BIOPHYSICAL CONSTRAINTS TO ECONOMIC GROWTH

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Summary

Continuous, aggregate economic growth has been the principal means for realizing many of our most cherished national economic and political goals. In the aggregate we must view our economic system as a global economy that relies on natural capital and transcends political boundaries. However, comprehensive and independent scientific investigations provide compelling evidence that the growth of the global economy is not sustainable, because it consumes many of the environmental services that underpin the production of goods and services. Neither does economic growth necessarily go hand-in-hand with increases in the wellbeing of people. Furthermore, the potential for nations to use foreign natural capital to sustain growth diminishes as rising populations and

incomes deplete global natural capital. Economic models must embody realistic limits to substitution of human-made capital for natural capital, and they must account for the critical role of ecosystem services as well as marketed natural resources.

1. Introduction

Stable consumer prices, full employment, and increasing per capita wealth are economic and political goals in nearly every nation. Aggregate economic growth has been the principal means for realizing these goals. Yet comprehensive and independent scientific investigations provide compelling evidence that the growth of the global economy is not sustainable because it consumes many of the environmental services that underpin the production of goods and services. There also is a growing realization that economic growth does not necessarily go hand-in-hand with growth in the wellbeing of people. Standard measures of economic output such as Gross National Product do not reflect the growing disparity between rich and poor in most nations, or the environmental degradation that diminishes the health of people, communities, ecosystems, and the economy.

Underlying the universal prescription for economic growth are theoretical models that describe the process of growth itself. These models (and their derivatives) reflect the conventional wisdom about the driving forces behind the historic growth in living standards, the role of the environment in the economic process, and the ability of substitution and technical change to overcome resource scarcity and environmental degradation.

These models fundamentally misrepresent these important relations, and therefore contribute to the expectation that the type of economic growth we have experienced since 1950 is sustainable. There has been much discussion since the 1970s about the role of resources in economic development and the compatibility of growth with environmental conservation. As indicated by recent exchanges between mainstream and ecological economists, this debate has not been settled.

2. The Standard Model of Economic Growth

The inclusion of environmental concerns in standard growth models is an active area of research in environmental economics. Many applications of the neoclassical theory of economic growth to environmental problems downplay the likelihood that resource depletion and environmental degradation can significantly constrain economic growth. However, there are a number of reasons to question this conclusion. The basic growth model in the Nobel-prize winning work published in 1956 by Solow does not include resources at all. This model subsequently was extended with nonrenewable resources, renewable resources, and some waste assimilation services. A common interpretation of standard growth theory is that substitution and technical change can effectively de-couple economic growth from resources and environmental services. Depleted resources or degraded environmental services can be replaced by more abundant substitutes, or by "equivalent" forms of human-made capital (people, machines, factories, etc.).

The neoclassical literature on growth and resources centers on what conditions permit continuing growth, or at least non-declining consumption or utility. I use the short-hand "sustainability" to refer to either continuing growth or non-declining consumption. Technical and institutional conditions determine whether or not sustainability is possible. Technical conditions refer to things such as the mix of renewable and nonrenewable resources, the initial endowments of capital and natural resources, and the ease of substitution among inputs. The institutional setting includes things such as market structure (competition versus central planning), the system of property rights (private versus common property), and the system of values towards future generations.

The elasticity of substitution (s) between what economists call capital (factories, machines, etc.) and inputs from the environment (natural resources, waste assimilation, ecosystem services) is a critical technical term that indicates by how much one of the inputs must be increased to maintain the same level of production when the use of the other input is reduced. A large s implies that the cost impact due to the rising price of one input, say natural resources, can easily be escaped by switching to a different technique of production that favors the use of another input, say capital.

As neoclassical economists are primarily interested in what institutional arrangements, and not what technical arrangements, will lead to sustainability, they typically assume *a priori* that sustainability is technically feasible. A unitary elasticity of substitution (s=1), referred to as "perfect substitutability," means that as the ratio of the two inputs is changed by a given percentage holding output constant, the ratio of their marginal products changes by the same percentage (in the opposite direction). Perfect substitutability does not mean that resources and capital are equivalently useful – in fact, as resource availability declines its marginal productivity rises *ad infinitum*. Even so, as we discuss below, perfect substitutability is an unrealistic assumption from a biophysical perspective. Economists often explicitly dispose of cases where σ for non-renewable resources and capital is greater or less than unity. In the former case substitution possibilities are large and therefore the possibility of non-sustainability is not an issue. In the latter case, sustainability is not feasible if an economy uses only non-renewable resources. Of course, where there are renewable resources sustainability is technically feasible, at least in the absence of population growth. (For more on capital substitution and its converse, capital complementarity, *see also chapter "The Limits of Capital Substitution")*

Substitution that is technically possible will not occur unless society invests in sufficient capital over time to replace the depleted natural resources and ecosystem services. How much investment does take place depends on the institutional setting of the economy. For example, in an economy where sustainability is just technically feasible (s=1) and there are only nonrenewable resources sustainability will not occur in either a competitive or a centrally-planned economy where the decision rule is the maximization of the discounted flow of utility of future generations using a constant and positive discount rate. Consumption *per capita* will eventually decline to zero after an initial period of economic growth because resources and ecosystem services are depleted faster than capital can be accumulated to replace them. Sustainability can be achieved under certain institutional settings. If the utility of individuals is given equal weight without regard to when they happen to live and the aim is to maximize the sum of utilities over time, then growth in consumption can occur indefinitely. This is equivalent to maximizing net present value with a zero discount rate. Obviously, therefore, a constant level of consumption over time also is feasible. An important result in this context is the Hartwick rule which shows that if sustainability is technically feasible, a constant level of consumption can be achieved by reinvesting resource rents in other forms of capital, which in turn can substitute for resources. The Hartwick rule has been extended to multiple capital stocks and to open economies.

How well do economic models reflect the material basis of the economy? Neoclassical economists argue that the class of growth models that include resources can account for mass balance and thermodynamic constraints with the "essentiality condition." If s is greater than one, then resources are "non-essential." If s is less than or equal to one, than resources are "essential." Essential in this case means that given positive non-resource inputs, output is only zero when the resource input is zero, and strictly positive otherwise. The Cobb-Douglas production function, a form frequently used in growth models, has the essentiality condition. Economists argue that this at least accounts for the fact that *some* amount of energy and materials are required to produce goods and services. But when the elasticity of substitution is unity this "essential" amount can be infinitesimal if sufficient manufactured capital is applied. Economists also note that resources and capital are interdependent in the neoclassical models, in that some positive quantity of resources is required to produce capital assets. Thus, the capital stock cannot be increased without depleting the resource stock. Some economists acknowledge that an assumed value for s of one or greater between energy and other inputs violates the laws of thermodynamics. But, in general, neither this important constraint nor its implications for substitution have been integrated into the main body of work on sustainability.

Modern growth theory has sought to improve the standard theory by "endogenizing" technical change through more explicit modeling of investments in human capital (education, health care) and new technology (research and development). These may prove to be important advances. In one group of models there are decreasing returns in the acquisition of knowledge, which is surely more physically realistic, but this school still assumes that human-made capital is perfectly substitutable for resources and environmental services.

In summary, environmental economists have paid increasing attention to the environment, extending the standard tools of micro- and macro-economics to problems of resource depletion and waste assimilation, and in doing so have provided insight into some of the costs and benefits of alternative plans to ameliorate environmental problems. Some environmental economists have engaged natural scientists and policy-makers in constructive debate about what if anything should be done about environmental problems. Yet, despite the increased emphasis by environmental economists on accounting for the role of the environment in economic production, their treatment of the topic remains incomplete. While some of the relevant mechanisms have been incorporated into individual models, models incorporating all of the important feedbacks have not been developed, and some models used in applied work continue to ignore resources and the environment.

Perhaps more importantly, it is difficult to avoid the conclusion that economics as opposed to individual environmental economists) does not take the material basis of the economy seriously. The majority of degree programs in economics at the undergraduate and graduate level do not require students to take courses in resource and/or environmental economics. The majority of standard texts pay little attention to resource and environmental issues; the indexes of some popular texts do not even include entries on energy, natural resources, pollution, or the environment.

3. The Ecological-Economic View of the Economy

Ecological economists have a fundamentally different "pre-analytic vision" of the economic process than neoclassical economists. The economic process is sustained by a flow of low entropy (high quality) energy, materials, and ecological services from the environment. Collectively, these resources and services are called natural capital. Ecological economists distinguish between natural capital, which generates natural resources and ecological services, and the more familiar form of capital manufactured by or residing in humans and their economies, cultures, and institutions. The latter form of capital takes two broad forms. Human-made or manufactured capital refers to factories, buildings, tools, and other physical artifacts. Human capital refers to the stock of education, skills, culture, and knowledge stored in human beings themselves.

Resource-augmenting technical change and substitution between natural and human capital are at the core of the debate about limits to growth and sustainable development, as evidenced by the long history of the debate. The most renowned exchanges in this debate are those between Herman Daly, Robert Solow, and Joseph Stiglitz. Daly criticizes the growth models of Solow and Stiglitz because the production functions they use assume perfect substitutability of manufactured capital for natural capital. Daly argues that the two forms of capital are in fact largely complementary, because human capital is ultimately derived from and sustained by energy, materials, and ecological services. Similar arguments have been made by a number of other ecological economists *(see also chapter "The Limits of Capital Substitution").* But it has also been noted that the substitute/complement debate has shed less light on the issue than it could, partly because it tends to characterize the human-natural capital relationship at one end of the spectrum or the other, when in fact it is a very complex issue that defies a single, universal label.

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Biographical Sketch

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