THE LIMITS OF CAPITAL SUBSTITUTION: STRONG Vs WEAK SUSTAINABILITY

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Summary

For decades, there has been debate among economists about the degree to which one form of capital, or *production factor*, can in principle substitute for another without limiting the capacity for production. We explore the assumptions behind neoclassical economic answers to this question, comment on the history of economic thought leading to these answers (as well as to alternative views), and describe the significance of these issues to the more general debate about sustainable economic development.

1. Introduction

In our finite world, human populations are growing fast, while human needs, wants, and expectations grow even faster. Rightly or wrongly, many of our needs and expectations regarding the quality of our lives are tied up with the production and consumption of goods and services. How can these needs and expectations be most nearly satisfied, for the greatest number of people, and over the long term? These are some of the basic economic questions seeking answers in the debate over "sustainable development" and how it might be achieved. From this perspective, sustainability has much to do with the means of production and distribution of goods and services—the traditional sphere of inquiry of economics. The traditional boundaries of economic thinking are today being increasingly permeated by perspectives from other disciplines. This article deals with one area of economic debate that has been strongly influenced by recent thinking from the physical and biological sciences. In the first section, we provide a brief summary of the debate and its underlying concepts. The second section compares and contrasts the neoclassical or mainstream economic position with ideas proposed by ecological economists in recent decades. This section also shows how some of these ideas are rooted in classical economic principles of the eighteenth and nineteenth centuries. A

third section contrasts the different notions of sustainability that fall under the headings of *strong* and *weak* sustainability. The concepts of substitutability and complementarity that underlie the debate are examined further in a fourth section, and other uses of these terms are analyzed in brief.

2. Production Factors and Functions

For decades, there has been debate among economists about the degree to which one form of capital, or *production factor*, can in principle substitute for another without limiting the capacity for production. Among economists, the phrase production factor is roughly synonymous with *productive inputs*. These are the inputs into the production process that drives the economy. Depending on the sector of the economy under discussion, as well as other variables, they can be mathematically represented by a variety of *production equations* or *production functions*. Inputs or factors have been broadly categorized as 1) *land* (together with all natural resources or "natural capital"), 2) *labor* (energy, person-hours, aspects of "human capital"), and 3) *capital* (including "real" and "working" capital, financial capital, manufactured capital, etc.). These conventionally recognized production factors have been supplemented, depending on the analytical viewpoint, by *energy* as a separate category, or by *entrepreneurship*, *research and development*, *information*, etc. At any time, one or more of these factors may be in short supply, while others may be more easily available. Imbalances are assumed to destabilize production and therefore to threaten sustainability of productive output. An important question is can one factor be substituted for another without too much disruption of the productive process? If so, stability of production will be facilitated and fluctuations in the availability of factors may be smoothed over. A loss of one factor may be offset, temporarily or in principle even permanently, by expanding the supply or extending the utility of another. Thus, *factor substitutability* is a theoretical pillar supporting the goal of continuous levels of industrial production over the long term.

In addition to theoretical and philosophical dimensions, the substitution debate clearly has important practical implications for sustainable development policy. In the terms of this debate, sustainable development has been defined as economic development (or continuous levels of consumption) constrained by the requirement of maintaining capital intact into the future. This definition remains incomplete unless it specifies whether the several forms of capital should be maintained in some more or less constant proportion or distribution of values, or whether capital stocks need only be maintained in the aggregate sense, as a constant sum of capital values. For instance, might an increase in manufactured capital compensate for and balance out an overall decrease in levels of natural capital? Or must each type of capital stock be maintained independently over time? This is partly an accounting question: much production entails loss or depreciation of natural capital stocks, but income derived from such production is rarely discounted, for instance in the prevailing system of national accounts. But the question also has a policy aspect: in forging a sustainable development path, should societies invest in all types of capital in some fixed proportion over time, or do different forms of capital have different "sustainability values"? What needs to be made explicit is the degree to which one form of capital can substitute for another, whether by means of technological progress, changes in taste and expectation, or by other means.

Much neoclassical economic thinking on this question has taken as a starting point the economic theories of production elaborated in the 1920s, especially the Cobb-Douglas production function, proposed in 1924. For mathematical simplicity, the two-factor case of this and similar production functions is most often employed. A model economy with only two production factors, and therefore two dimensions, is expressed by a variety of equations of the general form

$$Q = K^a L^b, \qquad (1)$$

where Q = production output, K = capital stock size, L = labor (or other resource input of interest), $0<a<1$, $b = 1–a$. This type of equation (multiplicative form) describes a situation in which the "elasticity of substitution" is very great (i.e. constant levels of production can be maintained by means of substitution of the more prevalent factor for the factor in shorter supply). In effect, the two factors represented by the Cobb-Douglas function are highly, indeed almost perfectly, substitutable for one another. Mathematically speaking, the elasticity of substitution is constrained to be equal to one. The Cobb-Douglas function was widely used for decades as the basis for a series of highly influential econometric studies, such as those of Solow and Stieglitz in 1974, that appeared to show that non-energy inputs could be freely substituted for energy inputs without any reduction in productive capacity. The motivation for these studies was to explore the conditions under which an economy could continue to grow despite the presence of limited natural resources.

The important elements in this "growth theory" were technological change and returns to scale, which were seen as potentially offsetting limitations set by population growth and exhaustible resources. Kenneth Arrow and others have devised more general forms of the production function, including the transcendental logarithmic ("translog") function and the constant elasticity of substitution function. These later models have attempted, by placing fewer restrictions on the elasticity of substitution, to eliminate the built-in assumption of the Cobb-Douglas model that factors are easily substitutable for one another. However, this assumption can be mathematically weakened or eliminated only at the cost of a substantial increase in model complexity and data sensitivity, and a loss of robustness of the models. Simple forms of production functions have remained in use into the 1990s, for instance in discussions of sustainable development.

Substitution between natural capital and manufactured capital can be either in production or consumption. Substitution might result from pressures on the supply side, like the drawing down of a resource, or on the demand side, like a change in tastes, a successful education campaign, or the institutionalization of a certification program. Hartwick-Solow models assume substitution in production, via the Cobb-Douglas function, implying a constant and unitary elasticity of substitution.

These models were developed in the early 1970s in response to the "limits to growth" controversy, for the purpose of defining conditions under which levels of consumption per capita *could* be maintained indefinitely. They relied heavily on the proviso that the elasticity of substitution between manufactured and natural capital would be greater than one. Actual empirical evidence for the possibility of substitutability is ambiguous, as we shall see below.

3. Complementarity: The Ecology of the Economy

Herman Daly, basing his thinking on that of economist N. Georgescu-Roegen and population ecologist A.J. Lotka among others, has mounted perhaps the most cogent and consistent argument against the assumption of easy substitutability among production factors. He has maintained that, far from being substitutes, the various forms of capital are, in fact, more nearly perfect complements. Thus, labor cannot be substituted for natural resources in any significant way, nor manufactured capital for natural resources. Different natural resource inputs may in some cases be substituted for one another (such as bricks for timber in the construction of a house), or different forms of labor or energy inputs (such as power saws for elbow grease). Indeed, according to Daly's "complementarist" point of view, the utility of one form of capital will be in large part determined by the availability of other forms, since each is dependent on the other. In this, as in other matters, Daly's thinking derives from some of the ideas of the classical economists of the eighteenth and nineteenth centuries, such as David Ricardo's theory of rent (articulated in *Principles of Political Economy and Taxation*, 1817) and John Stuart Mill's definitions of the production factors capital, labor and land (*Principles of Political Economy*, 1857).

Some economists have also found support for the complementarist position in some of the central writings from the early years of neoclassical economics. Alfred Marshall, considered the father of neoclassical economics, published his 1890 classic *Principles of Economics* with the Darwinian motto *Natura non facit saltum* ("Nature does not move by leaps and bounds") emblazoned on the frontispiece. In it he emphasizes the ineluctable nature of the natural world, and its essential role in all economic production. J.R. Hicks in *Value and Capital* (1946) defined a production factor as a stock that has a *marginal product*, meaning that if part of it were to be removed, production would diminish. Daly has interpreted this as implying that overall productivity will be constrained by the *limiting factor*, namely the form of capital in shortest supply. The economic concept of the limiting factor is a derivation from theoretical ecology, where for many decades Otto Leibig's *law of the minimum* has provided the framework for study of community dynamics such as competition and predation. The idea that the resource in shortest supply is the one setting limits on population growth is familiar to any ecologist. In ecology, resources such as nutrients, water, space, nesting sites, or mating opportunities are rarely substitutable for one another, since each is essential at some minimum level, although there may be varying degrees of substitutability within each resource category. Success (in the biological sense of genetic propagation into following generations, or even in the sense of population growth) is attainable only in the presence of sufficient quantities of each of the basic resource categories.

Interestingly, Hicks' influential definition of income as the "the maximum value which [a person, or a community] can consume in a week, and still expect to be as well off at the end of the week as he was at the beginning" contains in itself a very modern criterion for sustainability, since it clearly demands the maintenance (non-consumption) of capital. However, Hicks was writing principally about manufactured capital within the industrial process, and the idea has only recently been extended to natural capital. Wilfred Beckerman, a strong spokesman for the neoclassical position, has defended the "traditional" economic viewpoint that natural capital (what he calls "the environment") is merely a subcategory of capital, providing benefits indistinguishable in kind from

other subcategories—simply one among a suite of satisfactions or "utilities" that people derive from goods and services. According to this viewpoint, natural capital may be treated as an "ordinary commodity" in two senses: as a production input, or as a consumer good. In either case, the value of a given aspect of the natural world will be defined by how much people are willing to pay for it.

Writers such as Daly and Jacobs, in contrast, argue that some forms of natural capital, including natural services and processes, are both indispensable and non-replicable, and hence that they cannot be easily weighed against other forms of capital. Beckerman retorts that nothing gives protection of the environment any special "moral value" over other goods. This may or may not be true, but one need not necessarily appeal to moral values to see why the environment may indeed qualify as a good that cannot be bought and sold in the marketplace.

The concept of capital substitutability relies on market signals to provide feedback stimulating price rises at appropriate times, such as when commodities become rare. Without such feedback, there is little to pull technologies toward greater efficiency in resource use. But fluid market functioning depends on a series of conditions, many of which are only rarely or partially met in the real world. In any case, many natural services, though they are vital components of economic production activity, do not figure in markets. Waste absorptive capacity, climate stabilization processes, and pollination services are just three of many such indispensable yet non-market processes on which various aspects of our economic activities depend.

One of the assumed conditions for adequate consumer decision making in the neoclassical economic paradigm is the availability of information about the options, so that market prices realistically reflect the full value ("utility") to society of particular goods and services. But in fact, consumers often lack crucial information about the roles played by many of our natural life-support systems, how they function, and what life would be like without the full use of their services.

It may not be possible to repair environmental values once they have been degraded in favor of other values. As a result, social choices about how to balance the value of our environment against that of various other "amenities" may be myopic and destructive in the long run. We may not know the full range of choices, or fully understand the consequences of those choices; and we do not necessarily have the option of changing course later on. Additionally, the assumption of price responsiveness has never been tested on a global scale. The ability of the global economy to respond sensitively to signals from the environment, and to provide the right feedback in the form of price adjustments, is a matter of conjecture.

In sum, although neoclassical economics has, during the course of the twentieth century, moved away from the idea of the essential complementarity of forms of capital to embrace an often unexamined faith in factor substitutability, some of its most illustrious thinkers and founders have lent support to the intuitively satisfying—though mathematically unwieldy—notion of complementarity among the forms of capital. This notion has been taken up more recently by ecological economists, using a more generalized definition of terms.

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Biographical Sketch

Reinmar Seidler is a doctoral student in the Department of Environmental Biology at the University of Massachusetts at Boston. His research interests include tropical forest management and land-use change, the interface between the natural and social sciences, and the role of science in society. He has published on tropical forest management and sustainable development issues in the journal *Conservation Biology* (1998), the Academic Press *Encyclopedia of Biodiversity* (2000), and for Island Press.