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Resources Are Not; They Become: An Institutional Theory

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In common usage, as well as in traditional mainstream economics, material inputs for production have been thought of as physical resources. Classical economists defined the factors of production in material terms. Land was the "original and indestructible powers of the soil." Resources were "natural" and given. If land and mineral resources are material, then at least in a global sense they are fixed and finite. From an institutionalist perspective, however, following in the tradition of Clarence Ayres and Erich Zimmermann, "resources are not; they become." In the process of becoming, then, they are neither fixed nor finite, and, as we shall demonstrate, the process of becoming is one that is as much ideational as it is material.[1]

The material or physical aspect of resources exists before they become resources. Arguing from "the principle of indestructibility of matter," a view that would have to be modified in light of current physics, Ayres argues that "there is no such thing as a 'new material'." There are, however, new resources. "The history of every material is the same. It is one of novel combinations of existing devices and materials in such a fashion as to constitute a new device or a new material or both."[2] This creative process of fashioning the material and non-material stuff of our environment in a form usable and serviceable to human beings is determined by science and technology. It is the sum total of human knowledge and capability that is the prime resource and the one that defines all others.

Technology and Resource Creation: The Concept

To say that the term "resources" essentially has no meaning apart from a relationship to human beings does *not* mean that all things have a right to exist only to the extent that they serve human beings. We can speak about the living resources of planet Earth. We can argue that we *ought* to preserve and protect them. Calling them resources and saying that we should act in certain ways, then, means that there can be an operational meaning to the effect that it is in our best interest to preserve as large a genetic heritage as possible. This is an intelligent, sensible argument that many conservationists and environmentalists put forward. We can also argue that other living things have *rights* apart from their service to us.[3] For the sake of consistency in the use of language, we should not use the term "resources" when we are making specific reference to the rights of other creatures.

It is ironic that most mainstream economists have taken a position on resources that is not too different from that of the institutionalists. This was noted by Ayres four decades ago and resulted in some "confusion" for a discipline in which scarcity is the cornerstone.[4] Economists generally maintain that the issue of finite resources is not an interesting question. Reference is made to price changes, substitution, greater efficiency, and discovery. Occasionally, even science and technology are mentioned. Yet, without technology, one cannot indefinitely substitute one resource for another. Substitution alone merely delays reaching finite limits.

Mineral resources is not the only area in which the institutionalist perspective has become orthodoxy. The ideas of science-based agriculture, or of certain technologies as "land augmenting" or that investment creates arable land, make sense in a functional theory of resources, but not in one that assumes land as "natural" or as the non-human, non-manmade factor of production.[5] Direct investment creates arable land in many ways: by increasing crop intensities (more than one crop per season) through irrigation, or by developing crops with shorter growing seasons, or by creating higher yields in a particular crop because of improved seed. The basis for these resource-creating investments is the ongoing research in agriculture, which most agricultural economists find to be an investment that has paid extraordinary returns in recent years.

The focus on scientific research as a means of resource creation goes to the very heart of institutional economics. Wesley C. Mitchell stated precisely what should be a fundamental principle of all economics. "Incomparably greatest among human resources is knowledge. It is greatest because it is the mother of other resources."[6] Mitchell's claim is true both as a historical proposition and as an operating principle for policy.

Resources are not things or stuff or materials; they are a set of capabilities. These capabilities use the stuff of the material and non-material universe in a life-sustaining manner. These capabilities define a functional relationship that we call resources. This relationship is what Zimmermann referred to as the "fundamental concept of resources."[7] The relationship implies the prior physical existence of both humans and the material (or non-material) substance. Absent from the relationship, the term "resources" is meaningless. Humans are the active agent, having ideas that they use to transform the environment for human purposes. Resource, then, is a property of things—a property that is a result of human capability.

Logically, one resource—food—had to pre-exist the others. Before hominids, there were proto-hominids, and obviously their survival presumes the use of food resources. Beyond this very basic precondition, ideas precede, not only all other resources (including all other food resources), but also the emergence of homo sapiens. Proto-hominids had ideas and began to use certain objects in their environment, such as stones. This idea and subsequent action established the functional relationship that allows us to call the stones resources. Others saw possibilities of fashioning these stones so that they were more usable. The greater the usability, the greater the resource character of the stones. Tools are, then, used to create still newer and better ones, thus continuing the process of resource enhancement. The stones had not changed, but ideas, skills, and behavior had, and these literally created the resource.

These new tools allowed for more effective exploitation of the environment. New edible materials became accessible, tubers in rock-hard earth or large animals, and for humans these became food resources. The ability to harvest more food from an area increased the resource character of that land. This process continued through the domestication of plants and animals and on up to the present. It was agriculture that created arable land and not the reverse.

This simple illustration shows the dynamic interactions and reinforcing feedback mechanisms involved in the human generation of ideas and their embodiment in the process of technology and in the creation of resources. Other animals use tools, but both the tools and the resources they create are functionally limited. Humans engage in a dynamic open-ended process called technology. In a recent book of mine, I make an analogy to signals and language. Other animals have closed systems of communication using signs or signals; only humans have the dynamic, open-ended process of language.[8]

Tool-using created resources. It also created homo sapiens; for the use of tools favored certain members of the proto-hominids who had large areas of the brain controlling the hand that made the tools. This gave a direction to evolutionary processes and established another dynamic feedback relationship because with improved hands and brains one can make better tools.[9]

Tools may have been instrumental in our emergence as homo sapiens; they also made further evolutionary change unnecessary. Until the emergence of technology, living creatures exploited a limited number of resources in an environment. Environmental change wiped out resources and those life forms that could not evolve and adapt. Evolution is the means of adapting to change, and it is the means that allows movement from one environment to another. A sucessful species is one with the capability of exploiting its environment for continued survival. A failed species may be nothing more than a victim of an environmental change that was too rapid or dramatic to allow for evolutionary change.

With ideas and with the technology in which those ideas are embodied, resource creation can be continuous, and adaptation does not depend upon chance biological change. From a rather limited range of habitat, humans have spread around the globe, inhabiting every conceivable climate and environment. Unique among mammals, we have done this without speciation. The ways in which we use a technology to make an area habitable for humans, to make clothing, shelter, food, and materials, can only be described as resource creation. The very concept of habitability for an area that was previously uninhabited can only have meaning through resource creation.

Historic Concerns about Resources

Concern for the availability of resources is as old as the human endeavor itself. In the quote cited above about knowledge being the mother of other resources, Mitchell adds: "The bulk of man's resources are the result of human ingenuity aided by slowly, patiently, and painfully acquired knowledge and experience."[10] Various stones and pebbles became resources when humans learned to use them to make tools. These same materials ceased to be resources when humans acquired new skills in taking previously worthless earths and smelting them into metals. The new tools allowed humans to exploit more fully their environment and thereby to create still more resources. And so it has been ever since—humans create resources and use them to create still other resources. For all human beings are (virtually by definition) tool users. The very use of tools presupposes both resources to make them and resources to be exploited by them. The use of tools is central to the process of maintaining and sustaining human life. Peoples and cultures achieve levels of population density and styles of life based upon their use of tools, technology, and resources. Rarely, if ever, can a people abandon a technology and its resources and return to an older pattern without loss of life (that is, a lowered population density) and living standard. The ongoing concern for a secure supply of resources is vital to the very life and lifeways of a people. "All forms of life other than human beings deal only with renewable resources," and only humans have found a way to use so-called non-renewable resources.[11] Contrary to the doomsday critics, this is a strength and not a weakness of the human endeavor.

For a significant period in United States history, lack of access to resources was not a primary concern. An abundant natural endowment (as defined by the existing technology) and a seemingly endless frontier contributed to this attitude. By the beginning of the present century, this perspective began to change with the putative closing of the frontier in 1890. In the late 1920s, fear was expressed in official circles that we might be exhausting domestic sources of critical resources.

After World War II, domestic resource exhaustion was not the only resource concern of the United States. Continued uninterrupted access to foreign sources no longer seemed certain. A series of official commissions and studies testifies to the intensity of these resource concerns. The most famous and important of these studies is the Paley Commission Report (officially entitled *Resources for Freedom),* a comprehensive five-volume report issued in 1952.[12]

The Paley Commission began with the question, "Has the United States of America the material means to sustain its civilization?"[13] It found that:

> In area after area the same pattern seems discernible: soaring demands, shrinking resources, the consequent pressure toward rising real costs, the

risk of wartime shortages, the ultimate threat of an arrest of decline in the standard of living we cherish and hope to help others to attain. If such a threat is to be averted, it will not be by inaction. After successive years of thinking about unemployment, reemployment, full employment, about factory production, inflation and deflation, and hundreds of other matters in the structure of economic life, the United States must now give new and deep considerations to the fundamental upon which all employment, all daily activity, eventually rests: the contents of the earth and its physical environment.[14]

The issues of resource dependency gained a far wider constituency in the 1970s, reaching far beyond official circles. Phraseology featuring the "limits to growth" or an "era of limits" were in popular currency, as sophisticated computer models cranked out conclusions arguing that world-wide resource exhaustion was but decades away. The petroleum crisis also brought to the United States public a vivid sample of the meaning of resource dependency. In the 1960s, there also emerged doomsday and catastrophist theories, which I have attacked in other articles for the failure (fortunately) of their dire prophecies.

By the early 1980s, despite the utter failure of the doomsday prophesies, the proponents of alternate technology came up with newer, presumably more profound, reasons to be opposed to modern technology. Jeremy Rifkin, in his book, *Entropy,* boldly proclaimed "a new world view" in his subtitle.[15] The inexorable law of entropy in thermodynamics requires that matter and energy flow from high to low, from structure to randomness and from heterogeneity to homogeneity. Thus we move from order and complexity to chaos. Since this is a law of the cosmos and of the planet, it is not exactly clear in Rifkin how we could have achieved our current state of complexity and organization from which descent is inevitable. Similarly, Kirkpatrick Sale argued in *Human Scale* that smallness is an inherent biological virtue.[16] Unfortunately for Sale, he has no solid biological evidence to offer for his thesis. One source that he uses, J. B. S. Haldane's "On Being the Right Size," does speak of the advantages of smallness, but then turns to the advantages of bigness. Evidently, the author of this large book on smallness did not finish the Haldane essay before quoting it.[17]

Someone once joked that Karl Marx had carried classical economics to its logical absurdity. Much the same can be said of Sale and Rifkin. For the very logical structures that they conjured gave rise to implications the exact opposite of what they advocated. If resources are fixed and finite, then entropy does condemn us to inevitable and ineluctable decline. There is one thing that entropy and scientific and technological inquiry teach us; namely that no process such as recycling or conservation can be one hundred percent effective. Renewability is, at best, only partially successful. At each turn of the cycle, some bit of order becomes disorder, soil is lost, or a resource is dissipated. Thus, not only are we faced with decline, but also, in the case of Rifkin, we are at a loss to explain how we ever achieved an elevated status from which decline is possible. This decline occurs with constant population; any population growth accelerates the process. Negative population growth delays, but does not prevent, decline.

There is a more respectable and persuasive argument for renewability. In these, the constraints are relaxed, and we have a slightly open system for natural processes to create resources, but at a slow pace. Aquifers are recharged by rain; running water provides sources of energy; soil is created; and new species evolve to replace those that die out. Thus, it is not fixed limits but carrying capacity of a constrained, but open, system that determines sustainability. If we view carrying capacity as purely a "natural" process, then unfortunately, humans transcended these limits at least 10,000 years ago with the development of agriculture. We do not merely harvest the environment, we transform it. In so doing, we have altered the carrying capacity of the environment.

Viewed in these terms, carrying capacity refers not to the environment as it is, but to the environment as it can be. The issue, then, is what technologies are best able to transform the environment for human purposes on a sustainable basis.

This brings us back to the argument of fixed, finite resources. A technology predicated upon fixed, finite resources is one that dooms us to decline. It does this to the extent that it fulfills the assumptions of many of the theorists who advocate it and to the extent that it supplants the technologies that have been deemed to be bad. (This generalization does not apply to the technologies created by the many dedicated workers who are not operating out of cosmic concerns of grandiose philosophical theories but merely trying to solve practical problems.) However, just as the concept of carrying capacity has a technological component, so does that of resources. Resources are not fixed and finite because they are not natural. They are a product of human ingenuity resulting from the creation of technology and science.

Obviously, at any given time, with a given technology, there is a sense in which resources are fixed and finite. Given these parameters, we can say that some countries are better endowed with resources, be they mineral, soil, or energy, than others. We said "in a sense," for even under the constraint of a given technology, changes in prices can dramatically alter resource availability. In defining the resource endowment of a country, furthermore, it is difficult to distinguish between the rich resources, such as ore deposits, that may even have been found by expatriates, and the arable land resources that were created by investments in applied technology.

The idea of "carrying capacity" has in usage a relatively precise meaning. In a given ecosystem, up to a set number of animals can be pastured or so much water can be drawn from an aquifer with the "natural" regenerative forces allowing for sustainable use. Beyond these limits, an inevitable accelerating decline begins. As such, the concept is useful, cautionary, and scientific. Unfortunately, the term has acquired a more common parlance. We, meaning earth's human inhabitants, must live within our energy budget or within the carrying capacity of the planet. Simply stated, we must live within limits. If these statements are to be accepted as anything other than truisms, then there is the unstated assumption that the resource boundaries established by various policy advocates are fixed by nature. Like other statements of fixed, finite resources, it denies the possibility for technological innovations that alter the boundary conditions.

Technology and Resource Creation: Some Empirical Evidence in Minerals and Food Supply

By the mid-1970s, a series of studies and events appeared to lend scientific support and empirical evidence to the view that resources were being exhausted and that population was outrunning both food supply and resources. Studies such as the Club of Rome-sponsored *The Limits to Growth* used systems analysis and computer models to demonstrate that the mineral resources upon which civilization is based were being rapidly depleted and that some would be exhausted in a matter of decades unless corrective actions were taken.[18] The rapid rise in food prices in the early 1970s, accompanied by decreasing carryover food stocks and then followed by the oil embargoes and rapid escalation in price, all seemed to confirm the most dire forecasts.

In 1974 and 1975, there was a world conference on population and another on food production. Their conclusions were consistent with the temper of the times. World population had reached 4 billion with ever-increasing numbers being added, so that the dire prophecies of Malthus may have been delayed, but seemed now to be a reality. Famines, as severe as the one that struck the Sahel in Africa, would become frequent and involve more people until it became a permanent global condition. Added to all of this was a rising chorus of concerns about various forms of environmental contamination and destruction. Many argued that the enterprise of being human was about to enter resource bankruptcy unless it was saved by conversion to small-is-beautiful new age ideologies and pursuits. The most frequently cited villain was technology.

The irony of these dire forecasts of resource exhaustion was that they came at the end of a period in which the known reserves of most minerals had increased substantially. It is true that population growth rates were increasing during this period. But it was also true that birth rates were falling at record rates of decline and that the cause of global population increase was a dramatic and unprecedented decline in death rates. Despite record rates of population growth, food supply was growing even more rapidly, thereby raising world per capita food consumption. Per capita income was also growing throughout the globe. *The Limits to Growth* study was based on 1970 data and presumably should have reflected the sizeable increases in known mineral reserves that had accompanied the rapid increase in world industrialization and resource use. From the late 1940s to the late 1960s, reserves of iron ore increased 122.1 percent, manganese 27 percent, chromite 675 percent, copper 179 percent, and lead 115 percent.[19]

In the 1960s and 1970s, it was consistently found that the real price of most minerals had been falling throughout this century when measured in either the price of labor or in percent of total labor and total capital involved in extractive industries.[20] In 1986, the cost of all metal raw material for all uses came to $80 per person.[21] Similarly, the long-term trends of real food costs and food as a proportion of individual budgets showed a sustained downward movement, even despite the short-term upward movement of the early 1970s. In short, by all measures of scarcity, traditional or non-traditional, virtually all items in the class of economic inputs called land and natural resources were becoming less scarce and not more scarce, as had been predicted by the classical economists and echoed by contemporary catastrophists.

Not all of those who were forecasting a "new era of limits" were blind to the data. It was recognized that technology had rather consistently found new resources as we were seemingly running out of old ones. It was also recognized by some that food production had been growing faster than population and that generally standards of living had been increasing. But as the refrain went, we were living off capital and not income, since we were rapidly drawing down precious stocks of resources that had been slowly accumulated by natural processes. The very accelerated growth in well-being that was conceded was an acceleration in resource depletion that would bring us to limits within which we must learn to live. If such limits are exceeded, an inevitable decline of civilization will follow.

Others argued that growth since World War II was historically atypical (which it certainly was insofar as rapidity of change) and that this growth was the result of a fortuitous confluence of favorable events. In agriculture and food supply, for example, there were the "green revolutions" in wheat and rice, there was a run of favorable weather, the price of petroleum for fertilizer and energy was cheap and often falling, and there were still virgin fertile lands to bring under cultivation. These were all one-time conditions, the benefits of which were now realized and were unlikely to be replicated. Similiar fortuitous one-time only events were postulated to explain our overall economic fortune. Petroleum had provided an era of cheap energy that explained so much of our well-being, and its presumed imminent depletion presaged the closing of an era. The party, we were told, was over. Thus, while some used bad news to forecast economic catastrophe, others used good news to portend the same outcome. In the literature of the mid-1970s, however doomsday was forecast; there was an immediacy and an overwhelming sense of urgency for virtually instantaneous change in mental outlook, patterns of behavior, and economic policy.

The question remains whether or not we did make a historic transition in the 1970s because these one-time fortuitous circumstances were exhausted. As the accompanying table shows, from 1975 to 1985, most known mineral reserves increased, some rather substantially. Even for some that have experienced sizeable decline, the explanatory reasons are definitely not resource exhaustion. Tin, which shows the largest decline, has just experienced a virtual collapse of its market. Mines are being closed in Malaysia and Thailand, and Bolivia may exit the market entirely because capacity and production far exceed demand. Given that Brazil is emerging rapidly as a major, if not dominant, producer, it is not at all clear whether the data reflect the full extent of Brazil's known resources.

After World War II, many were fearful of exhausting high grade iron ore deposits. Since iron is the fourth largest constituent in the earth's crust or 5 percent of the crust by weight, there was never fear of exhausting it, only that lower grade ores would make the price prohibitive. Because of pelletization and other technological changes and the finding of new reserves, iron ore reserves substantially increased between World War II and the early 1970s. The apparent decline in re-

Table 1.

Mineral Name	*RESERVES* 1975	1976	1985	(%Δ based on year 1975)
Bauxite	17 B/T	24 B/T	23.2 B/T	+ 36%
Chromium	1.9 B/T	2.9 B/T	7.5 B/T	+294%
Cobalt	2.7 M/T	2.9 M/T	9.2 M/T	+240%
Columbium	22 M/P	22 B/P	9.1 B/P	−58%
Copper	450 M/T	506 M/T	525 M/T	+17%
Ilemenite	580 M/T	771 M/T	734 M/T	+26%
Iron Core	259 B/T	255 B/T	206 B/T	−20%
Lead	160 M/T	160 M/T	143 M/T	−10%
Manganese	6 B/T	6 B/T	12 B/T	+100%
Molybdenum	13 B/P	19.1 B/P	25.9 B/P	+99%
Nickel	60 M/T	61 M/T	111 M/T	+85%
Phosphate Rock	18 B/T	20 B/T	34 B/T	+88%
Platinum-Group Metals	561 M/O	560 M/O	1.2 B/O	+114%
Rare-Earth Metals	7.7 M/T	7.7 M/T	48 M/T	+523%
Rutile	13.7 M/T	37 M/T	133.4 M/T	+881%
Tantalum	110 M/P	130 M/P	76 M/P	−30%
Tin	10.2 M/T	10.2 M/T	3 M/T	−70%
Tungsten	3.9 B/P	4 B/P	3.5 M/T	−10%
Vanadium	21.4 B/P	21.4 B/P	36.5 B/P	+70%
Zinc	150 M/T	175 M/T	300 M/T	+100%

SOURCES: For 1975 and 1976— *Commodity Data Summaries,* Bureau of Mines, United States Department of the Interior, 1976 & 1977; for 1986—*Mineral Commodity Summaries,* Bureau of Mines, United States Department of the Interior.

B/T = Billions of Tons M/T = Millions of Tons
B/P = Billions of Pounds M/P = Millions of Pounds
B/O = Billions of Ounces M/O = Millions of Ounces

serves comes at a time when, at every stage of the process, from ore production to iron and steel, there is considerable excess capacity. More significantly, the relative importance of iron and steel is decreasing with the emergence of ceramics, composites, other metals, and a variety of specialty materials.

Using price as a measure of scarcity, we find that all categories of commodities, minerals, and various types of agricultural outputs have experienced, with few exceptions, decade-by-decade declines in real prices, so that the mid-1980s real prices for all categories are lower than they were in 1950.[22] The last decade fluctuations were such that the 1984 index of commodity prices in U.S. dollars was lower than in any year since 1976. In real terms, the measured decline was even greater, even allowing for the strong dollar as a measuring stick.[23] From 1980 to 1985, prices of metals decreased 30 percent, while the overall index of commodities fell 24 percent. "Moreover, real commodity prices so far in the 1980s have averaged about 16 percent below the average for the 1970s and in 1985 were about 20 percent below the average for 1960–1980."[24] Even if we question the faith that some mainstream economists have in price as the sole and absolute measure of scarcity, it is difficult to imagine the mechanism that would allow for these declines in prices in the world of increasing scarcity described by the limits-to-growth theorists. After all, an element of their prophecies that should not be forgotten is the higher real price we would have to pay for everything.

If there is one characteristic that tends to define the world's commodity markets, it is overcapacity and oversupply. World food production in 1985 set a new record, as it has for approximately thirty of the past thirty-five years. The record was both for total and for per capita production. Production in 1986 may be off somewhat, but still the problem in most parts of the world (except for Africa) is low prices and huge, unsold and presumably unsaleable mounds of surpluses of foodstuffs. Even in Africa, some countries such as Zimbabwe are accumulating surpluses of hard-to-sell, coarse grains. Asia, a region we have traditionally identified with poverty, hunger, and famine, is becoming a surplus food producer, even allowing for rising levels of domestic consumption because of rapidly rising incomes.[25] Asia is also the region we generally consider to be at the limits of environmental carrying capacity. Asia, more than almost any other area in the third world, has "created land" by increasing yields in existing areas far more that it has created land by bringing new lands under cultivation. If there is hunger in the world—and so there is, in abundance, even in wealthy countries—it is because of maldistribution of food, not insufficient global production. Hunger has always been with us, but today it is more rare, even though it receives much well-deserved media coverage. Hunger continues to exist today, not for the reasons predicted a decade ago—namely, that we were on an unsustainable consumption binge—but because we have not yet found a way to provide to everyone the capacity to earn sufficient income to obtain what is generally available.[26]

The metals markets are still suffering from overcapacity, even though there have been systematic closings of mines and production facilities in many metals. As this is being written, the real price index for metals (in a basket of currencies) is less than 80 percent of what it was in 1980.[27] Losses for some traders on the London Metal Exchange have been heavy. "Copper consumption seems set to decline by 2 percent during this year, while mine production is rising."[28] Ironically, the main hope from the perspective of the producers is that the low prices, having led to reduced exploration, will in time give rise to shortages.[29] Cobalt, which had risen to $50 per pound on the spot market in 1978 (because of political disruptions in Zaire), had fallen to $3.70 in August 1986 before rebounding to $6 per pound with some help from an attempt at cartelization by Zaire and Zambia.[30] Even the $6 price may be difficult to sustain because world production capacity is about 50 percent greater than demand.

It is close to a decade and a half since *The Limits to Growth* was published and well over two decades since catastrophic predictions of reaching limits became popular beliefs, yet no empirical evidence has yet emerged to support the thesis. In fact, the preponderance of evidence is pointing in the other direction. Since the surface area of the globe and the concentration of minerals in its crust are fixed (except for possible minuscule geological changes), the primary explanation for the increase in resources and output is technology. Studies such as *The Limits to Growth* were sufficiently specific in their forecasts that the data already available falsify a significant portion of them. Nobody could have accepted any portion of the doomsday literature of the 1960s and 1970s and believed that in the mid-1980s the world would be in surplus in most commodity production. Yet, though less shrill in tone, the belief in declining resource availability and in the limits to the earth's carrying capacity still predominate in the media. No matter how overwhelmingly the march of time emphatically refutes doomsday forecasts, there remains that lingering belief that good fortune has allowed us to delay the seemingly inevitable. But our luck will not last forever, and the inevitable will inevitably arrive.

A concept of fixed, finite resources provides the mindset that allows people to refuse to accept evidence of decreasing resource scarcity. The institutional theory of resource creation provides the necessary framework for correctly understanding the evidence. It is the only theoretical perspective that allowed us to forecast the trends of the post-World War II period. If some mainstream economists in recent years have joined the bandwagon, so much the better. However, it should be clear that, though mainstream economics can explain short-term trends by techniques such as substitution and increasing efficiency, their basic theory of finite resources does not allow for indefinite resource expansion. If some economists are now using the term "resource creation," then we should cheer and remind them of its origin. Similarly, the concept of "land augmentation" is another way of speaking of science and technology creating resources. Touting the institutionalist origins of such significant concepts is not for some purpose of creating intellectual property rights. Its purpose is to show the strength and power of a body of ideas. For whether or not humans have the food and other raw materials to continue the process of civilization is no small matter. The world has experienced a global revolution in food production, population growth, death rate decline, life expectancy increase, and per capita income increases of unprecedented proportions—all of which was understandable and predicted in institutional theory. If unmet need exists despite overproduction and overcapacity, then the problem is one of creating purchasing power, as institutionalists have long argued.[31] A body of theory with this strength should reasonably be called upon to formulate the policies that will allow the continuation of resource creation and civilizational advance.

Technology and Resource Creation: Arable Land and Mineral Resource Creation

Land as a human resource is created by technology (and science) in the same manner as minerals become resources. The first tools that allowed people to hunt and to harvest the land more intensely increased the resource character of that land. Stone tools that permitted early man to dig out roots from the rock-hard savanna soils made those roots into a human resource, and, with the domestication of plants, some of the wet, insect-invested river bottoms acquired the potential to be agricultural land. Agriculture created arable land.

The history of human migration and settlement is a history of people creating arable land by devising new means and new technologies to produce food. Theodore Schultz has long argued that some of the world's best agricultural land once had poor soil. "The original soils of western Europe, except for the Po Valley and some parts of England and France, were in general very poor in quality. As farmland, these soils are now highly productive." To Schultz, the inherent qualities of soils do not explain why agriculture is outstanding in some parts of the world and poor in others. He maintains that "a substantial part of the productivity of farmland is man-made by investments in land improvements."[32] N.W. Pirie voices essentially the same idea, that "good farmland is usually created by skilled farming."[33]

There are many ways of creating new land. Bringing uncultivated land into production is only one. Irrigation can not only bring cultivation to arid lands, it can also frequently add a second or third crop season to the agriculture of a region. Breeding crops with shorter growing seasons, allowing for an extra crop, is yet another way. Research has been, and continues to be, carried out to find or breed crops that are more tolerant of salt or can withstand the stress of acidity from aluminum-toxic soils. Biotechnology and other new breeding techniques give promise that not only will current trends be sustained, but that in the future they may even accelerate.[34]

A hundred-year decline in the real price of food is likely to continue. Clifford Lewis notes that "despite the weakness of data about global food trends, it is clear that global food production has grown at a generally increasing rate since the early decades of the 19th century and has consistently outstripped increases in global population." Lewis's data shows that the real price of wheat (in 1967 dollars) fell from $3.09 in 1890 to $2.10 in 1960 to $1.10 in 1982. There have been "temporary disruptions" in this downward trend, but they have been "when peace has not prevailed."[35]

The frontiers of technological research are as promising for the creation of new material resources as they are for the creation of land. Materials science is emerging as a prime area of research, as new technologies in every area of endeavor have performance demands that require material with specific qualities. Minerals previously little used are becoming vital to technological processes. Our ability to process these minerals is advancing as rapidly as the new materials that we are creating. Silicon chips, fiber optics, and ceramics have turned raw materials long in vast abundance into major resources. One of the problems with the metals market is in fact that these new "resources" are substituting for traditional ones, such as copper, decreasing the demand for them. In the case of fiber optics, the new material performs its task better, more efficiently, more reliably, and at a far lower material resource cost.

Even without new and improved technologies for resource utilization, there are additions to resource reserves because of new finds. The process of resource discovery is also subject to scientific and technological advances. Advances in geology, such as plate tectonics, and in geography give us new understanding of how various ores are formed, sorted, and where they are likely to be found. Remote sensing from satellites has added new dimensions to mapping and discovering minerals, though at times it is easier to be more enthusiastic about the potentials of remote sensing than is yet warranted by the data. Airborne and ground surveys, using a variety of technologies, aid in the search for new material sources.

Contrary to the pessimists, not only is technological change continuing, but the rate of change itself is accelerating.[36] Unchanging technology is resource-using. Changing technology is resource-creating. The history of technology and human societies today testify to these basic conditions. Thus, the growth in resources and the decline in their real price are not fortuitous, or accidental, or temporary, or paradoxical, but fundamental to the process of technological change. Because it is fundamental, it is reasonable to believe that the continued advances in science and technology, which everyone expects to occur, will create the resources necessary to sustain it. Furthermore, if the process is not entirely automatic, we can use our intelligence to structure the process so that we realize the full resource-creating potential of technological change.

The Life Process and the Conditions of Life

In the discourse on institutional economics, particularly in the writings of Veblen and Ayres, reference was made to the life process. Institutional economics was evolutionary economics drawing inspiration from the late nineteenth century post-Darwin period, rather than from the static conceptions of the eighteenth century. It is interesting that many of the current theories on life's origins make these references more appropriate than could be realized at the time. The first life forms "fed" on already existing organic matter, using it in chemical fermentation for life-sustaining energy. Clearly, there was a limited resource, as life was "consuming" organic matter faster than it was being created. Later, procaryotes would evolve photosynthesis, a new energy source that overcame the original resource constraint. Similar to human problem-solving endeavors, the solving of one problem creates new ones. The oxygen that was earlier being given off was creating an ozone layer that was shielding out the ultraviolet light that was creating organic food. To anaerobic procaryotes, moreover, oxygen was a deadly pollutant. Fortunately for us, eucaryotes evolved that were more efficient in energy use and were aerobic.[37]

To the extent that this scenario is correct, then the conditions (that is, the resources) for life as we know it did not exist; they were created by the evolution of life itself. The solution of some problems created others, but still we can understand problem-solving in an expanded energy-opportunity context. At any one point, "resources" are fixed and finite, and life seems doomed either to exhaust resources or to succumb to its own waste. The process that we are describing is one of emergent evolution. Had there been some kind of intelligence operating in or observing the early procaryotes, it would have proclaimed the limits to growth and the end of life. All logic and reasoning lead to one inevitable conclusion—death. Absolutely nothing in the situation could yield to any inquiry the hope for continuity. It is only after the transformation has occurred that one can begin to understand the process.

The same can be said for hunting and gathering humans. A widely respected thesis is that hunters and gatherers had reached the limits of their potential, creating a food crisis.[38] Where a growing population of hunters and gatherers are pushing the limits of the environment, there is again nothing that an intelligent observer could find in the situation that offered any escape from self-destruction. It is only in retrospect that we can understand the resource creating power of technology.

Having observed these and other processes, we can derive a theory of technological change and of the types of resource creation and other forms of novelty that emerge. This is, of course, part of what evolutionary economics is all about. It is a theory that, at least in outline form, helps us to understand the process and therefore to have an understanding of emerging possibilities. It clearly should make us aware that resources are not fixed and finite, and they definitely are not natural. As long as we do not run out of ideas, then we are not likely to run out of resources.

The assumption of fixed, finite resources has caused many to make catastrophic predictions of resource exhaustion. Fortunately, where these prophesies have been sufficently specific to be testable, the passage of time and events has falsified them. It has been my argument in several papers that the technologies the prophets offered as resource-conserving in fact would create the problem they claimed to be solving. Living within limits is inherently self-defeating, as the above illustrations demonstrate. Another principle, entropy, has been offered into the argument and guarantees decline.

The life process and the technological process form an enclave of negative entropy. Energy is taken from a source (that is, the sun) that would be experiencing increasing entropy in any case, and is used to build order and complexity (negative entropy). It is interesting that among the earliest recorded and recovered legends is that of ancient Sumerians and Babylonians about the separation of land from water, order from chaos. This legend celebrates the human achievement of negative entropy and the creation of arable land resources. Throughout the ancient Middle East and on into Greek and Roman culture was the basic proposition that was later expressed as *nihil ex nihilo*—out of nothing comes nothing. Creation out of nothing was impossible. Our idea of resource creation is consistent with that usage. Creation of resources is the creation of order out of chaos, the imposition of our ideas and will upon pre-existing substances.

The dynamic resource-creating power of technology has been central to evolutionary economic thought. It is ironic that mainstream economics has borrowed some modest semblence of this theory, or at least its conclusion, to counter the limits on growth theorists or the catastrophists. We might be wise to follow Ayres's lead and use this opening to raise more fundamental questions. If resources are not fixed but created, then the nature of the scarcity problem changes dramatically. For the technological means involved in the use of resources determines their creation and therefore the extent of their scarcity. The nature of the scarcity is not outside the process (that is, natural), but a condition of it.

Understanding the creative powers of technologies can be infectious to other areas of economic thought. Of the many definitions of capital, technology has to be a key component if we are to comprehend the dynamics of economic change. The other factor, labor, is increasingly addressed, not as a raw unit of measure of other things, but as human capital. Knowledge and skills, the very essence of technology and resource creation, are receiving attention for their critical role in the development process. Even entrepreneurship is about someone allegedly having a better idea.

Technology and Resource Creation: A Liberating Idea

Technology as ideas and as the creator of resources is not only correct, it is also liberating. It provides a conceptual basis for understanding the fact that the resource base of civilization has expanded, not contracted, with use. It gives us the kind of operational understanding necessary to frame the policies to sustain this resource-creating process. It provides a reasonable basis for optimism that the human endeavor can continue and can expand. It is, finally, the key component of a structure that challenges traditional ways of thought about the economy and opens new possibilities for creative inquiry and dialogue.

A little over two centuries ago, Adam Smith had a series of liberating ideas. The very title of his magnum opus, *An Inquiry into the Nature of Causes of the Wealth of Nations,* argues for the liberating idea that all nations can prosper and that nations need not impoverish their neighbor in order to succeed. He defined wealth as the annual produce of a nation, not merely of its sovereign. And he defined a relationship through markets by which those who participated in economic activity were supposed to be beneficiaries of it. Smith was inquiring into the causes of wealth in his economy, yet in reality he was in the first ferment of an industrial transformation that was to give concrete meaning to his liberal idea.

The idea of scarcity, which some conceive to be the fundamental organizing principal of economics, is a static concept and is counter to the liberating potential of Smith's ideas. To the extent that some see scarcity as based upon the principles of nature, then we are back to the concept of fixed, finite resources. The theory of technology as resource creating is dynamic. It removes scarcity as an organizing principle of economic inquiry. While it may be true that we do not have infinite resources from which to choose and to allocate, neither are we dealing with fixed resources. They are finite but unbounded. The very economic/technological processes that use "scarce" resources are also creating them; as we have argued, this historic process of allocating, and using, has created far more than it has used. If we define efficiency according to scarcity then we are dealing with a closed system. If we define efficiency according to the technology of resource creation, then we are describing and creating the conditions for an open-ended process.

The resource-creating power of technology is a never-ending problem solving process. It is a process by which people make choices and have even greater opportunities to make choices. By implication, the idea that problem solving continues indefinitely means that there will always be problems around to be solved. The critics of modern technology have confused using resources with using them up and see the existence of resource problems as an argument against modern technology. The simple fact is that without technology, there are no resources and therefore no resource problems. But the resource problems of human existence will only be terminated with the ending of the human endeavor itself. So-called alternate technologies that are resource conserving but not resource creating engender more problems than they solve.[39]

The biggest resource problems that technology creates are the hypothetical ones. The empirical argument that begins "if present trends continue" can inevitably demonstrate a future crisis if technology is held constant.[40] To counter that technology has historically made resources more available does not necessarily address the specifics of future resource needs and opportunities. Very simply, we can learn much from the historic process of technology that allows us to predict many aspects of the future course of events, as well as to plan and take action to make those events more favorable to the human enterprise.

Since we have described the process as one of emergent evolution, then, there are emergent possibilities that we cannot predict. Further, if the thesis is held true that we create the conditions of our existence, it is equally true that we can destroy the conditions of our existence. This has always been the case; it is only in modern times that it has been dramatically obvious. Of course we can do it in many ways. The one most frequently noted is to destroy ourselves with nuclear weapons. Out of fear of the unknown future, we can also do it by failing to carry forward resource-creating technology that is the basis for the sustainability of human civilization. It is our destiny to choose our future; not to choose is itself a choice as the existentialists have told us. What Albert Camus said about the individual is true for humankind: the most important choice we face is whether or not to commit suicide. Camus meant this as an affirmation, "as a lucid invitation to live and to create, in the very midst of the desert."[41] Similarly, we can understand technology transfer and economic development as a collective affirmation of the worth of life and the life process.

Technology, resource creation and emergent evolution engender not a world of unknown future but of emerging possibilities. Our destiny is not in being but in becoming. We as humans have turned adversaries into allies. What greater threat was there to primate life and habitat than fire? Yet fire was controlled and turned into a tool for converting ores into metals (that is, making clay into pottery and other dirts into ores) and for making the cold climates fit for human life. Ergot, a plant disease that threatens human life, is now used as a cure for migraines. Poisons from plants have been turned into life-saving or supporting drugs. The list is endless, and so is the future potential of humankind. Those who would turn us aside out of some fictitious fear of resource exhaustion would protect us from the dangers of the unknown but would also deny us its possibilities. The liberating idea of technology and resource creation is the human potential that is there, if we are aware of it and if we frame our policies accordingly. We will exhaust resources if we exhaust creative imagination. Technology as ideas and resource creation means that Descartes was more correct than he could possibly imagine when he said *cogito ergo sum,* that is, I think therefore I am. We think therefore we are and, more importantly, can be.

Notes

1. Quote from Erich Zimmermann, *World Resources and Industries* (New York: Harper & Bros., 1951), p. 15.
2. C. E. Ayres, *The Theory of Economic Progress* (Chapel Hill, N.C.: The University of North Carolina Press, 1943), p. 113.
3. One can find instances throughout human history of conservation and the protection of other species. Far more prevalent has been the wanton destruction of the environment and other life forms. As I argue in my book, *A Theory of Technology,* modern science and technology have created the understanding and conditions that have fostered the current wildlife and conservationist movements. Thomas R. De Gregori, *A Theory of Technology: Continuity and Change in Human Development* (Ames, Iowa: Iowa State University Press, 1985).
4. Ayres, *The Theory of Economic Progress,* p. 113.
5. Theodore Schultz, *Transforming Traditional Agriculture* (New Haven, Conn.: Yale University Press, 1964), is seen by many as the seminal work on science-based agriculture that generated a vast amount of empirical, theoretical, and applied work in world agriculture.
6. Wesley C. Mitchell, "Conservation, Liberty, and Economics," in *The Foundations of Conservation Education* (New York: National Wildlife Federation, 1941), p. 1.
7. Zimmermann, *World Resources and Industries,* p. 129.
8. De Gregori, *A Theory of Technology,* pp. 9–13.
9. Ibid., p. 12. The thesis used here is derived primarily from the work of Sherwood Washburn.
10. Mitchell, "Conservation, Liberty, and Economics," quoted in p. 1, Zimmermann, *World Resources and Industries,* p. 9. See also Robert C. Cowen, "Minerals: Breaking the Import Habit, Part 2: Knowledge, the Essential Raw Material," in *The Christian Science Monitor,* 12 January 1982, pp. 12–13.
11. Isaac Asimov, *A Choice of Catastrophes: The Disasters that Threaten Our World* (New York: Simon and Schuster, 1979), p. 291. Asimov notes that the word *metal* comes from the Greek, "to reach for," (p. 294), which is what humans do with metals and other resources; they reach for a better way of life.
12. *Resources for Freedom,* Communication from the President of the United States, Transmitting the Report of the President's Materials Policy Commission, June 1952, Washington D.C.: U.S. Government Printing Office, 1952. Five volumes, Doc. 527, 82nd Congress, 2nd Session.
13. Ibid., Vol. 1, *Foundations for Growth and Security,* p. 1.
14. Ibid. As in Dickens's *A Tale of Two Cities,* "It was the best of times, it was the worst of times . . . in short, the period was so far like the present period."
15. Jeremy Rifkin, *Entropy: A New World View* (New York: Viking, 1980).
16. Kirkpatrick Sale, *Human Scale* (New York: Coward, McCann and Geoghigan), 1980.
17. J. B. S. Haldane, "On Being the Right Size," in J. B. S. Haldane, *Possible Worlds* (New York: Harper & Row), 1928.

18. Donella H. Meadows et al., *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind* (New York: Universe Books), 1974.
19. DeGregori, *A Theory of Technology,* p. 61. Data are derived from J.S. Carman, *Obstacles to Mineral Development* (New York: Pergamon Press), 1979. Detailed data on population growth and food supply can be found in DeGregori, *A Theory of Technology,* Chap. 9, pp. 114–22 and p. 49.
20. H.J. Barnett and C. Morse, *Scarcity and Growth: The Economics of Natural Resource Availability* (Baltimore: Johns Hopkins University Press for Resources for the Future, 1963), and William Nordhaus, "Resources as a Constraint on Growth," *American Economic Review* 64 (May 1974): 22–26.
21. Max Singer, "How Dependent is the U.S. on Strategic Minerals?" *The Wall Street Journal,* 14 August 1986.
22. *World Development Report 1986* (New York: Oxford University Press for the World Bank, 1986), p. 7.
23. *World Economic Outlook,* April 1986, Washington, D.C.: International Monetary Fund 1986, pp. 139–45.
24. Ibid., pp. 139 and 141.
25. Leonard A. Pauleno, *Food in the Third World: Past Trends and Projections to 2000* (Washington, D.C.: International Food Policy Research Institute), Research Report 52, June 1986, pp. 41–42. Late projections for some food crops, such as wheat, hold the possibility that 1985/1986 may also set new records. Andrew Gowers, "World Harvest Record Forecast," Financial Times (London), 10 December 1986. And *World Agricultural Supply and Demand Estimates,* (WASDE-200), United States Department of Agriculture, Economic Research Service, Foreign Agricultural Service, 10 December 1986.
26. See Nicholas Eberstadt and Clifford M. Lewis, "How Many Are Hungry?", *The Atlantic,* May 1986, pp. 34–38, for an analysis of current greater food availability. See also Irma Adelman, "A Poverty-Focused Approach to Development," in *Development Strategies Reconsidered,* ed. John P. Lewis and Valeriana Kallab (New Brunswick, N.J.: Transaction Books, 1986), pp. 52–53, for data showing that the proportion of the world's population living below the poverty level fell from 39.8 percent to 22.4 percent between 1950 and 1980, even though inequality was increasing.
27. *Financial Times (London),* 4 November 1986.
28. *The Economist (London),* 4 October 1986, p. 75.
29. Ibid.
30. *Financial Times (London),* 20 November 1986.
31. See for example Louis Uchitelle, "A Worldwide Glut Crisis," *The New York Times,* 17 December 1986.
32. Theodore W. Schultz, Lectures in Agricultural Economics, Washington, D.C.: Economic Services Bicentennial Lecture Series Committee, 1977, pp. 16, 17.
33. N.W. Pirie, "The World Food Supply: Physical Limitations," in *Readings From Futures: A Collection of Articles From the Journal Futures,* ed. R. Jones (Guilford Surrey, England: Westbury House, 1981), p. 305.
34. DeGregori, *A Theory of Technology,* Chap. 10.
35. C. Lewis, "Global Food Security: A Manageable Problem," *Development*

Digest, 21 (July 1983): 106–121, at pp. 106, 107. See also Per Pinstrup-Andersen and Peter B.R. Hazell, "The Impact of the Green Revolution and Prospects for the Future," *Food Reviews International* 1 (1985): 1–25, and Frederick H. Buttel, Martin Kenney and Jack Klopperburg, Jr., "From Green Revolution to Biorevolution: Some Observations in the Third World," *Economic Development and Cultural Change* 34 (October 1985): 31–55.

36. John H. Lienhard, "Some Ideas About Growth and Quality in Technology," *Technological Forecasting and Social Change* 27 (1985): 265–81.
37. DeGregori, *A Theory of Technology,* pp. 3–9. These conclusions are drawn from many authors and reflect no individual inquiry by me.
38. Mark Nathan Cohen, *The Food Crisis in Prehistory: Overpopulation and the Origins of Agriculture,* New Haven, Conn.: Yale University Press, 1977.
39. On the rather limited gains from "appropriate" technologies, see R.S. Eckaus, "Appropriate Technology: The Movement Has Only a Few Clothes On," *Issues in Science and Technology* 3 (Winter 1987): 62–71.
40. In fact, it can be argued using data from work such as that of Lienhard, that historically, trends are more sustainable than the particular technologies driving them. For example, for any major endeavor today, such as computation or information transfer, it is clear that the trends over the last forty years were absurd or scientifically impossible and not sustainable under the known technologies of the time. That today we have such capabilities, or even greater capabilities, is the result of emergent possibilities of new technologies. Just since the completion of this article, developments in superconductivity have occurred that promise to greatly increase the resource character of barium, yttrium, and possibly lanthanum. Most of the material composites having superconductivity are ceramics, which are relatively cheap. Increasing efficiency in the transmission and use of electricity will also increase the resource character of the "stuffs" used to create electricity. All these factors will contribute to a continuing expansion in resources and a downward movement in real prices—and as problems of application are overcome, we will find new uses and unexpected possibilities for development.
41. Albert Camus, *The Myth of Sisyphus and Other Essays* (New York: Vintage Books), 1953, p. v.