way of knowing what is in them. But it does not follow that the end justifies the means in this case either.

To use the vernacular of judicial dissent, I would have thought that the one member of the United States Senate wearing the Conservative Party label would have been especially alert to the evil of expanding federal regulatory power beyond its constitutional bounds simply because the spending power opens the gate. I doubt if anyone would assert that the student records of local schools and colleges are within the reach of direct federal criminal law. Under the Buckley Amendment, however, we forfeit our federal support for research as well as students from the Office of Education if we do not comply with the regulatory requirements of access to student files imposed by legislation introduced by the Senator from New York.

A more highly particularized example of what some see happening was described this summer by John H. Bunzel, president of San Jose State University in a letter to his fellow presidents in the California state university and college system (CSUC). Bunzel said that federal auditors from HEW's San Francisco field office were demanding changes in San Jose's personnel and payroll practices to satisfy requirements for "effort reporting" on federal research projects. Bunzel predicted that the changes would affect the whole CSUC system and, in what to an outsider reads like a bureaucratic reductio ad absurdum, describes the auditors' demands as follows:

> In brief, they are demanding that effort expended on a Federal project be expressed as a percentage of a person's total effort, on a monthly after-the-fact basis, and that payment be made only for the certified percentage of effort, with an upper limit being the percentage budgeted. If, for instance, a faculty member works a 90 hour week, and is to be paid for 50% *of his effort* by Federal dollars, it is expected that 45 hours will be on the project. On the other hand, if he works only a 20 hour week, he is expected to spend 10 hours on the Federal project, and the pay is the same as it was for the 45 hour stint! (The auditors are reluctant to equate effort with hours, but there seems to be no other way to express it.)

It can be argued that the federal auditors and regulation writers are only doing their job carrying out the will of Congress. As it happens, the will of Congress is often imprecisely expressed in legislation, and by the time the law is transmuted into administrative regulations, the spirit and the letter have often parted company.

Nobody argues that colleges and universities should not be held strictly accountable for the federal funds they spend or should be exempt from social legislation. But institutions of higher education, increasingly, are being taxed and regulated like business and industry. They, however, cannot pass on the full costs to customers, with the result that their operating styles and values can be significantly affected.

The problems of the hidden costs of federal programs are beginning to receive attention in Washington. Congressional staff members say that only in the past year have the problems become definable "issues." Last fall, for example, the Senate Labor and Public Welfare Committee's subcommittee on education chaired by Senator Claiborne Pell (D–R.I.) heard from a panel of university presidents about the negative side of the federal impact on campus, but the presidents were unable to quantify their complaints. Legislators are expecting the witnesses from academe to come back with data to make their case more compelling. At Pell's behest, a bill is now being drafted which will address the matter of cost allowances to remunerate institutions for administering federal programs. And the House Appropriations Committee is looking again into the old issue of "cost sharing" on research projects, but there is no early prospect of relief. And the Big Brotherly implications which some see in federal regulatory activities have so far caused little alarm in Washington.

Of potential significance in the matter is the accession of David Mathews as HEW secretary. In his former post as president of the University of Alabama, he characterized federal regulations as threatening

> to bind the body of higher education in a Lilliputian nightmare of forms and formulas. The constraints emanate from various accrediting agencies, Federal bureaucracies, and state boards, but their effects are the same: a diminishing sense of able leadership on the campuses, a loss of institutional autonomy, and a serious threat to diversity, creativity, and reform. Most seriously, that injection of more regulations may even work against the accountability it seeks to foster, because it so dangerously diffuses responsibility.

Mathews will be reminded often of those words.—JOHN WALSH

Nicholas Georgescu-Roegen: Entropy the Measure of Economic Man

Nashville, Tennessee. Nashville styles itself the Athens of the South, and sports a perfect concrete replica of the Parthenon to establish the point. Another local temple, the Hall of Fame, attests to Nashville's position as the national focus of country music. Yet despite its 14 centers of higher learning, the city cannot even support a decent orchestra, grumbles Nicholas Georgescu-Roegen, a long-time resident who is professor of economics at Vanderbilt University.

Georgescu-Roegen, a Romanian by birth and a statistician by early training, is himself one of the ornaments of Nashville, though probably few of its citizens have ever heard of him. Only in the last few years has his name become known beyond the select fraternity of mathematical economists. There he has long been regarded as one of the specialty's pioneers. His colleagues consider his work to be Nobel prize material. Nobelist Paul Samuelson of the Massachusetts Institute of Technology, in the foreword to a collection of Georgescu-Roegen's essays, describes him as "a scholar's scholar, an economist's economist," a man whose ideas "will interest minds when today's skyscrapers have crumbled back to sand."

In the last few years Georgescu-Roegen has left the ivory tower altitudes of the pure theory of consumer choice and begun to adumbrate a theory of Malthusian comprehensiveness and all-but-Malthusian gloom. It implies, in brief, that unless man can reorient his technology and economy toward the energy that comes directly from the sun, his life as a species will be sharply limited by his "terrestrial dowry" of low entropy materials.

The theory has received less attention than it almost certainly merits. For one thing, Georgescu-Roegen believes that economic activity must not merely cease to grow, as the Club of Rome suggested in its *Limits to Growth*, but will eventually decline. Neither sentiment is at the pinnacle of economic intellectual fashion. For another, the full implications of the thesis have become apparent only within the last year. Its theoretical basis was laid out in 1971 in *The Entropy Law and the Economic Process*, a stimulating but difficult book which is probably more often praised than read. The practical consequences are described in "Energy and economic myths," a paper published this January in

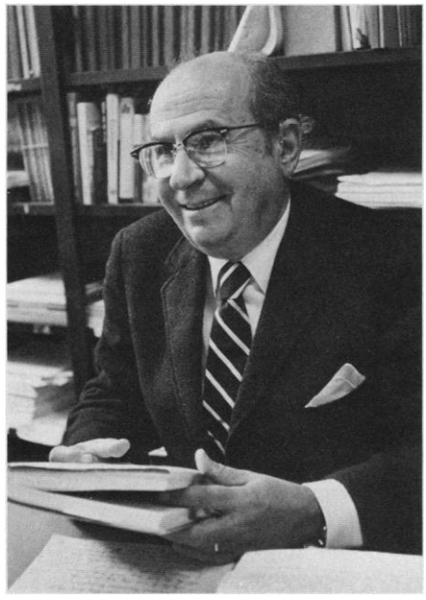
the *Southern Economic Journal*. The thesis has received resounding accolades from Georgescu-Roegen's intellectual allies, but has so far been largely ignored by orthodox economists. "The behavior of the economic growth people has been like the Sherlock Holmes case of the dog that barked in the night—strangely silent," comments Herman Daly of Louisiana State University. The thesis' claim to public attention, in other words, rests at present on its merits and on its author's formidable scholarly reputation, rather than on the unanimous plaudits of the economic profession.

The starting point of Georgescu-Roegen's theory is the entropy law, or second law of thermodynamics. The law is a broad, almost philosophical, concept which has had many formulations in its 110-year history. Central to all of them is the notion of irreversibility, that certain processes go in one direction only and can never be repeated except at far greater cost on the whole. A given lump of coal, for example, can be burned only once. There is of course the same amount of energy in the heat, smoke, and ashes as there was in the lump of coal (that is stipulated by the first law of thermodynamics governing the conservation of matter-energy), but the energy bound up in the combustion products is so dissipated that it is unavailable for use, unlike the "free" energy in the coal, and the process cannot be reversed.

Entropy is a measure of this bound or dissipated energy. The entropy law says that the entropy of a closed system always increases, the change being from free energy to bound, not the other way about. Entropy is also a measure of disorderliness (dissipated energy represents a more chaotic situation than that before the lump of coal was burned). So the entropy law is also saying that the natural state of things is to pass always from order to disorder. Whence the notion of entropy as time's arrow.

The idea of entropy as an index of disorder underlies the description of certain materials as possessing low entropy. An ingot of copper has low entropy because its atoms are disposed in a more orderly state than they were in the original copper ore. Did the refiner create low entropy in making the ingot? No, because in the smelting he engendered far more high entropy by converting free energy to bound. All man's activities, says the entropy law, end in deficit; you cannot get anything except at a far greater cost in low entropy.

There is one more tentacle of the entropy law to examine before considering how Georgescu-Roegen deploys it against the foundations of conventional economics. For a deep law of physics, the entropy law's distinction between free and bound, available and unavailable energy may



Nicholas Georgescu-Roegen

sound strangely anthropomorphic. And indeed it is anthropomorphic. A pure intellect would not comprehend the distinction: it would just see energy shifting about. The difference is important only to living organisms, because they exist on the slope between low entropy and high. They absorb low entropy by feeding, directly or indirectly, on sunlight, and they give out high entropy in the form of waste and heat.

All species depend on the sun as their ultimate source of low entropy except man, who has learned also to exploit the terrestrial stores of low entropy such as minerals and fossil fuels. Life feeds on low entropy; and so does economic life. Objects of economic value, such as fruit, cloth, china, lumber, and copper, are highly ordered, low entropy structures. For low entropy is the true taproot of economic scarcity.

What Georgescu-Roegen is saying is both profound and yet very simple. He asserts that the entropy law rules supreme over the economic process. The physics student who considers that an obvious truth should try looking for it in an economics textbook. He won't find it, because standard economists (says Georgescu-Roegen) assume a physical model of the world in which everything is perfectly reversible, in which after every disturbance the system comes back into equilibrium and all goes on as before. Standard economists teach that economics is a closed, circular process, an endless pendulum movement between production and consumption in which the exhaustibility of natural resources raises no problem, and the cure-all for pollution is simply to get prices right. Such conceptions are based on the mechanistic framework which economists borrowed long ago from physics, and which they have never revised to redress its basic omission, that of the law of entropy.

Once we recall that none of man's activities eludes the entropy law, the economic process appears in a very different light. For one thing, the process can now be recognized to be not circular and timeless, but irrevocable. It consists quintessentially of the continuous and irreversible transformation of low entropy into high. The basic inputs are drawn from the solar flow of low entropy and from the terrestrial stocks. The material output is high entropy in the form of pollution and dissipated matter and heat. The true—that is, the intended—output of the economic process is in fact an intangible: the enjoyment of life.

This is a radically different view of the economic process from that in the textbooks and, not surprisingly, it stresses different aspects. It places paramount emphasis on the inputs to the process (energy and natural resources) and on the output (pollution). Both are aspects which for long escaped serious attention, says Georgescu-Roegen, because of the propensity of standard economists (and of Marxists) to ignore the natural environment.

The economic process being by the entropy law irrevocable, Georgescu-Roegen is led also to stress its place in history, particularly the way in which the present pattern of economic activity will affect that of future generations. Because the terrestrial dowry of ordered material structures is finite, every Cadillac or every Zim we make today, let alone any instrument of war, "means fewer plowshares for future generations, and implicitly, fewer human beings too." Economic development, Georgescu-Roegen considers, "is definitely against the interest of the human species as a whole if its interest is to have a lifespan as long as is compatible with its dowry of low entropy."

Mechanized agriculture, including the Green Revolution, is also against the long-run interest of mankind, because of the vastly different abundances of solar and terrestrial low entropy. The earth's outstanding recoverable reserves of fossil fuel are estimated to be the equivalent of about 2 weeks' sunlight. Yet the modern method of agriculture replaces the water buffalo and its manure (both the product of solar energy, which is almost a free good) with the tractor and chemical fertilizer (both derived from terrestrial sources of low entropy). In doing so, it substitutes scarce elements for one that is abundant. This is why the Green Revolution, even though it is the only way to feed populations now, is in the long run such a bad deal for mankind.

Mechanized agriculture allows a larger population to survive now at the expense of a greater reduction in the amount of future life. What of the life-span of mankind as a species? If the worst befalls, when his terrestrial dowry is completely exhausted,

could not man revert to the cave and survive as once he did by berry picking? The thought ignores that, evolution being irrevocable, steps cannot be retraced in history. Mankind, Georgescu-Roegen believes, has become addicted to his "exosomatic" instruments, those organs which are part of his evolution but not part of his biological constitution. Man's exosomatic instruments, which economists call capital equipment, and which are the ultimate cause of the social conflict that distinguishes the human species (the advantage derived from their improvement became the basis of inequality between individuals and groups), are comforts that man will never give up.

How are we to preserve their share of the terrestrial dowry for future generations? "Standard" economists might suggest that the price mechanism will offset scarcities. But, says Georgescu-Roegen, prices are only a parochial expression of value unless everyone concerned can bid—and future generations are excluded from today's market, which is why oil, for example, still sells for the merest fraction of its true value. The only way to protect future generations from the present spasmic squandering of our energy bonanza is "by reeducating ourselves so as to feel some sympathy for our future fellow humans."

The monopoly of the present over future generations would be substantially reduced in an economy based primarily on the flow of solar energy. Such an economy would still need to tap the terrestrial dowry, especially for materials, and the depletion of these critical resources must therefore be rendered as small as possible. How is this to be accomplished? Georgescu-Roegen has proposed a "minimal bioeconomic program" which, though admittedly utopian, points in what he considers the right directions:

—Production of all instruments of war should be prohibited completely.

—With the productive forces thereby released, industrial nations should help the underdeveloped nations to arrive as quickly as possible at a good (but not luxurious) life.

—Mankind should gradually lower its population to a level that could be adequately fed only through organic agriculture, a burden that will fall most heavily on the underdeveloped nations.

—Until direct use of solar energy becomes a general convenience or controlled fusion is achieved, all waste of energy—by overheating, overcooling, overspeeding, and so forth—should be avoided, if necessary by regulation.

—Consumption for the sake of fashion, such as getting a new car each year, should be regarded as a bioeconomic crime; manufacturers should focus on durability, designing their products for long life and ease of repair.

"Will mankind listen to any program that implies a constriction of its addition to exosomatic comfort? Perhaps the destiny of man is to have a short, but fiery, exciting and extravagant life rather than a long, uneventful and vegetative existence. Let other species—the amoebas, for example—which have no spiritual ambitions, inherit an earth still bathed in plenty of sunshine."

Georgescu-Roegen's bioeconomic program, even if utopian, is a surprisingly practical platform for a man who has spent most of his academic life as a pure scholar. But Georgescu-Roegen has been through some very practical experiences. Born in Constanza, Romania, in 1906, he was turned toward mathematics by his father, a retired army officer. He won a government scholarship to study in Paris, and was advised to choose statistics, a specialty in short supply in Romania. His dissertation was on a method for discovering cycles in irregular phenomena. (He didn't apply it to business cycles, although that was the original inspiration, because of an intuition, which he later proved correct, that business cycles are not truly cyclical.) Georgescu-Roegen then studied in London under Karl Pearson, the founder of mathematical statistics, before returning to Romania where, at the age of 26, he obtained a professorial chair in statistics at Bucharest.

While in London he had applied for a Rockefeller fellowship to study with a program called the Harvard economic barometer. He took up the scholarship in 1934 only to discover on arrival that the barometer had perished long ago: it had issued, on the eve of the Black Tuesday that heralded the great stock exchange collapse, a public prediction that the economy was set fair. Instead, he studied with Joseph Schumpeter, the great economic theorist, and developed an interest in economics.

Despite Schumpeter's pleas, Georgescu-Roegen returned to Romania before World War II. He did statistical jobs for various ministries, acquired some reputation as an administrator, and after the war was appointed secretary-general of the armistice commission, the only Romanian

Briefing

NIH Institute Directors: One Gain, One Loss

The National Institutes of Health (NIH) has had its problems lately in recruiting people from the outside to take jobs as institute directors (*Science,* 3 October). The main impediment has been salary, which tops at $36,000 and is considerably less than senior medical people make in universities. But, where money is not an issue, the challenge of running an institute still has its appeal. No official announcement has been made yet, but next January David Scott, dean of the school of dentistry at Case-Western Reserve in Cleveland, will become director of the National Institute of Dental Research. Scott, whose research interests have been in crystallography and the ultrastructure of calcified tissues, spent 21 years at NIH as a commissioned officer in the Public Health Service before leaving for Cleveland in 1965. Now, he says, he would like to come back to Washington. Having worked both on the inside and on the outside of NIH, Scott is looking forward to the chance to tie his various experiences together. "I think it might be kind of fun. Good for me and good for them," he says. Scott's children are grown, and, even though he is taking a cut in pay to come back to NIH, Scott says that he is "fortunate that finances are not a big problem."

A couple of years ago, Norman Kretchmer said the same thing when he left a high-paying position as professor of pediatrics at Stanford to become director of the National Institute of Child Health and Human Development (NICHD). "I can live on $36,000 a year," he said when he arrived at NIH. Like Scott, he was not supporting a family of young college-bound children. What Kretchmer did not realize until recently was that he was giving up a lot in benefits as well as cash. This summer he was hospitalized for weeks after suffering a severe reaction to aspirin. He discovered that, had he been unable to return to work, he would have received very limited disability benefits because he had not been a federal employee for 5 years. One solution would have been to join the commissioned corps, where benefits are better, but for a number of reasons that was not possible in Kretchmer's case. He will resign as NICHD director, effective in about 8 months. After returning briefly to Stanford, he will move to New York as chairman of pediatrics at Mount Sinai.

—B.J.C.

authority the Russians would deal with. The period was not without strain. Requests that Russian soldiers would desist raping women and children were threateningly dismissed as insults to the honor of the Red Army; Georgescu-Roegen was powerless to complain when his own sister-in-law was killed trying to escape from Russian soldiers. He was also head of the Romanian delegation negotiating the payment of the crushing reparations demanded by the Russians—$300 million at 1938 prices. On the day fixed for signing the agreement, the Russians denounced the head of their own delegation as an impostor and the whole negotiation had to start over again.

Some months after these events, Georgescu-Roegen stowed away with his wife, Otilia, on a boat bound for Istanbul. He returned to Harvard, but the university could not immediately offer him a tenured position. At that stage, he wanted not to move again, and accepted a tenured post from Vanderbilt University. A symposium is being held there this month to mark his impending retirement after 27 years' service.

In conversation, Georgescu-Roegen speaks animatedly of his new theory and of the failure of the would-be critics among his colleagues to come out and debate with him. Asked the reason for his critics' muteness, he replies with a Romanian proverb—" 'Don't mention the cord in the house of the hanged.' " "I am very unpopular with economists," he says, comparing his attack on standard economics to the action of a man who confiscates marbles from children. "They will never forget that, but the next generation of economists will speak only my language."

Coming from a lesser man, the prediction might sound vainglorious. But Georgescu-Roegen inspires favorable reviews from independents and sky-high praise from those who agree with him. Economist Kenneth Boulding, in a review of *The Entropy Law and the Economic Process* (*Science*, 10 March 1972), wrote that the book had real defects but that "If . . . the right 500 people were to read it, science perhaps would never be quite the same again." Joseph J. Spengler of Duke University, a past president of the American Economic Association, believes that this and Georgescu-Roegen's earlier book "will come to be recognized as two of the greatest books we have had in the first three quarters of this century." According to Herman Daly, a proponent of the steady-state economy, Georgescu-Roegen's new thesis has not yet been fully digested but when it has been, "it will win him a place as one of the most important economists of our time. What he has done is to tie economics back to its biophysical foundations—it is that divorce that has led to many of our current problems such as pollution."

Alvin Weinberg, director of the Institute for Energy Analysis and a man whose outlook on energy might be expected to make him an opponent of Georgescu-Roegen's, describes him as a "highly original thinker" whose views people are now beginning to take more seriously. But Weinberg begs off detailed discussion of the thesis, saying he is not an economist. Similarly economist Paul Samuelson professes incompetence to judge Georgescu-Roegen's ideas on entropy, but adds that his tennis partner, a scientist, informs him they are essentially sound. Samuelson finds "everything he writes extremely stimulating," but notes that, as with Malthus, "there is not much refutable about 'Just-you-wait' statements."

Georgescu-Roegen is willing to put more urgency into his "just-you-wait statements" in conversation than he is in print. He regards man's present place in history as being near the end of an unrepeatable bonanza of cheap fuel. "When the bonanza disappears, we may get into the kind of experience similar to that of species like fish which find they have to adapt to living in shallower waters. But in our case it would be a political and sociological change, not a biological modification. Evolution, even exosomatic evolution, is not reversible—man would rather die in the penthouse than live in the cave."

Pressed to say how and when the crisis may come, Georgescu-Roegen replies, "For the near future, I don't know. But in 50 or 60 years the world might find itself in a half anarchic state. I am not saying there will not be a government in the United States. But the tendency for the state to become more and more important in the individual's life will reverse. People will live in isolation from the state. These hippies may be an avant-garde pre-adaptation. People would have to educate their children at home because there would not be enough taxes for schools. The population might have to go down, I don't know how—it might be from the disorganization in the means of communication or of hospital care."

Whether or not this verbal presentiment turns out to be accurate, Georgescu-Roegen's general theory is a powerful and ambitious synthesis that would seem to deserve more attention than has yet been its lot. Though some of his general conclusions have been touched on by others (notably by Kenneth Boulding in his 1966 essay "The economics of the coming spaceship earth"), Georgescu-Roegen has developed the scholarly underpinning of a broad theoretical framework. The theory offers potential support to many of the ideas of ecologists, environmentalists, advocates of zero population growth, opponents of economic growth, alternative technologists, and other critics of the established economic order. Here at least, if not also among "standard" economists, Georgescu-Roegen should find an increasing following.—NICHOLAS WADE

RESEARCH NEWS

New Materials: A Growing List of Nonmetallic Metals

Two years ago, scientists working in materials research were extremely excited by the announcement that a certain organic salt—which contains no metallic elements—showed signs of superconductivity. The conductivity of this particular salt, called TTF-TCNQ, increased as it was cooled below room temperature, until a very high value was reached at 58°K. A superconducting material at that temperature would have far outclassed the best of the "high temperature" superconducting metals which becomes lossless at 23°K.

The promise of superconductivity for TTF-TCNQ was never realized, but the material nevertheless enticed many researchers to study nonmetallic metals. The conduction properties of organic crystals were largely unknown at the time, and the novel behavior of TTF-TCNQ, plus the possibility of synthesizing many related salts by the techniques of organic chemistry, were more than enough to stimulate further research. That research has certainly borne fruit, as there are now nearly a dozen similar materials known. Besides being unusual for the fact that they are conducting at all, these materials behave like one-dimensional metals in that they conduct strongly in one direction but not in