11. How long can neoclassical economists ignore the contributions of Georgescu-Roegen?[1]

I. INTRODUCTION

Some will immediately object to my title—Nicholas Georgescu-Roegen has not been ignored, they will point out. He was a Distinguished Fellow of the American Economic Association; Paul Samuelson, the pope of American economists, called him "a scholar's scholar, an economist's economist" (1965); and Mark Blaug (1985) included him in his book *Great Economists Since Keynes*. All true. What I mean is that Georgescu-Roegen has been ignored in the sense of not being taken seriously. Samuelson has said little about Georgescu-Roegen since his 1965 paean. Did he change his mind? Why? Certainly none of Georgescu-Roegen's ideas on the biophysical foundations of economics ever made it into the canon of Samuelson's famous textbook. Nor have Samuelson's colleagues and students at MIT paid Georgescu-Roegen the slightest attention. Little notice was taken of his death by the American Economic Association. Hardly a trace of his influence remains in the Economics Department of Vanderbilt University where he taught for twenty years. Did someone subsequently refute the "economist's economist"? Who? Where? Why this combination of temporary recognition followed by apparent amnesia? Mark Blaug (1985, p. 71) gives a partial answer:

> It is only fair to add that Georgescu-Roegen's later books have not been well received, or rather, have been respectfully received and quickly put away. For various complex reasons, not to mention the difficult style in which they are written and the intimidating references they contain to theoretical developments in physics and biology, these works have received virtually no critical discussion from economists.

It would seem that economists are allergic to physics and biology, and should be excused from any contact with such irritating and intimidating sciences! After all, the neoclassicals had just made a very heavy investment

in learning mathematics, and that was thought sufficient to acquire scientific status, or at least the appearance thereof. Also if one starts encumbering mathematical growth models with biophysical dimensions one loses the analytical beauty and austere elegance of the pure mathematics. One also raises impolite political questions about biophysical limits to economic growth, and the sufficiency of economic growth as the panacea for poverty, unemployment, overpopulation, environmental degradation, and so on. One may even arrive at the very awkward conclusion that some very respected economists have been saying some very erroneous things for a very long time.

De Gleria (1995), in a thoughtful tribute to Georgescu-Roegen, argued that his was a mind that thought ahead of its time. If this is true, and I think it is, then the future should witness our catching up with his thinking. I believe this will eventually happen. Although it is ungracious to say so, Georgescu-Roegen's ideas may advance more rapidly now that he himself is no longer around to scare people away from them by his irascible nature and impatience to "suffer fools gladly." Some of Georgescu-Roegen's secret admirers may now openly take up his cause, no longer fearful that the master will disown them because of some minor difference.

In their excellent obituary essay and summary of Georgescu-Roegen's contributions, Maneschi and Zamagni (1997) remark that in spite of the recognition accorded him, "it is somewhat paradoxical that Georgescu seems to be better known outside than inside his adopted country, the United States" (p. 705). While in some ways adding to the puzzle, this remark also suggests a clue. European economists might have been more receptive because they learned from Georgescu-Roegen at a distance—more through his writings than in person. Also Europeans accord more respect to professors than do Americans, and that made personal relations with Georgescu-Roegen easier because, a European himself, he took the respectful deference of others as his due. Most importantly, Europeans are less under the domination of the MIT department of economics and its clones than are US economists. Samuelson's 1965 laudatio notwithstanding, the US neoclassicals found Georgescu-Roegen just too problematic to deal with. He was after all an accomplished mathematician who criticized the frequently excessive and pretentious use of mathematics in economics, and, as already emphasized, he was not an easy man to get along with. I once asked him why he thought that the neoclassical MIT "mafia" (his term) never referred to him or cited his work. He replied with a Romanian proverb to the effect that, "in the house of the condemned one must not mention the executioner." He was indeed something of a executioner, but usually a just one. A discussion of his critique of Solow/Stiglitz will provide an example of his justice, as well as of the neoclassical school's capacity to

stonewall for thirty years. Georgescu-Roegen's ire was not always unprovoked—not by any means!

As Gowdy and Mesner (1998) pointed out, in the end Georgescu-Roegen gave up on the standard economists, and resigned from the American Economic Association. His own assessment of the situation was given in the following words,

> If I finally realized that I was running against one current or another, it was not from any crossing of intellectual swords with my fellow economists, who have systematically shunned such an encounter, but from their personal attitudes toward me. I was a darling of the mathematical economists as long as I kept contributing pieces on mathematical economics. (Georgescu-Roegen, 1992, p. 156)

That the systematic shunning of any intellectual encounter with Georgescu-Roegen continues to be modus operandi of the neoclassical establishment, is evident from the forum discussion in *Ecological Economics* in September 1997. Parts of that discussion are repeated below.

II. GEORGESCU-ROEGEN'S CRITIQUE OF THE SOLOW/STIGLITZ NEOCLASSICAL VIEW OF PRODUCTION

In his Richard T. Ely Lecture to the American Economic Association, Robert Solow (1974, p. 11) stated that "If it is very easy to substitute other factors for natural resources, then there is in principle no 'problem'. The world can, in effect, get along without natural resources." As an "if–then" statement this is no less true than saying, "If wishes were horses then beggars would ride." But the facts are that wishes are not horses, and that natural resources and capital are generally not substitutes, but complements. While it is no doubt useful to state this conditional possibility for the sake of logical completeness in cataloging alternatives, one would expect that the production-without-resources case, once recognized, would be quickly set aside as unrealistic and unworthy of further analysis. However, Solow does not set it aside, but retains it as a real possibility. In fact, it is precisely this "real possibility" that has provided the foundation for a significant part of his previous work. His well-known work in growth theory is based on an aggregate production function in which resources do not appear at all, and which takes production to be a function only of capital and labor. That production function is a mathematically clear way of saying that "the world can, in effect, get along without natural resources."

What evidence does Solow offer for this remarkable affirmation about the way the world works? In the next paragraph he says, "Fortunately, what

little evidence there is suggests that there is quite a lot of substitutability between exhaustible resources and renewable or reproducible resources." True enough, but irrelevant. The issue is not substitution between two types of natural resource, rather it is one of substitution of capital for resources—an entirely different matter. Easy substitution between two types of natural resource will not help the world to get along without natural resources!

Since the production function is often explained as a technical recipe, we might say that Solow's recipe calls for making a cake with only the cook and his kitchen. We do not need flour, eggs, sugar, and so on, nor electricity or natural gas, nor even firewood. If we want a bigger cake, the cook simply stirs faster in a bigger bowl and cooks the empty bowl in a bigger oven that somehow heats itself. Nor does the cook have any cleaning up to do, because the production recipe produces no wastes. There are no rinds, peelings, husks, shells, or residues, nor is there any waste heat from the oven to be vented. Furthermore, we can make not only a cake, but any kind of dish—a gumbo, fried chicken, a paella, bananas foster, cherries jubilee—all without worrying about the qualitatively different ingredients, or even about the quantity of any ingredient at all! Real recipes in real cookbooks, by contrast, begin with a list of specific ingredients and amounts.

A technical production recipe that contradicts both the first and second laws of thermodynamics, as well as best practice in cooking, is more than a little troubling. It led Georgescu-Roegen to the following verdict on Solow:

> One must have a very erroneous view of the economic process as a whole not to see that there are no material factors other than natural resources. To maintain further that "the world can, in effect, get along without natural resources" is to ignore the difference between the actual world and the Garden of Eden. (Georgescu-Roegen, 1975, p. 361)

Perhaps as an unacknowledged concession to Georgescu-Roegen's criticism, we find some years later a new version of the production function in which resources appear along with labor and capital, all multiplied together in a Cobb-Douglas function. Georgescu labeled this the "Solow-Stiglitz variant," and showed that including R (resources) in this type of production function simply sweeps the contradiction under the rug, without removing it.

Georgescu-Roegen deserves to be quoted at length on this point. He writes the "Solow-Stiglitz variant" of the Cobb-Douglas function as:

$$Q = K^{a1} R^{a2} L^{a3} \quad (1)$$

where Q is output, K is the stock of capital, R is the flow of natural resources used in production, L is the labor supply, and a1+ a2 + a3 = 1 and of course, ai > 0.

From this formula it follows that with a constant labor power, L_o, one could obtain any Q_o, if the flow of natural resources satisfies the condition

$$R^{a2} = \frac{Q_o}{K^{a1}L_o^{a3}} \tag{2}$$

This shows that R may be as small as we wish, provided K is sufficiently large. Ergo, we can obtain a constant annual product indefinitely even from a very small stock of resources R > 0, if we decompose R into an infinite series $\Sigma R = R_i$, with $R_i \rightarrow 0$, use R_i in year i, and increase the stock of capital each year as required by (2). But this "ergo" is not valid in actuality. In actuality, the increase of capital implies an additional depletion of resources. And if K→ infinity, then R will rapidly be exhausted by the production of capital. Solow and Stiglitz could not have come out with their conjuring trick had they borne in mind, first, that any material process consists in the transformation of some materials into others (the flow elements) by some agents (the fund elements), and second, that natural resources are the very sap of the economic process. They are not just like any other production factor. A change in capital or labor can only diminish the amount of waste in the production of a commodity: no agent can create the material on which it works. Nor can capital create the stuff out of which it is made. In some cases it may also be that the same service can be provided by a design that requires less matter or energy. But even in this direction there exists a limit, unless we believe that the ultimate fate of the economic process is an earthly Garden of Eden.

The question that confronts us today is whether we are going to discover new sources of energy that can be safely used. No elasticities of some Cobb-Douglas function can help us to answer it. (Georgescu-Roegen, 1979, p. 98; see also Stiglitz, 1979, p. 41, fn 5)

To my knowledge neither Solow nor Stiglitz has ever replied to Georgescu-Roegen's critique. They were invited to do so in the above-mentioned September 1997 issue of *Ecological Economics*, and both chose to avoid even mentioning Georgescu-Roegen, much less reply to his specific criticism! What reply could they make? Let us consider a few possibilities that others have put forward in similar contexts.

First, it might be argued that resources can be left out of the production function because they are not really scarce. Air is usually necessary for production, but we do not explicitly enter it in the function because it is considered a free good. This argument loses plausibility as soon as we remember that most resources are not free goods. Furthermore, we cannot logically use price, even a zero price, as a coefficient of factors in the production function. The production function is a technical recipe with all terms in physical units, not value units. The fact that *aggregate* production functions must use prices as weights in calculating an aggregate quantity

index (dollar's worth) of capital (or labor or resources) is a fundamental problem that limits the usefulness of aggregate production functions, not an answer to the difficulty just raised. Also, expressing the quantities of different factors in units of the same numeraire reflects an assumption, not a demonstration, that the factors are substitutes.

Second, it is sometimes argued that leaving resources out of the production function is justified by the implicit assumption that resources can be perfectly substituted by reproducible capital. Nordhaus and Tobin (1972) are quite explicit:

> The prevailing standard model of growth assumes that there are no limits on the feasibility of expanding the supplies of nonhuman agents of production. It is basically a two-factor model in which production depends only on labor and reproducible capital. Land and resources, the third member of the classical triad, have generally been dropped . . . the tacit justification has been that reproducible capital is a near perfect substitute for land and other exhaustible resources."

If that were the case then we could equally well leave out capital and include natural resources (substitution is reversible), yet no one suggests doing that (for related discussion, see Victor, 1991). To do that would run counter to the whole animus of neoclassical theory, which is to deny any important role to nature.

The Solow-Stiglitz variant includes resources explicitly, but implicitly makes a similar assumption about near perfect substitution of capital for resources—what Georgescu-Roegen aptly dismissed as a "conjuring trick." In the Solow-Stiglitz variant, to make a cake we need not only the cook and his kitchen, but also some non-zero amount of flour, sugar, eggs, and so on. This seems a great step forward until we realize that we could make our cake a thousand times bigger with no extra ingredients, if we simply would stir faster and use bigger bowls and ovens. The conjuring trick is to give the appearance of respecting the first law of thermodynamics (material balance) without really doing so.

Another argument for the unimportance of resources was offered in the influential book *Scarcity and Growth* (1963, p. 11) by Barnett and Morse, who argued that

> Advances in fundamental science have made it possible to take advantage of the uniformity of matter/energy—a uniformity that makes it feasible without preassignable limit, to escape the quantitative constraints imposed by the character of the earth's crust . . . Nature imposes particular scarcities, not an inescapable general scarcity.

Just below the surface lies the alchemist's dream of converting lead into gold. All we need from nature are uniform, indestructible building blocks—the

alchemical "quintessence" or "fifth essence" to which the traditional four essences (earth, air, fire, and water) are thought to be reducible, and through which they become convertible one into the other. Given the building blocks, all the rest is transmutation—value added by capital and labor (and perhaps a few magic words or symbols). Technical improvement enables labor and capital to add more value to the inert building blocks, but nature remains unnecessary beyond the initial provision of those blocks. This view at least respects the first law of thermodynamics, but unfortunately crashes headlong into the second law. While it may be technically possible to convert lead into gold thereby eliminating the particular scarcity of gold, we do not thereby remove general scarcity, because the potential for making such conversions is itself scarce. That potential must be continually used up by the economy and re-supplied by nature in the form of low-entropy natural resources.

Another possible reply would be to take off from Georgescu-Roegen's qualification that in some cases "the same service may be provided by a design that requires less matter or energy." This implicitly introduces a distinction between substitution among factors within a given set of technologies (existing state of the art), and substitution among factors made possible by a new technology (improved state of the art). Even the latter case is limited—future technologies must also conform to the laws of thermodynamics, Georgescu-Roegen insists—but he leaves it at that. Just how far new technology can ease the burden of scarcity, within the constraint of physical laws, remains an open question. But that really is another subject from the one at hand, since in constructing their aggregate production function Solow/Stiglitz aim to represent actual production processes of today and the recent past—not unknown future possibilities. It is as an empirically based representation of actual production processes that their production function is intended, and it is as such that it fails. That it would also fail to depict future technologies is an a fortiori criticism.

In an article otherwise critical of neoclassical theory, Ayers (1996, p. 12) offers a last-ditch defense of Solow/Stiglitz, in the absence of which he considers Georgescu-Roegen's critique "devastating." Ayers's too-generous defense is that, "in the distant future the economic system need not produce significant amounts of material goods at all." Further down the same page he implicitly conflates the production function with the utility function to make the claim that, "nobody can define a finite absolute minimum material input required to produce a unit of economic welfare." Maybe not, but we were talking about physical output, not welfare. Even production functions that yield services are producing a physical output—the use of something or somebody for some period of time. That is different from utility or welfare. The service of my physician may not increase my welfare at all, and could even reduce it—but it remains a measurable service for which I am

charged. But even without this clarification Ayres found it necessary to immediately condition his statement questioning the existence of a minimum material input, by adding "with the obvious exception of food and drink." Are there not other obvious exceptions, for example clothing and shelter?

Maybe there are other replies to Georgescu-Roegen's criticism that are less unconvincing than those considered above, but if so then Solow or Stiglitz should break their silence and finally reply to Georgescu-Roegen's criticism of long standing. Of course Georgescu-Roegen is now deceased, but his critique did not die with him. Serious criticism and serious replies are both essential parts of science. When a fundamental critique from a very prominent economist goes for decades without a reply, we should worry about the health of our discipline!

Consider a further major difficulty resulting from the conjuring trick of just plugging R into a production function along with K and L. An immediate consequence is that the marginal physical products of K and L would have to be zero once R is included in the function. This is because the definition of marginal product of one factor requires that the amounts of all other factors be held constant as one more unit of the variable factor is added. But when resources are held constant then there can be no extra unit of output as labor or capital is increased because there is no extra physical substance for the extra output to be made from—it would have to be produced out of nothing, again fracturing the first law of thermodynamics. The point of course is not limited to Cobb-Douglas functions—any production function that obeys the first law of thermodynamics cannot avoid a strict complementarity between resources on the one hand and capital or labor on the other hand.

Zero marginal physical products of labor and capital, a necessary consequence of including R in any production function that obeys the most basic laws of nature, would destroy neoclassical distribution theory—perhaps too heavy a price to pay for admission that the world, in effect, cannot get along without natural resources! And once we admit that natural processes, as well as labor and capital, add value to the indestructible building blocks, then we must ask who has the right to appropriate nature's contribution? These are not trivial issues! Of course, we can continue to write mathematical functions that contradict physical laws, call them "production" functions, take the partial derivatives of L and K, and still label them marginal products of labor and capital. But then, as Georgescu-Roegen put it, this becomes a "mere paper-and-pencil operation" (PAP was his acronym).

Georgescu's fund-flow model of the production process is superior to the neoclassical production function. It emphasizes that physically what we call "production" is really transformation—of resources into useful products

and waste products. Labor and capital are agents of transformation (efficient causes), while resources, low-entropy matter/energy, are "that which is being transformed" (material causes). We can often substitute one efficient cause for another, or one material cause for another, but the relation between efficient and material cause is fundamentally one of complementarity, not substitutability.

If we wish to retain the neoclassical production function then we must at least include natural resource inputs and waste outputs, and must adopt mathematical representations that, unlike the customary multiplicative forms, do not assume that agents of transformation (funds) can substitute for the resources undergoing transformation (flows). Accuracy of analytical representation of reality must replace mathematical tractability as the main criterion of a good model. Once we recognize the reality of inputs from nature then we must inquire about their scarcity and about the ecological processes that regenerate them. Once we recognize the necessity of returning waste outputs to nature then we must inquire about the capacities of ecosystems to absorb those wastes. We will no longer be able to avoid the ecological economist's vision of the economy as an open subsystem of a complex ecosystem that is finite, entropic, non-growing, and materially closed. In effect, neoclassical economists will become ecological economists!

Perhaps the best way to get an answer to Georgescu-Roegen's critique is not to raise it again with the same people that have ignored it for thirty years, but rather to somehow get 10,000 students to ask their economics professors the following questions in class: (1) Do you believe that economic activities must satisfy mass balance? (2) Why is it that neoclassical production functions do not satisfy the condition of mass balance? (3) Do you believe that Georgescu-Roegen's interpretation of production as physical transformation is correct? (4) Do you agree that the economic system is embedded in the larger environmental system, and totally dependent on it as both source and sink for the matter/energy transformed by economic activity? (5) Do you believe that the matter/energy transformations required by economic activity are constrained by the entropy law?

In the aforementioned discussion forum in *Ecological Economics* (1997) these five questions were put to Solow and Stiglitz, along with G-R's resuscitated critique of their neoclassical model of production, as restated above. In their invited replies neither Solow nor Stiglitz even mentioned G-R! For the most part they chose to simply repeat their well-known position rather than to defend that position against the arguments G-R had raised against it. But in closing Solow offered some forthright, if brief, replies to the above questions. The five questions, Solow's replies, and my comment on each are given below.

1. Do you believe that economic activities must satisfy mass balance?
   Solow's answer: "Yes."
   Comment: Agreed.
2. Why is it that neoclassical production functions do not satisfy the condition of mass balance?
   Solow's answer: "Because up until now, and at the level of aggregation, geographic scope and temporal extent considered, mass balance has not been a controlling factor in the growth of industrial economies."
   Comment: Mass balance holds at all levels of aggregation, geographic scope, and temporal extent—so Solow's qualifications seem beside the point. I think what Solow means is that material balance is unimportant because materials themselves are unimportant, which is implied by his use of a production function in which material flows are either absent or somehow substitutable by capital stocks. If material flows themselves are not important then material balances would not be important either. That is why Georgescu-Roegen criticized Solow for analyzing "the Garden of Eden" rather than the real world. The criticism remains unanswered. Does the qualification "up until now" indicate an expectation that the situation is about to change, that the mass balance constraint is gaining relevance?
3. Do you believe that Georgescu-Roegen's interpretation of production as physical transformation is correct?
   Solow's answer: "This is no doubt one aspect of production."
   Comment: Yes, but Solow has treated it as a very unimportant aspect—one that could safely be abstracted from in the analytical representation of production. Georgescu-Roegen criticized him for that—for abstracting from the essential, rather than from the incidental. If production is essentially the transformation of a flow of resource inputs into product outputs, with capital and labor funds serving as agents of transformation, then capital and resources must be more in the nature of complements than substitutes. As Georgescu-Roegen noted, agents of transformation cannot create the materials they transform, nor the materials out of which the agents themselves are made. Agent of transformation and material undergoing transformation are basically complements—they can be substitutes only along the margin of reducing waste of materials-in-process to zero—for example using a press to make particle board out of wood chips and sawdust. But then the press (capital) and the wood chips (resources) are again complements. Solow makes no recognition at all of this fundamental complementarity. Complementarity is pushed further offstage by its more technical definition based on constant output (which rules complementarity

out of existence in a two-factor world). Georgescu-Roegen remains unanswered.

4. Do you agree that the economic system is embedded in the larger environmental system, and totally dependent on it as both source and sink for the matter/energy transformed by economic activity?
   Solow's answer: "Certainly, and I welcome any attempts to model the dependence in a transparent way, so that it can be incorporated into aggregative economics."
   Comment: One should take Solow at his word about what he now welcomes. His recent concern about the greenhouse effect is certainly welcomed by ecological economists.

   However, if one agrees that the macroeconomy is a subsystem embedded in an ecosystem that is finite, non-growing, and materially closed, then wouldn't one expect the macroeconomy to have an optimal scale relative to the total ecosystem—a scale beyond which its growth is uneconomic? Why is it that each micro activity has an optimal scale, while the aggregate of all microeconomic activities is supposed to grow forever, unconstrained by any notion of optimal scale of the macroeconomy relative to the ecosystem? Ecological economists would welcome any attempts by Solow to model the limit to growth resulting from optimal scale of the macroeconomy.
5. Do you believe that the matter/energy transformations required by economic activity are constrained by the entropy law?
   Solow's answer: "No doubt everything is subject to the entropy law, but this is of no immediate practical importance for modeling what is after all a brief instant of time in a small corner of the universe."
   Comment: Solow seems to identify the entropy law only with the ultimate heat death of the universe. I don't worry much about that either, and neither did Georgescu-Roegen, whose critique of Solow was not based on such a remote cosmic event. But the entropy law has more immediate and relevant implication: that you can't burn the same lump of coal twice; that when you do burn it once you get soot, ashes, CO_2, and waste heat, as well as useful heat. The entropy law also tells us that recycling energy is always a losing proposition, that there are limits to the efficiency of conversion of energy from one form to another, and that there is a practical limit to materials recycling—all in the here and now, not just in the cosmic by and by. Would Solow suggest to engineers designing real production recipes that they can neglect the second law of thermodynamics because we are concerned only with "a brief instant of time in a small corner of the universe"?

   Low-entropy matter/energy is the physical coordinate of usefulness; the basic necessity that humans must use up but cannot create, and for

which the human economy is totally dependent on nature's services. Entropy is the qualitative difference that distinguishes useful resources from an equal quantity of useless waste. Solow's statement that entropy is "of no immediate practical importance" to economic life is evidence in support of Georgescu-Roegen's indictment that Solow "must have a very erroneous view of the economic process as a whole." In any event Georgescu-Roegen's criticisms remain unanswered.

These unanswered criticisms bring us back to the question posed in the title—how long can neoclassical economists ignore G-R? The answer, as far as production theory is concerned, seems to be "thirty years and still stonewalling." This is disgraceful, and it is time for those of us who understood Georgescu-Roegen to press his arguments and not allow them to be brushed aside.

NOTE

1. Originally published in Kozo Mayumi and John Gowdy (eds), *Bioeconomics and Sustainability: Essays in Honor of Nicholas Georgescu-Roegen*, Edward Elgar, Cheltenham, UK, 1999, pp. 13–24.

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