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FOSSILS AND THE SOCIAL FUTURE OF SCIENCE

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ILLUSTRATION: ALLAN M. BURCH

My ambition as a boy was to become a scientist. The objects, phenomena, and living things we discovered on frequent family outings to the Dutch countryside, and later in New Jersey, ignited in me a life-long curiosity about nature, a curiosity that I have since been able to satisfy through the study of living and fossil creatures in the wild throughout the world. Generous funding made it possible for me to acquaint myself with the accumulated knowledge housed in the world's libraries, and to mine the riches in the greatest museum collections. Universities first taught and then employed me, enabling me to devote myself and to introduce others to scholarship.

Had I lived in the Middle Ages, things would have been different. I might well have ended up as a blind beggar on the streets, or have pondered theology at a monastery, or even faced burning at the stake as a heretic. In any case, I would not have become a scientist. Even a century ago, my ambitions would probably have been channeled into pursuits more consistent with society's expectations for the blind, such as music or employment in a sheltered workshop. But I grew up in an age of unprecedented opportunity, in an era when children were expected to do better than their parents, and when a life in science lay within reach even for blind immigrant boys in modest financial circumstances.

We have come to take the economic growth that accompanies such upward social mobility for granted. In fact, the world economy has grown so dependent upon expansion that most mainstream economists, and politicians of every persuasion, are united in their desire for more growth, and in their unwillingness to contemplate a dynamically stable system. In his 1960 book, *The Stages of Economic Growth*, Rostow confidently predicted that "Billions of people must live in the world, if we preserve it, over the century or so until the age of high mass-consumption becomes universal."* For him and for many like him, sustained growth in a high-consumption society of opulence is the final stage of economic development.

Science, too, is caught up in this quest. From the 16th century on it held a key role in the intellectual revolution that created a climate favorable to independent thought and economic activity, and for the past century and a half it has been instrumental in powering human economic expansion. The fivefold increase in the size of the human population since the year 1600, and the more than fivefold rise in the per capita demand for energy since 1900,† were the consequences, both directly and indirectly, of dramatic advances in agriculture, medicine, technology, and nearly every other branch of pure and applied science. Those of us fortunate enough to have realized our desire to become scientists and scholars have benefited from the economic system that, on the one hand, encouraged and became dependent upon an increase in knowledge, and, on the other, imperiled our environment, spawned destructive arms races, and forced rapid cultural change in society.

Economic growth cannot continue forever. Even if we can increase the efficiency with which we use resources and transform energy, continued expansion and the taking of the world's primary and secondary biological production will reach limits dictated by food, space, or some other secondary resource. During the last few hundred years science has helped to devise effective hypotheses about ourselves and our environment in the expansionist mode. Now it must help to guide us through an orderly transition from a growing to a dynamically stable economy, a transition that will cause far-reaching social changes. Not least among these changes will be shifts in how, to what ends, and by whom new knowledge will be gained and applied.

My perspective on these matters derives from my studies of the evolution and history of life as revealed by the fossil record. Dobzhansky once famously remarked that "Nothing in biology makes sense except in the light of evolution."‡ He might just as aptly have said, "Everything in evolution makes sense in the light of economics" or, "Nothing in economics makes sense except in the light of evolution." Human society is, in many ways, a microcosm of the biosphere or, perhaps more accurately in this age of ecological domination by *Homo sapiens*, the biosphere has become a microcosm of human society. Both are economic systems in which the production and distribution of goods and services obey rules set by the costs and benefits of competition and cooperation among component entities. Humans have the capacity to predict and to plan, which other living things and the process of natural selection that shaped life, do not. This gives us greater scope for altering the environment, for selfish exploitation of resources, and for making grievous errors. Yet our ability

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*W. W. Rostow, *The Stages of Economic Growth: A Non-Communist Manifesto* (Cambridge University Press, London, 1960), pp. 166–167. †J. E. Cohen, *How Many People Can the Earth Support?* (Norton, New York, 1995). ‡T. Dobzhansky, *American Biology Teacher* **35**, 125 (1973). §W. Sterrer, *Evolution and Cognition* 1, 101 (1992). ‖D. S. Landes, *The Wealth and Poverty of Nations: Why Some Are Rich and Some Are Poor* (Norton, New York, 1998).

to forecast and to anticipate does not in any fundamental way alter the nature or the outcomes intrinsic to a system in which finite resources are divided among interacting, metabolizing participants. Both the natural and the human economy are characterized by trade, by the division of labor, and by regulation, and both have witnessed repeated episodes of growth and contraction or stability as circumstances change and as economic players cause and adapt to these changes.

Sterrer (p. 106) captured the essence of the economy of nature when he observed that "An organism represents a hypothesis of its environment, continually tested by selection for its predictive value and modified by adaptation for a better fit."[§] From time to time in Earth history, physiologically favorable circumstances, together with biochemical and organizational innovations, triggered large-scale increases in the control that living things wield over each other and over the supply of raw materials on which life depends. "Living hypotheses" of environments changed along with the environments themselves, resulting in great evolutionary ferment.

Those species whose individuals, either alone or in coalitions, transformed the greatest quantities of energy came to dominate and therefore to exercise effective evolutionary control over other, less energy-intensive life forms. Some of the latter were relegated to the ecological fringes of the biosphere, where they helped to raise initially low rates of biological production, as in the early stages of colonization of the dry land by animals and by vascular plants. Such expansions, including episodes centered on the Cambrian explosion some 540 million years ago, and the middle Cretaceous renewal about 120 million years ago, involved cascades of feedbacks, which collectively brought about profound changes in the metabolism and complexity of the natural economy. Growth eventually stopped, or at least slowed down, as potential directions of improvement became ever more constrained by functionally conflicting requirements. Novelties still arose, but the prevalence of negative feedbacks often prevented their establishment until rare and unpredictable events such as mass extinctions temporarily disturbed the economic status quo. Conservatism became the hallmark of many of the economically dominant life forms, just as it had already done among the subordinates on the biosphere's economic margins.

On a vastly shorter time scale, human economic history has unfolded in a similar manner. Times of growth, such as the industrial and information revolutions and the period immediately preceding the Black Death in Europe,[‖] brought with them the emergence of the rich and powerful, who controlled and created an increasingly competitive economic system. The elite in societies undergoing economic growth could afford huge investments in resource-intensive military arms races, great public works, the arts, and profligate consumption. When growth slowed, competition still prevailed and may even have intensified, but adaptive responses to it became limited as outlays for one purpose necessarily denied allocations for others. The best strategy in the face of stiff competition in a world of strict trade-offs was conservatism and the pursuit of the exploitation and spending that had proven successful in the past and that would maintain society on a more or less even keel, however tilted in favor of those in power. Lavish spending on weapons as well as on the public luxuries of civilized life, such as science and the arts, yielded, in part, to maintenance of the necessities of life.

What do such historical patterns say about science? In today's already fiercely competitive research establishment, in which the number of scientists is increasing faster than the budget for research in many fields, scientists have learned that programs along well-established lines and with more or less predictable results are more likely to be funded than are less focused explorations of new directions. Instead of promoting innovation, competition in many fields is leading more and more scientists whose research is very expensive either to steer their efforts into well-charted territory or to abandon them altogether. Moreover, as science becomes disarticulated from the economic engine it once helped to power, it will face an uphill struggle to make the discoveries that will enable humans to adapt to a saturated world. Some commentators claim that science will soon run out of things to discover and explain, and that we shall, within the foreseeable future, know all that is knowable. On the contrary, I believe that a great deal will remain to be discovered for a long time to come, but that the economic opportunities for exploration, as well as for more focused research, will diminish as funds and talent are diverted to the more mundane business of "holding our own."

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Humans have a collective say in how resources are allocated. We could, and I think should, break with historical precedence and decide that science—even the kind of science that seems only to satisfy idle curiosity—deserves a significant slice of the financial pie, an insurance policy against unforeseen crises and an investment in making life civilized. We may neither need nor wish science to fuel expansion on Earth, but we must maintain and nurture our capacity to adapt and to probe. In abandoning, or at least reducing, science's economic role, we must not repeat the mistake of so many societies before ours who abandoned science itself. Just as it is unthinkable to place our fate in the hands of a despotic ruler, we must not allow tradition and religious superstition to choke rational inquiry and curiosity.

I like to believe that I could still have found my way into science in a nonexpansionist civilization of the future, where upward social mobility and its attendant opportunities would no longer be taken for granted to the degree that they have been in recent centuries. The preservation of opportunity in the face of unforgiving trade-offs, and the capacity to exercise a degree of freedom to pursue one's talent, strike me as a centrally important principle in the emerging society. The pursuit of scientific knowledge may become more like the arts, a way of rendering life meaningful and fulfilling rather than as an instrument of economic gain. Be that as it may, we must ensure that the social climate for the pursuit of science remains favorable so that we may, to some degree, prepare for unpredictable events that may sorely test our collective wisdom.

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