SUSTAINABLE GROWTH

Santanu Roy
Florida International University, Miami, FL, USA

Keywords: sustainable growth, concepts, framework, economic growth theory, framework, environmental factors, capital formation, environmental decay, nonrenewable resources, substitution possibility, pollution, abatement, intertemporal optimality**.**

Contents

Summary

Economic growth is the process by which a society expands its production and consumption opportunities over time. Sustainable growth refers to a process of growth where the welfare of society does not steadily decline over time due to excessive use of limited environmental resources or environmental damage caused by production and consumption activities. We provide an exposition of the basic issues in sustainable growth involving intertemporal tradeoffs and dynamic opportunity costs of accumulation. The framework adopted is that of optimal economic growth in an infinite horizon economy with one consumption/capital good where the intertemporal optimality criterion is the maximization of discounted sum of welfare. We begin by

outlining the factors influencing the possibility of sustainable growth in an economy where neither production nor welfare depends on the natural environment. Next, we consider an economy with a finite stock of a nonrenewable resource that enters the production process. We show that the possibility of sustainable growth is seriously constrained by the extent to which the resource may be substituted by renewable inputs such as physical capital. Technological progress helps the economy to overcome the limits to sustainable growth. Finally, we analyze the growth process in an economy where the production process creates environmental damage through pollution, which has a negative effect on social welfare. Sustainable growth is possible only if the capital stock is small enough. Indefinite expansion of output and consumption is not likely to be optimal unless technological progress reduces pollution intensity and sustains productivity increase in this economy. The possibility of pollution abatement can raise the steady state consumption level and expand the set of initial states from which sustainable growth occurs.

1. Sustainable Growth: Concepts and Framework

1.1 Economic Growth

Economic growth is the process by which a society expands its production and consumption opportunities over time. It involves increased output of commodities (goods as well as services) as well as creation of new commodities that are either directly consumed or enter as inputs in production of other commodities. It is reflected in improvements in the material standards of living—though the share of such improvements accruing to individuals may vary widely across society. A generally accepted measure of economic growth is the change in real per capita income over time. Sustained economic growth can be defined as the event that per capita income in a society exhibits a secular or long-run tendency to expand over time, though the process may be marked by intermittent periods of stagnation and decay such as those caused by business cycles.

We live in an era of economic growth. Since the industrial revolution, countries in Western Europe and North America have experienced sustained and often accelerated economic growth in a manner never observed in previous history. The real gross domestic product per worker hour (whose changes over time may be reasonably expected to be closely related to movements in per capita income) experienced dramatic acceleration as the process of industrial revolution, modern technology, and globalization unfolded. During the period 1580–1820 (most of this period precedes the Industrial Revolution), the Netherlands was the leading industrial nation in the world, and there the index (real gross domestic product per worker hour) grew at an average annual rate of about 0.2 %. The United Kingdom, which had become the leader during the period 1820–1890, experienced an annual growth of the index at an average rate of 1.2 %. Since 1890, the United States usurped the position of the leader in economic growth, and there the index has grown at an average annual rate of 2.2 % per year (in the period 1890–1989).

In the second half of the twentieth century, an increasing number of newly industrializing countries in Asia and other parts of the world have been experiencing high rates of economic growth. In some cases, the growth rates achieved in the initial phases of industrialization of these nations have far exceeded the historical experience of older industrial nations in similar phases of development. While there are many parts of the world where societies have not moved to a regime of sustained growth, it is nevertheless clear that this is exactly what they seek to achieve. The rapid breakdown of economic and communication barriers between nations and the emerging process of globalization fostered by new technology (as well as the breakdown of government-imposed barriers to movement of commodities, ideas, and capital) imply that economic growth is likely to be a global phenomenon. However, wide disparities between the levels of income and consumption (both within and between nations) may well persist.

1.2 Sustainable Development

The current epoch of economic growth and, more generally, the process of social and economic development, have also been accompanied by serious damage to the natural environment. The last few decades—particularly, the 1980s—have been marked by a sharp increase in social and political concern about the destruction of the ecological system in many parts of the world and other irreversible damages caused to the natural environment by industrialization, population pressures, consumerism, and urban growth. Human beings are increasingly informed about the long-term consequences of current production and consumption activities—such as the effect of using carbon based fuels on global warming or the effect of chopping down rainforest on irreversible loss of biodiversity—which will eventually cause grave damage to the quality of human life and even threaten our survival. As a result, public opinion has moved towards pressurizing governments to take remedial measures by restricting the nature and scale of production and consumption activities.

One of the important ideas that became fashionable in the 1980s as part of this social process of environmental consciousness and activism is the concept of sustainable development. The notion of "sustainable growth," which is the focus of this article, is inextricably tied to this concept. The term "sustainability" or "sustainable use" has been used for a long time by ecologists and biologists in the context of biological natural resource systems. The population of these resources—such as fisheries or forests—can regenerate and grow over time. Levels of extraction, exploitation, or use of such ecological systems by human society are said to be at a sustainable level if they do not lead to progressive diminution of the population size or, more generally, the valued qualities of the system. The notion of sustainable use is purely based on the physical properties of these ecological resources—their reproductive properties and their interdependencies. It has nothing to do with the (dynamic) opportunity costs and benefits of utilization of these resources by society, that is, it is not based on any economic consideration.

The proponents of "sustainable development" borrow the ecological notion of sustainable use and impose it as a normative restriction on economic and social development. The phrase "sustainable development" became well known after the publication of the World Commission of Environment and Development's report *Our Common Future* in 1987. The report contained the following widely quoted definition:

> Sustainable development is development that meets the needs of the present without compromising the ability of the future generations to meet their own needs.

The issue was the focus of the "Earth Summit" in Rio de Janeiro in June 1992, and the concept has since been embodied in the resulting UN Framework Convention on Sustainable Development. An enormous literature has grown in various fields of social and natural sciences around this concept. However, the exact interpretation of sustainable development varies widely. Even if one looks carefully at the definition quoted above, one can see that it can lend itself to wildly different interpretations. One might interpret it (as has been done by environmentalists who believe that sustaining the environment in as pristine state as possible is an end in itself) as a requirement that the present society should leave the state of the natural environment unaltered—exactly as it is today—for future needs. Such an interpretation ignores any form of cost–benefit analysis of conservation or any possibility of substitution between resources in production and consumption processes, as well as the possibility of technological change. It is also absurd—if our Stone Age human ancestors had followed such a precept, then human society would still be in the Stone Age.

On the other hand, one may interpret sustainable development as a process of social, economic, and ecological change that does not compromise the opportunities of future generations to gain at least as good a quality of life as at present, after explicitly recognizing the dependence of quality of life on the state of the natural environment, and the dependence of material production possibilities on environmental resources. This interpretation appears reasonable to many because it is based on the principle that conservation of the natural environment cannot be an end in itself—welfare of human society has to be the ultimate criterion. This is, of course, no different from the fundamental utilitarian premise that underlies all economic models of allocation of resources (not just environmental resources). What distinguishes the concept of "sustainable development" is its emphasis on the long-term welfare of human society—the concern for welfare of future generations—and the need to explicitly take into account changes in the ecological and natural resource systems, the interdependence between the ecology and the economy, and the dependence of human welfare on the state of the natural environment.

1.3 Sustainable Growth

With this interpretation of sustainable development in mind, we can formulate a precise definition of sustainable growth. The difference between the two concepts arises because economic growth as we have defined it is a much narrower concept than economic and social development (though there are numerous writers who often use the terms "growth" and "development" or "sustainable growth" and "sustainable development" interchangeably).

Sustainable growth is a process of economic growth (that is, expansion of per capita material output) where the welfare of human society does not exhibit a tendency to decline over time.

There are several reasons why welfare may decline even though economic growth occurs, that is, why a path of sustained economic growth need not be path of sustainable growth. Production of more output requires more inputs, and the earth's "sources" of natural resources could be depleted by continued growth of production and consumption. Further, more output means more emissions and wastes, and so the world's "sinks" could inevitably become overburdened by continued economic growth. Economic activity may eventually exceed the "carrying capacity" of the biosphere with dire consequences for human and biological welfare. Therefore, once we realize the dependence of welfare and production on the natural environment and the way economic activities affect the environment, it becomes important to move beyond the concept of economic growth or expansion of physical output over time and to ask whether sustainable growth occurs; that is, whether human welfare stays undiminished over time.

However—and contrary to the beliefs of many environmentalists—there is no necessary contradiction between sustained economic growth and sustainable growth. This is because the *scale* of economic activity is but one determinant of the rate of depletion of natural resources and the rate of production of waste materials and gases. Equally important are the *composition* of economic output and the *techniques* used to produce it. If, along with economic growth, there comes a transformation in the structure of the economy, as well as the substitution of cleaner and resource-conserving technologies for dirtier, resource-using technologies (as also substitution of old goods by new goods satisfying similar needs), then growth can continue to provide even higher standards of material living without threatening the nonmaterial aspects of human well being.

Whether or not sustainable growth occurs in an economy depends on the way that resources are allocated over time and across activities at any instant of time. It is important to recognize that environmental decay—though important—need not be the only reason behind decline in welfare of future generations. In fact, even if one ignores environmental resources and quality, human welfare will decline in societies where the current generation uses up most of its available resources in current consumption and leisure activities, and ignores investment in physical and human capital and in creation of knowledge. Societies often behave this way if they are myopic or if they perceive the future returns to investment as being not worth the current sacrifice. Human history is replete with instances of steep decline of nations and civilizations—and not all of them are due to environmental disasters.

1.4 Economic Growth Theory as a Framework for Analyzing Sustainable Growth

Economic theories of growth have traditionally studied factors that limit expansion of human welfare in frameworks where welfare depended only on material consumption—"sustainable growth" was equivalent to economic growth in these frameworks. These theories bring out clearly the limits on the capacity of a society to secure sustained increase in per capita welfare through material goods—such as impatience, lack of information, human population dynamics, law of diminishing returns, nature of preference for goods, possibility of technological change, and so on. In particular, they bring out the fact that the intertemporal tradeoff between current and future welfare and the way that society resolves it is by far the most fundamental economic factor determining the growth process. A theory of sustainable growth requires an extension of this analysis to a framework where we incorporate the dependence of the production process on environmental inputs, the consequent changes in the natural environment, and their impact on quality of life.

Long before the hype about sustainability, economists analyzed the limits to growth of per capita consumption and well being arising from the finiteness of natural resources and population growth. The eighteenth century writings of the great classical political economists Ricardo, Malthus, and Mill explored these issues—Ricardo addressed the distributional problems; Malthus wrote about the pressures of population growth on finite land; Mill investigated the economic contents of a steady state with natural resources. In recent times, particularly in the 1970s, neoclassical growth theory has explored the consequence of finiteness of nonrenewable resources for sustainability of positive consumption and growth. More recently, this has been extended to include environmental inputs as directly affecting human welfare and damage to the environment caused by pollution and other by-products of the consumption and production process. This article will provide an exposition of some of the basic insights on sustainable growth gained from this specific literature on "growth with environmental factors."

The exposition will be carried out using one of the most widely used and basic models of intertemporal resource allocation in neoclassical economics—the aggregative optimal growth model (the "discounted" Ramsey model). In the version of the model we choose, the social welfare in each period is summarized by a utility function that depends on consumption of material goods and may depend on the state of the natural environment. Decisions on current consumption and use of environmental resources determine the amount of resources that can be devoted towards capital formation for the future and the future of the environment. These, in turn, determine the possibilities for material consumption in the future. A social planner makes these decisions in a way that maximizes the discounted sum of welfare over an infinite horizon.

This model brings out clearly the nature of the intertemporal tradeoff faced by society—current versus future welfare, the dynamic opportunity costs of resource use, the role of the weight placed on current and future welfare, and the economic incentives for capital formation, technological change, and preservation of the natural environment. While the analysis is carried out in terms of the dynamic optimization problem of a social planner, in certain contexts, the solution to this optimization problem can be shown to be equivalent to that of a market based growth process where economic agents make decentralized decisions based on their own incentives. For example, this holds if the economy can be described by a representative agent who maximizes the discounted sum of utility over time, if all markets are complete and perfectly competitive, if preferences and technologies are not characterized by non-convexities, and if there are no externalities or information problems.

However, markets for environmental assets are often missing or incomplete, and a large number of environmental assets have a public good characteristic. Natural resource markets such as that of crude oil are often characterized by concentration and market imperfections. Futures markets (as well as risk markets) for natural resources are noticeably absent—often reflected in instability in the spot markets. A large number of natural resources are harvested under open access conditions leading to market failure—the familiar "tragedy of the commons." The property rights for many environmental assets are not established. Environmental assets provide the classical examples of market failures. This limits the scope of interpreting the optimal growth process as a decentralized market based growth path.

The problem of market failure and incompleteness is, however, a more general economic problem that affects a large number of economic processes—not just the growth process. There are well known schemes of government intervention, mechanism designs, and institutional innovations that, in principle, can handle many of these problems. More specifically, a number of countries have taken steps towards creation of property rights and active markets for the use of environmental assets. International coordination has moved towards resolving many of the free-rider problems associated with global emissions. Democracy, scientific research, and increasing public awareness of the state of the environment and its implications are forces that are likely to strengthen the pressures to make these markets more effective.

However, there is one question of undeniable significance: once we take care of all the market failures, imperfections, and incompleteness, would there still be a problem of sustainable growth? The framework of optimal economic growth provides a useful benchmark to answer this question and to understand the distinctive elements of the problem. This article will provide an exposition of some of these elements.

2. Economic Growth Without Environmental Factors: A Basic Model

In this section, we develop a benchmark model of economic growth in an economy where the natural environment does not enter the economic system or the welfare of society. We provide an exposition of some of the basic factors that determine the possibility of economic growth, which is equivalent to sustainable growth in this setting. The framework that we adopt is that of optimal economic growth in an economy with one physical good that can be used for consumption as well as investment. A social planner determines the optimal dynamic path of the economy using an intertemporal welfare criterion. More specifically, the planner maximizes the discounted sum of one-period welfare over an infinite horizon. The production and welfare functions are assumed to satisfy concavity and other regularity conditions. The optimal growth path of this economy is equivalent to the dynamic path resulting from competitive market-based resource allocation and decentralized decision making in a representative agent economy (where the representative agent is infinitely lived, maximizes the discounted sum of utility, and all markets are complete and perfectly competitive with no externalities or information problems).

2.1 The Model

The economy begins with an initial endowment k_0 of the physical good in period 0. For simplicity, we abstract from issues arising due to population growth and assume that the labor endowment of the representative agent is exogenously fixed at 1. This means that there is no difference between per capita and total consumption / output in our economy.

Consumption in period t, denoted by c_t, yields immediate welfare summarized by a utility function $u(c_t)$—one can think of this as the per period utility function of a representative agent. In what follows, we shall use the terms “utility” and “welfare” interchangeably. We assume that the one-period utility function u is strictly increasing, differentiable, and strictly concave in current consumption. Further, we assume that the marginal utility of consumption becomes infinitely large as consumption grows to zero that is, $u'(c) \to \infty$ as $c \downarrow 0$.

The production side of this economy is described by a production function. Output is produced using capital and labor. The production function in period t is given by $F(k_t, L_t)$, where k_t is the capital stock entering production in period t and L_t is the labor input in period t. The function F is differentiable, concave, and strictly increasing in both inputs. As the supply of labor is equal to 1 in every period, we work with a production function f where:

$$f(k_t) = F(k_t, 1) \tag{1}$$

We assume that the marginal productivity of capital is greater than one when the capital stock is small enough, that is, the production technology is not entirely unproductive.

The dynamic optimization problem for the social planner is as follows. Given $k_0 > 0$:

$$Max \sum_{t=0}^{\infty} \delta^t \quad u(c_t) \tag{2}$$

subject to:

$$k_{t+1} = (1-d) k_t + (y_t - c_t) \tag{3}$$

$$y_t = f(k_t) \tag{4}$$

$$c_t \geq 0, \; k_t \geq 0 \tag{5}$$

where $\delta \in (0, 1)$ is the discount factor (the inverse of the rate at which future utility is discounted) and $d \in [0, 1]$ is the depreciation rate for the capital stock. Under some additional technical restrictions, it can be shown that there is a unique optimal path that solves the dynamic optimization problem. (These restrictions ensure that even in circumstances where it is feasible for output and consumption to expand indefinitely, the maximum discounted sum of utility is finite, so the dynamic optimization problem is well defined.)

With some abuse of notation, let $\{c_t\}$ be an optimal consumption sequence. Under our assumptions on u, it can be shown that $c_t > 0$ for all t. Standard arguments can be used to derive the first-order necessary condition for maximization (the “Ramsey–Euler” equation) in this dynamic optimization problem:

$$u'(c_t) = \delta\left[u'(c_{t+1})\right]\left[(1-d) + f'(k_{t+1})\right] \tag{6}$$

Eq. (6) describes the basic intertemporal tradeoff between current and future consumption and how it is resolved in the optimal growth path of the economy. In any period, the marginal benefit from consumption is its current marginal utility as evidenced on the left hand side of Eq. (6). The opportunity cost of the marginal unit of current consumption is the value of marginal addition to future capital stock that could be generated by investing this unit in physical capital formation (instead of consuming it). The latter, in turn, is given by the additional gross or total output next period (the total output in any period t is $[(1 - d)k_t + f(k_t)]$) generated by a marginal addition to the capital stock (we can call this the "rate of return on investment"), valued by the marginal utility of consumption next period, and then discounted in order to reduce it to present value terms. This is exactly what we have on the right hand side of Eq. (6) and we can call this the "marginal present value of investment." Eq. (6) states that society will consume to the point at which the current marginal utility from consumption is exactly balanced by the marginal present value of investment.

-
-
-

Bibliography

Beltratti A. (1996). *Models of Economic Growth with Environmental Assets*. 113 pp. Dordrecht: Kluwer Academic Publishers. [A useful source of references on models of growth with natural resources and environmental use, including models using alternative criteria for intertemporal optimality; Chapter 6 contains a good exposition of the concept of "sustainable growth."]

Brock W. A. (1973). A polluted golden age. In V. L. Smith, ed. *Economics of Natural and Environmental Resources*, Chapter 25. New York: Gordon and Breach. [A classic paper on the problem of optimal growth with pollution.]

Daly H. E. (1991). *Steady State Economics, Second Edition*. 302 pp. Washington, DC: Island Press. [A passionate exposition of the radical approach to sustainable development; the author argues against any possibility of sustainable growth and against the entire economic approach to the problem.]

Dasgupta P. and Heal G. H. (1979). *Economic Theory and Exhaustible Resources*. 501 pp. Cambridge: Cambridge University Press. [A definitive and clear exposition of the economics of nonrenewable natural resources and a useful summary of the literature on limits to growth due to finiteness of such resources.]

Goldin I. and Winters L. A., eds. (1995). *The Economics of Sustainable Growth*. 314 pp. Cambridge: Cambridge University Press. [Contains several seminal contemporary contributions providing a perspective on the main issues in the debate on sustainable growth; see, in particular, chapters by Goldin and Winters, Grossman, Baldwin, Dasgupta and Beltratti, Chichilnisky and Heal.]

Heal G. H. (1982). The use of common property resources. In V. Smith and J. Krutilla, eds. *Explorations in Natural Resource Economics*. Baltimore, MD: Johns Hopkins University Press for Resources for the Future. [A useful discussion of the problem of growth with pollution and other environmental resources—particularly the role of stock effects; also see references cited there.]

Heal G. H., ed. (1993). The Economics of Exhaustible Resources. *International Library of Critical Writings in Economics,* Volume **32**, 656 pp. Hants: Edward Elgar Publishing Company. [A collection of the most important papers in the literature on economics of nonrenewable natural resources; see, in particular, papers by Solow, Dasgupta and Heal, Dasgupta, Heal and Majumdar in Part I, by Stiglitz in Part II, and by Krautkraemer in Part V.]

Jones L. E. and Manuelli R. E. (1997). The sources of growth. *Journal of Economic Dynamics and Control* **21**, 75–114. [A useful exposition of the basic issues and models of economic growth—particularly sustained long-run growth.]

Meadows D. (1972). *The Limits to Growth*. 205 pp. New York: Universe Books. [A classic study that generated the sustainable development debate in the 1970s, particularly in the context of exhaustible natural resources.]

Solow R. M. (1986). On the intergenerational allocation of natural resources. *Scandinavian Journal of Economics* **88**, 141–149. [A seminal contribution by the Nobel economist summarizing some of his earlier work on growth with natural resources and concern for intergenerational equity.]

Solow R. M. (1992). *An almost practical step towards sustainability*. Invited Lecture for the Fortieth Anniversary of Resources for the Future, Washington, DC. [A critique of the confusion surrounding various interpretations of sustainable development, and a clear exposition of the concept based on economic principles.]

Stiglitz J. (1974). Growth with exhaustible natural resources: Efficient and optimal growth paths. Symposium on the Economics of Exhaustible Resources. *Review of Economic Studies* 123–137. [Another classic paper on this issue.]

Stokey N. L. (1998). Are there limits to growth? *International Economic Review* **39**, 1–31. [A recent paper on growth with pollution that also explains the bell-shaped relationship between output and pollution.]

Toman M. A., Pezzey J., and Krautkraemer J. (1995). Neoclassical economic growth theory and sustainability. In D. W. Bromley, ed. *Handbook of Environmental Economics*. Cambridge, MA: Blackwell. [A useful survey of the literature on sustainable growth and a good source for references.]

World Commission on Environment and Development (1987). *Our Common Future* (The “Brundtland Report”). 383 pp. Oxford: Oxford University Press. [The classic report that summarized the major issues in sustainable development and provided a definition of the concept.]

Biographical Sketch

Santanu Roy received his Ph.D. from Cornell University in 1991 and taught at Erasmus University, Rotterdam (The Netherlands) before joining the faculty at Florida International University, Miami. He is the author of a number of important theoretical papers on economic survival, conservation & extinction of natural resources, industry dynamics and dynamics of markets with asymmetric information.