



The Evolution of Georgescu-Roegen's Bioeconomics

John Gowdy and Susan Mesner
Rensselaer Polytechnic Institute

Abstract Georgescu-Roegen's work is usually divided into two categories, his earlier work on consumer and production theory and his later concern with entropy and bioeconomics beginning with his 1966 introductory essay to his collected theoretical papers published in the volume *Analytical Economics*. Most economists usually praise his earlier work on pure theory and ignore his later work which is highly critical of neoclassical economics. Those economists sympathetic to his later work usually take the position that he "saw the light" and gave up neoclassical theory some time in the 1960s to turn his attention to the issues of resource scarcity and social institutions. It is argued here that there is an unbroken path running from Georgescu's work in pure theory in the 1930s, 1940s, and 1950s, through his writings on peasant economies in the 1960s, leading to his preoccupation with entropy and bioeconomics in the last 25 years of his life. That common thread is his preoccupation with "valuation." The choices our species makes about resource use and the distribution of economic output depends upon our valuation framework. Georgescu-Roegen's work begins in the 1930s with a critical examination of the difficulties with the hedonistic valuation framework of neoclassical economics, moves in the 1960s to the conflict between social and hedonistic valuation, and culminates in the 1970s and 1980s with his examination of the conflict between individual, social, and environmental values. This paper traces the evolution of Georgescu-Roegen's thought about valuation and the environmental and social policy recommendations which arise out of his bioeconomic framework.

Keywords: agrarian economics, bioeconomics, entropy, Georgescu-Roegen, sustainability, utility theory, valuation

Only economists still put the cart before the horse by claiming that the growing turmoil of mankind can be eliminated if prices are right. The truth is that only if our values are right will prices also be so.

(Georgescu-Roegen 1976a: xix)

INTRODUCTION

Georgescu-Roegen's contribution to social economics was his development of a comprehensive theory of economy, society, and biophysical constraints. He called this new approach "bioeconomics" and published his most accessible statement of it in this *Review* (Georgescu-Roegen 1977). In that important paper he argued that the subject matter of economics was much broader than a description of market exchange and that the policy recommendations of economists were doomed to failure unless they were based upon an understanding of the biophysical and social context of consumption and production. The realization that resource constraints, social instability, and the social organization of economic activity are interrelated is now increasingly accepted (Dasgupta 1995; Gowdy and McDaniel 1995; Gurr 1985; Homer-Dixon 1991; Homer-Dixon, Bouthwell, and Rathjens 1993; Norgaard 1994), and it seems appropriate to revisit Georgescu-Roegen's neglected contribution to the debate.

Georgescu-Roegen's work is usually divided into two categories, his earlier work on consumer and production theory, and his concern with entropy and bioeconomics beginning with his 1966 introductory essay to a collection of his theoretical papers published in the volume *Analytical Economics* (Georgescu-Roegen 1966). Neoclassical economists praise his earlier work in utility and production theory but usually ignore his later contributions.¹ Those economists sympathetic to Georgescu-Roegen usually see his early work as being more or less mainstream, and claim that he turned away from standard theory some time in the 1960s (Seifert 1994; Zamagni 1987a). Although Georgescu-Roegen's research interests changed over time, we argue here that an unbroken path runs from Georgescu-Roegen's work in pure theory in the 1930s, 1940s, and 1950s, through his writings on peasant economies in the 1960s, leading to his preoccupation with entropy and bioeconomics in the last 25 years of his life. The theme that unites his early work on utility theory and production theory, his rejection of mechanistic economics in favor of one based on thermodynamics, and

1 The list of Georgescu-Roegen's contributions to economic theory is as tragic as it is remarkable. He was the first to postulate several major theorems in economics that are invariably attributed to others. In his 1936 paper in the *Quarterly Journal of Economics*, "The Pure Theory of Consumer's Behavior," he postulated the "principle of perseverance of nonpreference directions" upon which Paul Samuelson based his idea of revealed preference. The "non-substitution theorem" relating to Leontief's static system is usually attributed to Samuelson although Georgescu-Roegen (1950b) proposed it first. (Samuelson himself has always acknowledged Georgescu's priority.) Likewise the Hawkins-Simon condition was formulated first and in a more general way by Georgescu-Roegen (1950b). The continuity postulate, necessary for the existence of indifference curves, is attributed to Herman Wold, who formulated his version in papers published in 1943 and 1944, several years after Georgescu-Roegen's (1936b) *QJE* article.

finally his return to social economics in his later years, is his lifelong preoccupation with the nature of economic value. From his earliest published work in the 1930s until his death in 1994, Georgescu-Roegen insisted that descriptions of economic phenomena, especially mathematical descriptions, must go beyond relative market prices. They must be grounded in reality, that is, in the physical and social universe of which humans are embedded.

GEORGESCU'S STUDY ABROAD AND HIS WORK IN ROMANIA

Georgescu-Roegen was born in Constanța, Romania, in February, 1906. His mother came from a humble family and taught needlework in a trade school for girls. His father was an army officer who died when Nicholas was only seven years old. As a promising student in Romania, Georgescu-Roegen received an outstanding education in mathematics that paved the way for his later contributions in economic theory. Indeed, he points to a seminar on the singularities of differential equations at Bucharest University in 1926 as giving him the basis for one of his most important papers, "The Pure Theory of Consumer's Behavior" (Georgescu-Roegen 1936b), published ten years later (Georgescu-Roegen 1989a: 105).

Between 1927 and 1930 Georgescu-Roegen studied at the *Institut de Statistique* in Paris. His award-winning dissertation was "On the problem of finding out the cyclical components of a phenomenon" (Georgescu-Roegen 1930). His work in periodical phenomena in Paris convinced him that social phenomena could never be described by the mechanical methods of classical statistics. He took only two economics courses at the Sorbonne, but from those courses he reached the conclusion that "economic phenomena cannot be described by a mathematical system, a faith that I have never renounced" (Georgescu-Roegen 1992b: 181). During a stay in England while studying with Karl Pearson (1930–32), his work attracted the attention of economists at the Harvard Economic Barometer (probably due to the intervention of Pearson) and he received a Rockefeller Foundation Fellowship to work on this project.

Upon arriving in Cambridge, Massachusetts, in the fall of 1934, Georgescu-Roegen tried to locate the offices of the Harvard Economic Barometer only to learn that the project no longer existed (Georgescu-Roegen 1992a:130).² In desperation, he asked for an appointment with Joseph Schumpeter, who was working on his book *Business Cycles*. This fortuitous meeting led to Georgescu-

2 The Harvard Economic Barometer disappeared soon after the stock market crash of 1929 because it had made a rosy prediction of future economic growth just one week before Black Tuesday (Georgescu-Roegen 1989: 117; 1993a).

Roegen's becoming a member of one of the most remarkable collection of economists ever working at the same place. His colleagues and companions in many late-night discussions included Schumpeter, Wassily Leontief, Edgar Hoover, Frank Taussig, Oskar Lange, Fritz Machlup, Gerhard Tintner, Nicholas Kaldor, and Paul Sweezy, among others (Georgescu-Roegen 1989a).

This was a period of intense intellectual activity for Georgescu-Roegen and it was during this time that he became an economist. In Schumpeter he found a sympathetic mentor who shared his view that the most important changes in the economy are qualitative, not quantitative. His work at Harvard reinforced his belief that historical processes are unique and impossible to describe precisely by a mathematical formula (Georgescu-Roegen 1989a: 120). His year at Harvard was marked by the publication of four papers that laid the foundation for his theories of utility (Georgescu-Roegen 1935a; 1936a; 1936b) and production (Georgescu-Roegen 1935b).

Georgescu-Roegen's experiences in Romania in his childhood and his activity as a member of the Central Committee of the Romanian National Peasant Party after his return in the late 1930s also provided an intellectual and empirical foundation for his questioning of the adequacy of standard economic theory, whether of the neoclassical or Marxian variety. One of his earliest professional projects was his work on the economic contributions to the 1943 edition of *Romania's Encyclopedia*. The preface to "An Overview of the National Economy" reads:

The economic life is not only the endeavor of a people to gain the material means that are necessary for it, but its endeavor for the achievement of all the goods it uses in its life. Even the superior, selfless cultural achievements involve, beside the technical effort creating values, an economic activity by which these values are put at the disposal of those who use them . . .

the reader will learn the activity of the Romanian people meant to produce all the things it needs, from the closest to an earthly being: food, dwelling, dress, to the closest to a spiritual being: intellectual needs, comfort and luxury.

(quoted by Demetrescu 1994)

In this early work can be seen the kernel of Georgescu-Roegen's later approach to a theory of value; economic value is more than market exchange and more than mere material needs. In 1976, at the age of 70, he looked back to early experiences in Romania to find the roots of his dissatisfaction with traditional economics and his preoccupation with entropy and irreversible evolutionary change:

The idea that the economic process is not a mechanical analogue, but an entropic, unidirectional transformation began to turn over in my mind long ago, as I witnessed

the oil wells of the Ploesti field of both World Wars' fame becoming dry one by one and as I grew aware of the Romanian peasants' struggle against the deterioration of their farming soil by continuous use and by rains as well. However, it was the new representation of a process that enabled me to crystallize my thoughts in describing for the first time the economic process as the entropic transformation of valuable natural resources (low entropy) into valueless waste (high entropy). I may hasten to add ... that this is only the material side of the process. The true product of the economic process is an immaterial flux, the enjoyment of life, whose relation with the entropic transformation of matter-energy is still wrapped in mystery.

(Georgescu-Roegen 1976a: xiv)

According to Georgescu-Roegen himself (1992a: 146), his realization that the survival of humankind depends upon scarce resources came from two sources. The first was Emile Borel's monograph on statistical mechanics (the subject of Georgescu-Roegen's dissertation at the Sorbonne in 1930) and the second was his experiences in economic planning during his "Romanian exile" in the 1930s and 1940s.³ Georgescu-Roegen's first mention of entropic degradation, although he did not use that term, was in his dissertation on periodic phenomena where he noted the importance of the long-term loss of fertility of agricultural soil through leaching out by rainfall. His early training and practical experience led him to question from the outset monolithic theories of value.⁴

UTILITY THEORY

Georgescu-Roegen's shift from statistician to economist while at Harvard was a rapid one, and he wasted no time in tackling one of the most thorny analytical problems in economic theory with his customary lucidity and originality—that of utility theory. He would return repeatedly to the subject over the next 40 years, yielding critiques that were both mathematical and philosophical, both theoretical and practical. His articles on utility theory illustrate clearly his insistence that theory be grounded in reality. In his article on utility published in *The International Encyclopedia of Social Science*, he states: "The pragmatic reason why utility theory constitutes an important chapter of modern economics is that it greatly simplifies demand theory" (1968: 238), but he then goes on to demolish

3 In 1936 Schumpeter proposed to write a book on theoretical economics with Georgescu-Roegen and Georgescu was offered a position at Harvard. Despite pleas from Schumpeter he returned to Romania to "help his native land become a happier place for all" (Georgescu-Roegen 1992a: 132).

4 Georgescu has often been wrongly accused of holding an energy theory of value because of statements such as "entropy is the taproot of economic scarcity." In fact he consistently criticized energetic theories of value (Georgescu-Roegen 1971: 283; 1979). He has also been wrongly accused of being too neoclassical (Mirowski 1988) despite his consistent criticism of single-measure theories of value and utility.

much of the credibility of using utility theory as a link between the analysis of consumer behavior and observable reality (Maneschi and Zamagni 1997).

Critique of the Notion of Indifference

Fundamental to the theory of consumer choice is the notion of indifference, which is treated in the literature as a logical necessity on the grounds that there must be a region of indifference between preference and non-preference. In his 1936 article on consumer behavior, which Georgescu-Roegen considered one of his most important contributions to economic theory (1936b; 1989a: 123), he formulated the theory of directional choice and a special postulate (the continuity postulate) that he showed to be indispensable for the existence of indifference varieties. His surprising finding was that consumer choice does not necessarily display the attribute of transitivity. His analysis of preference directions resulted in several highly technical expositions on what is called the "integrability problem" of the utility function. He concluded that assumptions of utility maximization guided by the principle of instrumental rationality were untestable and, therefore, consumer theory was empirically unacceptable (Maneschi and Zamagni 1997; Georgescu-Roegen 1992a). Georgescu-Roegen (1936b) also showed that Pareto's theory of choice failed to include two essential axioms:

- 1 any commodity may be substituted for another so that two commodity baskets can be completely indifferent, and
- 2 binary choice is transitive (Georgescu-Roegen 1973).

Not surprisingly, his critique was virtually ignored by other economists, despite his important insight that the economic issue was not integrability but whether market data showed that binary choice is transitive. For him, the integrability controversy was another instance of confusing mathematical concepts with economic reality.

Criticism of the indifference postulate took other forms. The existence of a continuous, downward-sloping indifference curve in neoclassical theory rests on assumptions of a willingness to trade as well as substitutability in choice, but Georgescu-Roegen pointed to preference orderings that violated these assumptions, instead displaying the "principle of irreducibility," that is, lexicographic orderings. In his critique of the ordinal measurability of utility, he used Menger's hierarchy of needs as his point of departure, differentiating among biological, social, and personal wants. Biological and social wants, however, are irreducible: "He who does not have enough to eat cannot satisfy his hunger by wearing more shirts" (Georgescu-Roegen 1973: 457). Borne out by recent empirical work on the valuation of environmental goods (Spash and Hanley 1995; Stevens, More, and

Glass 1994), lexicographic preferences imply an unwillingness or inability to make tradeoffs between commodity bundles. He warned that preference orderings should not be taken as a measure—even an ordinal one—of these preferences, coining the term *ordinalist fallacy* to represent the failure to distinguish between comparability and measurability, and the mistaken belief that “where there is ‘more’ or ‘less’ there is also quantity” (Georgescu-Roegen 1971: 83).

Critique of Single-Value Measures

There is a further problem with the axiomatic basis of indifference curves, related to the existence of lexicographic preferences. Willingness to trade and perfect substitutability imply a single metric of utility whereby all objects of utility can be compared, that is, a commensurability of commodities, or wants, is required. In his early articles, and throughout much of his life’s work, he criticized the slavish devotion within the economics profession to a monistic scale of economic value.

Georgescu-Roegen pointed to difficulties even with the seemingly unassailable assumption that *commodities* are cardinally measurable, giving the examples of a stamp collection or vacation to show that in certain instances a commodity is *not* the sum of perfectly identical units. “The truly vulnerable assumption,” however, is “that utility, too, is cardinally measurable” (1973: 454). Without the property of cardinal measurability, utility (and in some cases commodities) cannot be summed, making a sham of the principle of decreasing marginal utility. Because money is the one economic unit that is always cardinally measurable, the “mapping” has gone from money to physical properties of commodities to utility. Neoclassical economists have reversed the process, claiming that causation runs from utility to commodities to money and concluding that money value is an accurate reflection of underlying marginal utility.

The Importance of Social and Historical Context

Georgescu-Roegen’s contributions in consumer theory offered considerably more than a better representation of an individual’s preferences. In addition to his emphasis on the qualitative aspects of preferences, he insisted that the role of time was essential in understanding consumption activity. He saw utility as being dependent not only on the length of time that a consumer expects a commodity to last but, more importantly, on the hysteresis effect. In “The Theory of Choice and the Constancy of Economic Laws” (1950a), he proposed the hereditary postulate, in which utility is dependent on past experience—the duration and intensity of past experience and the amount of time that has elapsed since the relevant experience took place (Gowdy 1993: 235). If an individual is choosing between two commodities, x and y , and C represents combinations of x and y in

which the individual is indifferent and S is the set of all combinations of these same two commodities that the consumer has experienced in the past, then at a given moment an individual's indifference varieties are represented by the equation $\varphi(C;S) = \text{constant}$. Georgescu was a great admirer of H. H. Gossen (1810–1858), an economist whose approach to utility theory he considered to be superior to the modern formulation. Georgescu considered Gossen's work to be a precursor to many of his own ideas, especially the importance of the time factor in establishing preference relations (Georgescu-Roegen 1968; 1983).

Georgescu-Roegen's early work on utility contained the major themes that were to characterize his more well-known criticisms of economics in his later work on entropy and bioeconomics. Primary among these is his insistence that economic theory be grounded in biophysical reality and his insistence that economic phenomena are dialectical, that is, they are characterized by qualitative distinctions that cannot be adequately described by purely mathematical formulations. Georgescu-Roegen's approach to the process of choice, stemming from a hierarchy of needs perspective, also led him to see the difference between "Economic Man" described by neoclassical theory and humans acting in a social context, which became further elaborated when he turned his attention to agrarianism.

AGRARIAN ECONOMICS

His publications on agrarian economics in the 1960s brought together his experiences in Romania, his early work on utility and production theory, and his longstanding emphasis on institutional and biophysical constraints on the economic process. It also signaled the beginning of a relentless epistemological critique on the limitations of economic science, which he would sustain for the remainder of his life. He defined agrarianism as "the economics of an overpopulated agricultural economy," and sought to point out errors in Marxian and neoclassical economic approaches, noting that they shared unacknowledged institutional biases. Although seemingly diametrically opposed to each other, both systems assume an exclusively urban, capitalistic, individualistic orientation marked by assumptions of profit maximization motive both in industry and agriculture, and characterized by underpopulation rather than overpopulation. His work came at a time when "economic development" was all the rage, a field later tarnished by failure to deliver on its promises and its more than occasional alliance with dictatorial regimes (Martinez-Alier 1996; Norgaard 1994). Though Georgescu-Roegen's two articles on agrarian economics (Georgescu-Roegen 1960; 1965a) laid the foundation for the emerging field of bioeconomics and ecological economics, his lucid and profound insights into developing agrarian economies have been sadly relegated to the dusty shelves of historical curiosity.

In his paper "Economic Theory and Agrarian Economics" (1960), Georgescu-Roegen reformulated his utility equation such that $\Omega = \psi(Y; Y_s)$, where Y_s represents the particular criteria by which the individual considers the welfare of his or her community. Utility to an individual in this construction is not only a function of the quantities of commodities in his or her possession (Y) but also of the distribution of commodities within the community (Y_s). "The individual . . . still reacts *hedonistically*—that is, as he desires—but not *strictly hedonistically*" (Georgescu-Roegen 1960: 129). Georgescu-Roegen stressed the crucial feature of the community's size in such a formulation, noting that only in a small community does an individual know the situation of all the others and understand that one's actions will influence his own utility indirectly, via the coordinate Y_s , as well as directly. Not surprisingly, individuals who also act as members of a social group with a unique history make different consumption decisions than individuals acting "strictly hedonistically." In a large community, the isolated actions of an individual exert virtually no influence upon the variable Y_s , and after a "prolonged eclipse of the social variable," it effectively drops out of the utility function.⁵ Georgescu-Roegen remarked on the similarity between the individual in these circumstances (*Homo capitalisticus*) and the individual producer in an atomistic industry, concluding that the success of neoclassical economic theory stems from the simplicity of this atomistic structure and the fact that successful applications of the theory have always concerned a capitalist economy.

The radical break with neoclassical theory embodied by a utility function of this basic form has led more than one economist to credit his 1960 agrarian economics article, and the one on peasant economics published five years later, as the "decisive break with standard neoclassical economics" (Seifert 1994). Yet, as we have seen, even in his earlier utility theory work he questioned the notion of indifference and the maximization principle, the difference between market behavior and social behavior, and the use of mathematical formulations not based on economic reality.⁶

5 One could argue, however, that appeals to volunteerism in the wake of the dismantling of welfare programs are basically an appeal to Y_s .

6 Georgescu-Roegen's bioeconomics sprang directly from his fundamental belief that theories should be grounded in everyday observations. This is made clear by a personal recollection from his time in his native Romania: "I happened once to visit a hilly village where some sociologist friends were engaged in field work. As it was in early spring when the greatest harm is done to the toilers of the soil by the rain torrents washing away the good soil, we spent some time talking about the economic consequences of that calamity. I walked away while that problem was still turning in my mind and, as I got on a bridge over the Olt, one of the biggest rivers of Romania, I just kept gazing at its waters of dark chocolate color furiously running toward their final destination. Out of that simple panorama a definite thought came to me: There goes, I said to myself, our daily bread of tomorrows! With a quick reminiscence of what I had learned from Borel's volume the scaffold of my bioeconomics appeared well sketched in my mind at that very moment" (Georgescu-Roegen 1989b: 5–6).

Rather than look at Georgescu-Roegen's work merely from the perspective of its relative adherence to neoclassical theory, it is perhaps more useful to see this period as reflecting "a fundamental change in [his] orientation as an economist" (Georgescu-Roegen 1976a: ix). He did not dramatically change his views on economic theory but perhaps he did change his view of his place in the economics profession. After years of attempting to change the profession from within he essentially gave up on the ability of the economics establishment to reform itself.⁷

Agrarianism and peasant economics were synonymous terms for Georgescu-Roegen. He maintained that it was the village community, not the individual, that "constitutes the analytical atom in the phenomenal domain of peasant sociology" because "a peasant village, as long as it remains peasant, is indivisible" (1965a: 205). He took pains to distinguish the peasant community from a civil society, emphasizing that the former is an indivisible social and economic whole characterized by interdependence and strong feelings of unity among its members. Standard notions of individuality are also swept away. Peasant communities, however, are not undifferentiated masses of people without any notion of personal worth or ambition, but they are individualistic only in the sense that no one in the community is a stranger, where "even the poorest fellow is *someone*, not a mere name or a number" (Georgescu-Roegen 1965a: 221).

The difficulty in constructing an analytical framework stems from several features of the peasant village. First is its tremendous variability in social forms. Georgescu-Roegen notes the evolutionary aspects of village institutions, but rejects the possibility of developing a village taxonomy due to the much greater flexibility in evolving social forms than biological forms. The analytical challenge stems not only from the diversity of forms but also because "evolution is subject to pure uncertainty" (Georgescu-Roegen 1960: 135). Second, the choice function of the peasant— $\Omega = \psi(Y; Y_s)$ —as first formulated by Georgescu-Roegen in his 1960 paper, represents the condition of reciprocity between village institutions and individual behavior. But in a warning that anticipates his new epistemology,

7 After a series of professional incidents in which his work was treated cavalierly and even with disrespect (described in Georgescu-Roegen 1992a), and after some particularly questionable articles were published in *The American Economic Review*, Georgescu-Roegen resigned from the American Economic Association. "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 1992a: 156). One wonders if the neoclassical economists who praised Georgescu's contributions to mathematical economics recognized the radical critique of economic theory they contained (Mayumi 1995).

he emphasizes that such a formula is merely a simile and should not be thought to quantify behavior that is more strongly influenced by cultural values than economic coordinates. "Nothing justifies the hope of constructing a strictly quantitative model of the traditional type for the village economy," and, in fact, "the use of the standard analytical tools, which have been designed for handling the isolated parts of the civil society, can only result in the destruction of the very phenomenon one wants to study" (Georgescu-Roegen 1965a: 223). In a finding that further undermines the universality of economic theory, he points to the role of tradition, especially oral tradition, in providing the continuity and stability of peasant communities, and draws the conclusion that adherence to tradition often produces economic results that violate the principle of product or utility maximization. He stresses the foolishness of pursuing profit maximization in an overpopulated economy (where $MP_L = 0$) because it would merely increase unemployment while decreasing the national product.

A third feature of peasant villages that complicates the task of formal analysis has to do with property rights and the distribution of income from production. Georgescu-Roegen separates the notion of *property*, as being equated with the rights of ownership, from the practice in peasant communities of exclusive right to use a piece of land that one has worked to clear. This "exclusive right" extended only to the fruits produced by one's labor; the windfalls belonged to all. Coupled with the institutions of common-use lands and waters and the periodic redistribution of land, Georgescu-Roegen asserts that "the institutions of peasant communities have never sought to control the 'fund' factors of the economy (land) but the 'flows' factors (the incomes from land)" (1965a: 209).

Although Georgescu-Roegen was genuinely interested in underdeveloped and overpopulated agrarian economies, and made significant contributions to a broader understanding of those economies, these two works also served as the ideal vehicle to expose some of his most significant insights and a prelude to his work on bioeconomics. In examining agrarian life, Georgescu-Roegen emphasized the peasant's obvious dependence on biological and seasonal cycles, which he was quick to point out did not lend themselves to economic theories derived from a mechanical analog. At this point he felt justified in pronouncing that "the biological has burst through its economic shell" (1965a: 226). The impact of biological processes on economic activity is not confined to peasant societies, however. Invoking the Second Law of Thermodynamics, Georgescu-Roegen incorporates the idea of entropic degradation as a fundamental constraint on *all* economic activity. He further delineates economic drawdowns of low entropy into a mining of *stocks* and the husbandry of *flows*, which laid the groundwork for his monumental book *The Entropy Law and the Economic Process*, published in 1971. The unmistakable message to economists was the necessity of recognizing



humans as a biological species bound by biophysical processes and as social beings shaped by institutional patterns.

Again, a close reading of Georgescu's work shows that his publications on agrarian economics in the 1960s had their roots much earlier, in the conditions in his native Romania and in his lifelong conviction that economic theory should be based on reality not on purely mathematical axioms. In fact, his 1960 paper in the journal *Oxford Economic Papers* was first presented at a symposium at the University of Chicago in 1948, shortly after his return from his 12-year hiatus in Romania (Georgescu-Roegen 1992a: 156). Because of the cool reception to this paper he did not submit it for publication until invited to do so by the editor of *Oxford Economic Papers* twelve years later (Georgescu-Roegen 1992b: 184). By his own account, the economics profession never forgave him for committing two cardinal sins in this paper: contending that marginal cost pricing is inappropriate for an overpopulated agrarian economy and pointing out that the Arrow-Debreu proof of Walrasian general equilibrium is based on an absurd assumption, namely that every individual has a sufficient lifetime income.

ENTROPY AND BIOECONOMICS: LINKING ENVIRONMENT, INSTITUTIONS, AND PRODUCTION

Georgescu-Roegen is best known for his use of the Entropy Law, the Second Law of Thermodynamics, as a metaphor for economic activity. He described the Entropy Law as "the most economic in nature of all natural laws" and "the taproot of economic scarcity." Several features of thermodynamics—qualitative change, irreversibility, indeterminateness, true scarcity—stand in stark opposition to the mechanical model of the economic process, producing a radically different picture of economic activity than the common circular diagram where there is no impact on external systems or resources (Georgescu-Roegen 1965b). He emphasized the fact that we, like all biological creatures, depend on energy available in usable form (the distinction between free or available energy, and bound or unavailable energy is crucial and one he made repeatedly). Entropy measures a system's unavailable energy, and humankind has the distinction of currently being the most significant contributor to entropic degradation by the increasing rates of extraction of natural resources and elimination of wastes into the environment.

A paper he presented at a conference of the International Economic Association in 1965, entitled "Process in Farming Versus Process in Manufacturing: A Problem of Balanced Development," provided a critical link between his work on agrarian economics and development on the one hand and production processes and entropy on the other. It stands as a major contribution to the theory of production, marked by the same penetrating analysis that Georgescu-Roegen had brought to consumer

theory thirty years earlier. Beginning with a critique of the neoclassical production function, in which he attacks the economist's exclusive reliance on mathematical formalism while ignoring the "empirical scaffold of the production function"⁸ (1965b: 73), Georgescu-Roegen goes on to distinguish between *stock* and *fund* and *flow* and *service*, an analytical framework which he expanded in *The Entropy Law and the Economic Process* (1971).⁹ Fund elements are those productive agents unchanged in the process, that is, inputs that enter and exit in a form that is economically the same (e.g. labor). Flow elements are those inputs changed by fund agents into productive output, which is the focus of economic inquiry. The former represents the material base of the production process and the latter the transformation achieved with the services of this base. Although the distinctions can be sharply drawn, Georgescu-Roegen was quick to point out that the analytical boundaries could render a commodity a flow in one process and a fund in another. (His example was clover seed, which is a fund in a process of producing clover seed but is a flow in a process of producing clover fodder.)

A stock is a type of productive input that may be used to generate flows at any given rate. For example, we may burn a ton of coal a day for 30 days, or we may burn the entire 30 tons in one day to produce the same total quantity of heat. A fund, on the other hand, may be used to generate services only at a limited rate. An individual laborer may dig one ditch a day for a month, but cannot dig 30 ditches in one day. The water filtering capacity of a wetland decreases if the amount of water flow exceeds some maximum rate. A stock is capable of producing a physical *flow* at any desired rate, but a fund is capable of producing a *service* only at a limited rate. It is limited by the time dimension as well as by biophysical and institutional contexts. Funds are the "agents of production" that transform the flow of natural resources into a flow of economically valuable products (Daly 1995: 153; De Gleria 1995). Funds must be maintained by the sustaining functions which support labor power, all capital, and Ricardian land. For example, a tired worker at the end of the working day must be refreshed by the sustaining functions of the household before she reenters the production process the next day.

8 Georgescu-Roegen did not reject abstraction, or even formalism, in economic theory: "Let me hasten to add that the usual denunciation of standard economics on the sole ground that it treats of 'imaginary individuals coming to imaginary markets with ready-made scales of bid and offer prices' is patently inept . . . In the social sciences, as Marx forcefully argued, it is all the more indispensable since there 'the force of abstraction' must compensate for the impossibility of using microscopes or chemical reactions. However, the task of science is not to climb up the easiest ladder and remain there forever distilling and redistilling the same pure stuff" (Georgescu-Roegen 1971: 319).

9 For a concise and accessible discussion of Georgescu's model of production see Zamagni (1987b).

In Georgescu-Roegen's model of production, he examined how fund factors are employed in light of the economist's analytical tool of the partial process (1965b). The factory system, which is able to combine a number of partial processes in such a way that no fund factor is idle, stands as one of the greatest economic innovations in history, according to Georgescu-Roegen, but he warns that the system is not suitable for all production sectors and for some processes, such as agriculture in temperate climates, idleness of funds will remain a fact of life. Although all production processes do not obey the same economic laws, all economic processes, like biological processes, are subject to the Entropy Law.

In the 1970s, Georgescu-Roegen coined the term *bioeconomics* for a new approach in economics: "The term is intended to make us bear in mind continuously the biological origin of the economic process and thus spotlight the problem of mankind's existence with a limited store of *accessible* resources, unevenly located and unequally appropriated" (1977: 361). His shift to bioeconomics, the last major stage of his life's work, built on past work but it is here that he most thoroughly integrated the environmental and social components of human economic activity in the developed economies. Borrowing from the biologist Alfred Lotka, he adopted the terminology of *exosomatic* organs to designate the seemingly endless variety of "detachable limbs" humans have invented to extend the range and scope of their activity. He ascribes much of the current mess we find ourselves in—widespread ecological devastation and "malignant inequalities"—to the course of exosomatic evolution. Humankind's long history of utilizing these "exosomatic organs" has created an "addiction" to the comfort and pleasure they provide. The difficulty arises because their production is dependent on finite stocks of available energy and matter, bringing our species' obsession with more and better "things" on a collision course with unavoidable biophysical limits.

A second feature of exosomatic evolution is the presence of social conflict. Georgescu-Roegen saw the division into social classes as a function of a production process that divides people into "governors" and "governees" and a distribution process where benefits from the production and use of these "exosomatic organs" falls along the same lines. He takes aim at economists for looking at market equilibrium only mathematically: "we have missed the essential part, namely, that the Walrasian equilibrium presupposes the existence of an initial income distribution and that this distribution is determined by the division into social classes" (1977: 367).

Georgescu-Roegen's integration of economics, institutions, and biophysical reality culminated in his model of the productive process first presented in 1965 and later elaborated in *The Entropy Law and the Economic Process* and subsequent writings (Georgescu-Roegen 1984). In his model of production he defined a technology as *viable* if and only if it can maintain the corresponding

material structure which supports its resource flows and sustaining functions, and can consequently support the human species indefinitely under current environmental conditions. Viability requires then that funds should be unchanged in the production process. Without the sustaining functions which maintain the funds, the ability of the economic process to produce flows cannot be maintained (Gowdy and O'Hara 1997). According to Georgescu-Roegen's definition of viability, funds should be unchanged in a viable production process.

According to Georgescu-Roegen, the sustainability of any subsystem should be judged on the sustainability of the entire system containing it, not just part of it. Without maintaining the sustaining functions of the fund elements, an economic process cannot continue to produce economic flows through time (Gowdy and O'Hara 1997). This is why Georgescu-Roegen always insisted that time must be a parameter in any production function. The length of the time period considered is rarely made explicit in discussions of sustainability but it is *the* critical point. Georgescu-Roegen writes:

Perhaps the earth can support even forty-five billion people, but certainly not ad infinitum. We should therefore ask "*how long* can the earth maintain a population of forty-five billion people?" And if the answer is, say, one thousand years, we still have to ask "*what will happen thereafter?*"

(Georgescu-Roegen 1971: 20)

The concept of viability is the basis for Georgescu-Roegen's bioeconomic program. Viability implies that

- 1 a technology is not viable unless it can support itself without drawing down irreplaceable stocks, and that
- 2 a technology is not viable if it impairs the ability of the fund factors to maintain the economic process.

The concept of viability contains the major themes Georgescu stressed throughout his life: time, context, and the nature of economic value.

GEORGESCU-ROEGEN'S BIOECONOMIC PROGRAM

The public policy recommendations that flowed from his bioeconomic approach are often dismissed as unrealistic and unwarranted, further proof that the "dismal science" has not yet escaped Carlyle's epithet. Georgescu-Roegen was unequivocal in asserting that residents of "developed" nations must accept a lower standard of living if "underdeveloped" countries are ever to escape poverty. Due to rapidly increasing population, the uneven distribution of national populations and natural resources around the world, and the monopsonistic-type power

exercised by the developed nations over world resources, he saw little alternative but a declining economy in some parts of the world so that the poorer nations could reach a "modest" level of development that would perforce become the standard for all. Ultimately, he envisioned the necessity of shifting the world's economy from one based on stocks to one based on the flow of solar energy. His "minimal bioeconomic program" (Georgescu-Roegen 1976b: 33–34) offered eight concrete recommendations to move human society in the right direction:

- 1 the complete prohibition of weapons production, thereby releasing productive forces for more constructive purposes;
- 2 immediate aid to underdeveloped nations;
- 3 gradual decrease in population to a level that could be maintained only by organic agriculture;
- 4 avoidance, and strict regulation if necessary, of wasteful energy use;
- 5 abandon our attachment to "extravagant gadgetry";
- 6 "get rid of fashion";
- 7 make goods more durable and repairable; and
- 8 cure ourselves of workaholic habits by rebalancing the time spent on work and leisure, a shift that will become incumbent as the effects of the other changes make themselves felt.

Despite the desirability and common-sense appeal of many of these recommendations, even his most ardent supporters blanch at the political and social obstacles to such radical change. Georgescu-Roegen himself used to joke about driving a "two-garage car," proof enough that the gulf between what we ought to do and what most of us actually do is wide indeed. And in fact he was sometimes skeptical of humankind's acceptance of any program that called for a reduction in material 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 1976b: 35)¹⁰

10 This quote has an important insight that many environmentalists do not grasp. No matter what humans do we will not "destroy the environment." The Earth has been through much worse than even the most pessimistic scenarios of global warming or biodiversity loss. Planet Earth has done quite well without humans for most of its existence and will do quite well after we're gone. The reason we should protect the environment is to protect ourselves. Stephen Jay Gould (1990: 30) writes with his usual eloquence on this point: "I suggest that we execute a pact with our planet. She holds all the cards and has immense power over us—so such a compact, which we desperately need but she does not at her own time scale, would be a blessing for us, and an indulgence for her. We had better sign the papers while she is willing to make a deal. If we treat her nicely, she will keep us going for a while. If we scratch her, she will bleed, kick us out, bandage up, and go about her business at her planetary scale."

At the core of the bioeconomic approach is a call for a change in values, where decisions are made based on the idea that the earth's supply of available matter and energy is humankind's dowry and should be conserved to the greatest extent possible for future generations. The implications are biological, economic, and political. Georgescu-Roegen called for the principle of discounting and maximizing utility to be abandoned in favor of the more sensible principle of minimizing regrets (1977).

Any individual must certainly discount the future for the indisputable reason that, being mortal, he stands a chance of dying any day. But a nation, let alone the whole of mankind, cannot behave on the idea that it might die tomorrow. They behave as if they are immortal and, hence, value future welfare situations without discounting. Of course, if the discount rate is zero, Hotelling's beautiful mathematical construction collapses. But that does not mean that a program that tends to treat all generations on virtually the same footing is senseless.

(Georgescu-Roegen 1986: 13)

Daly and Cobb refer to the practice of discounting as belonging to *chrematistics*, a word they define as "the branch of political economy relating to the manipulation of property and wealth so as to maximize short-term monetary exchange value to the owner" (Daly and Cobb 1989: 138). The subject matter of neoclassical economics has been reduced to chrematistics, as value has become synonymous with exchange value and the maximization principle equated with rationality.

One outcome of the debates over some of the major environmental issues facing our species, such as biodiversity loss and global warming, has been to expose the shortcomings of policies based on neoclassical economic theory, that is, on the narrow self-interests of isolated individuals living at a specific point in time. Assumptions about human nature underlying neoclassical utility theory were once the subject of lively debate within the economics profession. This debate has been resurrected in recent years by a number of economists and philosophers who have challenged the notion of individual rationality which lies at the base of neoclassical utility theory (Bromley 1990; Daly and Cobb 1989; Gowdy 1997; O'Neill 1993; Sagoff 1994; Sen 1977). This debate can be enriched by building on the contributions of Georgescu-Roegen.¹¹

¹¹ One reviewer asked perceptively how Georgescu-Roegen's ideas could be made more accessible. How could an introductory economics text be written from a bioeconomic viewpoint? First and foremost such a text should stress economics in context. It should begin with a history of the human species stressing the point that the market system described by modern economic theory is quite new and quite unusual. The division between micro and macro economics could be kept with a third major section focusing on the social context of micro and macro behavior. Microeconomics would include discussion of different categories of value other than market value (for an attempt to

The nature of value and the role of time are recurring themes in Georgescu-Roegen's work, consistently placing him outside the static, strictly quantitative and monistic approach of neoclassical economics. And his heretical insistence that markets, societies, and ecosystems all share a common dependence on energy and the relentless laws of thermodynamics led him to the unpopular conclusion that modern human society is not sustainable. Shunning even the alternative visions of steady state, appropriate technology, "small is beautiful," and sustainable development as so much "snake oil" (Georgescu-Roegen 1993b; 1993c), he stubbornly refused to tailor his message for a population infatuated with slogans and sound bites. For Georgescu-Roegen, a realistic view of the entropic nature of existence translated simply into a wise use of resources; by squandering resources needlessly and carelessly, we reduce future choices, shortening the timespan of our species. "In the past we went from 'Thou shalt not kill' to 'Thou shalt love thy neighbor as thyself.' The time calls for a new commandment: 'Thou shalt love thy species as thyself'" (1977: 374). If our species is to have a long future our value system must go well beyond market valuation and even beyond the traditional human community values of concern to social economics. A "viable" value system must take into account the finiteness of our unique planet, our dependence upon the web of life which surrounds us, and the fragility of our species at this remarkable moment in time.

In a context of increasing income disparity amidst continual reassurance of the potential for unlimited economic growth, Georgescu-Roegen's call for reducing material living standards has little popular appeal. The now substantial body of literature on sustainable development underscores the political difficulty of this position. Document after document on sustainability, typified by the Brundtland report (Brundtland Commission 1987), begins with a sobering description of what human activity has done to the planet only to end with a call for more economic growth to bring us to environmental sustainability. Georgescu-Roegen's position may be unpalatable, but to sugarcoat his message is not only to do an injustice to him but to continue to avoid discussing the tough choices we now face.

do this see Gowdy and O'Hara 1995) and include discussion of the institutional and biophysical foundations of production (see Zamagni 1987b). Macroeconomics would stress the biophysical limits to economic activities, and especially, the issue of growth and scale (see Daly 1991). The key issue here, we believe, is the lack of sympathy to these ideas on the part of most teachers of economics. A broader training of economic students in the biophysical sciences, philosophy and ethics would perhaps force a change in the way economics is presented in textbooks.

REFERENCES

- Bromley, D. (1990) "The Ideology of Efficiency: Searching for a Theory of Policy Analysis," *Journal of Environmental Economics and Management* 19: 86–107.
- Brundtland Commission (WCED) (1987) *Our Common Future*, Oxford: Oxford University Press.
- Daly, H. (1991) "Towards an Environmental Macroeconomics," *Land Economics*, 67: 255–259.
- (1995) "On Nicholas Georgescu-Roegen's Contribution to Economics: An Obituary Essay," *Ecological Economics* 13: 149–154.
- Daly, H. and Cobb, J., Jr. (1989) *For the Common Good*, Boston: Beacon Press.
- Dasgupta, P. (1995) *An Inquiry into Well-Being and Destitution*, New York: Oxford.
- De Gleria, S. (1995) "Nicholas Georgescu-Roegen: A Mind that Thought Above His Time," *Economica Internazionale* XLVII, 3: 3–32.
- Demetrescu, M. C. (1994) "The Scientific Activity of Nicholas Georgescu-Roegen in Romania," Presented at the Second Conference of the European Association for Bioeconomic Studies, Mallorca, Spain.
- Georgescu-Roegen, N. (1930) "Le Probleme de la Recherche des Composantes Cycliques d'un Phénomène" (dissertation), *Journal de la Société de Statistique de Paris*, October: 5–52.
- (1935a) "Note on a Proposition of Pareto," *Quarterly Journal of Economics* 49: 706–714.
- (1935b) "Fixed Coefficients of Production and the Marginal Productivity Theory," *Review of Economic Studies* XX, October: 40–49.
- (1936a) "Marginal Utility of Money and Elasticities of Demand," *Quarterly Journal of Economics* 50, May: 533–539.
- (1936b) "The Pure Theory of Consumer's Behavior," *Quarterly Journal of Economics* 50, August: 545–593.
- (1950a) "The Theory of Choice and the Constancy of Economic Laws," *Quarterly Journal of Economics* 64, February: 125–138.
- (1950b) "Leontief's System in the Light of Recent Results," *Review of Economics and Statistics* 32: 214–222.
- (1960) "Economic Theory and Agrarian Economics," *Oxford Economic Papers*, N.S. 28, February, 1–40. Reprinted in *Energy and Economic Myths*, New York: Pergamon Press, 1976. The page numbers in text refer to the 1976 reprint.
- (1965a) "The Institutional Aspects of Peasant Economies: A Historical and Analytical Review," paper presented at the A/D/C Seminar on Subsistence and Peasant Economies, February 28–March 6, East-West Center, Honolulu, Hawaii. A shorter version of this paper was reprinted in *Energy and Economic Myths*, New York: Pergamon Press, 1976. The page numbers in the text refer to the reprinted version.
- (1965b) "Process in Farming Versus Process in Manufacturing: A Problem of Balanced Development," in U. Papi and C. Nunn, (eds.) *Economic Problems of Agriculture in Industrial Societies*, London: MacMillan, reprinted in *Energy and Economic Myths*, New York: Pergamon Press, 1976.
- (1966) *Analytical Economics*, Cambridge, MA: Harvard University Press.
- (1968) "Utility," in *The International Encyclopedia of the Social Sciences*, Vol. XVI, New York: Macmillan, 236–267.

- (1971) *The Entropy Law and the Economic Process*, Cambridge, MA: Harvard University Press.
- (1973) "Utility and Value in Economic Thought," *Dictionary of the History of Ideas*, New York: Scribner's, Vol. IV, 450–458.
- (1976a) "Foreword," *Energy and Economic Myths*, New York: Pergamon Press, ix–xxvi.
- (1976b) "Energy and Economic Myths," *Energy and Economic Myths*, New York: Pergamon Press, 3–36.
- (1977) "Inequality, Limits and Growth from a Bioeconomic Viewpoint," *Review of Social Economy* XXXV, 3: 361–375.
- (1979) "Energy Analysis and Economic Valuation," *Southern Economic Journal* 45: 1023–1058.
- (1983) "Hermann Heinrich Gossens: His Life and Work in Historical Perspective," Introduction to Hermann Heinrich Gossens, *The Laws of Human Relations and the Rules of Human Actions Derived Therefrom*, R.C. Blitz (translator), Cambridge, MA: MIT Press.
- (1984) "Feasible Recipes Versus Viable Technologies," *Atlantic Economic Journal* XII, March, 21–31.
- (1986) "The Entropy Law and the Economic Process in Retrospect," *Eastern Economic Journal* XII: 3–25.
- (1989a) "An Emigrant from a Developing Country: Autobiographical Notes I," in J. A. Kregel (ed.) *Reflections of Eminent Economists*, New York: Macmillan.
- (1989b) "Quo Vadis Homo sapiens sapiens," Mimeo. Georgescu-Roegen Collection, Special Collections Library, Duke University.
- (1992a) "Nicholas Georgescu-Roegen About Himself," in Michael Szenberg (ed.) *Eminent Economists and Their Life Philosophies*, Cambridge: Cambridge University Press: 128–160.
- (1992b) "Nicholas Georgescu-Roegen," in Philip Arestis and Malcolm Sawyer (eds.) *A Biographical Dictionary of Dissenting Economists*, London: Edward Elgar, 179–187.
- (1993a) "An Emigrant from a Developing Country: Autobiographical Notes – II," *BNL Quarterly Review*, 184, March: 3–30.
- (1993b) "Thermodynamics and We the Humans," in Juan Martinez-Alier and Eberhard Seifert (eds.) *Entropy and Bioeconomics*, Milan: Nagard, 184–201.
- (1993c) "Looking Back," in Juan Martinez-Alier and Eberhard Seifert (eds.) *Entropy and Bioeconomics*, Milan: Nagard, 11–21.
- Gould, S. J. (1990) "The Golden Rule—A Proper Scale for Our Environmental Crisis," *Natural History*, September: 24–30.
- Gowdy, J. (1993) "Georgescu-Roegen's Utility Theory Applied to Environmental Economics," in Juan Martinez-Alier and Eberhard Seifert (eds.) *Entropy and Bioeconomics*, Milan: Nagard: 230–240.
- (1997) "The Value of Biodiversity: Markets, Society, and Ecosystems," *Land Economics* 73: 25–41.
- Gowdy, J. and McDaniel, C. (1995) "One World, One Experiment: Addressing the Biodiversity–Economics Conflict," *Ecological Economics* 15: 181–192.
- Gowdy, J. and O'Hara, S. (1995) *Economic Theory for Environmentalists*, Delray Beach, FL: St. Lucie Press.

- (1997) "Weak Sustainability and Viable Technologies," *Ecological Economics*, 22: 239–247.
- Gurr, T. (1985) "On the Political Consequences of Scarcity and Economic Decline," *International Studies Quarterly*, 29: 51–75.
- Homer-Dixon, T. (1991) "On the Threshold: Environmental Changes as Causes of Acute Conflict," *International Security*, 16: 76–116.
- Homer-Dixon, T., Boutwell, J. and Rathjens, G. (1993) "Environmental Change and Violent Conflict," *Scientific American* 268: 38–45.
- Maneschi, A. and Zamagni, S. (1997) "Nicholas Georgescu-Roegen, 1906–1994," *Economic Journal* 107: 695–707.
- Martinez-Alier, J. (1996) "Some Issues in Agrarian and Ecological Economics: In Memory of Georgescu-Roegen," mimeo, Universitat Autònoma de Barcelona.
- Mirowski, P. (1988) "Energy and Energetics in Economic Theory: A Review Essay," *Journal of Economic Issues* 22: 811–830.
- Mayumi, K. (1995) "Nicholas Georgescu-Roegen (1906–1994): An Admirable Epistemologist," *Structural Change and Economic Dynamics* 6: 261–265.
- Norgaard, R. (1994) *Development Betrayed*, New York: Routledge.
- O'Neill, J. (1993) *Ecology, Policy and Politics*, New York: Routledge.
- Sagoff, M. (1994) "Should Preferences Count?" *Land Economics* 70: 127–144.
- Seifert, E. (1994) "Georgescu-Roegen, Nicholas," in Geoffrey Hodgson, Warren Samuels, and Marc Tool (eds.), *The Elgar Companion to Institutional and Evolutionary Economics*, Aldershot: Edward Elgar, vol. 1, 277–283.
- Sen, A. (1977) "Rational Fools: A Critique of the Behavioral Foundations of Economic Theory," *Philosophy and Public Affairs* 6: 317–344.
- Spash, C. and Hanley, N. (1995) "Preferences, Information, and Biodiversity Preservation," *Ecological Economics* 12: 191–208.
- Stevens, T., More, T. and Glass, R. (1994) "Interpretation and Temporal Stability of CV Bids for Wildlife Existence," *Land Economics* 70: 355–363.
- Zamagni, S. (1987a) "Nicholas Georgescu-Roegen," in J. Eatwell, M. Milgate, and P. Newman (eds.) *The New Palgrave Dictionary of Economics*, London: Macmillan Press.
- (1987b) *Microeconomic Theory: An Introduction*, Oxford: Blackwell.

Copyright of Review of Social Economy is the property of Routledge, Ltd.. The copyright in an individual article may be maintained by the author in certain cases. Content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.