subsidiary and can be neglected in global policy assessments or cross-national comparisons.

One way to avoid that risk could be to abandon the encompassing ambition of the ANS and respecialize it, at least temporarily, on the domains on which it is the most relevant: these include standard capital accumulation, human capital accumulation, and also probably the depletion of fossil resources. The interest of such a specialized index is that it would keep the most interesting messages from the ANS, i.e. the fact that it gives the right warnings to countries that do not sufficiently replenish or expand their stock of physical capital, that pay too little attention to investment in health or education, or to countries whose main wealth are mineral non-renewable resources and that do not reinvest a sufficient share of the rent that is drawn from these resources. All these messages are important messages that are ignored by purely environmental approaches and we need an indicator that conveys such useful information: it is typically for this task that the ANS has a strong comparative advantage. But we would avoid giving the undue feeling that the ANS is able to do everything: even if it can in theory, it is far from being able to do so in practice. In the current state of the art, the corrections it makes for damages to the environment are not able to treat them in more than a marginal way. To put these environmental issues in crude light, it is preferable to treat them completely separately, under a form that remains to be made more precise. Such a compromise is stylized on the last line of table 3. This third option has the advantage of avoiding environmental dimensions being overshadowed by more traditional economic ones.

We shall not conclude at this stage on which of the three solutions is to be retained. In that sense, we have no definitive answer to the statistician's perplexity that we had referred to in our introduction. But we hope at least to have made the available options clearer.

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