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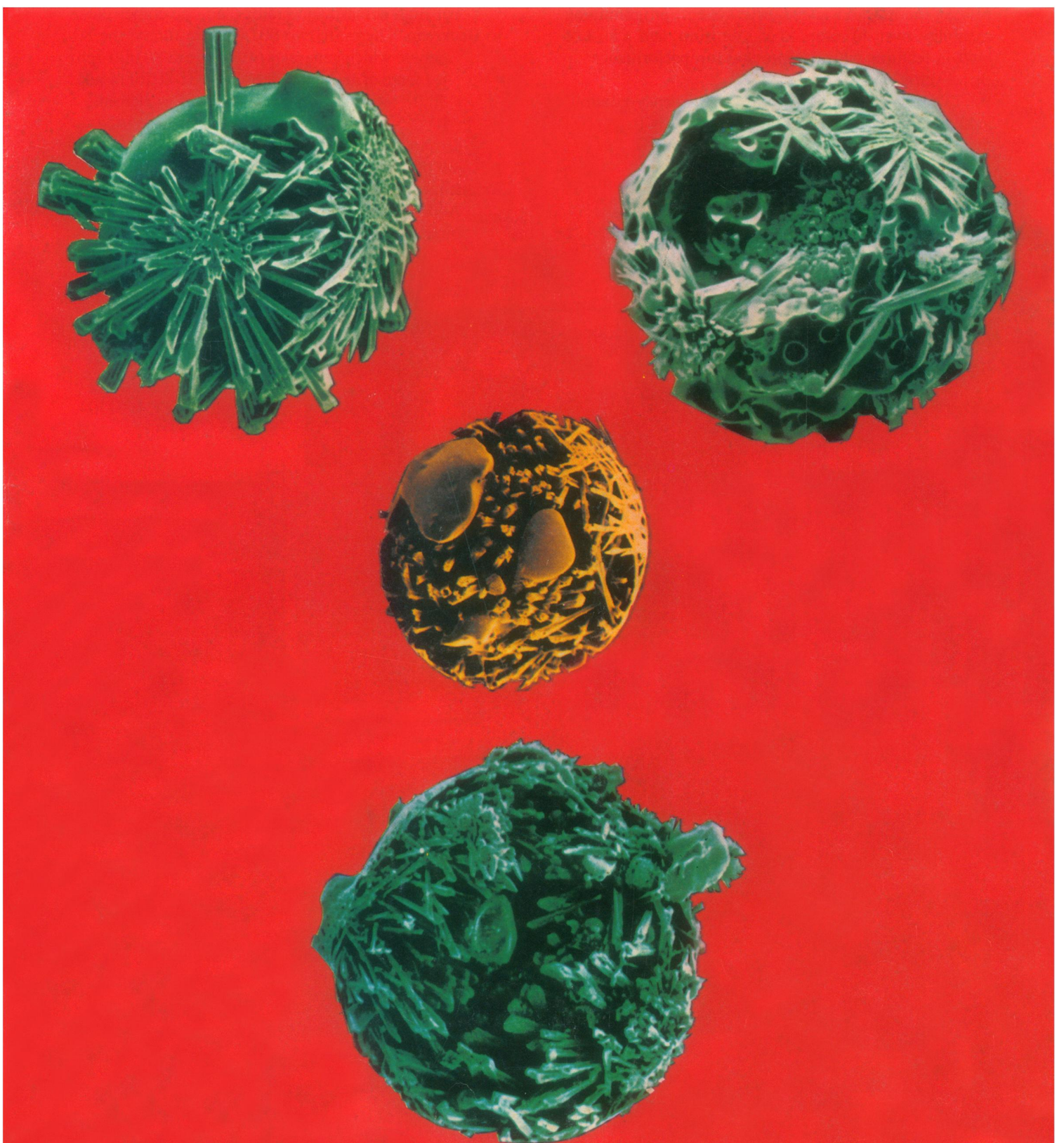

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1. J.A. Eisman, et. al., The Lancet, December 22/29, 1335-1336 (1979)

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COVER

Scanning electron photomicrographs of fly ash particles that have been etched in 1 percent hydrogen fluoride (×2200). Glass phases and the toxic elements contained within them have been removed, leaving crystalline residues of mullite (needles) and quartz. These are relatively pure and may be a recoverable resource that can be used in commercial ceramic manufacture. See page 1356. [Photomicrographs, Oak Ridge National Laboratory Analytical Chemistry Division, Oak Ridge, Tennessee 37830]

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tionality, such means are now being replaced with materials- and energy-frugal ones precisely because of the emerging scarcities that he denies. Such (economic) responses to scarcity make society better off than it would be in the absence of the responses, but not, in general, better off than it would be in the absence of the initial scarcity (*1*).

Simon would have us believe that the OPEC (Organization of Petroleum Exporting Countries) price for oil says nothing about oil scarcity, inasmuch as that price is far above OPEC's production cost. The fact is that OPEC is able to maintain its price largely *because* of increasing scarcity of oil (and a lack of immediately available alternatives) in most non-OPEC countries. This scarcity precludes meeting demand entirely from sources with production costs below the OPEC price, and ensures that the last units bought are bought on OPEC's terms. Substitution of alternatives—increased efficiency, synfuels from coal and shale—may gradually bring down the quantity of oil demanded at today's OPEC price; but these alternatives are more expensive than oil used to be and they can only ameliorate, not eliminate, the costs of the scarcity of oil.

Simon offers the price of electricity as "an interesting measure of the consumer cost of energy" and, by implication, a measure of energy scarcity. He says the price of electricity rose "after 1973" owing to the "improved market power of coal and uranium suppliers" in the wake of OPEC oil price rises. Then, dismissing this with the statement that "the long-run cost of electricity clearly has been downward," he concludes, "In short, the data show that energy has not been getting scarcer in basic economic terms, but rather has been getting more plentiful." The fact is that real electricity prices bottomed in 1971 and were already up 18 percent from that low point in 1972, before OPEC's actions (*2*). The fact is that OPEC's price hikes and the "improved market power" of coal and uranium *both* reflected a new reality based on emerging scarcity of oil and natural gas (*3*).

What follows Simon's errors about the economics of scarcity is a discussion of the physical underpinnings of the subject in which he tells us that "the term 'finite' is not only inappropriate but downright misleading in the context of natural resources," because, among other reasons and examples, "copper can be made from other metals." Indeed! Perhaps Simon here has in mind the technique of elemental transformation by bombard-

ment with subatomic particles in accelerators. Producing microgram quantities of copper by this means would be a gargantuan feat. Any implication that production in industrial quantities might be economically or energetically feasible is preposterous, as are his further assertions on this general topic (for instance, "Even the total weight of the earth is not a theoretical limit to the amount of copper that might be available to earthlings in the future. Only the total weight of the universe . . . would be such a theoretical limit. . . .").

With respect to food, Simon is enthusiastic about expanding land under cultivation by, for example, "irrigating deserts." But he does not discuss at all the constraints placed by lack of water on food production from arid and semiarid lands (*4*). The withdrawal of water for existing irrigation schemes already has drained some major rivers, such as the Colorado, nearly dry, and rapid depletion of "fossil" water supplies is of enormous concern in areas such as the plains of Texas. Interregional water-transfer schemes are staggeringly expensive and usually beset with political obstacles (*5*), not to mention their environmental liabilities. Desalination remains too expensive in energy and in dollars for use on staple crops (*6*). And in times of prolonged drought, which are certain to occur in the future as they have in the past, nations relying too heavily on irrigated arid lands for food will be crippled.

On the environmental side, irrigated arid lands are subject to salt-clogging, which reduces and eventually destroys their productivity; this problem plagues arid-land agriculture in the southwestern United States as well as in less-developed countries (*7*). Bringing more land under the plow by deforesting hilly terrain in temperate and tropical regions can lead to severe erosion, whereby the extra carrying capacity temporarily gained is literally washed away. On some tropical soils, the benefits of land clearing for agriculture are even shorter lived, as laterization turns the exposed soil to rock. And if deforestation for agriculture proceeds on a large enough scale, the resulting pulse of carbon dioxide may combine with that from increasing fossil-fuel combustion to alter global climate in a way that undermines food production to an unprecedented degree (*8*).

Simon proposes that it is not only possible but proper to appropriate all the earth's resources (and more!) for the direct support of human beings. This notion is not unprecedented (*9*, *10*). Per-

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haps economics cannot deal with concepts as resistant to monetization as the rights of nonhuman species to exist (*10*) and the aesthetic poverty of a world with no room for unmanaged environments. But even if one were to accept the maximization of the mass of human protoplasm sustainable on earth as a goal superordinate to all others, it would be a monstrous error to think that this goal could be realized without the services derived from largely unmanaged biogeophysical processes.

Today such processes regulate climate and the availability of water, screen out harmful radiation from the sun, maintain soil fertility and the chemical quality of air and water, control most potential crop pests and agents and vectors of human disease, and maintain a library of genetic information uniquely useful for the protection of existing food crops and the development of new ones, the development of new drugs and vaccines, the development of new industrial materials, and the understanding of life itself (*11*). The intricacy and the immensity of these processes preclude replacing them or their services with technological substitutes on any interesting time scale. . . .

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References and Notes

1. The general nature of the responses is to substitute, for the increasingly scarce resources, inputs that are less expensive than the scarce resources now are but more expensive than those resources used to be. Thus, installing insulation may save oil at a cost equivalent to paying $10 a barrel for the oil saved; this is a saving compared to buying world-market oil at $30 a barrel, but a net cost (due to oil's increasing scarcity) compared to the cost of keeping warm when oil was $3 a barrel.
2. S. Schurr, J. Darmstadter, H. Perry, W. Ramsay, M. Russell, *Energy in America's Future* (Johns Hopkins Press for Resources for the Future, Baltimore, 1979), p. 93.
3. Interestingly, this turning point was predicted accurately (on basic physical grounds) more than two decades in advance of the event. See, for example, M. K. Hubbert, *Science* **109**, 103 (1949); and President's Materials Policy Commission, *Resources for Freedom* (Government Printing Office, Washington, D.C., 1952).
4. H. E. Dregne, Ed., *Arid Lands in Transition* (American Association for the Advancement of Science, Washington, D.C., 1970).
5. J. Hirshleifer, J. DeHaven, J. Milliman, *Water Supply* (Univ. of Chicago Press, Chicago, 1969).
6. M. Clawson, H. H. Landsberg, L. T. Alexander, *Science* **164**, 1141 (1969). Developments since 1969 have not altered this assessment's conclusion.
7. Council on Environmental Quality, *Environmental Quality—1978* (Government Printing Office, Washington, D.C., 1978), pp. 472–474.
8. Because agriculture is highly adapted to existing climatic patterns, it is far more likely that any major change will reduce food production in the short term than that it will improve it. See, for example, S. H. Schneider and L. Mesirow, *The Genesis Strategy* (Plenum, New York, 1976).
9. See, for example, C. Marchetti, *Energy* 4, 1107 (1979); H. Kahn, W. Brown, L. Martel, *The Next 200 Years* (Morrow, New York, 1976).
10. D. Ehrenfeld, *The Arrogance of Humanism* (Oxford Univ. Press, New York, 1978).
11. P. Ehrlich, A. Ehrlich, J. Holdren, *Ecoscience* (Freeman, San Francisco, 1977).

Overall, Simon's reassurances concerning world population and resources are at best unconvincing. His article begins very well with an example of a U.N. demographer's report being misconstrued. In the rest of the article he shows us (unintentionally) why such reports are so easily misconstrued by the formats and arguments he uses in presenting his own data.

For instance: The U.N. Food and Agriculture Organization (FAO) published data on per capita food production from individual countries. Simon evidently recognized that he could best serve his argument by tabulating the data on a worldwide basis. His table shows a 1969 index of 119 rising to 128 in 1976. However, FAO data show that Africa (the subject of Simon's first reassuring tale) suffered a decline from index = 100 in 1969 to 94 in 1976 and was at 90 in 1977 and 1978. In addition, FAO data show that the per capita food *supply* (often higher than food production in underdeveloped countries) has dropped for the countries termed "most severely affected" by food shortages, from 2040 calories in 1962 to 2030 in 1973. This tells a different tale from one that would be produced by Simon's technique, the worldwide food supply having increased during that same period from 2410 to 2550 calories. . . .

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As practitioners of geography, a discipline which has raised questions about areal variations in resources, population, and environment since the Yu Kung resource analysis of China in the 5th century B.C., we question some of Simon's use of linear conclusions from aggregate statistics.

Simon says that news stories "originating from" a book by Eric Eckholm (*1*) "clearly imply a more general proposition: that the world's supply of arable land is decreasing. Yet the truth is exactly the opposite." First, it should be made clear that Eckholm nowhere makes this general proposition. He specifies the location of his examples of loss-

es of arable lands such as the Thar Desert of Rajasthan, the Gamu Highlands south of Addis Ababa, or the Kosi catchment area of eastern Nepal. Eckholm's findings are empirical, and those who have viewed the environmental degradation on the ground or even from an airplane will corroborate his evidence.

Eckholm is careful not to use the often biased aggregate statistics of national governments. Moreover, Simon's source, Joginder Kumar, documents the limitations of government statistics on arable land.* Simon, determined to use the evidence as good news, omits caveats.

Simon implies that the aggregate figures showing the increase in the percentage of both arable and cultivated arable are not bad news. Eckholm avoids mention of poorly defined concepts like arable or cultivated land. Perhaps Eckholm was more aware that when discussing arable land, as Kumar carefully documents, there is little exactness in the "truth." Eckholm focuses his analysis on the underlying processes: "the incipient breakdown of sustainable agricultural systems." The processes seem to be of little importance to Simon, who does not mention Kumar's other finding (*2*) that fallow land decreased by 8 percent between 1950 and 1960. This lessening of the degrees of freedom—as people begin to use petroleum-dependent irrigation in areas where water (a critical resource Simon does not consider) is scarce and where slopes are prone to soil erosion—may indeed be bad news. . . .

Not only, as Kumar suggests, are "data on arable land classified in several ways," but also differences in technology may change the amounts of arable land; for example, no-till agriculture may permit the cropping of former pastures and woodlands on steep slopes. On the other hand, increases in energy costs may diminish the acreages that can be irrigated by pumping in poorer countries, such as Bangladesh, which are becoming increasingly dependent on deep agricultural tube wells.

Simon has standardized world per capita food production between 1948 and 1976 in his table 2. World production per capita certainly increases, but it is poor evidence of the food situation in developing countries. A report from the Asian Development Bank entitled *Rural Asia* (*3*) chronicles the decline in real wages through the 1970's and increasing unemployment or underemployment in its developing member countries. Raj Krishna, of the Indian Planning Commission, sums up the situation: "Food surpluses are bogus when the malnourished have no purchasing power" (*4*). Neither cost nor price is a comprehensive measure of scarcity for the starving family that has no purchasing power. Chen and Chowdhury (*5*) and Currey (*6*) have shown that there need be no per capita food shortage in Bangladesh to have a famine and widespread starvation. Bhatia (*7*) illustrated the same situation in India, and Habicht (*8*) found the same situation in Indonesia. . . .

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**Editor's Note:* The reference for the source of data in Simon's table on land use was misnumbered. The intended reference was to the book by Kumar (*2*) cited in the text of the article.

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8. J. P. Habicht, personal communication, June 1980.

We applaud Simon's article for its systematic reconsideration of much of the "false bad news" which is fed to the public in the guise of careful analysis. In particular, we enthusiastically endorse his criticism of the Paddock brothers' *Famine—1975!* (*1*) and of the reprehensible notion that a policy of "triage" should determine the allocation of aid to less-developed countries.

One segment of the article, however—the discussion of the relation between population growth and economic growth—leaves an impression that seems to us to be quite unwarranted. It is certainly true that this relation is complex and poorly understood. That the zero-order correlation between population growth and per capita income growth is low is one indication of this complexity. It is our view that in some circumstances rapid population growth can be quite detrimental to a country's development prospects, while in other circumstances it may even be helpful. One question on

the frontier of our discipline is how to distinguish between these two cases.

Simon's simulation model is not very helpful in addressing this question. First, it lumps all less-developed countries together. Second, it makes a number of assumptions which appear to us to be of questionable applicability to many less-developed countries (*2–4*). One dubious feature of the model is the assumption that members of large families will work harder and therefore produce more. "Certainly in countries like India or Bangladesh," as one of us has said elsewhere, "where population growth is exacerbating the progressive fragmentation of holdings and the increase in the number of landless laborers, it seems much more likely that increased population pressure in rural areas will lead to further reduction in calorie intake and impaired capacity for work among the poor" (*2*, pp. 886–887). Another questionable feature of the model is that social overhead capital in it "drops like manna from heaven whenever the labor force grows" (*3*, pp. 98–99).

The news about the relation between population and economic growth does not all come from the media or from individuals or institutions looking for their own financial gain. Government policymakers in countries accounting for some 90 percent of the world's population have now adopted policies to promote family planning even though it is recognized that the issue is politically sensitive. This is, of course, consistent with a recognition that progress in improving per capita well-being is a function of changes in both the numerator (production) and the denominator (population) and that development policies need to be concerned with improving the rate of growth, the distribution, and the composition of output as well as with slowing the increase in population. The reversal of policy in the People's Republic of China is of particular interest (*5*). . . .

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4. _____, *Economic-Demographic Simulation Models: A Review of Their Usefulness for Policy Analysis* (RM-80-14, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1980).
5. C. Muhua, *Fam. Plann. Perspect.* **11** (No. 6), 348 (1979).

. . . There is no justification for Simon's implied assumption that a trend of the past will continue into the future ("raising our standard of living from what it was 20,000 years ago, 200 years ago, 20 years ago, to what it is now"). He quotes a work of 1682 to support his thesis that the more people there are on earth the larger the number of innovative minds to further economic progress. Population and resource usage today are scarcely comparable to what they were in 1682. Nor is there justification, on a finite planet whose surface area and mineral wealth per person must decrease with each population increment, to imply as Simon does that because a larger population gives us more potential for producing a "supermarket clerk who develops a quicker way to stamp the prices on cans" it will improve our material well-being. If absolute numbers reflect the numbers of "ingenious curious" minds, and if "additional persons . . . lead to an increase in per worker output," then the intellectual and productive leadership among nations would show China and India at the top, and Bangladesh leading Norway by an order of magnitude.

Economist Simon seems not to recognize the law of diminishing returns. He seems to imply that if x babies born today become productive in 25 years, nx, resulting in population growth, would be desirable ("additional children have positive long-run effects upon the standard of living"). This is no more logical than taking two dozen aspirin when the doctor prescribes two. One does not have to be an animal ecologist (as I am) to recognize that human beings, like any other species, have the biological ability to overrun the carrying capacity of their habitat.

With regard to mineral resources Simon brings up a new version of a tired old argument long advanced by economists who seem to know nothing about geology: when supplies get low prices rise, exploration increases, and supplies rebound; increasing efficiencies in mining and processing drive prices down, creating disincentive for exploration until scarcity looms again. Once again we have the implied assumption that because this has happened in the past it will happen in the future. But geologists recognize that, with few exceptions, mineral resources are unevenly distributed. As lodes are depleted it becomes ever more difficult to find replacements. When the silver mines of Idaho play out, production cannot be restored by explorations in Kentucky, no matter how high the price of silver may be.

Regarding energy scarcity, Simon says

advancing technology has lowered the cost of oil production to $0.05 to $0.15 per barrel. From this fact he concludes that the "long-run downward trend in the price of oil will resume its course." That conclusion defies logic. The significant cost is not the pumping cost but the cost of finding as a replacement another barrel of oil or a comparable energy source. This cost has been rising dramatically. Like many other people, Simon confuses oil production with oil consumption. No one is producing any significant amount of oil these days, because the cost of producing it from recent photosynthetic products is greater than the price of OPEC oil. Rather, we are consuming that which was produced by natural forces in a past geological era. We have not solved our problem of declining oil reserves by increasing the efficiency of our pumping technology. . . .

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. . . Simon repeatedly commits the same fallacy he notes in others: past trends are simply extrapolated into the future. It is worth recalling the story of the person who leaped from a very tall building and on being asked how things were going as he passed the 20th floor replied, "Fine, so far."

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I do not say that all is well everywhere, and I do not predict that all will be rosy in the future. Children are hungry and sick; people live out lives of physical or intellectual poverty, and lack of opportunity; war or some new pollution may finish us. What I *am* saying is that for most relevant economic matters I have checked, aggregate *trends* are improving rather than deteriorating. And I doubt that it helps the world's troubled people to say that things are getting worse though they are really getting better.

On only two points did letters challenge my data's accuracy:

1) In response to my statement that "long-run cost of electricity clearly has been downward," and that prices rose after 1973 due to OPEC pricing, Holdren *et al.* write: "The fact is that real electricity prices bottomed in 1971 and were already up 18 percent from that low point in 1972, before OPEC's actions."

I was taken aback; Holdren and Harte are energy scholars. I checked Fig. 1 and other sources but could see no sign of

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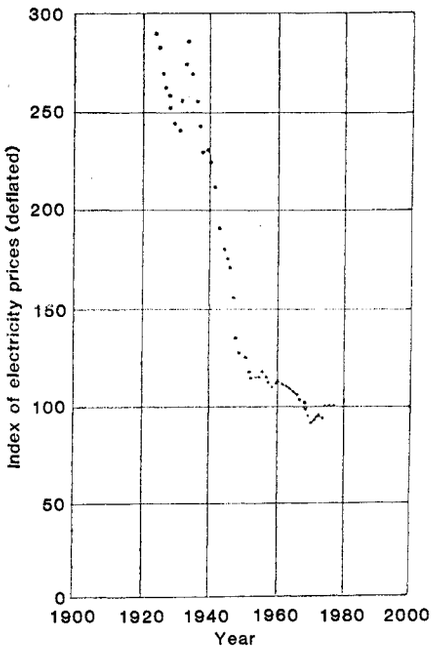

Fig. 1. Price of electricity relative to consumer price index (*9*).

their 18 percent. I therefore called the senior author of their reference (*1*), and Schurr's assistant read these index numbers: 1967, 100; 1970, 91; 1971, 80.2; 1972, 94.9; 1973, 93.8; 1974, 99.9; 1975, 103.6; 1976, 104.2; 1977, 104.3.

To find out more about the 1971 figure, the basis of the Holdren *et al.* assertion, Schurr's assistant suggested calling coauthor Darmstadter. He, too, was puzzled. Upon investigation, the 1971 number (80.2) proved a typographical error and should have been 93.3. So much for Holdren *et al.*'s "fact."

Central here, however, is not the typo. Even if correct, it would seem scientifically imprudent to rely for any general conclusion upon a single number against the contrary evidence of a sweep of data three-quarters of a century long (Figure 1) that tells a radically different story, especially when widening the inspection slightly would have changed their conclusion entirely.

Upon this one incorrect number, concerning just one among practically all raw materials for which the data show long-run price falls, Holdren *et al.* build their case that I make "errors about the economics of scarcity." Does not this unfounded bad news reinforce the central point of my article? Perhaps this example and the next will convince some that my arguments are not simply defective scholarship or improper data selection.

2) A letter originally set in galleys, but omitted after I responded, called "incorrect" my statement that there have been "sharp improvements [in environmental quality] in the last decade." As evidence the author reproduced a recent *Scientific American* graph of Likens *et al.* (*2*) which he said shows "an overall deterioration in air quality due to sulfur dioxide" from 1974 to 1976. (My graph stopped at 1974.) But Likens *et al.*'s graph does not refer to air quality, but rather to SO_2 emissions; one is not an index of the other. And the lastest Environmental Protection Agency data about SO_2 and air quality show continued improvement in "national trends" (*3*).

If specialists can believe that the long-run trends in electricity prices and in U.S. air quality are worsening despite easily accessible data, what *will* convince people that things are getting better even when they are? In July 1980, an Associated Press article mentioned "the 1972–74 drought, when 300,000 or more died in Ethiopia and the Sahel belt South of the Sahara" (*4*), a mortality figure higher than ever despite evidence discrediting even much lower figures.

Several letters criticize using aggregate global data. Bodoia says: "Simon evidently recognized that he could best serve his argument by tabulating the [food] data on a worldwide basis" (an insulting insinuation too typical of the letters.) And Street *et al.* refer to the data I use as "biased aggregate [land] statistics." Of course aggregated food and land data contain inaccuracy, maybe more than most economic data. But I believe that such aggregates are more reliable for statements about the world as a whole than Eckholm's anecdotal pick-and-choose technique which Street *et al.* recommend.

Holdren *et al.* and others had a good laugh about alchemy and making copper from other metals. Even if what I wrote was physically impossible (which it is not), the point would not bear importantly upon the argument, and therefore it is simply a debating device questioning my competence. However, I am not in error in principle, as Holdren *et al.* note; rather, they claim it is "preposterous" because it is impractical now. But—this is my point—so was electricity considered impractical a century ago. And in perhaps the first full-scale attempt by a great social scientist to evaluate the future energy situation, Jevons (*5*) concluded in 1865 that oil could never relieve the coal crunch he predicted would strangle Great Britain's economic growth about 1900. (England now exports both coal and oil.)

A letter originally scheduled for publication counterposed the *Global 2000 Report*'s conclusions of which "Simon seems to be unaware." My forthcoming

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19 December 1980, Volume 210, Number 4476 **SCIENCE**

World Energy in Transition

The geopolitics of oil will be a very troublesome factor in global relationships during the next two decades. That is the message of a report issued on 20 November by the Senate Committee on Energy and Natural Resources, chaired by Senator Henry Jackson.* The document is the product of a year-long study that included 15 hearings on the worldwide political, social, military, and economic problems that will contribute in major ways to determining the price and availability of oil through the rest of the century.

In a foreword to the report, Senator Jackson said, "[S]ociety in the 20th century has developed around easy-to-use, cheap oil, and most of our major institutions, including our military, are heavily dependent upon this particular form of energy. Oil is the lifeblood of the modern world. Without oil no modern economy can presently exist. . . . [T]he basic reason why the government must be concerned about access to oil is because of the threat to our national security and to world peace of oil supply disruptions and political manipulation of the consuming nations' access to oil."

For most of the world the era of cheap and secure oil supplies has ended. Every thoughtful person knew that eventually petroleum must become scarce. But what few people foresaw was how rapidly prices would increase or how many contingencies could arise leading to interruptions of supplies. A few years ago, it was commonly argued that world reserves were sufficient for 30 years and hence it was not necessary to move urgently toward greater energy efficiency or development of alternatives to oil. This seemed particularly true for the United States, where domestic sources supply about 83 percent of total energy consumption and more than half of petroleum requirements. Were the United States to assemble an emergency reserve of oil, it could place itself in a fairly good position to endure a year-long interruption. Moreover, deregulation of domestic oil and natural gas is leading to greater energy efficiency, enhanced discoveries of natural gas, more tertiary recovery of oil, substitution of coal for oil and natural gas, and conversion of residual oil to more useful products. The United States is on its way toward energy independence. But what of Western Europe, Japan, and the Third World, which are more heavily dependent on imported oil? During the next decades their economies, political stability, and international policies will be subject to drastic upheavals by forces not under their own control. They will be candidates for manipulation by the petroleum exporting countries and, what is even more menacing, by the Soviet Union. Control of energy supplies by the U.S.S.R. could lead to a Russian bid for control of the Eurasian landmass.

During last summer and autumn, I met with leaders of science and technology in France, West Germany, and Japan. In all those countries I sensed an attitude of desperation. West Germany has been importing about 50 percent of its energy supplies, France about 73 percent, and Japan about 90 percent. Virtually all the oil these countries use is imported. Especially in France and Japan I encountered a steely determination to do whatever seemed necessary to move toward energy independence. The most impressive example was the Japanese actions with respect to nuclear energy. That country has had terrifying experiences with nuclear explosions. It has also endured enormously destructive earthquakes. Extrapolating from long historical records, the Japanese know that in the future they will be subject to more earthquakes and that no place on their main island is quake-free. Despite these circumstances, Japan is building and operating power reactors and in a few years will be second in the world in terms of installed nuclear power capacity. Already the Japanese are replacing oil in other applications by natural gas and coal.

The world will never be risk-free. But it will be safer when it becomes less dependent on oil from the Persian Gulf. The United States can do its part by developing alternative energy sources, lessening its imports of oil, and making more of its coal available for export.—PHILIP H. ABELSON

*"The Geopolitics of Oil" (Government Printing Office, Washington, D.C., 1980). The Executive Summary is reprinted in this issue; see p. 1324.

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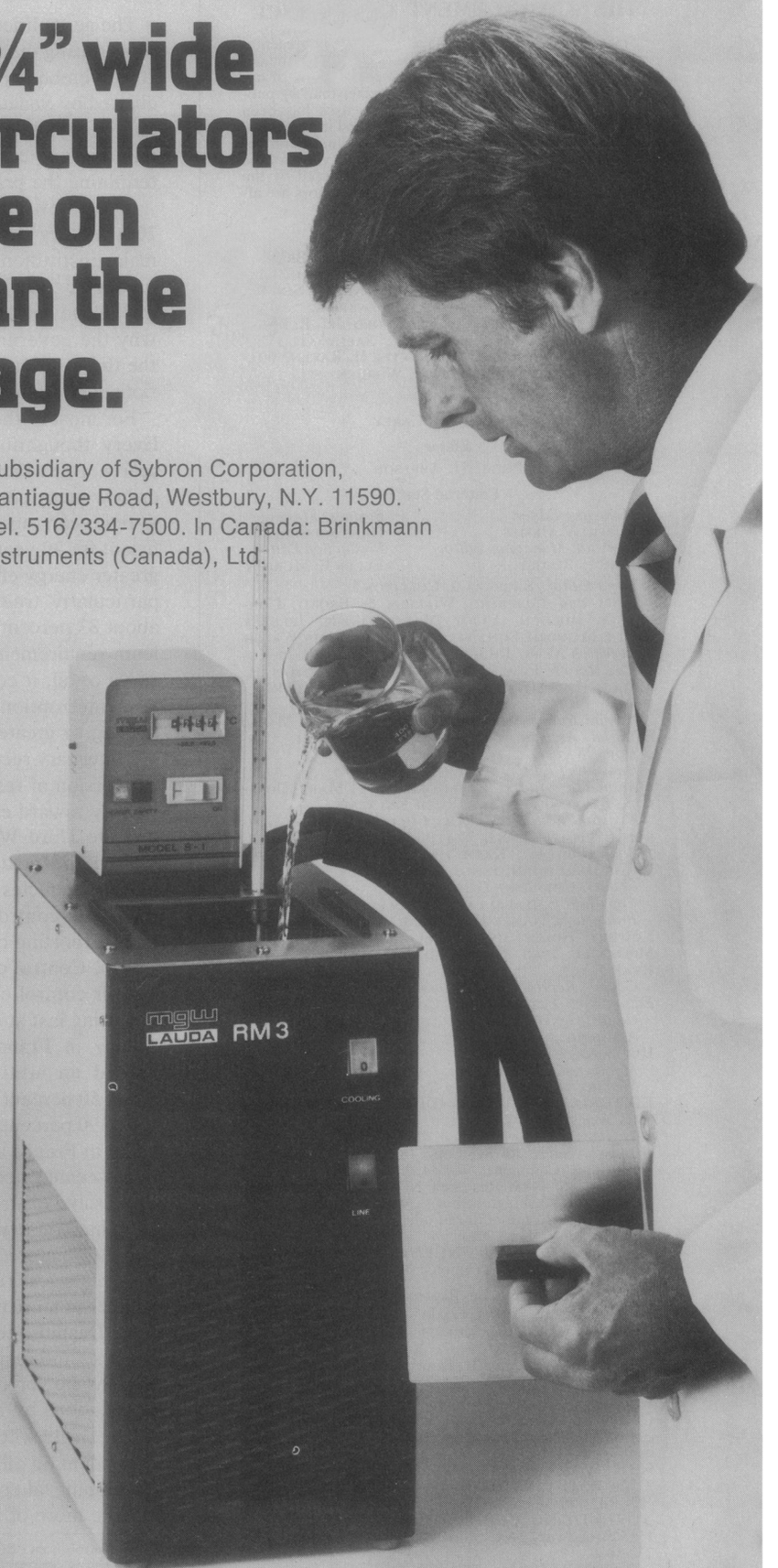

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