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Review

Sustainable Development: Between Moral Injunctions and Natural Constraints

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Abstract: Sustainable development must satisfy the needs of present generations without compromising the ability of future generations to meet theirs. Although it looks at the economic, environmental and social aspects of sustainability, this article focuses specifically on an analysis of the concept in conjunction with the use and protection of natural resources. It shows how taking account of environmental goods, including the finite nature of certain natural resources, can change the way economists deal with the issues of growth, development and equity between generations. In this context, after a brief historical perspective on the concept of development, the paper shows how the potential for substitutability between natural and manufactured capital, for example in production technologies, lead to two paradigms, that of weak sustainability and that of strong sustainability. These two approaches are presented in an effort to explain how their merits can be mutually reinforcing.

Keywords: development; sustainable development; weak and strong sustainability; intergenerational equity; natural resources; indicators

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1. Introduction

The purpose of this article is to show how economic research can approach and analyze the issue of sustainability, its significance and its challenges. We do not offer an exhaustive overview of the literature [1] but, more modestly, a working framework that highlights and articulates the major ideas in this area. Two principal concerns can clearly be distinguished; one which debates ethical issues and the other that draws attention to natural limits on growth. The two approaches are often opposed, perhaps too hastily. One might also consider that the two ideas may feed a dialogue where principles—for example, a concern for intergenerational equity—are called into question because of the practical obstacles to them or, on the contrary, where purely pragmatic considerations are insufficient to support the ethical stakes. For example, in principle one can advocate an equal sharing of oil resources among generations. But these resources are nearing exhaustion and most of future generations will not have any. Conversely, purely ecological reasons might decree forest areas must not fall below a certain threshold as entire ecosystems could disappear; but how to choose among multiple forest use policies that all meet the particular threshold?

In Section 2, a rapid review of the historical context is useful to understand the evolution of the notion of development during the past century, in such a way that today the adjective "sustainable" is almost always associated with it, referring to the promotion of economic growth that takes account of its environmental and social impacts on both present and future generations. In Section 3, we shall then define the concept of sustainability in more specific terms. Such delimitation and clarification is not an easy task. Indeed, there are hundreds of different definitions of this notion! We shall first of all highlight the crucial importance of technology, and more specifically the possibilities for substitution between natural and manufactured capital. A distinction will thus be made between studies based on a concept of weak sustainability which accepts that natural capital can be replaced by manufactured capital, and those based on a concept of strong sustainability which supposes that certain types of natural capital cannot fall below critical thresholds (or so-called minimum safeguard levels). In the context of weak sustainability (Section 3.1), we shall emphasize the considerable difficulty in taking account of intergenerational equity (to avoid favoring one generation, whichever that may be). We shall then try to clarify the limitations of weak sustainability (Section 3.2). Finally, in the context of strong sustainability (Section 3.3), we shall emphasize the problems posed by defining critical types of natural capital and sustainable development indicators.

2. A Historical Perspective

2.1. Development

Throughout the first half of the 20th century, no-one, at least in developed countries, contested the idea that economic growth was a key factor in "progress" and "modernization". Questions of equity and social justice were only rarely taken into account. The situation changed at the end of the Second World War when governments focused more specifically on improving the economic and social status of as many people as possible, including the poorest nations in the world in the context of decolonization. Development economics in its modern form was thus born. This branch of economics could not restrict itself to being a positive theory (describing how things were, rather than how they

should be). It also needed to be a normative theory that could define the targets to be attained and the resources required to achieve this.

During the 1960s, following the theories put forward by Rostow [2], economic development was generally considered as a linear process in which five successive stages could be identified: Traditional society, preconditions for take-off, take-off, drive to maturity and the age of high mass consumption. This concept of economic development determined the prime objective assigned to development policies, which was to raise standards of living by supplying growing populations with the goods and services that would allow them to attain the final level of development. In this context, it was a priority for efforts to focus on agriculture (to increase yields) and industry (to encourage the industrialization of the least developed countries).

At the end of the 1970s, greater importance was given to the "basic needs" of populations (see for instance Herrera *et al.* [3], Chichilnisky [4,5]. The development of a country should no longer be assessed in terms of its Growth Domestic Product (GDP) alone. It should also take account of aspects relative to education, health, nutrition and employment, *etc.* As from the early 1980s, questions of structural adjustment were introduced, with a definition of the "guidelines" to be followed in order to emerge from "under-development". There is insufficient space here to describe the details of the structural adjustment policies implemented in recent decades, their advantages and drawbacks and their successes or failures. We should nonetheless consider the two major criticisms made of them. Firstly, the inequitable distribution of the benefits of development within a given country, where inequalities with respect to income, access to food, education or health services continue to prevail. And secondly, the adverse effects of development on social structures and the environment. Generally speaking, and thus in a simplified form, sustainable development aims to correct these two deficiencies. And it goes further by focusing not only on present generations but also on those of the future.

2.2. Sustainable Development

It should not be deduced from the above that sustainable development is a recent idea. It was first mentioned in a limited form at the beginning of the 18th century in the context of forest economics, restricted to problems concerning the optimum management of a renewable resource. More generally, the views of Malthus at the end of the 18th century, and of Ricardo in the early 19th century, were associated with the first economic analyses designed explicitly to study the degree to which a scarcity of natural resources, and more specifically a scarcity of agricultural land, could constitute a brake on economic and population growth and on a rise in living standards.

Although the concept of sustainable development was, at least implicitly, introduced as early as 1852 in the forestry laws of the Habsburg Empire, a more specific definition was proposed much later in 1987, in the context of the Brundtland report [6]. It was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The expression "sustainable development" met very rapidly with extraordinary success. In 1989, just two years after publication of the Brundtland report, Pezzey [7] listed more than sixty definitions of sustainable development, and seven years later, Dobson [8] found a total of 300! As noted by Rotillon [9], this abundance of definitions, and intensive use of the expression (it is now difficult to

find an economic or political measure, whether it be local, national or international, which is not justified by the label "sustainable development") led to questions as to the true value of this concept.

Although there is no single definition of sustainable development that is acceptable to all, we shall base our arguments on the consensus view according to which it covers three areas: Environmental protection, economic growth and social equity. And in terms of its social aspects, we shall limit ourselves to the challenges of intergenerational equity.

3. Weak and Strong Sustainability: Definitions and Lessons

There is a potential for tension between the exhaustible nature of natural resources that are today widely used for production, such as oil, gas and coal, which account for more than 80% of overall world energy consumption, and the infinity of generations that could in principle benefit from them. This tension will only be potential for as long as production technologies enable the substitution of exhaustible natural resources by manufactured, and hence reproducible, capital [10]. Indeed, these technological possibilities enable a distinction between, on the one hand, a so-called weak sustainability approach which, implicitly or explicitly supposes that it is or will always be possible to replace natural capital by manufactured capital, and on the other hand, the concept of strong sustainability which requires that at least some natural goods must not fall below so-called critical thresholds.

3.1. Weak Sustainability

If natural capital and manufactured capital can perfectly substitute for each other (or, in other words, if natural capital is not an essential input in the production process), a reduction of the possibilities for consumption over time is not inevitable; it is possible to maintain them at the same level by increasing the share of manufactured capital in production inputs. According to this viewpoint, there is no reason to conserve natural capital; depending on the baseline conditions, an initial phase of growth in consumption, before stagnation, might even be envisaged. But the question is then: How can a distinction be made between all the possible trajectories?

As a general rule, studies on weak sustainability have sought to maximize an intertemporal social choice criterion under the different constraints that characterize the economy under consideration. They form part of the general context of economic growth theories. The two principal challenges posed when choosing a criterion are: *i)* to indicate whether the benefits of using exhaustible resources are maximized, and *ii)* to specify how they will be distributed between generations.

3.1.1. The discounted utility criterion or the dictatorship of the present

Each generation consumes during its life cycle, gaining satisfaction from this which is measured by a so-called utility function that is supposed to grow in line with consumption. In most cases, it is also assumed that the utility function is concave, as the additional utility drawn from consuming a supplementary unit of the resource is less than that drawn from consuming the previous unit. Economists then refer to the declining marginal utility of consumption.

Let us suppose that the intertemporal social criterion to be maximized is the infinite sum of discounted satisfactions [11], where "discounted" implies giving increasingly less importance to a generation as it becomes distant in time. Such a practice may shock some readers. But we need to resign ourselves to accepting the fact that any decision-making rule involves a distribution of consumption between different generations (Howard and Norgaard [12]). Concretely, the discounting criterion gives weighting to the utility of each generation of individuals. More specifically, it supposes that the utility of the current generation is assigned a unit weight, while that of the second generation is assigned weight $(1+a)^{-1}$, and that of the third generation is given $(1+a)^{-2}$, *etc.*, where a is the discounting rate. The latter measures the preference for the present. In practice, it indicates the equivalence between a unit of satisfaction for the present generation and $1+a$ units of satisfaction for the second generation, or $(1+a)^2$ units of satisfaction for the third generation, *etc.* If the discounting rate a is null, there is no difference between the satisfaction of today and that of tomorrow. But if the discounting rate a is strictly positive, there is a preference for the present, which becomes stronger as the parameter rises. However, as mentioned above, whatever the strictly positive value of the latter, the future is always overwhelmed at proportions that grow as it becomes more distant. Under a linear utility function, if the discounting rate is 10%, then renouncing €1 of consumption of a resource is only justified if this allows the consumption of €120 in 50 years' time and €14,000 in 100 years' time. Under a 5% rate, renouncing €1 of consumption today is only justified if this allows the consumption of €130 in 100 years' time and €17,000 in 200 years' time (Guesnerie [13]).

These few figures show that the criterion of the discounted infinite sum will prefer exploitation trajectories that privilege current consumption. This *dictatorship of the present* (Chichilnisky [14]) is in contradiction with one of the objectives of sustainable development, or more specifically with that of intergenerational equity.

For this reason, when utility is only dependent upon consumption of an exhaustible resource, the optimum exploitation rule leads to its depletion, which may come up against the "conservationist" requirement that many associate with the notion of sustainability. This concern may disappear when the utility function depends not only on consumption of the resource but also upon its stocks (Krautkraemer [15]). In this case, the individuals of a given generation will also draw satisfaction from the resource for reasons other than consumption (e.g., in the case of a forest, because of the eco-system and recreational services it provides, or because of the simple fact of its existence, independent of any use). The optimum timetable for the extraction of the resource then requires the conservation of a certain stock of this resource with declining consumption over time, but which becomes null when the floor of the stock is reached.

3.1.2. The Green Golden Rule or the dictatorship of the future

According to the so-called *Green Golden Rule*, the search is for consumption trajectories that will lead to the highest level of stationary utility (Chichilnisky *et al.* [16]). By its construction, the Green Golden Rule thus avoids any dictatorship of the present. But in order to maximise the utilities of the most distant generations, it recommends a null consumption of exhaustible resources and thereafter the maintenance of stocks at their initial levels. Thus, whereas the discounted utilitarian criterion

implicates a dictatorship of the present, that of the infinite limit of utility imposes a *dictatorship of the future*.

3.1.3. The maximin criterion, Hartwick's rule or the dictatorship of the most underprivileged generation

According to the *maximin criterion*, sometimes referred to incorrectly as the Rawls' criterion, the aim is to maximize the utility of the least favored generation. As shown by Solow [17], use of such a criterion in a growth model with exhaustible resources leads to null growth. For as long as growth remains positive, it is indeed always possible to increase the utility of the least favored generation (the first) by reducing its savings ratio, and an equilibrium is only achieved when this savings ratio is null for the current generation and those in the future, *i.e.*, when growth is null. Using such a criterion, a poor economy will remain so indefinitely (Dasgupta and Heal [18], Rotillon [9]).

We would like to avoid blocking growth without consenting to the inequality between generations. The initial and technical conditions being what they are, can we invest so as to keep consumption constant from one generation to another? When physical capital and natural capital are perfect substitutes in the production function of a consumption good, a particular optimal exploitation pattern exists that guarantees constant consumption. It is necessary for the income drawn from natural resources to be reinvested at all times in the physical capital. This is *Hartwick's rule* [19].

However, maintaining consumption at a constant level, including when the initial conditions would permit its growth over time, can still be assimilated to a dictatorship, which in this case is that of the most underprivileged generation which, with finite savings (even at a low level) will produce an increase in consumption for the infinity of its descendents.

3.1.4. The problem of taking account of intergenerational equity

Dictatorships of the present, the future or the most underprivileged generation clash with the ethical intuition which implies that special attention should not be paid to a generation solely because of its chronological position. Ultimately, why should the same weight not be given to all generations? In 1928, Ramsey [20] was already proposing use of the non-discounted sum of deviations between current utility and the level of bliss (defined technically as the maximum utility possible, or "bliss point"). He thus explicitly set aside discounting, which he deemed devoid of any ethical foundations. In principle, treating all generations anonymously [21], as suggested by Ramsey, should meet with spontaneous approval; this principle is indeed widely adopted in finite contexts. But the infinity of the generation chain generates two major criticisms of Ramsey's criterion. Firstly, when production capacities are sufficient, anonymity may lead to an excessive reduction in consumption for the current generation. Indeed, whatever our sacrifice today, it is justified because it has only a finite weight in the face of endless advantages (by undiscounted summation) for all generations to come. Secondly, if discounting is not applied, the sum of the utility time series does not necessarily converge. This raises the question of the best possible trajectory when several of them produce a criterion with an infinite value. In other words, Ramsey's criterion is not complete, *i.e.*, it does not enable the comparison of some of the possible trajectories [22].

It has recently been shown (Zamé [23], Lauwers [24]) that no single, explicit intertemporal criterion can satisfy both the demands of the "Weak Pareto principle" (*i.e.*, if the utility of each generation increases, the value of the criterion increases strictly in line with this) and "finite anonymity" (switching round the utility of two generations leaves the value of the criterion unchanged). In some ways, this finding is the culmination of a somewhat technical and difficult literature, but the core of the problem can be presented relatively simply. A criterion that deals with all generations in an anonymous manner will not differ between the two sequences of utility: (0,1,0,1,0,…) and (1,0,1,0,…). The second sequence is in fact obtained from the first by simply changing round the generations in pairs; the first switches its place on the time scale with the second, the third switches with the fourth, and so on. By virtue of anonymity, the second sequence must also be deemed to be equivalent to (1,1,0,1,0,…) because it is possible to move from one to the other by means of permutations (which only start as from generation 2). And by transitivity, the third sequence must also be declared as not differing from the first... in violation of the Pareto principle! Indeed, when moving from the first sequence to the third, the outcome of all the generations is unchanged except that of the first, which is strictly better.

In reaction to this impossibility result, one can, for example, weaken the requirement for anonymity but without accepting the dictatorships of the present and future. This results in particular in two mixed criteria [25], in the sense that they are built as a weighted mean of two of the previous criteria. These are: (i) Chichilnisky's criterion [14], a mean of the discounted utilitarian criterion and the Green Golden Rule, and (ii) the mixed Bentham-Rawls criterion (Alvarez-Cuadrado and Long [26]; Figuières, Tidball and Long [27]) which is the mean of the discounted utilitarian criterion and the maximin.

3.1.5. Chichilinisky's criterion

Taking as the criterion, the weighted mean of a dictatorship of the present (the discounted utilitarian criterion) and a dictatorship of the future (the Green Golden Rule), leads to a criterion that does not suffer from any of these defects. Adding three other properties—continuity, linearity (called independence by Chichilnisky, 1996) and sensitivity—then it is indeed the only criterion that avoids these two dictatorships. This axiomatic characterization gives for the first time the same robustness, clarity and foundational features to define sustainability, as Koopmans [28] once gave to the literature on social choice over time. Based on this criterion, Chichilnisky [29] established that the optimum trajectory for an economy implies conservation of stocks of exhaustible resources at a certain floor threshold (denoted s), which is higher than the minimum stock that must be conserved under the discounted model (su) and lower than that necessary under the Green Golden rule (sv).

Three main objections have been addressed to this criterion, for which answers exist now.

First of all, when it is applied to the management of a renewable resource, there is no trajectory that can maximize it. This initial difficulty has given rise to a technical literature that proposes similar solutions and discusses their merits (Figuières and Tidball, [30]; Chichilnisky, [31]).

Secondly, the question arises as to the choice of the weighting coefficient used to construct Chichilnisky criterion and that covers all values between 0 and 1, but not the two extremes. Nevertheless, if we know how to identify a stock value of particular importance (for example, maintenance above that level could prevent its extinction), Chichilnisky [31] shows that a weighting

coefficient exists, based on which it can be ensured that the optimum trajectory, for her criterion, converges at infinity for a stock that is at least equal to this minimum. This particular weighting coefficient value is linked to the Fréchet derivative of her criterion, evaluated at the point of extinction [32]. This derivative gives the "marginal value" of the resource when it reaches her point of extinction, which must be incorporated correctly in the intertemporal social criterion so as to highlight any arbitration between the interests of generations at infinity and those of previous generations.

Finally, Chichilnisky's criterion generally leads to a trajectory for the economy which, in the first instance, is similar to that which would have been obtained using the discounted utilitarian criterion, and secondly which is similar to that which would have been obtained with the utility criterion at infinity. This second part of Chichilnisky's trajectory requires a large quantity of manufactured/human capital, which supposes that intermediate generations save a lot and consume little. In other words, and put more simply, Chichilnisky's criterion can lead to the sacrifice of intermediate generations. However, the lower the weighting coefficient, the lower the sacrifice of intermediate generations (see Figuières and Tidball, [30]).

3.1.6. The mixed Bentham-Rawls criterion and Rawls' principle of just saving

Rawls' position in terms of *just saving* does not require any sacrifices from intermediate generations relative to the first or the last [33]. Rawls defends a "two-step" logic. During the first step, each generation must save so that it can transfer more to the next generation than it inherited from the last, until, during the second step "once fair institutions are firmly established, and all basic freedoms are effectively implemented, the net accumulation required falls to zero" (Rawls, [34]). The idea is thus that of an accumulation phase during which saving is required if the initial conditions are bad, followed by a stable phase during which saving may be allowed, but dissaving is forbidden.

If the principle of equality that prevails during the second phase recalls the maximin logic, it is subordinate to the need for a minimum take-off from the condition of under-development. Should this be seen as a lexicographic criterion in which a type of dictatorship of the future is also expressed? Not necessarily. In fact, this "two-step" logic is also indicative of a second, mixed, and weighted mean of the maximin criterion and the discounted utilitarian criterion. As shown by Alvarez-Cuadrado and Long [26], this second mixed criterion is reached when an absence of dictatorships of the present and future is imposed, but without requiring linearity, as applied by Chichilnisky. The other properties of this mixed Bentham-Rawls criterion, notably the shape of optimum trajectories, have been analyzed by Figuières, Long and Tidball [27].

3.2. The Limits of Weak Sustainability

3.2.1. The search for invariants

Under the aforementioned approaches, different criteria are proposed with reference to ethical principles. As a second stage, the consequences of their use, notably in terms of the evolution of a resource, are then analyzed. Martinet and Rotillon [35], and Martinet, Rotillon and Costes [36] suggested looking at the problem in reverse. Rather than starting from an initial choice of a criterion to be maximized, they suggested that in a maximization model that seeks to represent a growing economy

with environmental constraints, sustainable development will be possible if at least one invariant specific to this representation is present. By doing this, they agreed with the ideas of Solow [37] who considered that sustainable development consists in conserving something over the long term; however, he was not able to conclude as to the nature of this "something". Thus, in a dynamic representation of an economy, it is necessary to find invariants that are defined throughout the optimum trajectories. And this is precisely what is enabled by Noether's theorem [38].

They used this technique to study the two canonical growth models involving discounted utility criteria with exhaustible resources; the "cake-eating" model and the Dasgupta and Heal model [18]. Unfortunately, although they found many invariants that could always be interpreted as the global income consistency of the economy, it was only under extremely restrictive hypotheses such as equality in the rates of technical progress and of discounting, or the particular type of the production function.

The accumulation of "negative" results described above raises questions as to the validity of using discounted utility criteria (with constant rates or not) in economics, to consider the question of sustainable development.

3.2.2. The viability theory

The approach based on the viability theory [39] is similar to that described above and based on the determination of invariants. It is also free of any reflections concerning moral or ethical injunctions (at least in a first approach), in that it focuses on a technical definition of sustainable development. It is based on a series of constraints and characterized by all the decisions and trajectories compatible with these constraints.

In an economy based on an exhaustible resource and on manufactured capital, all constraints can include a guaranteed level of consumption for each generation and a minimum stock for natural capital. The "viability kernel" is all the initial resources, both natural and manufactured, based on which it is possible to deploy acceptable exploitation regimes that will satisfy the constraints over time. If at some time an economy finds itself outside the kernel, there is no sustainable decision, *i.e.*, one which will satisfy the constraints over time. Optimizing a criterion, such as those in the section above, is then of no interest. In other words, once the need for constraints is accepted, the non-vacuity of the viability kernel is an essential condition if considerations regarding intergenerational equity are to be deployed.

Not surprisingly, when the exhaustible resource is a highly essential input (the production technology involves complementary factors and a non-null level of the resource is required to reach the minimum consumption threshold), the economy is not sustainable with respect to viability (Martinet and Doyen [40]). By contrast, when the production technology involves substitutable factors (the resource is not essential), then the economy is sustainable in terms of viability. In intermediate cases, *i.e.*, when the substitutability of factors is imperfect, the economy is sustainable if, and only if, the elasticity of production relative to the resource, is less than the same elasticity relative to manufactured capital. Then, according to the initial configurations of natural and manufactured capitals, several exploitation regimes are possible that will sustain the viability kernel over time. In general, these regimes do not imply a constant level of consumption over time (*i.e.*, following Hartwick's rule) except when the constraints become saturated.

3.3. Strong Sustainability

Studies concerning the strong sustainability approach differ from those on weak sustainability because natural capital is assumed to be an essential production factor (or, in the same way, natural capital and manufactured/human capital are not perfect substitutes for each other).

3.3.1. Critical natural capitals

According to Daly [41], "natural capital and manufactured capital are fundamentally complementary and only marginally substitutes for each other". Under the hypothesis of complementarity, it is clear that the neoclassical approach of weak sustainability described in Section 3.2. leads to an impasse, insofar as attempts to ensure the efficient allocation of resources on the basis of growth models cannot be sustainable. Toman [42] suggested a solution to this incompatibility based on an intuitive, and in principle extremely reasonable distinction, even though it is not operational. In practice, he proposed a distinction between questions that could be resolved (or as a minimum analyzed) on the basis of growth models, and the neoclassical criterion of efficient resource allocation, from those necessitating the use of a conservative approach in order to protect the natural resources and environmental functions that he qualified as essential. This proposal actually defines among all types of natural capital those critical natural capitals that must not be allowed to decline below certain thresholds (minimum safeguard levels).

Some may be concerned that this so-called strong sustainability approach poses more problems than it solves. In particular, it raises the issue of choosing those natural capitals that may be critical, and the minimum threshold levels below which they must not fall. Not surprisingly, the literature on strong sustainability has evolved in recent years, with a particular attention to the issue of the definition of critical natural assets. The journal "Ecological Economics" devoted a special issue to this topic (see especially the contributions of Ekins *et al.* [43], and Ekins [44]) and Neumayer ([45], chapters 4 and 6 which offers a detailed account of it).

3.3.2. Indicators of sustainable development

The substitutability of goods that underlies the concept of weak sustainability enables the construction of synthetic indicators, such as, for example, the value of the GDP. Thereafter, it is possible to imagine a classification of development alternatives based on the results of cost-benefit analyses that can be broadened to include natural resources and take account of impacts on future generations.

By contrast, the complementarity of goods that is intrinsic to the concept of strong sustainability does not allow the construction of a synthetic indicator but only a series of indices, each being associated with a natural good, or a group of non-substitutable natural goods. The definition of such indices comes up against the two problems raised above, *i.e.*, the definition of non-substitutable resources and that of a severity scale for the damage measured using these indicators.

One cannot question the *ex-post* usefulness of sustainable development indicators which can, and should, be used as instruments for alert, diagnosis or even *a posteriori* evaluations of a policy (on condition, however, that the mechanisms upon which this policy is based are clearly identified and

measured). The *ex-ante* value of sustainable development indicators is much more limited, and in particular those relative to strong sustainability which cannot be used to define optimum policies or, more simply, to grade the different policies that need to be implemented to achieve sustainability targets (targets which are not indeed explicitly defined in studies on sustainable development indicators). In other words, policies need indicators, but indicators cannot constitute a policy because they may not suffice to solve the problem of allocating rare, and thus costly, resources within an economy; however, if a target is set, it is possible to define optimal trajectories to reach it.

Two further points deserve to be underlined. Firstly, the danger of defining sustainability and the indicators of sustainable development of a given productive sector, whatever its type, while taking insufficient account of the rest of the economy. And secondly, the even greater danger of constructing synthetic (single-dimensional) sustainability scores by means of aggregation and weighting, also with very *ad hoc* foundations for the different indicators that constitute sustainable development. Such scores imply that damage may be reversible, in the sense that, for example, the optimum efficiency of a firm, from an economic point of view, may be able to compensate for poorer efficiency in environmental terms, so that this firm can be considered to be "as sustainable" as a firm which is economically less efficient but more respectful of the environment and natural resources. From this point of view, it may be better to apply methods that place greater emphasis on the construction of three, independent and non-cumulative scores associated with the three aspects (economic, social and environmental) of sustainability (as is the case, for example, of the French IDEA method (*Indicateurs de Durabilité des Exploitations agricoles* or farm sustainability indicators; Vilain [46]. Nevertheless, the problem referred to above remains; it is simply displaced because it is now, for example, at the environmental level that the question arises as to implicit compensations between positive and negative effects.

4. Conclusions

Society utilizes nature to produce. Is this use now being made at a scale that threatens the survival of our planet? Optimists will point out that the Malthusian fears expressed in the past have not always been realized; they will put their trust in opportunities for substitution between manufactured capital and natural capital or they will hope that technical progress will somehow push back the limits of nature. In this case, the issue of equity between generations is wide open. Pessimists will, by contrast, put forward examples of societies, such as the Sumerians or the population of Easter Island, which disappeared because they had not understood how to conserve the ecological resources required for their production. Were their substitution possibilities too limited? Did technical progress prove to be insufficient? Were they not capable of preserving some natural resources at levels above their critical thresholds?

Ultimately, economics, either alone or in tandem with other disciplines such as philosophy or ecology, plays an important role in the debate on sustainability. It forces us to reclaim the values of society, under the natural constraints that now seem more pressing than ever. What can be "good" scenarios of long-term development within an approach that is concerned with natural constraints, equity between generations, and efficiency? The suggestions we saw in this article resonate already beyond the strictly academic circle. For example, the distinction between weak and strong

sustainability partly underlies the Integrated Environmental and Economic Accounting proposed by the United Nations (for a critical discussion of this system of accounts, see Dietz and Neumayer [47]). And the concern for equity between generations is reflected in the question of the "good" discount rate, a central and much debated concern in intertemporal cost-benefits analysis, such as the famous Stern Review on the Economics of Climate Change [48].

There is a second role for economics on the sustainability debate which was not addressed in this article. If there were a consensus on the definition of a "sustainable" development, by what means can it be achieved? This raises the issue of implementation. There is no reason that a particular idea of sustainability could result from various decisions by autonomous agents in an economy. In particular, there is a very real risk of compromising our quality of life or even the existence of our descendents. These risks do not necessarily arise from any malicious intent or indifference on our part with respect to nature and to our children. They result from ill-fitting rules and perverse incentives that economics may help to understand and redirect. But we can ask whether current debates on sustainable development are not focusing to an excessive degree, and/or too prematurely, on the instruments that need to be deployed, before clear choices as to the objectives to be attained have even been made?

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References and Notes

1. For such a review, see for example Neumayer [45]. For questions focused more specifically on intergenerational equity, consult Asheim [49] or Roemer and Suzumura [50].
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10. Substitution may also occur on consumption side, that is at the level of utility functions; see Neumayer [45], Chapter 2.

11. From a philosophical point of view, defining the intertemporal social choice criterion as a certain aggregation of utilities is a practice derived from the utilitarian doctrine which supposes that the utility of individuals is retained as the only yardstick for value. Although obtained in this context, the results we present in this section are not necessarily linked to the choice of the utility measurement unit; some of them may remain valid, for example using as starting point indices for standards of living or human development. But to our knowledge, no systematic study has been performed to clarify this point.
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21. Anonymously in the sense that if we interchange the role of generations in the chronological order, the value of the criterion is not affected .The discounted utilitarian criterion and the *Green Gold rule* clearly do not meet this requirement.
22. Using an axiomatic approach Koopmans [28] tried to avoid incompleteness. Furthermore, he sought an order that respects other reasonable properties (continuity, a strong Pareto principle, separability and stationarity) which in principle are not linked to a form of impatience amongst planners. However, and this is the surprising nature of Koopmans' analysis, the logical implication of these properties is… the discounted criterion, and hence a dictatorship of the present. Asheim *et al.* [51] were able to identify the particular assumption among those made by Koopmans [28] which leads to the discounted criterion. The culprit is a separability condition, listed as Postulate 3a' by Koopmans [28] and referred to as independent present by Asheim *et al.* [51]. This axiom requires that the evaluation of two streams of utilities which differ during only the first two periods not depend on what the common continuation stream is. Dropping this requirement, Asheim *et al.* [51] obtain a recursive social welfare function which is neither a dictatorship of the present, nor a dictatorship of the future.
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