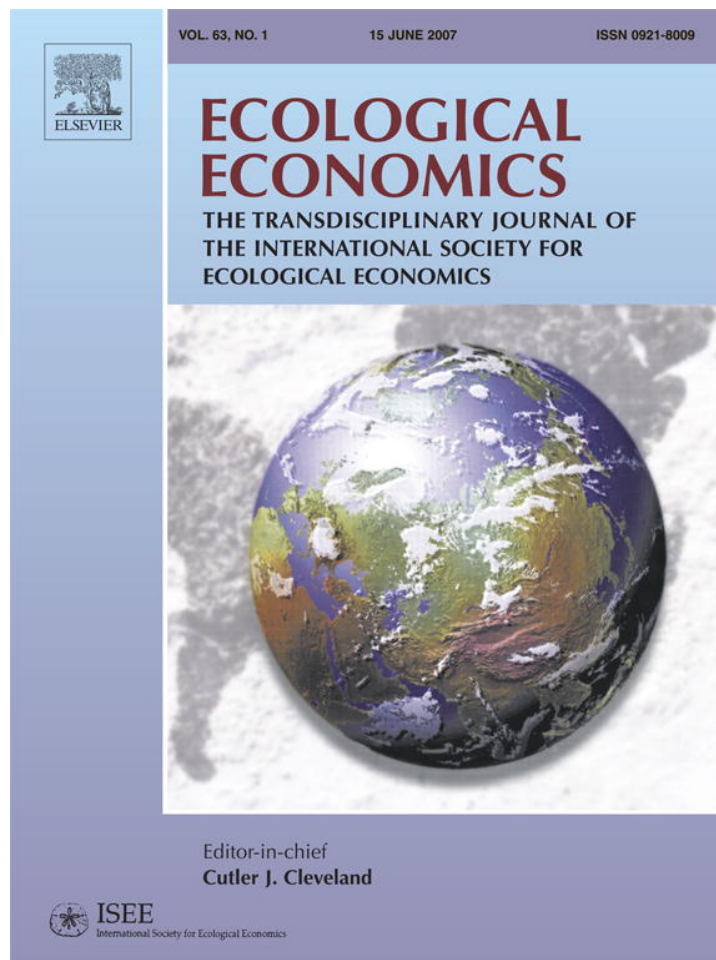


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ANALYSIS

Reconciling sustainability, systems theory and discounting

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ABSTRACT

Most definitions of sustainability imply that a system is to be maintained at a certain level, held within certain limits, into the indefinite future. Sustainability denies run-away growth, but it also avoids any decline or destruction. This sustainability path is hard to reconcile with the renewal cycle that can be observed in many natural systems developing according to their intrinsic mechanisms and in social systems responding to internal and external pressures. Systems are parts of hierarchies where systems of higher levels are made up of subsystems from lower levels. Renewal in components is an important factor of adaptation and evolution. If a system is sustained for too long, it borrows from the sustainability of a supersystem and rests upon lack of sustainability in subsystems. Therefore by sustaining certain systems beyond their renewal cycle, we decrease the sustainability of larger, higher-level systems. For example, Schumpeter's theory of creative destruction posits that in a capitalist economy, the collapse and renewal of firms and industries is necessary to sustain the vitality of the larger economic system. However, if the capitalist economic system relies on endless growth, then sustaining it for too long will inevitably borrow from the sustainability of the global ecosystem. This could prove catastrophic for humans and other species. To reconcile sustainability with hierarchy theory, we must decide which hierarchical level in a system we want to sustain indefinitely, and accept that lower level subsystems must have shorter life spans. In economic analysis, inter-temporal discount rates essentially tell us how long we should care about sustaining any given system. Economists distinguish between discount rates for individuals based on personal time preference, lower discount rates for firms based on the opportunity cost of capital, and even lower discount rates for society. For issues affecting even higher-level systems, such as global climate change, many economists question the suitability of discounting future values at all. We argue that to reconcile sustainability with inter-temporal discounting, discount rates should be determined by the hierarchical level of the system being analyzed.

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1. Introduction

The World Commission on Environment and Development (WCED, 1987) introduced the idea of sustainable development

nearly 20 years ago, but there is still no single agreed upon definition for sustainability. Terms bandied about include ecological sustainability, economic sustainability, strong sustainability, weak sustainability (Pearce and Atkinson, 1993),

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and so on. People tend to define sustainability in the ways that suit their particular applications, goals, priorities, and vested interests, and often use the term with no explicit evidence and recognition of the exact meaning being implied. Just like biodiversity (Ghilarov, 1996) sustainability has become more of a political issue than a scientifically supported concept. As Norton (2005) describes it: "...sustainable, used by so many to evoke so much, has been rendered meaningless by the very inclusiveness that makes it a politically useful, large-umbrella characterization of environmentalists' goals and objectives" (p.47). In fact, in many cases the use of the term becomes quite divorced from environmental and ecological priorities.

To a certain extent this may be because once scientific analysis is applied to popular conceptions of sustainability the term turns out to be either redundant, or ambiguous. In particular, sustainability seems to clash with the renewal cycle that has been recognized in many dynamic systems, and with the cyclic pattern in life histories of complex systems that functions as an adaptive mechanism serving the needs of evolution. Hegel's dialectic viewed development of systems as a cyclic process of change where negation of a system was a prerequisite of synthesis (Hegel, 1953). Nietzsche argued that within human society, the creation of the new and the good required destruction of the old, and saw preservation as stagnation (Nietzsche, 2003; Reinert and Reinert, 2006). Schumpeter understood that capitalism requires the continual emergence of creative new ideas, firms and industries, which lead to the destruction of the old (Schumpeter, 1962). Cycles have been observed in numerous systems of very different nature. At first glance, this cyclic nature of development appears contrary to the goal of sustainability, which is aimed at the preservation or maintenance of a certain state or function. Understood in this narrow context, sustainability is a human intervention that is imposed on a system as part of human activity and is totally controlled and managed by humans in order to preserve the system in a state that is desired.

In this paper we examine sustainability from within the framework of systems analysis, seeking to reconcile the concept of sustainability with such systemic properties as hierarchy and cycling. Our work offers several important insights into the concept of sustainability. If renewal is an adaptation mechanism that provides flexibility and potential for change, then sustainability of a system borrows from sustainability of a supersystem and rests on lack of sustainability in subsystems (Voinov, 1998). This means it is extremely important that we decide exactly what it is we want to sustain, and for how long, as striving for sustainability at one hierarchical level within a system may undermine sustainability at even more desirable levels. We will show how this approach helps us reconcile sustainability with seemingly contradictory concepts, such as evolution (cultural, economic, and even genetic), economic growth, creative destruction and inter-temporal discounting.

The approach also has practical applications. There is an ongoing debate on what society should do about large-scale, long term problems such as global climate change, biodiversity loss and toxic waste emissions. Conventional cost benefit analyses have played an important role in this debate, but their results depend critically on inter-temporal discount

rates, as well as other questionable assumptions (Neumayer, 1999a; Padilla, 2002; Ackerman and Heinzerling, 2004). Based on theoretical and empirical evidence, we show that appropriate discount rates should be determined by the hierarchical level of the system being analyzed. This result can have profound implications for policy recommendations.

2. Sustainability vs. renewal

Most sustainability definitions originate from the relationship between humans and the resources they use. Wimberly (1993: 1) states that "to be sustainable is to provide for food, fiber, and other natural and social resources needed for the survival of a group – such as a national or international society, an economic sector, or residential category – and to provide in a manner that maintains the essential resources for present and future generations". This is very much along the lines of the original definition of the Brundtland Commission that was defining sustainable development as the one that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987), except as we will see later, the scale is diversified: the WCED never mentions sectors or residential areas. Norton (1992: 25) argues that "sustainability is a relationship between dynamic human economic systems and larger, dynamic, but normally slower changing ecological systems, such that human life can continue indefinitely, human individuals can flourish, and human cultures can develop – but also a relationship in which the effects of human activities remain within bounds so as not to destroy the health and integrity of self-organizing systems that provide the environmental context for these activities". Costanza (1992: 25) emphasizes systems properties, stressing that "sustainability...implies the system's ability to maintain its structure (organization) and function (vigor) over time in the face of external stress (resilience)". Solow (1991) claims that the system is sustainable as long as the total capital (human made plus natural capital) of the system is equal or greater in every next generation, implying the possibility of actually measuring and comparing these types of capital. Costanza and Daly (1992) argue that sustainability only occurs when there is no decline in natural capital.

More recently there has been considerable debate about the so-called weak and strong sustainability paradigms. Neumayer (1999a,b: 9) defines sustainable development as one that "does not decrease the capacity to provide non-declining per capita utility for infinity", begging the question of how we measure utility, a highly controversial issue. Those items that form the capacity to provide utility are called capital, which is then defined as a stock that provides a flow of services. For weak sustainability it is then necessary to preserve the value of the total aggregate stock of capital, as Solow (1991) argued. This obviously implies that in their contributions to the utility function, different types of capital are substitutable, also a highly controversial assumption. "Strong sustainability instead calls for preserving the natural capital stock itself as well" (Neumayer, 1999b: 11).

Whatever may be the focus of the different definitions, whether it is strong or weak sustainability, there is one common component in all of them. All of them talk about

maintenance, sustenance, or continuity of a certain resource, system, condition, or relationship; in all cases there is the goal of keeping something at a certain level, of avoiding decline. However, this kind of behavior is characteristic of neither natural ecological nor man-made economic or social systems. Instead of maintaining a certain state or condition, living systems tend to go through a life cycle. Gumilev (1978, 1990) observed this for ethnic systems. Schumpeter (1962) posited that growth in a market economy can only be sustained through creative destruction—radical innovations by entrepreneurs allow them to outcompete and destroy existing firms and monopolies, frequently leading to new temporary monopolies destined to succumb to future radical innovations. Holling (1986, 1992) generalized this cyclic behavior for ecological and socioeconomic systems. Zotin and Zotina (1993) have documented the thermodynamics of very much similar cycles in the cellular level. In all cases, the renewal cycle assumes that a system goes through a series of stages, starting from growth, followed by conservation (inertia and homeostasis in Gumilev's terms), then release (obscurity) and finally renewal.

Within the framework of the renewal cycle, sustainability would conventionally be interpreted as the goal of breaking the cycle, of extending a certain stage in the system life pattern. Many economists talk about sustainable growth, which implies an indefinite extension of the growth cycle. Those more cognizant of the laws of thermodynamics recognize that all physical production requires raw material inputs, so that sustainable growth in the physical output of an economy is a thermodynamically impossible oxymoron. Sustainability in this case implies an indefinite extension of the conservation stage. Both approaches are in distinct contrast with the renewal cycle, in which growth and conservation are followed by breakdown, release and recombination.

According to Holling (2000), "sustainability is the capacity to create, test, and maintain adaptive capability". This definition is quite revolutionary since it says nothing about "no decline", it offers more flexibility and even allows certain things to get worse, as long as this is needed for adaptation. It is easier to use in the diverse regional context, since it makes no prescriptions about maintenance of natural capital, and therefore does not necessarily imply a slowdown of physical economic growth. As long as the system can adapt it is sustainable. In this case the system can go through change, can follow the renewal cycle for a longer period of time, but not all the way. The release phase should still be excluded, since we do want to maintain the system that is to be able to adapt. We cannot let it die. Still we see that sustainability assumes extension of existence of a certain system. Renewal assumes the release phase, when the system components are disintegrated and set free to recombine. Therefore the goal of sustainability of a system contradicts renewal. The phase of release is the end, the collapse of a system per se. It does not necessarily mean extinction of all components or species that make the system, but it implies that the systemic function that they perform is modified, at least temporarily. The released components may recombine to perform again as a similar system but the system itself will be different. Bankruptcy of a company when employees are laid off, and

assets are sold (release) is the end of the company. It comes when the business as a socioeconomic system is no longer sustainable, and can no longer extend the conservation stage. The components (human and material resources) may recombine in the form of another company (renewal), but that will be a different system. Ethnic systems as documented by Gumilev (1990) also die, when their passion, vigor declines and they lose the drive to persist. Eventually people recombine as new ethnoid, but those will be different from the original one. Forest fires release organic material and nutrients thus ending a system. Forests may grow afterwards in the same place, but those will be different forests: they may have a different spatial and species organization.

3. Hierarchical systems

Renewal allows for readjustment and adaptation. However it is the next hierarchical level that benefits from this adaptation. Renewal in components helps a system to persist. Therefore, for a hierarchical system to extend its existence, to be sustainable, its subsystems need to go through renewal cycles. In this way, death of subsystems contributes to sustainability of the supersystem, providing material and space for reorganization and adaptation. Costanza and Patten (1995: 196) looking at sustainability in terms of component longevity or existence time, recognize that "evolution cannot occur unless there is limited longevity of the component parts so that new alternatives can be selected". Systems are not static, but evolve as a combination of dynamically occurring renewals in their components. A system cannot be singled out as a closed domain delimited by certain borders. It evolves in space and in time, throwing out tentacles and constantly changing through the renewal in its subsystems. A system constantly "sacrifices" its components to protect its own persistence, its sustainability. A system made of components that are readily dissipated and reorganized will be more sustainable than the one made of durable and persistent blocks that have no potential for such change in their organization. Evolution needs material for adaptation.

Economies can be viewed as hierarchical system moving from individuals to firms to industries to sectors. The human economic life cycle is clearly one of hiring, rapid learning (growth in economic ability and earning potential), conservation (steady employment), and release (retirement or dismissal). Renewal is the hiring of a new person by a firm, or from the individual's perspective, the hiring of a new member of the household. We may also observe renewal in subsystems when branches or departments are closed down or reorganized for the benefit of the firm as a whole. Without this renewal, firms would become less competitive and rapidly collapse. Firms of course also appear, grow, prosper and die, frequently succumbing to the forces of creative destruction. Any effort to sustain firms against these forces could seriously weaken an entire industry. Efforts to sustain failing industries and even sectors would prevent capital from being reallocated to other more dynamic ones in their growth stages, such as the information or service sectors. Almost any recession in an economy is accompanied by layoffs, bankruptcies and reorganizations, which is an indicator of subsystems going through

renewal. The system benefits from renewal in its components. In this way the overall economic system adjusts and manages to sustain itself further, extending its conservation phase (sustainability). If we want the overall economic system to persist, we must allow release and renewal in each of the lower hierarchical levels. One could argue that the collapse of the Soviet Union resulted from the lack of renewal mechanisms in the planned economic system. Inefficient enterprises were kept afloat by huge subsidies keeping human and material resources unavailable for recombination, and decreasing the overall adaptive capacity of the socioeconomic system.

Ecological systems display quite similar behavior, when components are renewed for the benefit of the whole system. In ecology there has been much attention paid to the concept of stability, which may be considered analogous to sustainability, if considered narrowly within an ecosystem. Forest fires, infestations, predators controlling prey populations—all act as mechanisms of release and renewal. Moreover there are numerous examples of systems deteriorating, if they do not undergo renewal in a timely fashion. Fires in the Florida Everglades are fairly frequent and they burn out huge areas (Gunderson, 1994). In several seasons the vegetation is usually restored to its initial biomass and species composition. However if a fire is delayed by some reason and abnormally high biomasses are accumulated, when it eventually breaks out, its intensity will be much higher. As a result not only the vegetation, but the soil substrate as well will be destroyed, exposing bedrock, thus totally changing the function of the system. This is a negative effect not only for the particular landscape unit (subsystem), but for the whole regional ecosystem (supersystem) as well.

Holling (1986) reviewed 23 examples of managed ecosystems that fell into 4 major classes—forest insects, forest fire, savanna grazing and aquatic harvesting. He concluded that any attempt to manage ecological variables in order to maintain a certain state, to control variability of a target resulted in a slow change of the ecosystem, that eventually led to even more dramatic and irreversible perturbations. When a normally fluctuating ecological variable was bounded and artificially sustained, ecosystems became more spatially homogeneous over the landscape scale. This led to less resilient systems that were more likely to degrade under disturbances that could be previously absorbed. “The very success in managing a target variable for sustained production of food or fiber apparently leads inevitably to an ultimate pathology of less resilient and more vulnerable ecosystems” (Holling, 1996: 8). Note that the collapse in these cases is usually observed at the next hierarchical scale, over landscapes.

The economic system itself is a managed sub-ecosystem of the sustaining and containing global ecosystem. Human society is currently engaged in a global effort to sustain the growth phase of this subsystem. There is more than abundant evidence that we are achieving this only at the cost of higher hierarchical levels. Simply sustaining existing populations and consumption levels may threaten global ecosystems. Collapse of these higher hierarchical levels is something that the human species, and indeed, many, many other species, cannot afford. While most people are more concerned with local economic systems than the global economy, sustaining

some smaller subsystems comes at the expense of the higher levels in the hierarchy.

4. Is there sustainability without renewal?

There seems to be an internal contradiction in the sustainability concept. Sustainability of a system borrows from sustainability of a supersystem and rests on lack of sustainability in subsystems. At first glance it seems that a system made of sustainable, lasting components should be sustainable as well. But in systems theory it has been long recognized that “the whole is more than the sum of parts” (Bertalanfy, 1968: 55), that a system function is not provided only by the functions of its components and therefore, in fact, system sustainability is not a product of sustainable parts, and vice versa. This is especially true for living, dynamically evolving systems. Hannon and Ruth (1997) report a behavior of this kind in a modeling exercise, where competitors operate in adjoining patches of a landscape and find that their patch populations rise and fall with the inevitable catastrophes, while the total biomass at the landscape (collective patches) level remains steady. This is true as long as the catastrophic events in the patches are temporally uncorrelated. This interrelation of ‘sustainabilities’ in various hierarchical scales is important for many applications.

Much concern, for example, is expressed about how to make economic activities sustainable in the face of environmental degradation. Several theories seeking to explain the environmental Kuznets curve postulate that in some cases economic growth turns out to be beneficial for the environment (Arrow et al., 1995). However, the inverted U-shaped curve for environmental degradation as a function of economic growth, advocated by protagonists of economic growth, pertains only to regional systems, where such trends, even when observed, cannot be extended to the global level (Stern et al., 1996). At the global level, economic growth clearly results in the decay of natural capital and growing environmental degradation. The regional successes in the more economically developed countries, that seem to provide examples of quasi-sustainable systems, should cause increasing concern rather than contentment. Local sustainability is achieved as a result of either decreased sustainability of other regional subsystems, or decreased sustainability of the global system as a whole, or both (Arrow et al., 1995; Stern et al., 1996; Mayer et al., 2005). This analysis would certainly benefit from a measure of sustainability that could be used to track the state of the system and compare it at various stages. However, as long as sustainability is not clearly defined and allows various interpretations and understanding, there can hardly be an unambiguous way to measure it.

There is a considerable effort to develop indicators of sustainability (Moldan, 1995), but the indicators are numerous and in many cases qualitative, which hardly helps in defining a universal measure to evaluate and compare sustainability of systems. Nevertheless qualitative analysis is still useful, especially when operating in the conceptual level. Describing the renewal cycle, Holling (1986) proposes looking at capital accumulated by the system and notes the cyclic pattern that this variable follows. Starting at low levels, the system

gradually accumulates capital, reaching a maximum at the end of the conservation stage, after which the release of capital begins. The cycle starts again after the renewal stage. Gumilev (1978) describes the dynamics of passion, which he views as a driving force for the development of an ethnos in his theory. Similarly, passion grows at first, reaches the acme and then gradually declines as the system turns to homeostasis and then obscurity. Peak of passion in Gumilev's terms or vigor in Costanza's terms (1992), as a measure of system activity, metabolism, or productivity, tends to precede the peak in capital. Generalizing these measures allows us to assess sustainability in two dimensions. Capital represents the stock of material accumulated in the system. Depending upon the type of the system this could be biomass, population numbers, financial capital, and so on. Vigor is the potential for growth, growth rate, or net activity of a system unit. This parameter is yet harder to define and measure. For cells Zotin and Zotina (1993) were measuring the thermodynamic potential. It is not clear how to measure Gumilev's passion, but some indirect estimates, like the amount of volunteer work performed in the society, could probably be useful. We may chart these two variables and find numerous examples of systems whose dynamics approximately follow this trend. Smith and Voinov (1996), for example, observe this pattern for capital in forestry and vigor in fishery systems. In these terms the sustainability concept can be then introduced by extending the period of the higher values of both vigor and capital beyond those that would be reached within a renewal cycle.

There is a staggering resemblance between the sustainability concept presented in this form and the variations in the thermodynamic potential measured by Zotin and Zotina (1993: 42) for some abnormally developing cells. In both cases systems tend to be sustainable in terms of going through the stages of birth and development and then maintaining higher levels of vigor in the conservation phase instead of declining. Noteworthy, the cells that displayed this type of life cycling in the observations of Zotin and Zotina were the cancerous cells. The effect of their "sustainability" on the wellbeing of the supersystem—the whole living organism in this case—is well known.

One way to resolve this contradiction between sustainability of a socioeconomic ecological system and its components is to recognize that the time span over which we strive to sustain a system depends on the scale of that subsystem within the overall system hierarchy. The only systems we should strive to sustain indefinitely are the top-level systems, humanity as a whole and the biosphere as a whole in our case. The global scale in this context seems to be the maximal that humans can influence at the present level of their development. It is also the scale that affects humanity as a whole, the system that is shared by all people, and should therefore be of a major concern to all. If this is the case, then we must also recognize that sustainability in lower hierarchical levels, in subsystems of the global system, may work against sustainability of humanity and the biosphere. Achieving sustainability for an individual (e.g. immortality, or at least dramatically increased life spans), firm, industry, economy, or even culture may decrease sustainability of higher order systems and even the biosphere by reducing the potential for change and adaptation.

In theory, success in sustaining even individual species and specific ecosystems might come only at the cost of the global system. Ecosystems persist longer than species, and even the typical mammal species has a life expectancy of a million years (Foley, 1999), so historically the time scales involved were too long to be relevant to humans. As our efforts to sustain economic growth lead to increasing rates of change in higher order systems, however, we may have to accept that even efforts to sustain a given species or ecosystem will reduce the chances for a sustainable global system. This is particularly true if we attempt to sustain specific ecosystems along with economic growth. For example, in the northeastern United States we are successfully striving to sustain our forest ecosystems by removing timber more slowly than it grows, but we achieve this in part by importing timber from other countries that are unsustainably harvesting their forests. China is trying to sustain its remaining forests along with economic growth by drawing on Indonesia's dwindling forest resources (Perlez and Suhartono, 2006); Finland is doing the same by importing timber from Russia (Mayer et al., 2005). The net result may be more rapid collapse of global ecosystems. A very similar pattern is now looming with the production of biofuel. As fossil energy becomes scarcer, there will be more interest in producing biofuel. As a result vast forest areas are sacrificed in the developing countries to produce fuel for the developed economies. Oil from palm trees is the most likely source. In Sumatra and Borneo, some 4 million hectares of forest have been converted to palm farms. Now a further 6 million hectares are scheduled for clearance in Malaysia, and 16.5 million in Indonesia (Monbiot, 2005). Large tracts of the Brazilian Amazon are being cleared for soybean production, and this will only increase if Brazil moves forward with its plans for soy-based biodiesel (Brazilian Federal Government, 2004; Rohter, 2003).

Unfortunately, the global level is still very difficult to analyze, predict and interpret. Among decision and policy makers of today there is little understanding of the interaction between local and global sustainability. Concern for local or regional levels seems to dominate, being easier to perceive and to "sell" to the public and the electorate. There are numerous citizen groups that are developing sustainable development plans for their regions and communities. People tend to become much more easily involved in the wellbeing of their neighborhood, than in the future of more remote and abstract systems, like the planet Earth. Examples are numerous. Plans for sustainable development are drawn for counties (Jaklitsch et al., 1996), watersheds (e.g. the Rio Grande/Rio Bravo basin or the Chesapeake Bay), and countries. In Russia, the notion of sustainability has reached the highest echelons of power and became an issue of a 1994 presidential decree on "stable development", according to which all regions were supposed to come up with a regional plan of stable development for their particular region. Naturally it was assumed that such "stable" regional development would result in sustainability in the national level as well.

Similar examples of a local approach to sustainability can be found worldwide. The Fourth International Conference on Urban Regeneration and Sustainability in 2006 is called "The Sustainable City" (City, 2005). Once again the call for papers refers to the first Sustainable City Conference held in Rio in

2000 and defines the concept of sustainability as applied to a city as “the ability of the urban area and its region to continue to function at levels of quality of life desired by the community, without restricting the options available to the present and future generations and without causing adverse impacts inside and outside the urban boundary”. The persisting assumption is that the systems per se stay in place, are maintained, and sustained. These local efforts may be certainly beneficial in the sense that they generate public involvement and awareness, but they are hardly feasible, taking into account the interconnectedness and, eventually, mutual dependence of all the subsystems and their dependence upon the higher hierarchical levels. The limited scope of these efforts is not duly exposed, while the analogy with the cancerous cells is too close to be neglected. By extending the longevity of subsystems beyond their natural life spans, the systems of higher levels are deprived of potential to adapt; they become brittle and more likely to fall apart. The failure of the higher-level systems is very likely to result in major perturbations, if not death, for the subsystems as well.

Appeals for local sustainability are deceptive. All local systems still share the same planet, the same climate, the same air and water cycles. They are also part of the larger, increasingly globalized economy and mass media. Isolating certain subsystems and sustaining them and only them in separation from the other local systems and the global system as a whole, is futile, and hardly feasible.

5. Implications for inter-temporal discounting

Sustainability is all about inter-temporal preferences—we care about sustainability because we care about the future. In most economic analysis, inter-temporal costs and benefits are weighted by a discount factor, so that the further into the future an event occurs, the less importance we place on it today. There are numerous reviews of the justifications for discounting as well as the problems it entails (see for example Portney and Weyant, 1999; Price, 1993; Lind et al., 1982). Among the more serious problems, conventional exponential discount rates, even very low ones, treat catastrophic events that occur far enough in the future as essentially irrelevant today. Global warming is a case in point. Some economic analyses of global warming discount the future at rates as high as 6% (IPCC, 1995). At such rates, we would not spend \$2500 today to prevent a \$30 trillion loss (the approximate gross global product today) in 400 years.

In spite of such absurd conclusions, there are nonetheless compelling reasons for discounting the future. Most economists argue that economics is all about human preferences, and as most individuals discount the future, economists must do so as well—to do otherwise would actually be anti-democratic (Arrow and Kurz, 1970). People discount due presumably to both impatience and uncertainty—we have short and uncertain life spans, and may not even be alive when the future arrives. Empirical evidence shows that individual discount rates can be very high in the short term—how many people in America (a country with low interest rates) are holding credit card debt at 18% or higher? However, while economists use such evidence to justify exponential discounting, empirical studies actually

find that while an individual might prefer \$100 today over \$200 next year, she is likely to prefer \$200 in 10 years over \$100 in 9 years. This suggests that people discount at a fairly high rate over short time horizon, but at a lower rate over longer time horizons. In other words, if we plot the discount function (the weight placed on payoffs received at different points in time) on the y-axis against time on the x-axis, it takes the shape of a hyperbola. Economists refer to such discount rates as ‘hyperbolic’ (Frederick et al., 2002).

Another justification for discounting, one appropriate to businesses and to individuals as investors, is the marginal opportunity cost of capital. If a firm can keep reinvesting its assets in activities that generate 7% returns (which is the average real rate of return on long term stock market investments (Johnson, 2005)), one dollar invested today will turn into \$114 in 70 years. Conversely, a firm should count \$114 in 70 years as worth only one dollar today (an investor will presumably be dead in 70 years, and might count \$114 at that time as nothing today). This approach of course assumes continuous investment opportunities that average 7%, but over the very long term, no investment opportunity can offer returns greater than the growth rate of the economy, or else the part must become greater than the whole!

Few natural resource stocks can sustain growth rates equal to the marginal opportunity cost of capital, in which case the profit maximizing approach to resource management may be liquidation, with investment of the profits in higher yielding assets (Daly and Farley, 2004). Curiously, another justification for discounting the future value of natural resources is that new technologies will provide superior substitutes, making existing resources less valuable. The irony is that more often than not, technology seems to develop new uses for resources more rapidly than substitutes, increasing their value, which if anything would suggest a negative discount rate. Oil is a case in point.

It is generally accepted that social discount rates should be lower than the rates used by individuals or firms, though there are a number of very different justifications for this, and no clear idea of what the exact discount rate should be (Lind et al., 1982; Portney and Weyant, 1999). One justification is that society is more stable and longer-lived than individuals so should not discount the future based on uncertainty and impatience (Pigou, 1952). Related to this is the injunction in economics against interpersonal utility comparisons, which should not allow this generation to give less weight to a future generation’s wellbeing, though the assumption that the future will be richer than the present is often used to justify a social discount rate in spite of the fact that this involves interpersonal utility comparisons (Padilla, 2002). Other economists argue that discount rates will change over time, and the certainty equivalent discount rate is much lower than the average discount rate (Weitzman, 1998; Sumaila and Walters, 2005). Yet other theoretical arguments for a lower social discount rate, both normative and positive, exist (e.g. Marglin, 1963; Caplin and Leahy, 2004; Lind et al., 1982). Empirically, individuals seem to favor lower discount rates for social decisions than for private ones (Marglin, 1963; Sumaila and Walters, 2005). Empirical evidence suggests that social discount rates are hyperbolic as well (Henderson and Bateman, 1995).

Theoretically, lower discount rates could actually lead to increasing levels of ecological degradation, and thus be less compatible with sustainability. For example, if significant up front infrastructure investments are required to initiate exploitation of a resource while returns to resource extraction are delayed, lower discount rates will give larger weight to future income flows, increasing the net present value of the project. This outcome is only likely to hold however if ecological costs are ignored.

Based primarily on normative arguments, many economists who accept inter-temporal discounting in general do not accept it for very long term, large-scale problems such as global climate change (e.g. Solow, 1974; Ramsey, 1928). As Weitzman (1998) points out, most economists sense that something is amiss about treating a distant future event as something that can simply be discounted away. Consensus on this issue is still distant, largely because so many of these arguments are normative (Portney and Weyant, 1999).

Some research suggests that sustainable discount rates need not be zero even at higher hierarchical levels of a system. Hannon (1984) shows that the components of a model ecosystem appear to value near term energy flows into storage more than similar flows in the distant future. This is equivalent to a positive discount rate, which in the steady state, Hannon finds, is equal to the terminal marginal respiration rate. In a study of 'optimal' deforestation in the Brazilian Amazon, Farley (1999) showed that the system is sustainable for any discount rate lower than the regeneration rate of forest biomass. In both cases, a sustainable discount rate is determined by ecological factors, not economic ones. However, if human activities are diminishing the capacity of ecosystems to capture solar energy over time, so that the ecosystem as a whole shows negative growth rates, then the ecologically justifiable discount rate may actually be negative.

Regardless of the arguments used in defense of discounting, the fact is that for any positive discount rate, events that occur far enough out in the future carry a trivial weight. If we believe that sustainability into the distant future is desirable in a non-trivial way, then our beliefs are incompatible with long term discounting. In other words, if we care about sustainability, discounting the distant future may be anti-democratic.

Though not discussing it in these terms, economists seem to agree that as unit of analysis encompasses higher-level systems in a hierarchy, inter-temporal discount rates should decrease, possibly reaching zero at the level of the global ecosystem. We see the same empirical results if we look at human behavior. An individual may have a very high discount rate as an individual, but a lower discount rate as part of a family or as part of a country. For example, parents might smoke or over-eat, valuing the present well over the future, but will simultaneously invest heavily in their children's education, even when the net present value of such investments is negative (Sumaila and Walters, 2005). People give up their lives for their families or for their countries, sacrificing everything now for future gains they will never see. Government and religious institutions (larger hierarchical levels of society) have repeatedly invested in infrastructure projects with life spans of hundreds or even thousands of years, some of which have taken several generations to build.

Extremely wealthy and powerful individuals, private institutions and corporations have also been known to invest in infrastructure or monuments designed to outlast them by centuries. While some such as the Sears Tower or Chrysler building probably show a positive net present value with conventional discount rates based on the opportunity cost of capital, others, such as the numerous monuments in Florence, Italy funded by the Medici family were designed to last hundreds of years while offering no monetary returns. Many of these institutions represent the interests of thousands of stakeholders, have greater wealth and political power than entire nations and function at a transnational level. Perhaps the discount rates implicit in such long term investments reflect the hierarchical level at which these entities operate.

Our effort to reconcile hierarchy theory and sustainability provides a positive (albeit qualitative) justification for decreasing discount rates. We want things to persist longer at higher hierarchical levels in a system, and for this to occur, the components of lower hierarchical levels cannot persist as long. At the lowest hierarchical level, the individual, we should use the highest discount rate, the hyperbolic pure time preference rate of consumption, which reflects in part an individual's mortality. Firms and businesses should use the opportunity cost of capital. Looking at modest public investments over moderate time scales, economists should use much lower social discount rates. For decisions that potentially affect human survival or global ecosystems, the highest hierarchical levels, which we want to persist indefinitely, no discounting is acceptable—we would in fact agree with Padilla (2002) that any application of cost benefit analysis to such problems is probably inappropriate.

6. Conclusions

There is no evidence that a sustainable system is necessarily composed of sustainable parts. Fostering sustainability for too long at local and regional scales, and for lower level subsystems of the global human system and the global ecosystem may be detrimental to global sustainability. The function of the biosphere is more than a sum of functions of continents, countries and regions; local and regional goals and priorities may conflict with global ones and therefore we cannot envision the sustainable global design as a hierarchy of sustainable subsystems. Humanity is more than the sum of its social, economic, political and cultural institutions. There are external and internal factors that change and the global system has to have the potential to adapt to such changes. This may require change or even destruction in components. Sustainability or increased longevity of components, be they cultural or ecological, may be limiting for the adaptation and sustainability of the whole. Our current obsession with sustaining a growth-driven economic system may be the biggest threat of all. Actually there are not many regional systems for which sustainability can really be the issue. Systems in transition in the developing countries or Former Soviet Union are hardly interested in becoming sustainable, because by definition they are apt to change

and transition rather than to simply maintain themselves. They are either in the release or renewal stages, that no one would want to sustain, or have just entered the growth stage, when it is still hard to start thinking in terms of a steady state economy (Daly, 1977) and sustainability. Economic transition assumes wide shifts in social and political institutions. These shifts or adjustments become possible as a result of discontent and rejection of the status quo by the majority of the population, while sustainability is based on social contentment and agreement. Sustainability is certainly enticing for the developed economic systems, which have reached the conservation phase, and would prefer to prolong this stage for as long as possible. In this case there is a clear goal for maintenance and sustainable development seems to be desirable and realistic. Unfortunately there is little awareness of the fact that in most cases sustainability can be ensured only by borrowing energy, resources (capital) and adaptive potential from outside of the system, or by decreasing the sustainability of the global system. Sustainability of a subsystem is achieved only at the expense of the supersystem or other subsystems. Therefore the institutions and organizations that are to maintain life support systems on this planet need to emphasize the global priorities and first of all test policies and strategies against the sustainability of the biosphere and of humanity as a whole, rather than the regional or local interests of stakeholders, representing particular localities, communities, districts or countries. While in most cases the local, place-based efforts result in some negotiated agreement as to the desired qualities of a different and improved place to live and work in, which assumes certain changes in the characteristics of the system, the subsystems, they stop short of allowing for the destruction of the local system itself. While designing a sustainable Burlington, we are happy to consider a different Burlington, but we do not allow for the release, for a “no-Burlington”, for a totally different system that may replace the city of Burlington.

Interestingly, in the report “Our Common Future” (WCED, 1987), the document that has paved the way for the term sustainable development and which actually generated so much attention to the issues of sustainability, we can hardly find any discussion of types of sustainability other than the global one. The whole purpose of the report was focused primarily on designing scenarios of global sustainable development, recognizing that the local level is no solution to the global problems, and even while most of the action is available in the local level it is the global level that should be of major concern and be the ultimate goal. The original essence of the concept seems to be in the unified vision of the development of this planet as a whole, and it would be a pity for this integrating mission of sustainability to be eventually torn apart and grounded in local declaratively “self-sufficient” and “self-centered” efforts. Twelve years later, another respectable body of scientists, the National Research Council, conducted its analysis of the trends and futures of sustainable development and concluded that “The primary goals of a transition toward sustainability over the next two generations should be to meet the needs of a much larger stabilizing human population, to sustain the life support systems of the planet, and to substantially

reduce hunger and poverty” (National Research Council, 1999: 31). Once again the main focus is made on the planet as whole.

So to reiterate, how do we reconcile sustainability with systems dynamics in an ecological-economic system? The obvious conclusion is that how long a subsystem should be sustained depends on its place within the system hierarchy. Firms may need to lay off and retire individuals to hire and promote new blood, to receive an influx of new ideas and vigor. Creative destruction of firms and industries is necessary to sustain economic growth in a capitalist system. Examples abound of governments trying to sustain outmoded firms and industries often at a dramatic cost to their economy, which, as we argued above, helps explain the collapse of the Soviet Union. As ecological economists point out, if we try to sustain a capitalist economic system dependent on unending economic growth, it will be at the cost of higher-level systems. Sustainability of human society and the global ecosystem demands continually evolving economic systems (Gowdy, 1994). It is time for the growth-driven industrial economy to release its capital for reorganization, to allow renewal through the emergence of an ecological economy, which will grow (meaning more of the natural, human and social capitals, and less built capital), stabilize for a time, then give way in its turn to a new economic system so that humanity and the global ecosystem may persist.

Sustainability is not about a lack of change. Rather, it is about appropriate rates of change for different levels in a system hierarchy. In economic analysis, this means discount rates appropriate to the scale of analysis, and how long we want to sustain the system being analyzed. We conclude with a quote from a review of a recent book on creative destruction: “a common mistake made by new sustainability converts is to see it as a conservative concept, about stability, continuity. That’s a big mistake. Indeed, if we are to build sustainable economies able to support a human population of 8bn–10bn, one inescapable conclusion is that we must destroy much of today’s growth-driven economy and jettison many of the lifestyles it supports. Forget conservation; think “creative destruction”.” (Elkington, 2001).

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