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The discussion of sustainability in environmental economics continues to be plagued by considerable disagreement and obscurity as to both the conceptual and the operational content of the term. These disagreements arise due to different disciplinary perspectives, the axiomatic foundations of the models that are used to explore the concept, and interpretations of sustainability at the policy level. The discussion is further plagued by ill-defined philosophical and ethical differences over issues of both intra- and inter-generational equity. This paper seeks to clarify matters through the development of a mathematical model of resource allocation that embraces both economic and ecological concepts of sustainability, drawing on models and insights from both fields. Specifically, the Solow/Hartwick approach from economics and the Holling approach from ecology have been selected.

Economics: Solow Sustainability

Consumption is the starting point for treating sustainability within the utilitarian framework of the neoclassical model. Consumption refers to that portion of the total goods and services produced that is currently utilized to satisfy a set of wants, all within the constraints imposed by a given set of resource endowments. Wants are determined exogenously, and their satisfaction is used as a measure of system performance. The endowment set is an exogenous heritage of resources, along with the property rights that map these resources into the consumer's constraint set. Property rights are assumed to be external to the productive system as well.

The implications of this definition of consumption for sustainability can be found by relating it to income. The Hicks/Lindahl concept of sustainable net income is defined as the maximum amount that can be spent on consumption during a given period without reducing either the expected capital value of prospective receipts in future periods or the real consumption expenditure in future periods. Income so defined presupposes the deduction of expenditures to make good the depreciation and degradation of the productive asset base such that society is as well off at the end of the period as it was at the beginning. Thus a suitably defined capital stock must be maintained which ensures that the constraint set does not tighten over time.

A theory of sustainable resource utilization based on this definition must establish how a constant real consumption expenditure can be maintained with an exhaustible resource base. Solow, adopting the egalitarian arguments of Rawls, proposed a "Rawlsian" maximin approach to the intertemporal distribution of consumption. Solow, Hartwick, and others produced a simple result known as the Hartwick rule: "Consumption may be held constant in the face of exhaustible resources only if the rents deriving from the intertemporally efficient use of those resources are reinvested in reproducible capital."(10) In other words, the returns from exhaustible assets must be invested in non-exhaustible assets.

The investment rule that this implies rests on an assumption that, although capital inputs are heterogeneous, there exists sufficient substitutability between reproducible and exhaustible stocks within the relevant production functions. Therefore, the rule itself is, in fact, more a condition for intertemporal efficiency than it is for sustainability per se. The well behaved production functions used by Solow and Hartwick have had to be modified to admit the non-substitutability of certain types of natural and produced capital. Thus, in some models upper bounds on the waste absorptive capacity of the environment have been set, along with lower bounds on the level of stocks that can support sustainable development.

Whatever the variations, the notion that some suitably defined capital stock should be kept constant is a crucial component of this definition of sustainability, and it is generally agreed that the only meaningful measure of these stocks is a measure of value. Moreover, for this measure to produce optimal allocations it must not be based on market prices, but on shadow prices that reflect the true social value over time. Thus, in order for resources to be allocated according to the rule, there must either exist a complete set of competitive markets from today until infinity, or all economic agents must contract in today's markets on the basis of rational expectations for the future. If one of these conditions cannot be met, then there is no assurance of reaching an efficient, intertemporal, competitive equilibrium.

Ecology: Holling-Sustainability

The difficulty with the above from an ecological perspective is that it ignores the fact that the human economy is an integral part of a closed evolutionary system. The assumptions are often blind to the physical principles informing a materially closed, thermodynamic system, and to the feedback effects of dynamically interactive human and environmental productive systems. To address these shortcomings, Holling's work on resilience and stability of ecosystems is the starting point. He distinguishes two levels of stability: 1) stability per se, i.e., the propensity of populations in an ecosystem to return to an equilibrium condition following a perturbation; and 2) resilience, i.e., the propensity of a system to retain its organizational structure following a perturbation. The distinction between the two implies a difference in the focus of analysis within an ecosystem; there can be either a micro focus on a population of organisms within the system, or a macro focus on the larger community of organisms. Individual populations can only be Holling-stable if the ecosystem is Holling-resilient, though Holling-resilience does not necessarily imply Holling-stability.

Ecosystems that are open with respect to energy flows have a tendency to self-organize within the constraints imposed by an evolutionary and fluctuating environment. Any point at which the self-organizing forces of the system balance the disorganizing forces of the environment may be said to be an optimum operating point of that system. There may therefore be multiple equilibrium points for an individual population that could be considered Holling-stable. The Holling-resilience of the system as a whole may then be measured by its ability to "accommodate the stress imposed by its environment through selection of a different operating point along the same thermodynamic path without undergoing some catastrophic change in organizational structure."(18) The important feature of resilience then is the capacity it implies to adapt to the stresses imposed on a system through its interdependence with other systems.

Holling characterizes endeavors to manage ecosystems as "weak experiments testing a general hypothesis of stability/resilience."[1] This is exemplified by historical attempts to stabilize ecosystems in the Holling-stable sense, which have often been successful in the short term, but have led to qualitative changes in the larger system, generally with adverse consequences for the resilience of that wider system. Most often this is due to decreasing diversity of communities within the system due to the economic focus upon a single community. A narrower range of communities reduces the level of interaction and the complexity of the system, characteristics that are argued to be necessary to maintain its resilience.

The Ecological Economics of Sustainability

The fundamental difference between the Solow and Holling models is in the way each perceives the interrelationships between the economy and the ecology. In the Solow model, the economic system does not affect the physical system in which it is imbedded. By assuming that the economy receives free gifts from the environment (as a source of natural goods and a receptor of pollution and wastes) the Solow model does not consider the important dynamic implications of resource use. On the other hand, the Holling model privileges the system over its component parts. The Solow model considers just the economic system, whereas the Holling model takes a macroscopic systems view.

The model presented here takes a systems approach and considers the biophysical and economic system simultaneously. It considers a problem of resource allocation over time given a social welfare function and a constraint. The biophysical system is the constraint on economic activity, and this constraint changes with exploitation of resources and imposition of wastes into the ecosystem by the economic system. Social welfare depends on both the income derived and the state of the resource base that the present generation bequeaths to future generations; i.e., social welfare depends on the welfare of both present and future generations.

The most shocking conclusion of the model described above is that the concepts of Solow-sustainability and Holling-sustainability are disjoint. This implies that there may be no close relationship between economic efficiency and ecological sustainability. In fact, historical evidence suggests that economies that have managed the resource base in an ecologically sustainable manner have not performed well by intertemporal economic efficiency criteria. This is not to suggest that economically efficient systems cannot be ecologically sustainable, though for this to be so would require some improbable conditions. An ecological economics approach requires that resources be allocated in such a fashion that they threaten neither the system as a whole nor the key components of the system. For the system to be sustainable it must serve consumption and production objectives that are themselves sustainable. If existing preferences and technologies, as perpetuated and sanctified in the concept of consumer sovereignty, are not sustainable, then the system as a whole will be unstable. The appropriate policy instruments to address these concerns are varied and complex, and are not discussed here. What is important is that ecological economics privileges the needs of the system over those of individuals.

Notes

1. C.S. Holling, "The Resilience of Terrestrial Ecosystems: Local Surprise and Global Change," in Sustainable Development of the Biosphere, ed. W.C. Clark and R.E. Munn (Cambridge: Cambridge University Press, 1986); cited by Common and Perrings, 18.