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Energy and Energetics in Economic Theory: A Review Essay

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[Author's note: This essay was prompted by two recent books: J. C. Dragan and M. Demetrescu, *Entropy and Bioeconomics* (1986), and W. van Gool and J. Bruggink, eds., *Energy and Time in the Economic and Physical Sciences* (1985).]

One of the most striking and least noticed aspects of the history of anti-neoclassical thought in the twentieth century is the sheer volume of scientists—that is, research workers trained in physics, chemistry and biology—who have been under the impression that they were the first to believe that the only "true" economic value is energy. In fact, the variants on this theme are more luxuriant than the biological metaphors with which they are sometimes entwined. Since there are more varieties of proto-scientific economic theory that you can shake a stick at, we shall proceed by erecting some basic taxonomies that will help to guide us through the underworld of unorthodox economcs, which are represented by the two books here under review.

The first distinction to be made is between those who literally believe that energy is identical to economic value, and those who regard the physics merely as a metaphorical resource and a cornucopia of ready-made mathematical models. We shall dub the former group the *neo-energeticists,* and the latter group the *neo-simulators.* The neo-energeticists may then be sub-divided into three separate categories: (1) those who never venture beyond the postulation of a crude identity of

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energy and value; (2) those who actually attempt to quantify energy and implement their theory of energy as a value substance; and (3) Nicholas Georgescu-Roegen, who deserves a category unto himself. While some of the papers in the W. van Gool and J. Bruggink book are written from the viewpoint of the neo-simulators, we shall restrict ourselves in this review to consideration of the phenomenon of neo-energetics.

Neo-energetics, the conviction that there exists a literal identity between the physical concept of energy and the economic concept of value (leaving aside whether it is qualified as "available" energy), has a long and illustrious history, dating back to the 1860s. Moreover, neo-energetics has not been confined to obscurity, but has always enjoyed a certain visibility within the scientific community. It has encompassed in its rank Nobel Laureates and holders of chairs at major research institutions. More significantly, the tradition has maintained itself for well over a century, but curiously enough, it has also remained congenitally peripatetic, never remaining within the boundaries of any particular academic discipline for more than a generation. It has displayed a tenacity that has proven capable of fending off empirical and theoretical criticisms with aplomb and therefore may shed some light on the similar tenacity and durability of neoclassical economic theory.

The postulation of an identity between energy and economic value began as an offshoot of the energetics movement, discussed in my book *More Heat Than Light* [Mirowski 1988]. By the 1880s, the physicist Georg Helm and the physical chemist and Nobel Laureate Wilhelm Ostwald were claiming that the program of energetics intended to unite all of the sciences under a small set of principles and concepts, and "all" clearly included the nascent social sciences. Researchers anxious to elevate the tone and status of social inquiry were quick to pick up the hint. Soon, all over Europe, aspirants were proclaiming that energy would render economics, biology, and physics all subsets of the same unified science.

In the 1880s, for instance, Sergei Podolinsky was trying to convince Marxists that scientific materialism had come to fruition in the energy concept, and that energy was a more correct value principle than embodied labor [Alier and Naredo 1982]. Patrick Geddes, trained in the biological sciences but later to gain fame as an advocate of town planning, read two papers to Section F (Economics and Statistics) of the British Association for the Advancement of Science in 1885 and 1886 asserting that embodied energy explained most important physical and biological phenomena, and therefore it followed that energy was the ultimate fact and constraint of economic value. Interestingly enough, he cited Jevons's *Coal Question,* but he did not deign to discuss neoclassical utility theory. At the turn of the century in Lausanne, Switzerland, Leon Winiarsky was attempting to extend the energetics program into sociology; and simultaneously was complaining that neoclassical economics had coopted the format of energy as value without comprehension of its revolutionary message: namely, that physical value and social value were identical, and therefore there existed only a single set of natural laws [Winiarsky 1967]. In Belgium, the physical chemist and manufacturer Ernest Solvay acted directly to forge links between the physical and social sciences by funding the *Institut des Sciences Sociales* in 1894 and the famous Solvay Conferences in physics and the International Institute of Physics in 1911–1912 [Mehra 1975]. Solvay himself wrote numerous works on social energetics, including *L'Energétique considérée comme principe d'orientation rationelle pour la sociologie* (1904) and *Questions d'énergétiques sociales* (1910).

The physicists, such as Albert Einstein, Walther Nernst, Max Planck and Ernest Rutherford, who attended the Solvay conferences apparently overlooked the enthusiasms of their patron, although Solvay had better luck when it came to purchasing social scientists. Scores of researchers in the first three decades of this century were engaged in attempting to measure the physiological and psychological manifestations of energy; the thirty-three volumes of the *Bulletin de l'Institut de Sociologie Solvay* stand as a testament to their perspicacity and their vision of a social science. The seeming encroachment upon social theory by phalanxes of chemists and engineers was taken quite seriously by other social theorists at the turn of the century, to the extent that Max Weber felt impelled to write an essay explicitly attacking Ostwald and Solvay [Weber 1909].

The doctrine of energy as the ultimate source of economic value actually gained further illustrious adherents in the 1920s. The population biologist Alfred Lotka asserted that the goal of his research was to lay bare the "biophysical foundations of economics," and that the fundamental principle underlying the foundations was energy [Lotka 1924]. Simms popularized the notion of net energy production, while T.N. Carver, a professor of economics at Harvard in the 1920s, wrote a book on *The Economy of Human Energy* [Sims 1924; Carver 1924]. Nevertheless, the most famous and most consistent advocate of an energy theory of value in the 1920s and 1930s was Frederick Soddy, Nobel Laureate in physical chemistry and the co-discoverer with Rutherford of the radioactive disintegration of the nucleus of the atom, as well as inventor of the concept of the isotope [Kauffman 1986].

Soddy's story is somewhat tragic and deserves more attention than we are capable of paying it here. Up until World War I, Soddy was an active and prolific researcher in physical chemistry. He was not a scientist of limited horizons and was clearly motivated by a conviction that his work held the utmost significance for the human predicament. His discoveries of the transmutation through radioactive decay of some of the elements and the attendant stores of energy released suggested to him that scarcity itself was potentially able to be abolished by science. Yet after witnessing the barbarism of World War I he grew despondent and lost his impetus as a chemical researcher.

Soddy came to believe that the real human predicament was not located in the physical or chemical world, but rather in human social interactions, particularly in the sphere of the economy. He became frightened of the potential military uses of the atomic processes he had had a hand in developing and thought the only hope lay in postponing further scientific advances until such time as the society displayed sufficient wisdom to make correct use of them [Kauffman 1986, p.185]. In the meantime, the task of the intellectual should be to understand the social fetters on the true telos of science; hence Soddy turned his attention to economics and rapidly turned into one of its harsher critics. In his most elaborate treatise on economics, *Wealth, Virtual Wealth and Debt,* he displayed a sensitivity to the premier problem of economic theory:

> This inquiry commenced with the attempt to obtain a physical conception of wealth that would obey the physical laws of conservation. . . . No exact science can progress until it has established within its province laws of conservation, and decided what are the real quantities which do not change with the progress of time and circumstance. . . . It might be thought that the idea of conservation, whilst useful and necessary to the original formulation of the laws of energy, was, nevertheless, of the nature of a scaffolding that might be abandoned when the building is complete . . . it is sometimes said that potential energy is a mere means of saving the face of the law of conservation. However, there is something physical and real to show for the disappearance of kinetic energy . . . and the more correct view is that the term potential energy cloaks an ignorance as to the nature of the action at work [Soddy 1961, pp. 21, 133–134].

Unfortunately, and by his own admission, Soddy was not much of a mathematician, and thus was incapable of following up the lines of inquiry suggested by such statements. Instead, he merely put forward a very rudimentary energy theory of value, and used it to embark upon a crusade against bankers and financiers, since they wielded economic power with no grounding in "real" energy relations. Although he is now often lumped together with the other "money cranks"of the 1930s, such as Major Douglas and Silvio Gesell, a case can be made that he was a different kettle of fish. He at least possessed a theory of value and derived some analytical statements concerning monetary divergences from those value principles. Be that as it may, Soddy's monetary theories were not very acute, his Oxford colleagues did not appreciate the attacks on bankers, and the temper of the times tended to the view that the scientist was justified in abdication of all responsibility for the way his results were later used. Hence Soddy died without honor among either chemists or economists.

Another cadre of support for the energy theory of value was recruited from within the American engineering profession, with phase one starting with Taylorism and terminating with the Technocracy movement of the 1930s. Frederick Taylor, the father of "scientific management," was the initial proponent of this variant of social physics, a version narrowly centered on "efficient" control on the workshop floor. The literature on Taylorism rarely points out that his doctrines were explicitly a form of energetics, because Taylor's original purpose was to discover the law governing the parameters of a full day's work by quantifying correlations between fatigue and the number of foot-pounds of exertion [Layton 1971, p.136]. Taylorism was the major vehicle by which the engineering profession expanded into managerial and economic roles, under the pretext that the identity of physical power and human labor dictated that expertise in one was expertise in the other.

The cult of the expert engineer reached new extremes in the Technocracy movement of the 1930s [Scott 1933; White 1980; Berndt 1985]. Howard Scott, apparently a charismatic figure, became attached to something called the Committee on Technocracy in the Department of Industrial Engineering at Columbia University and proceeded to tell the *New York Times* in 1932 that a group of engineers had been working for more than a decade on a survey of the industrial system of the United States in energy consumption rather than in dollars, because dollars were a "rubber yardstick." He then claimed the substitution of machine energy for manhours had so disrupted the economy that the unemployment of the previous few years had been inevitable.

Scott became an overnight celebrity, and the amount of attention accorded to Technocracy by "reputable" social scientists was prodigious. Reactions ranged from cautious skepticism to raving rhetoric. One of the better instances of the latter as by the poet Archibald MacLeish:

> The infantile cowardice of our time which demands an external pattern, a non-human authority, has manufactured a new nurse. And that nurse is the Law of Physics. One mechanistic nipple replaces another . . . All that is required of man in the Technocractic World is to submit to the laws of physics, measure all life by the common denominator of physical energy,

> discard all activities which are not susceptible of physical mensuration, and wait for the "next most probable energy state"—the millenium. It is a picture shrewdly painted to appeal to American babbitry with its childish longing to believe in Science and Scientific Truths and Scientific Thinkers [quoted in Berndt, 1985, p.350].

Although Scott was discredited in some eyes when an investigative reporter revealed he had never earned an advanced degree, and in others when Technocracy, Inc. adopted some of the overtones of a paramilitary organization, the movement grew and survived well into the 1960s in the western United States and in Canada. Although Technocracy itself was exiled to the fringes of society, the energy theory of value continued to reappear in new and different contexts. In academic circles, it next popped up in anthropology and in the new field of ecology. For instance, in a 1943 lead article in the *American Anthropologist,* Leslie White proposed that all culture be conceptualized as a manifestation of "the amount of energy per capita per year harnessed and put to work" [White 1943]. This theme was taken up by many other anthropologists, such as Adams [Adams 1975; 1982]. In the nascent science of ecology, the energy theory of value was popularized by Frederick Cottrell and was introduced into textbooks by E. and H. Odum. [Cottrell 1953; 1971, chap. 3; Odum and Odum 1976]. More recently, it has taken root in the scrublands of sociobiology, for instance in T. Parsons and B. Harrison's article, "Energy Utilization and Evaluation" [Parsons and Harrison 1981].

What this all adds up to is a nearly continuous espousal of the energy theory of value from the 1880s to the present by groups that do not acknowledge the hegemony of neoclassical economic theory. The thing that stands out about this sequence is that the persistence of the energy theory is predicated upon two odd conditions: one, that the energy theory of value was never developed with any seriousness or concerted effort by any of the groups mentioned above; and two, that the metaphor owes its longevity to the fact that it never resided very long within any academic disciplinary boundaries, but rather hopped about peripatetically from one fledgling discipline to another.

It does seem inexorable, however, that the two concepts of energy and economic value are perdurably twinned. Generation after generation returns to it as an inexhaustible metaphorical resource whenever there is a need to link the social world to the natural world, in order to yet again proclaim a truly scientific theory of society. There was no need for any of these visionaries to read any of their precursors (as indeed none of the above did) because the metaphor was in the air, as natural as life and death. The actual nitty-gritty elaboration of the metaphor was treated as secondary, since its magic derived mainly from the suggestion that a single principle could unite all knowledge. The allure resided more in the promise than in the actualization.

Notwithstanding this pattern, as we approach the present we discover a new phenomenon: a new breed of neo-energeticist who actually attempts to quantify energy as economic value and to grapple with some of the analytical objections. Not unexpectedly, this new breed consists almost entirely of engineers who have taken it upon themselves to improve the scientific tenor of economics. One distinguishing mark of the newer movement is its circumvention of conventional orthodox economics outlets such as the reputable journals and conferences, the promulgation of their program in generalist natural science journals, and the founding of their own separate periodicals [Slesser 1975; Gilliland 1975; Costanza 1980; Stone 1978; Ayres 1978; Roberts 1982; Cleveland Costanza, Hall, and Kaufman 1984; Daly and Umaña 1981; Proops 1983; Van Gool and Bruggink 1985]. This change in the character of the program may suggest that this rival to neoclassicism may prove a bit more formidable.

The energy theory of value received a tremendous boost from the OPEC oil crisis and embargo of 1973. In the ensuing atmosphere of hysteria, one found public figures such as Senator Mark Hatfield claiming that "a way to begin would be to set up a capability in government to budget according to flows of energy rather than money " [Daly and Umaña 1981]. In 1974 the U. S. Congress passed the Nonnuclear Energy Research and Development Act, which stipulated that all prospective energy technologies had to be assessed according to their net energy output. The way was paved for some experts to provide the facts and figures, and the newer neo-energeticists drove their theory of value home.

The modern neoenergetics movement sports some similarities to the theories mentioned above, but there also exist some methodological differences that subtly set it apart, lending some unity and coherence to the research program. First, there is the treatment of energy as if it were an embodied value substance in a manner nearly indistinguishable from the classical labor theory of value. Many of the arguments tendered for an energy theory of value are strangely reminiscent of those tendered in Marxian economic theory, especially with regard to an *a priori* common denominator of all commodities. For instance, one prominent neo-energeticist, Robert Costanza, has pleaded "Can anyone seriously suggest that labor creates sunlight! The reverse is obviously more accurate" [Daly and Umaña 1981, p. 167].

Second, neo-energeticists have resorted to the mathematical formalisms of input/output matricies in order to facilitate their calculations of energy values. Of course, this choice is a direct consequence of their advocacy of a substance theory of value, be it consciously intended or not. It does reveal, however, that their analytical bases do not derive as much from modern physics as they do from previous developments in economic metaphors.

Third, modern neo-energeticists persistently refer to their program as synthesizing *biology*, physics, and economics into a single science. Yet, so far, biological theories play no role in their energy theories of value, nor do biological analogies seem to carry much analytical weight. One suspects the purpose of such claims is to keep hold of the promise of the unification of all the sciences, as well as to play on the simile between human labor and energy [Gilliland, 1975, p. 98].

As the neo-energeticists succeeded in capturing support, funding, and the attention of a public fearing the wolf at the door and the auto stranded in the garage, neoclassical economists finally began to sit up and take notice. The mobilization of the neoclassical program to meet this challenge to their hegemony was initially traumatic and disorganized, but eventually an effective response to neo-energetics was generated. With only a few exceptions in out-of-the-way journals [Huettner 1976; Berndt 1978; Berry, Salomon and Heal 1978; Berndt 1985], by and large the neoclassical economics profession chose to refute neo-energetics by meeting it with a conspiracy of silence.[1] Yet concurrently it mobilized to coopt the movement by conjuring a new orthodox subfield of economics called "energy economics."

Energy economics comprises one of the most involuted *dedoublements* of the metaphor of energy in the entire history of economic thought. Consider, if you will, a research program that attempts to elevate something called "energy" to the same analytical status of "capital" and "labor" in a neoclassical production function, whenceforth one discovers *three* distinct value substances with no fixed rates of conversion. Next, the program asserts that this "energy" stuff could logically have its physical principles expressed within the compass of the field metaphor version of the production function, in the sense that all the relevant physical laws and engineering principles could be given full expression through the functional form of the isoquants or cost functions [Mirowski 1988, chap. 6]. Then, this motley ensemble of concepts is asserted to be subject to the utility theory of value, that is, the primal physics metaphor, in order to finally arrive at something called "the price of energy" [Berndt and Wood 1979].

The Neoclassical Analysis of Energy

The problems that surround the neoclassical analysis of energy, advocated by a number of authors in the van Gool and Bruggink volume is best represented by Ernest Berndt [Berndt 1978]. He begins by lamenting that, "Indeed, classical economists paid little attention to energy." Indeed they did, primarily because energy was only invented in physics in the period roughly 1850 to 1870, when classical political economy was already in decline. It was the *neoclassicals* who were fascinated with energy, but not in the way Berndt might wish to commend [Mirowski 1988]. He then proceeds to criticize the neo-energetics movement without confronting the fact that their aim is to displace neoclassical value theory: "The different prices of energy forms per BTU illustrate the fact that end-users of energy are concerned with attributes other than heat content. Thus an aggregate index of energy based only on BTU heat content fails to capture the other attributes of energy—weight, cleanliness, safety, volatility, amenability to storage, quality, etc." [Berndt 1978, p. 241]. In other words, energy is not a homogeneous substance at all, and not really a distinct commodity. But Berndt recoils from drawing the obvious conclusion, that there is no such thing as "energy economics." Instead, he correctly observes that quantitative estimates of energy efficiency based solely on the first law of thermodynamics neglect the fact that much energy is dissipated as inaccessible heat: in other words, they ignore the entropy law. This could be a very significant criticism of the neo-energetics movement, calling into question their appeals to "science" because of the fact that many neo-energeticists ignore the second law of thermodynamics. Yet again, Berndt does not draw the natural conclusion, but rather proposes an index of "second law efficiency," defined as the "minimum work required to perform a given task divided by the maximum possible work that could be extracted from a fuel consumed in a given task" [Berndt 1978, p. 230]. Of course, were one to ever seriously attempt to calculate such an index, one would rapidly learn that both the numerator and the denominator were so dependent upon the particular context of use—that is, that the quantities involved are so *path-dependent* that the index had no meaning. And further, the role of the energy concept is to formalize path-independent states, so one would expect that it would not be an appropriate index for these purposes. Berndt may perhaps have known this was all merely a smokescreen, since he never makes use of his index, either in this article, or elsewhere [Berndt and Wood 1979]. On the contrary, he really wants to play the same game as the neo-energeticists, appropriating a substance notion of energy just like theirs, only to plug it into a neoclassical production function, and hence purportedly to subordinate it to a utility theory of value. Only in an obscure footnote does he exhibit a momentary loss of nerve: "At first glance it might be conjectured that constancy of substitution possibilities [in a CES production function] is inconsistent with the ultimate limits implied by the Second Law of Thermodynamics. . . . This limiting possibility rules out further substitution of available energy for nonenergy inputs, but does not rule out continued interfuel substitution" [Berndt 1978, p. 246fn]. The second sentence of this quote in no way qualifies or ameliorates the problem recognized in the first sentence. The fact of the matter is that putting energy in a neoclassical production function makes a mockery of the physics, imposing upon it properties that contradict its treatment in physics. All in all, energy economics is an unwitting parody of the "scientific rigor" that has motivated the entire history of neoclassical theory [Mirowski 1988].

The neo-energetics movement harbors some serious logical flaws, but neoclassical economists have proved unable to isolate and identify those flaws, if only because in many cases they shared them. This reflexive hesitation proves a boon to the neo-energetics movement, since palpable disarray in the neoclassical camp, juxtaposed with their own cool legitimacy as engineers, has earned them government grants and research institutes. The only economist who has produced a serious scholarly discussion and critique of the neo-energetics movement has been, ironically, someone publicly perceived as being associated with that movement, Nicholas Georgescu-Roegen.

Nicholas Georgescu-Roegen

One of the books under review (Dragan and Demetrescu [1986] is subtitled, "The New Paradigm of Nicholas Georgescu-Roegen." Unfortunately, it does little to clarify the place of Georgescu-Roegen in the history of twentieth century economics, instead making the rhetorical error of quoting such authors as Fritjof Capra and Douglas Hofstadter in support of the implausible thesis of the rise of a new age in the area of epistemology. The phenomenon of Nicholas Georgescu-Roegen is better understood in the context of the playing out of the logic of an economic energetics that began with the rise of neoclassical economic theory.

Georgescu-Roegen is the author of one of the great unsung classics of economics in the twentieth century, *The Entropy Law and the Economic Process* [1971]. His reputation within the economics discipline prior to that volume had been a venerable one, primarily because of his publications in mathematical neoclassical theory dating back to the 1930s. However, he appeared to be experiencing skeptical second thoughts by the late 1960s, if not earlier, and the product of those meditations was a brilliant amalgam of philosophy, the history of science, and economic theory. Though this book teemed with dazzling insights concerning the impact of mathematical formalism on economic theory, the place of hysteresis in physics and economics, the intellectual validity of statistical mechanics and the arithmomorphism of physical concepts, it must be acknowledged that Georgescu-Roegen did not exert the effort required to bring the average reader (much less the average economist) up to snuff in such disparate disciplines; and consequently, the only aspects of the book most economists understood were those passages sporting close familial resemblances to the neo-energetics program. These included an extended censure of neoclassical economics for neglecting the dictates of the laws of thermodynamics in models of production, as well as a number of passages that sounded like endorsements of an energy theory of value [Georgescu-Roegen 1971, pp. 278, 282], even though a close reading reveals that he did disassociate himself from an embodied energy theory of value [Georgescu-Roegen 1971, p. 283]; there was also a detailed discussion of Leontief-style input/output models, which incorporated terms for natural resources and energy [Georgescu-Roegen 1971, pp. 254–75]. Finally, there was a promise that the goal of his inquiries would be the institution of a novel "bioeconomics."[2] For those readers oblivious to the subtleties of the argument, it looked like a duck, it waddled like a duck, and it quacked like a duck, and therefore, to the average neoclassical economist, *The Entropy Law* could be shunned as another species of the canard of neoenergetics.

Hence, after the OPEC oil embargo, partisans of neo-energetics began to quote Georgescu-Roegen in support of their energy theory of value [Costanza 1980; Daly and Umaña 1981]. Georgescu-Roegen, discomfitted by his newfound allies, reacted by subsequently publishing extended critiques of the theory of embodied energy value [Georgescu-Roegen 1979; Baranzini and Scazzieri 1986]. Since these papers constitute the only thorough and competent discussion of the neo-energetics movement by a sophisticated economist familiar with physics, his explicit repudiation of the energy theory of value deserves to be examined in some detail:

> My position has been (and still is) that the Entropy Law is the taproot of economic scarcity. In a world in which that law did not operate, the same energy could be used over and over again at any velocity of circulation one pleased and material objects would never wear out. But life would certainly not exist either. . . . It is for these reasons that the economic process is entropic in all its material fibres. But I have also maintained (without being read correctly) that although low entropy is a

> necessary condition for usefulness, it is not also a sufficient one (just as usefulness is a necessary but not sufficient condition for economic value). . . . It is now perfectly clear that in *absolutely* no situation is it possible for the energy equivalents to represent economic valuations [Georgescu-Roegen 1979, pp. 1041, 1042, 1048].

Georgescu-Roegen brought four separate indictments against the neo-energetics movement. The first, retailed under the slogan that "matter matters too," is a critique of the misuse of the theory of relativity by both physicists and economists. Although Einstein's infamous $E=mc^2$ has become an ubiquitous totem in our culture, the conventional interpretation, which asserts that matter and energy are physically interchangeable, betokens a severe misunderstanding of the physics. As an example, it is not often realized that, with the exception of some extremely transient events at the sub-atomic level, matter has never actually been precipitated solely from energy. All the relevant transformations have proceeded in the opposite direction. The dearth of reversible transformations just illustrates the fact that there is no Philosopher's Stone, and most conversions of matter from one form to another are effectively prohibited. Georgescu-Roegen has chosen to state this prohibition as a parallel to the entropy law in the domain of matter: matter, too, continuously undergoes degradation and is dispersed in ever-more unusable or inaccessible forms. Yet, there exists a profound distinction between matter and energy that should block a parallel formalization of this "entropy law" in a manner similar to Gibbs's free energy:

> the rub is that unlike mass and energy, matter is a highly heterogeneous category. Every chemical element has at least one property that characterizes it completely and hence renders it indispensable in some technical recipes. We must therefore expect that, in contrast with the general theory of energy (thermodynamics), the study of transformations of matter in bulk should be hard going [Georgescu-Roegen 1979, p. 1035].

A little more familiarity with the history of physics should enhance our appreciation of the profundity of this observation. The energy concept was invented primarily for the purpose of the expression of a certain class of regularities in physical phenomena, abstracting away other "secondary" heterogeneous properties. In part for historical reasons, energy itself became reified in the popular mind as a homogeneous substance. When Einstein derived certain mathematical implications of a portrait of a world consisting solely of symmetries and homogeneous relationships, the temptation was to interpret his work as a final vindication of the tenacious image of a single homogenous substrate that suffused all physical phenomena. What had been forgotten in the interim was that the energy concept had purposely left out the heterogeneous character of physical phenomena, and had swept it under the rug by first dumping it into the portmanteau concept of matter. Hence it was by definition a fallacy to deduce that matter and energy were identical. Such an assertion would be tantamount to claiming that all languages "really" consisted solely of verbs, although such errors of reification are not unknown in intellectual history.

This slighting of matter is but one manifestation of what Georgescu-Roegen calls the "energetics bias," namely, the predisposition to downplay the diversity of phenomena in favor of simple homogeneous relationships. In neo-energetics, matter/energy is treated in the abstract as a conserved entity, denuded of the specific multiform properties of matter so crucial for the specification of production processes. These properties are continuously undergoing degradation, and this fact constrains the expansion of economic processes just as surely as does the second law of thermodynamics. Moreover, these properties of matter are an indispensible prerequisite for harnessing various energy sources.

In this context, Georgescu-Roegen astutely observed that fossil fuels have been particularly cheap in the past precisely because they require relatively little in the way of matter configurations in their utilization. As we have moved towards nuclear energy and solar energy, we have discovered to our dismay that the matter configurations required merely to extract the energy and convert it to useful forms have exceeded the requirements of fossil fuels to an exorbitant degree. The message here is that monism must give way to (at least) dualism.

Georgescu-Roegen's second indictment of neo-energetics is that there is no rigorous definition of "net energy." In their empirical work, the neo-energeticists generally opt to express energy content in the calorific values of fuels—most commonly in British Thermal Units (BTUs), denominated in the quantity of heat required to raise the temperature of one pound of water by one degree Fahrenheit. As his first indictment explained that all physical phenomena are not reducible to a homogenous energy, this measure has already been compromised. But worse, the neo-energeticists have papered over the fact that there is no accepted calorific value for nuclear fuels, and that calorific estimates for solor energy are only indirect inferences, dependent upon ideal conversions into mechanical energy [Baranzini and Scazzieri 1986, p. 266]. Further confusions arise as to whether the calorific value of sunlight required to raise the entire surface of the earth to ambient temperature ought to be included in their calculations, or whether the energy involved in human exertion should be part of the energy accounts. The totality of these considerations argued that the comprehensive quantification of all economic phenomena by reduction to energy equivalents was a stunning metaphor, but that physics alone did not provide operational algorithms for its calculation or conceptualization.

Georgescu-Roegen's third indictment of neo-energetics evokes overtones of Ludwig Boltzmann and Planck's critique of Georg Helm and Wilhelm Ostwald in the 1890s. The neo-energeticists, innocent of the history of science, recapitulate the errors of the original energetics movement by confining their analysis to the first law of thermodynamics, to the neglect of the second law. On the simplest plane, a theory of value that asserts the proportionality of prices to embodied energy has already abstracted away the effects of the dissipation and the degradation of energy, and thus violated the second law [Baranzini and Scazzieri 1986, p. 272]. This original mistake then exfoliates error throughout neo-energetics, from an inability to confront the fundamental irreversibility of economic processes to the absence of an energy content index independent of context. For Georgescu-Roegen, all that really happens when coal is mined and burned to generate electricity is that humanity has drawn upon a fixed and limited store of low entropy and degraded much of it into dissipated heat. The failure of both the energetics and neo-energetics movements was a failure of analogy [Deltete 1983, p. 569]: both succumbed to the allure of energy conceptualized as a substance, and therefore both relinquished any legitimacy that might have been derived from metaphorical reasoning predicated upon physical theory. Modern energy analysts have made some headway in quantifying "available energy," but their findings have discouraged them from forging any direct links with economic value [O'Connor 1986].

Georgescu-Roegen's fourth and final complaint about neo-energetics is that it frequently does not practice what it preaches. Neo-energetics aims to usurp orthodox economics by reducing all phenomena to their energetic essences; but when it comes to actual practice, they persistently and stubbornly confute energetic and monetary categories. For example, the input/output matricies upon which the neo-energeticists rely so heavily were generated by economists working from pecuniary sales and purchase data and are not derived directly from technological specifications. Since the so-called embodied energy coefficients are calculated from these tables, what masquerades as a reduction is in fact a circular argument: energy values are derived from pecuniary values, and then the energy values are purported to explain the configuration of economic relations [Baranzini and Scazzieri 1986, p. 272]. The close correlation of economic variables and "energy values" results from a hat trick and not to any fundamental causality in either direction.

Georgescu-Roegen's bill of indictments against neo-energetics displayed a familiarity with the issues that no neoclassical economist could muster, and yet, it ultimately was not intended as a sympathetic critique. His most recent pronouncements are uncompromising on that score. To sample the strength of his aversion to neo-energetics, let M_0 represent the matter requirement of a technology, and e_1 represent the energy requirement of the same technology. Then:

> The upshot is that since there is no potential Ψ (M_0, e_1)=constant on which to base a technological grid (similar to that of utility preference), the choice between two technologies such that $e^1{}_1 > e^2{}_1$ and $M^1{}_0 < M^2{}_0$ cannot be decided by physico-chemical considerations alone. The upshot is that the nature of any choice between any two technologies is essentially bioeconomic. . . . Economic phenomena certainly are not independent of the chemico-physical laws that govern our external and internal environment, but they are not determined by those laws. It is because the economic has its proper laws that one dollar spent on caviar does not buy the same free energy as when spent on potatoes [Georgescu-Roegen in Baranzini and Scazzieri 1986, pp. 269, 272].

The great weakness in this, as in all of Georgescu-Roegen's impressive *oeuvre* of the past two decades, has been the tantalizingly vague character of those "proper laws" of the economic sphere and that delectable sounding "bioeconomics." Although he has periodically promised a work that would sketch the outlines of that new bioeconomics, no such tome has issued from his pen. Perhaps more disappointingly, Georgescu-Roegen often has seemed to pull his punches, never extending his critiques to their most devastating conclusions. It should become apparent to the reader that each of his indictments of neo-energetics could just as easily be nailed to the door of the economics departments at MIT, Harvard, Chicago and UCLA. Georgescu-Roegen is not totally blind to that fact, and in a few places half-heartedly acknowledged that neoclassical economics is little more than crypto-physics.[3] But his zeal and ire in these areas has been muted, and inexplicably, he has never prosecuted further research into the perversions of the physics metaphor in an explicit neoclassical context.

There are numerous instances where Georgescu-Roegen seems to falter just as he approaches a profound criticism of neoclassicism. He has been the only sophisticated economist to ridicule the myth that the specifications of neoclassical production functions are derived from physical and technological principles. His language appears to be implacable: "the value of the standard form of the production function as a blueprint of reality is nil. It is absurd therefore to hold onto it in practical applications. . . . Marginal productivity, too, comes out an empty word" [Georgescu-Roegen 1971, p. 244]. And yet, when one realizes that the neoclassical portrayal of technology as a field was only a further involution of the original physics metaphor of the field, it becomes a conundrum why his criticisms have not simply been extended to the neoclassical concept of utility. Indeed, the bulk of Georgescu-Roegen's research program can be seen as revealing that underneath the smoke and flash of theoretical disputes in twentieth century economics is a single subterranean tectonics, namely, the imperatives of the model of energy appropriated from physics in the 1870s [Mirowski 1984].

Although an explanation of why Georgescu-Roegen did not innovate a viable "bioeconomics" and follow out the logic of his inquiries to their bitter conclusions must, of necessity, have an exceedingly speculative character, one suspects that the impediment lay in his conception of the theory of value. Equivocation with respect to the theory of value inevitably dooms a research program in economics, and Georgescu-Roegen has equivocated in the deconstruction of the neoclassical theory of value. At one point in *The Entropy Law,* he wrote, "Apt though we are to lose sight of the fact, the primary objective of economic activity is the self-preservation of the human species" [Georgescu-Roegen 1971, p. 277]. While such bromides may make us feel warm and cozy, they do not represent a serious confrontation of the problem of value—and this is the case *even if that statement were true.* If the purpose of "the economy" really were the self-preservation of the species, then much economic activity would have to be written off as anomalous or perverse: a stance often adopted by Georgescu-Roegen in his more curmudgeonly moods. Elsewhere he wrote:

> Were we to set out the balance-sheet of value . . . we would arrive at the absurd conclusion that the value of the low entropy flow on which the maintenance of life itself depends is equal to the value of the flow of waste, that is, to zero. The apparent paradox vanishes when we acknowledge that the true "product" of economic processes is not a material *flow,* but a psychic *flux*—the enjoyment of life by every member of the population [Georgescu-Roegen 1971, p. 284].

Likewise, the postulation of the net product of economic life to be a "flux" reveals a weakness of the critical conception. Georgescu-Roegen's resort to the archaic physical terminology of fluxes only betrays an ambivalence about the serious use of the pleasure concept as a foundation for an *economic* theory of value. Fluxes have no clear analogical meaning, much less quantitative integrity. This is a mortal flaw because the theory of economic value must explain why prices are expressed as rational numbers, as well as why those prices assume the values they do.

Ultimately, Georgescu-Roegen has been unwilling to make a clean break with his erstwhile identity as a neoclassical economist in good standing; and it is this that explains the gaps and silences in his otherwise formidable works. His conviction that it is pleasure that makes the economic world go round has blocked him from extending his critical reflections upon science to the neoclassical utility concept. Alas, his instincts for the preservation of the neoclassical orthodoxy has prompted his vigorous attack of the neo-energetics movement, but blinded him to the very same dangers in his own backyard.

The Romanian Connection

There is one last tangential comment to be made with respect to the books under review. There exists the curious phenomenon of the extraordinarily high proportion of Romanians concerned with this literature. Georgescu-Roegen was himself born and educated in Romania; the authors of *Entropy and Bioeconomics* are likewise distinguished Romanian intellectuals; and one of the most staunch supporters of the neo-energetic position in the volume edited by van Gool and Bruggink, Professor Gheorghe, also hails from that Balkan nation. Could there be anything special about that nation that serves as such fertile soil for neo-energetic thought?

In an interview, Georgescu-Roegen offered one interpretation of the wellsprings of his inspiration:

> My line of thought was almost entirely guided by the events I had witnessed in many parts of the world, but especially in Romania, where I often contemplated how the tempestuous waters of the Olt were carrying away our tomorrow's bread and where the famous oil deposits in the Prahova valley had been almost depleted. The result was a synthesis in which the economic process appears as a continuation of biological evolution [Dragan and Demetrescu 1986, p. 146].

There is another, rather more prosaic, explanation of the larger phenomenon. It is a little-known fact that Romania has the distinction of being probably the only nation where neo-energeticists have managed to gain the ear of a powerful leader—in this case, Nicholas Ceausescu—who then proceeded to attempt to implement their theories, and in the process has nearly destroyed its economy. The blinkered fixation upon the depletion of energy stores within Romania, coupled with its political determination to buck the hegemony of the Comecon block in Eastern Europe, led its planners to embark upon a great push to become a major refiner of oil and a major coal producer, to the detriment of agriculture and consumer goods production. For instance, part of the plan of "Energy Independence" involved an agreement with the Shah of Iran to build oil refinery capacity and to re-export the refined products back to Iran. Just as Romania had constructed refinery capacity three times greater than domestic production requirements at great expense (financed by foreign borrowing), the Shah fell, and Romanians were left with a great white elephant [Anonymous 1986]. Likewise, coal production was pushed even though the low-grade ores found held little attraction for world markets.

The fruits of neo-energetics have fallen hard upon the Romanian population over the last decade. Embarrassed by the failure of these and other projects, and yet beholden to foreign lenders, the regime decided simply to squeeze the standard of living to pay off the external debt. To this day, the strongest lightbulb sold in Bucharest is 40 watts; it is illegal to use more than one lamp per room; TV programming is reduced to two hours per day; private cars are banned during the winter months; and horror stories of the dearth of heat in the winter abound. Although there certainly also are political causes, the Romanian predicament mainly stems from a peculiar conceptualization of the "fundamental determinants" of economic growth that themselves derive from neo-energetic doctrines. It is undoubtedly a heightened sensitivity to the pain and disruption caused by these doctrines that have prompted Romanians to be in the forefront of the reconsideration of energy economics.

Notes

1. "An informed sociologist of science would perhaps be able to explain why a paper concerning the essence of economic value found an enthusiastic reception in *Science*, a weekly devoted to the natural sciences, and also why the *American Economic Review* refused to publish a paper having to do with the refutation of that dogma" [Georgescu-Roegen in Baranzini and Scazzieri 1986, p. 271].
2. Even the valuable bibliography of Georgescu-Roegen's works appended to the Dragan and Demetrescu volume includes a mysterious book entitled "Bioeconomics" purportedly forthcoming from Princeton University Press, which has been promised in his writings for something approaching two decades [Dragan and Demetrescu 1986, pp. 215–24].
3. "Any system that involves a conservation principle (given means) and a maximization rule (optimal satisfaction) is a mechanical analogue" [Georgescu-Roegen 1971, p. 318]. This is one of the most profound observations in twentieth century economic theory. For an elaboration, see Mirowski [1988].

References

Adams, Richard. 1975. *Energy and Structure.* Austin: University of Texas Press.

______. 1982. *Paradoxical Harvest: Energy and Explanation in British History.* New York: Cambridge University Press.

Alier, J., and J. Naredo. 1982. "A Marxist Precursor of Energy Economics." *Journal of Peasant Studies* (9): 207–24.

Anonymous. 1986. "Birth and Death in Romania." *New York Review of Books,* 23 October: pp. 10–18.

Ayres, Robert. 1978. *Resources, Environment and Economics.* New York: Wiley.

Baranzini, M. and R. Scazzieri. 1986. *Foundations of Economics.* Oxford: Basil Blackwell.

Berndt, Ernst. 1978. "Aggregate Energy, Efficiency, and Productivity Measurement." *Annual Review of Energy* 9: 409–26.

______. "From Technocracy to Net Energy Analysis", in *Progress in Natural Resource Economics,* ed. Anthony Scott. Oxford: Clarendon Press.

Berndt, Ernst and D. Wood. 1979. "Engineering and Econometric Interpretations of Energy-Capital Complementary." *American Economic Review* 69: 342–54.

Berry, R., P. Saloman, and G. Heal. 1978. "On a Relation Between Economic and Thermodynamic Optima." *Resources and Energy* 1: 125–37.

Carver, T. 1924. *The Economy of Human Energy.* New York: Macmillan.

Cleveland, C., R. Costanza, A. Hall, and R. Kaufman. 1984. "Energy and the United States Economy." *Science* (225): 890--97.

Costanza, Robert. 1980. "Embodied Energy and Economic Valuation." *Science* (210): 1219–24.

Cottrell, Frederick. 1953. *Energy and Society.* New York: McGraw Hill.

Daly, Herman, and Alvaro Umaña. 1981. *Energy, Economics and the Environment.* Boulder: Westview.

Deltete, Robert. 1983. *The Energetics Controversy.* Ph.D. Thesis, Yale University.

Dragan, J.C., and M. Demetresu. 1986. *Entropy and Bioeconomics.*

Georgescu-Roegen, Nicholas. 1971. *The Entropy Law and the Economic Process.* Cambridge: Harvard University Press.

______. 1979. "Energy Analysis and Economic Valuation." *Southern Economic Journal* 45: 1023–58.

Gilliland, Martha. 1975. "Energy Analysis and Public Policy." *Science* (189): 1051–56.

Hannon, Bruce. 1973. "An Energy Standard of Value." *Annals of the American Academy of Political Science* (410): 139–53.

Huettner, David. 1976. "Net Energy Analysis: An Economic Assessment." *Science* (192): 101–4.

Kauffman, George, ed. 1986. *Frederick Soddy 1877–1956.* Boston: Reidel.

Layton, Edwin. 1971. *The Revolt of the Engineers.* Cleveland: Case Western Reserve University Press.

Lotka, Alfred. 1924. *Elements of Physical Biology.* New York: Dover.

Mehra, Jagdish. 1975. *The Solvay Conferences in Physics.* Boston: Reidel.

Mirowski, Philip. 1984. "Physics and the Marginalist Revolution." *Cambridge Journal of Economics* (December): 361–79.

______. 1988. *More Heat Than Light.* New York: Cambridge University Press.
O'Connor, Martin. 1986. "Theoretical Issues in Resource Depletion Policy." Discussion paper. University of Aukland.
Odum, E. 1971. *Fundamentals of Ecology.* Philadelphia: Saunders.
Odum, E., and H. Odum. 1976. *Energy Basis of Man and Nature.* New York: McGraw Hill.
Parsons, T., and B. Harrison. 1981. "Energy Utilization and Evaluation." *Journal of Social and Biological Structures* 4: 1–15.
Proops, John. 1983. "Organization and Dissipation in Economic Systems." *Journal of Social and Biological Structures* 6: 353–66.
Roberts, P. 1982. "Energy and Value." *Energy Policy* 10: 171–80.
Scott, Howard. 1933. *Introduction to Technocracy.* New York: John Day.
Sims, N.L. 1924. *Society and its Surplus.* New York: Viking.
Slesser, Malcolm. 1975. "Accounting for Energy." *Nature* (254): 170–72.
Soddy, Frederick. 1961. *Wealth, Virtual Wealth and Debt.* Hawthorne: Omni.
Stone, Mel. 1978. "Synthesizing Economics and Physics." *Speculations in Science and Technology* (1): 453–463.
van Gool, W. and J. Bruggink, eds. 1985. *Energy and Time in the Economic and Physical Sciences.* Amsterdam: North Holland.
Weber, Max. 1909. "Energetische Kulturtheoren." In *Gesammelte Aufsatze zur Wissenschaftlehre.* Tubingen: Mohr.
White, Cathy. 1980. "The Single Factor Theories of Marxism, Technocracy and Net Energy Analysis." Unpublished paper, University of British Columbia.
White, Lesley, 1943. "Energy and the Evolution of Culture." *American Anthropologist* 45: 335–56.
Winiarsky, Leon. 1967. *Essais sur la Mecanique Sociale.* Geneva: Droz.