Population and Economics

A Bioeconomic Analysis

by Herman E. Daly

The concept of optimal population has an honorable place in the history of economic thought. But it no longer occupies any place at all in modern standard economic theory. The belief today is that the concept is of no interest because the niche which the human population occupies is itself expandable by human action. The main way to expand the human niche is to accumulate manmade capital. We simply transform more of the natural world, which has traditionally been considered superabundant, into manmade capital (the stock of producer goods and durable consumer goods embodying human technologies) and thereby expand our niche as fast, or faster, than we expand our numbers. The limiting factor in determining the size of our niche has traditionally been manmade capital.

But recently we have entered a new era in which the limiting factor is remaining natural capital. Economic theory has taught that natural and manmade capital are near-perfect substitutes rather than complements, so the problem of one being a limiting factor simply does not arise. Consequently, for standard economics we have not and cannot enter a new era in which natural capital has replaced manmade capital as the limitative factor, and so the old confidence that the human niche can be indefinitely expanded continues to be dogma. Yet in reality, manmade and natural capital *are* complements – for example, the manmade capital of a sawmill is complementary with the natural capital of a forest. When factors are complementary, then productive capacity is limited by the one in shortest supply – a kind of generalized Liebig's Law of the Minimum – valid for industrial as well as agricultural production. When what was previously limiting ceases to be, and what was previously superabundant becomes limiting, then behavior has to change if it is to remain *economic*. We must maximize the productivity of the factor in short supply – that used to mean maximize the productivity of manmade capital; now it means maximize the productivity of natural capital. Moreover it means that expansion of manmade capital at the expense of natural capital no longer expands the human niche – it reduces it.

How is it that we have passed such an important watershed without economics having noticed it? Three abstractions have blinded economic theorists.

First, economics naturally abstracts from whatever is not scarce. The source and sink functions of nature were not scarce when the scale of the human economy was small, and it was during this period that economics developed.

> *"When factors are complementary, then productive capacity is limited by the one in shortest supply."*

Second, the basic preanalytic vision from which modern economic analysis begins is that of the circular flow of abstract purchasing power, with no entry or exit of either matter or energy (Georgescu-Roegen, 1971). If interpreted as a physical description of production and consumption, as it

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sometimes is in textbooks, the circular flow is in stark contradiction with the Second Law of Thermodynamics.

Third, modern neoclassical economics has taught that manmade capital is a near-perfect substitute for flow of natural resources, and consequently for the stock of natural capital that yields that flow of resources. This is a major misconception. If natural resources and manmade capital were perfect substitutes then why would we ever have developed manmade capital to begin with, since we already had a perfect substitute? It is obvious that capital and resources are complements, not substitutes. There may be some very marginal substitutibility between capital and resources at the level of recycling prompt scrap, as when sawdust is collected and compressed into particle board. The capital equipment for doing this means slightly fewer trees have to be cut, because we use each tree a bit more efficiently. But this marginal substitutibility hardly alters the fact that resources and capital are on the whole complements in production. When factors are complements, production is limited by the one in shortest supply; for substitutes such a limit is nonexistent. Indeed perfect substitutes should not even be considered different factors from an economic perspective since their economic functions would be identical. The very concept of factor assumes some complementarity, or at least nonsubstitutibility.

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If the limiting factor on production is now remaining natural capital, then reducing natural capital further to make more room for manmade capital will reduce rather than increase production. More manmade capital no longer creates more living space for human beings – it uses it up. Populations of human beings, and populations of their extensions in the form of manmade capital, have always competed for available low entropy matter/energy from the environment supplied by natural capital, which was not considered capital because scarce. No longer should we maximize productivity of labor or capital by using natural resources lavishly (thus minimizing resource productivity) – rather we must move into the mode of maximizing natural resource productivity, subject to restraints imposed by a desirable or sufficient standard of living. The most practical operational way of doing this seems to be to return to the notion of optimal population, generalized a bit to arrive at the concept of optimal scale. Scale is defined in its flow dimension as population times per capita resource use. In its stock dimension, it may be thought of as the total population of humans and their artifacts – the sum total of human organs, both endosomatic and exosomatic, to use the terminology of Lotka (1956).

The maintenance of the grand total of human organs which support our life and its enjoyment requires an entropic throughput from the environment. Just as our endosomatic organs are maintained by an endosomatic digestive tract, so our exosomatic organs require an exosomatic digestive tract. Both digestive tracts convert low entropy matter/energy into high entropy matter/energy, thus placing similar burdens on the regenerative and assimilative capacities of the ecosystem. The entropic nature of the throughput of the two digestive tracts further gives the lie to the notion that more manmade capital (exosomatic organs) makes room for more endosomatic organs (human beings). They compete for the same life space. As long as that life space was very large relative to the scale of demands coming from both sources there was no problem. But human endosomatic and exosomatic capital combined now directly and indirectly preempt 25% of global net primary production (NPP) of photosynthesis of the 40% of land-based NPP (Vitousek, et al., 1986).

The notion of exosomatic organs is more than just a metaphor. Our lives and well being are as dependent on automobiles, airplanes, heating and cooling systems, electric and communications networks, pipelines, and sewerage systems as on our heart, liver or lungs. Both sets of organs support life and its enjoyment, and both are dissipative

structures maintained in a quasi-steady-state by an entropic throughput from and back to the environment. This is well-expressed in the following quote from A. J. Lotka (1956, p. 369):

> *The most singular features of the artificial extensions of our natural body is that they are shared in common by a number of individuals. When the sick man consults the physician, who, we will say, makes a microscopic examination, for example, the patient is virtually hiring a pair of high power eyes. When you drop a nickel into a telephone box, you are hiring the use of an ear to listen to your friend's voice five or ten miles distant. When the workingman accepts a wage of forty dollars for his weekly labor, he is in fact paying to his employers an undetermined amount for the privilege of using his machines as artificial members to manufacture marketable wares.*
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> *The modern development of artificial aids to our organs and faculties has exerted two opposing influences.*
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> *On the one hand, it has in a most real way bound men together into one body: so very real and material is the bond that society might aptly be described as one huge multiple Siamese twin.*
>
> *On the other hand, since the control over certain portions of this common body is unevenly distributed among the separate individuals, certain of them may be said in a measure to own parts of the bodies of others, holding them in a species of refined slavery, and though neither of the two parties concerned may be clearly conscious of the fact, it is often resented in a more or less vague way by the one less favored.*

Let us continue a bit Lotka's very suggestive thoughts.

There are some further important similarities and differences between endosomatic and exosomatic organs (or endosomatic and exosomatic capital as the economist might say).

First, our exosomatic organs evolve much more rapidly than our endosomatic ones. We fly with exosomatic wings and dive with exosomatic gills.

Second, most of our exosomatic organs have evolved in dependence on stocks of minerals and fossil fuels, which in the long run are the scarcer of our two sources of low entropy, the other being solar energy (Georgescu-Roegen, 1971). More precisely, solar energy is unlimited in its stock dimension, the sun, but strictly limited in its flow dimension of arrival on earth. We have not learned to mine the sun (fortunately). Terrestrial deposits of minerals and fossil fuels, which we have learned to mine, are strictly limited in the stock dimension, but relatively unlimited in the flow dimension in the sense that for a while at least, we can use them up at a rate of our own choosing. And we have chosen to use them quickly to construct marvelous exosomatic organs, some of which we devote to further increasing the rate of extraction to make still more marvelous exosomatic organs.

Third, while ownership of endosomatic organs is very egalitarian (each person has one heart, two kidneys, etc.), exosomatic organs are owned more by some than by others, as Lotka noted. Consequently we can expect social conflict to be exacerbated as we deplete the terrestrial source of low entropy.

Social conflict up to now has been eased by more rapid growth, or at least the promise thereof. But now growth in exosomatic organs competes directly with humans for the maintenance of their endosomatic organs – witness in Brazil the competition for agricultural land between fuel for *Mechanistra automobilica* (sugar cane) and food for *Homo sapiens brasiliensus* (rice and beans). Not many years ago some scientists were claiming that we would be converting petroleum into food to feed the world. Georgescu-Roegen, on the basis of the distinctions made above about the stock-flow patterns of scarcity, was able to predict just the opposite direction of substitution – food into petroleum substitutes – a reversion towards the more abundant solar source of low entropy.

If we accept that: (1) we have reached the scale beyond which exosomatic organs significantly compete with the endosomatic organs for a share of the limited stock of terrestrial low entropy, and (2) that manmade capital is not a substitute for natural capital, but

rather a complement whose productivity is limited by natural capital availability, then the implications are that we should limit the scale of the human presence, and seek to maximize the productivity of resources rather than of labor or capital, and should seek to diminish poverty through wealth redistribution and population control, rather than growth.

The following policy would be a step in that direction. Enact a heavy severance tax on resources, especially fossil energy, and reduce the income tax, especially on low incomes, by the amount needed to achieve revenue neutrality. This will have the following desirable consequences: (1) The scale of resource throughput would be limited and with it the gross load on the ecosystem and the rate of takeover of habitats of other species; (2) Resource prices would increase inducing resource-saving technologies and patterns of consumption; (3) Equity would be served by reducing the income tax mainly on lower incomes, and perhaps even by instituting a negative income tax for very low income levels, financed by the resource severance tax; (4) A resource tax can raise any amount of revenue since resources are necessary for production, and a severance tax is less avoidable than an income tax; (5) Reducing taxes on income would increase both incentives to work and employment opportunities; (6) The shift from income to resource taxes could be carried out gradually, and modified according to experience.

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Our bioeconomic analysis shows us that the scale of the human niche is limited; that scale is measured by population times per capita resource use (in flow terms), or the sum of exosomatic and endosomatic organs (in stock terms). There remains the question of how the total scale should be divided between its two components – many people with low per capita resource use, or fewer people with higher per capita resource use. This is a question of ethics and values that transcends bioeconomics. How much resource use per capita is necessary for a good life? As an ethical principle to clarify discussion of this latter issue, I suggest the following: That we should strive to maximize the cumulative number of lives ever to be lived over time at a level of per capita resource use that is sufficient for a good life. This means that we cannot have too many people alive simultaneously lest we destroy carrying capacity and thereby reduce the number of lives possible in all subsequent time periods. It also means that the basic question "What is needed for a good life?" cannot forever be avoided. Sufficiency must join efficiency as a key concept in economic thought. •

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