

44. G. M. Smith and P. Gund, *J. Chem. Inf. Comp. Sci.* **18**, 207 (1978).
45. R. J. Feldmann, *Annu. Rev. Biophys. Bioeng.* **5**, 477 (1976).
46. Processed by Holographic Film Company, New York, N.Y.
47. D. L. Vickers, G. S. Smith, S. R. Levine, *Trans. Am. Crystallogr. Assoc.* **12**, 85 (1976).
48. The structure was modeled by analogy with known crystal structures by R. W. Ratcliffe.
49. J. M. T. Hamilton-Miller, D. W. Kerry, W. Brumfitt, *J. Antibiot.* **27**, 42 (1974).
50. The hologram was exhibited at the 10th International Congress of Chemotherapy at Zurich, September 1977.
51. S. C. Nyburg, *Acta Crystallogr. Sect. B* **30**, 251 (1974).
52. D. S. Fullerton, K. Yoshioka, D. C. Rohrer, A. H. L. From, K. Ahmed, *Science* **205**, 917 (1979).
53. T. M. Dyott, A. J. Stuper, G. S. Zander, *J. Chem. Inf. Comp. Sci.* **20**, 28 (1980).
54. J. D. Andose and M. Pensak, unpublished Fortran program.
55. R. Freidinger and D. F. Veber, *J. Am. Chem. Soc.* **101**, 6129 (1979).
56. G. M. Smith and H. B. Schlegel, unpublished results.
57. W. T. Wipke and P. H. Gund, *J. Am. Chem. Soc.* **96**, 299 (1974); *ibid.* **98**, 8107 (1976).
58. R. J. Feldmann, D. H. Bing, B. C. Furie, B. Furie, *Proc. Natl. Acad. Sci. U.S.A.* **75**, 5409 (1978).
59. C. M. Anderson, F. H. Zucker, T. A. Steitz, *Science* **204**, 375 (1979).
60. R. L. Smith, D. W. Cochran, P. Gund, E. J. Cragoe, Jr., *J. Am. Chem. Soc.* **101**, 191 (1979).
61. R. L. Smith, D. W. Cochran, E. J. Cragoe, Jr., P. Gund, in *Amiloride and Epithelial Sodium Transport*, A. W. Cuthbert, G. M. Fanelli, Jr., A. Scriabine, Eds. (Urban & Schwarzenberg, Baltimore, 1979), p. 21.
62. G. M. Cole, E. F. Meyer, Jr., S. M. Swanson, W. G. White, in *Computer-Assisted Drug Design* (Symp. Ser. No. 112, American Chemical Society, Washington, D.C., 1979), p. 189.
63. G. R. Marshall, C. D. Barry, H. E. Bosshard, R. A. Dammkoehler, D. A. Dunn, in *ibid.*, p. 205.
64. D. Hodges, D. Nordby, G. Marshall, in *169th National Meeting of the American Chemical Society, Philadelphia, Pa., 6 to 17 April 1975*, abstracts COMP-7 and 16.
65. D. F. Eaton and D. A. Pensak, *J. Am. Chem. Soc.* **100**, 7428 (1978).
66. A. W. Douglas, M. H. Fisher, J. J. Fishinger, P. Gund, E. E. Harris, G. Olson, A. A. Patchett, W. V. Ruyle, *J. Med. Chem.* **20**, 939 (1977).
67. P. Gund and D. F. Veber, *J. Am. Chem. Soc.* **101**, 1885 (1979).
68. W. C. Lumma, Jr., R. D. Hartman, W. S. Saari, E. L. Englehardt, R. Hirschmann, B. V. Clineschmidt, M. L. Torchiana, C. A. Stone, *J. Med. Chem.* **21**, 536 (1978).
69. P. Gund, J. Springer, W. Halczenko, J. S. Murphy, K. L. Shepard, in *Southeast Regional Meeting of the American Chemical Society, Roanoke, Va., October 1979*, abstract 279.
70. G. Hartman, in *10th annual Meeting of the Environmental Mutagen Society, New Orleans, March 1979*, abstract Cd-13.
71. J. C. Fontecilla-Camps, C. E. Bugg, C. Temple, Jr., J. D. Rose, J. A. Montgomery, R. L. Kisliuk, *J. Am. Chem. Soc.* **101**, 6114 (1979).
72. We thank E. Fluder, M. Pensak, J. Wendoloski, and H. B. Schlegel for contributing to the design and implementation of MMMS; W. T. Wipke, K. Wiberg, and B. Christensen for early advice and guidance; H. D. Brown for support and encouragement; R. F. Hirschmann for his advocacy of the MMMS and for helpful discussions; and a large number of scientists in Rahway, West Point, and Montreal for their acceptance of and enthusiasm for MMMS, and their helpful suggestions for improvements.

Resources, Population, Environment: An Oversupply of False Bad News

Julian L. Simon

In September 1977 *Newsweek* reported that "more than 100,000 West Africans perished of hunger" in the Sahel between 1968 and 1973 because of drought (1). Upon inquiry, the writer of the account, Peter Gwynne, informed me that

saying, "Who can forget the horror of millions of men, women and children starving, with more than 100,000 dying, because of an ecological calamity that turned grazing land and farms into bleak desert?" (ii) A two-page excerpt from a

Summary. False bad news about population growth, natural resources, and the environment is published widely in the face of contradictory evidence. For example, the world supply of arable land has actually been increasing, the scarcity of natural resources including food and energy has been decreasing, and basic measures of U.S. environmental quality show positive trends. The aggregate data show no long-run negative effect of population growth upon the standard of living. Models that embody forces omitted in the past, especially the influence of population size upon productivity increase, suggest a long-run positive effect of additional people.

the estimate came from Kurt Waldheim's message to the United Nations' Desertification Conference. I therefore wrote to Waldheim asking for the source of the estimate.

Three mutually contradictory documents came back from the United Nations' Public Inquiries Unit: (i) Waldheim's message to the conference,

memo by the U.N. Sahelian Office, dated 8 November 1974, saying, "It is not possible to calculate the present and future impact of this tragedy, on the populations. . . . Although precise figures are not available, indeed unobtainable . . . certainly there has been an extensive and tragic loss of life. . . ." (iii) A one-page memo written for the United

Nations by Helen Ware, an Australian expert on African demography, who was a visiting fellow at the University of Ibadan in March 1975 when she wrote it. From calculations of the normal death rate for the area, together with "the highest death rate in any group of nomads" during the drought, she estimated "an absolute, and most improbable, upper limit [of] a hundred thousand. . . . Even as a maximum [this estimate] represents an unreal limit."

Ware's statement, which makes nonsense of Waldheim's well-publicized assessment, was on page one of a document written for the United Nations well before the Desertification Conference. Apparently it was the only calculation the United Nations had, and it was grossly misinterpreted.

More recently, the U.N. press releases have retreated to the more modest assertion that "tens of thousands" died in the Sahelian drought (2). But even this assertion is undocumented. "The problem with deaths in the Sahel," Ware says, "is precisely that there was so little evidence of them—rather like the photograph of the dead cow which kept turning up in illustration to every newspaper story" (3). A recent summary of the scientific evidence on the drought's effects by John Caldwell, a demographer who was familiar with the area prior to the drought and spent 1973 there, says, "One cannot certainly identify the existence of the drought in the vital statistics . . . nutritional levels, although poor, were similar to those found before

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the drought in other parts of Africa. The only possible exception was that of very young children" (4).

This is an example of a common phenomenon: Bad news about population growth, natural resources, and the environment that is based on flimsy evidence or no evidence at all is published widely in the face of contradictory evidence.

Another example comes from the same *Newsweek* piece: "More than one-third of all the land is desert or near-desert. And deserts are spreading inexorably, turning arable land into stony waste or heaps of drifting sand . . . annually destroying twelve million to seventeen million acres" (1). The headline on a front-page story in the *New York Times* said, "14 Million Acres a Year Vanishing as Deserts Spread Around Globe" (5).

Some arable land surely is deteriorating. But these news stories, and the many others originating from the book *Losing Ground* (6), by Erik Eckholm of Worldwatch Institute, clearly imply a

more general proposition: that the world's supply of arable land is decreasing. Yet the truth is exactly the opposite: Joginder Kumar made a country-by-country survey of the changes in arable land from 1950 to 1960 (7). His finding: There was 9 percent more total arable land in 1960 than in 1950 in the 87 countries for which he could find data (constituting 73 percent of the land area of the world)—a gain of almost 1 percent per year (Table 1). And the more recent Food and Agriculture Organization data show a rise in "arable and permanent cropland" from 1403 to 1507 million hectares in the world as a whole from 1961-65 to 1974, an annual increase of roughly 0.7 percent. In the developing countries the area increased by 1.1 percent annually over the decade 1960 to 1970 (8).

The increase in the quantity of land that is cultivated rose even faster than 1 percent per year—from 8.9 percent of the total area to 9.9 percent during 1950 to 1960 (Table 1). And the increase in ef-

fective crop area was greater yet, because of the increase in multiple cropping in Asia and elsewhere. In some places the extension of cultivation has reduced the quality of land, of course, but in other places the process has improved the quality of land (9).

But does not a larger population necessarily mean "more pressure" on the land, so that ultimately everyone will be scratching out three skimpy meals from 18 hours of work a day on a plot the size of a window box? There has been such a trend in countries that have not yet entered into modernization and industrialization. For example, farm size declined as population increased in Poland from 1787 to 1937 and in China from 1870 to 1930 (10). But the more general trend points in the opposite direction. In all the higher-income industrialized countries in Europe and North America, and in Japan, a smaller absolute number of farmers are producing much more food and feeding much larger populations than in the past. An extrapolation of this benign

Table 1. Land use, 1950 and 1960. [Data from (6, p. 107)]

Region	Arable as % of total		Cultivated as % of arable		Cultivated as % of total		Arable plus pasture as % of total	
	1950	1960	1950	1960	1950	1960	1950	1960
Africa	14.27	15.30	36.21	42.72	5.2	6.5	46.50	49.02
Middle East	12.87	13.91	52.11	57.88	6.7	8.1	13.06	17.34
Asia	19.03	20.78	82.06	86.17	15.6	17.9	46.35	49.60
Frontier countries (North and South America, U.S.S.R., Australia, New Zealand)	6.88	7.75	82.85	82.96	5.7	6.4	34.27	38.59
Europe	30.79	30.98	89.02	90.06	27.4	27.9	45.63	46.10
All Regions	10.73	11.73	82.74	83.99	8.9	9.9	37.35	41.07

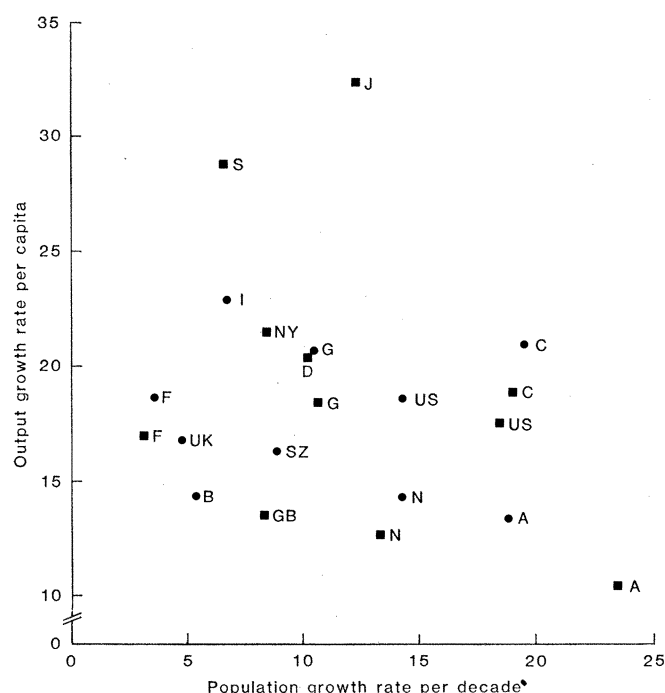


Fig. 1. The nonrelationship between population growth and growth of living standards over half a century (●) and a century (■). A, Australia (1900-04 to 1963-67 and 1861-69 to 1963-67); B, Belgium (1900-04 to 1963-67); C, Canada (1920-24 to 1963-67 and 1870-74 to 1963-67); D, Denmark (1865-69 to 1963-67); F, France (1896 to 1963-66 and 1861-70 to 1963-66); G, Germany (1910-13 to 1963-67 and 1850-59 to 1963-67); GB, Great Britain (1855-64 to 1963-67); I, Italy (1895-99 to 1963-67); J, Japan (1874-79 to 1963-67); N, Netherlands (1900-09 to 1963-67 and 1860-70 to 1963-67); NY, Norway (1865-69 to 1963-67); S, Sweden (1861-69 to 1963-67); SZ, Switzerland (1910 to 1963-67); UK, United Kingdom (1920-24 to 1963-67); US, United States (1910-14 to 1963-67 and 1859 to 1963-67). [Data from (38)]

Table 2. Per capita food production in the world, 1948 to 1976. [Data from (40)]

Year	Ex- cluding main- land China (1952-56 = 100)	In- cluding main- land China (1961-65 = 100)	Com- bined index (1948-52 = 100)
1948-50	93		100
1952	97		104
1953	100		108
1954	99		106
1955	101		109
1956	103		111
1957	102		110
1958	106		114
1959	106		114
1960	107		115
1961	106		114
1962	108		116
1963	108		116
1964	109	102	118
1965	108	100	116
1966	111	103	119
1967	113	105	121
1968		106	123
1969		105	119
1970		106	123
1971		107	125
1972		104	120
1973		108	126
1974		107	125
1975		108	126
1976		110	128

trend, carried to the same absurdity as the nightmare above, would suggest that eventually one person will be farming all the cropland in the United States and feeding everyone. The less-developed countries have not begun this trend, though the relative proportions of their populations that are in agriculture are falling rapidly. We may expect that as they get richer smaller absolute numbers of persons will be doing the farming for larger populations, on ever-larger farm units.

Some Other Myths About Population and Resources

Here are some other examples of publicized, false, bad news and the unpublicized, good-news truth:

Statement: The food situation in less-developed countries is worsening. "Serious World Food Gap Is Seen Over the Long Run" is a typical *New York Times* headline.

Perhaps most influential in furthering that idea was Paul Ehrlich's best-selling book *The Population Bomb*, which begins: "The battle to feed all of humanity is over. In the 1970's the world will undergo famines—hundreds of millions of people are going to starve to death" (11). Many writers view the situation as so

threatening that they call for strong measures to restrict population growth—"compulsion if voluntary methods fail," as Ehrlich put it (11). Some, such as Paul and William Paddock, authors of the 1967 book *Famine—1975!*, find warrant in these assertions for such policies as "triage—letting the least fit die in order to save the more robust victims of hunger" (12). "My [one of the Paddocks] own opinion as the triage classification of these sample nations is: Haiti, Can't-be-saved; Egypt, Can't-be-saved; The Gambia, Walking Wounded; Tunisia, Should Receive Food; Libya, Walking Wounded; India, Can't-be-saved; Pakistan, Should Receive Food" (13).

Fact: Per capita food production has been increasing at roughly 1 percent yearly—25 percent during the last quarter century (Table 2). Even in less-developed countries food production has increased substantially. World food stocks are high now, and even India has large amounts of food in storage. In the United States farmers are worrying about disaster from too much food.

Some countries have done far worse than the average, and have even had declining production, often because of war or political upheaval. And progress in food production has not been steady. But there has been no year, or series of years, so bad as to support a conclusion of long-term retrogression. Some readers might wonder whether my assertions are overly influenced by recent events, but the first draft of this material, for publication in my technical book (14), was written in 1971 and 1972, when food production was having its worst time in recent decades.

What about the data the other fellows quote to support their worried forecasts? In simple fact there are no other basic data. The data shown in Table 2 were published by the United Nations, collected from the individual countries. Of course the data are less reliable than one would like; economic data usually are. But these are the only official data, and data that would show a worsening trend in recent decades simply do not exist.

Statement: The danger of famine is increasing. The U.N. Economic and Social Commission for Asia and the Pacific predicts "500 million starvation deaths in Asia between 1980 and 2025" (15).

Contrary evidence: The course of famines is difficult to measure quantitatively. But D. Gale Johnson, an agricultural economist who has studied the history of famines intensively, estimates that since World War II there has been a "dramatic decline" in famines. Only a tenth as many people died of famine in the third

Table 3. Monies obligated (loans and disbursements) for population and health programs by the Agency for International Development, 1965 to 1977 (in millions of U.S. dollars). [Data from (41)]

Fiscal year	Popu- lation	Health	Total
1965	1.9	32.4	34.3
1966	3.8	58.7	62.5
1967	4.3	98.1	102.4
1968	34.4	131.3	165.7
1969	43.9	38.3	82.0
1970	73.1	37.1	110.2
1971	94.0	57.7	151.7
1972	120.9	35.4	156.3
1973	121.7	42.9	164.6
1974	100.1	81.5	181.6
1975	100.0	54.5	154.5
1976	103.0	54.4	157.4
1977*	143.4	93.6	237.0

*Estimated.

quarter of the 20th century as in the last quarter of the 19th century, despite the much larger population now (16). A key cause of the decline in famine deaths has been the improvements in road systems, which allow food to be moved from regions of plenty to regions of shortage. The road-system improvements are themselves a product of increased population density (17) as well as of improvements in technology.

Statement: Higher population growth implies lower per capita economic growth. This has been almost gospel for the World Bank, the State Department's Agency for International Development (AID), and other development agencies.

Contrary evidence: Empirical studies find no statistical correlation between countries' population growth and their per capita economic growth, either over the long run or in recent decades. Decadal growth rates of population and output per capita for those countries where long-run data are available are shown in Fig. 1. No strong relationship appears. Contemporary cross-national comparisons of current rates of population growth and economic growth are another source of evidence. Many such studies have been done by now, and they agree that population growth does not have a negative effect upon economic growth in either more-developed or less-developed countries (18). These overlapping empirical studies do not show that fast population growth increases per capita income, but they certainly imply that one should not confidently assert that population growth decreases economic growth.

Statement: Sophisticated computer models show that for the next 30 years an increase in population causes a decrease in per capita income.

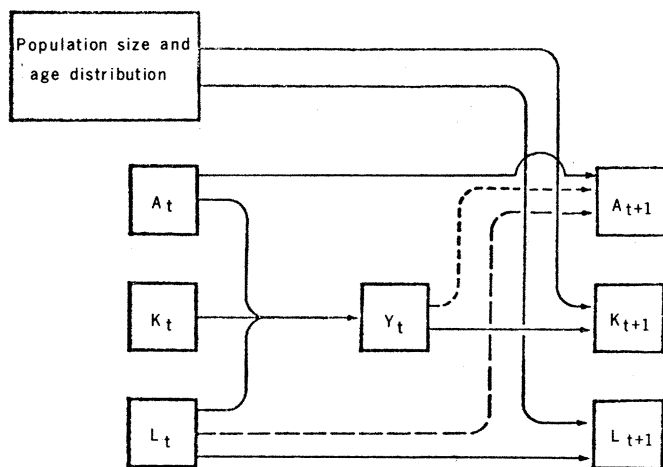


Fig. 2. Schematic of MDC model. A_t , level of technology in year t ; K_t , capital; L_t , labor; Y_t , national income. The model is run for 160 periods, the output from each year t becoming the input for year $t + 1$. The model was run with various specifications of the technical progress function

$$A_t - A_{t-1} = f\left[A_{t-1}, L_{t-1}, \left(\frac{Y}{L}\right)_{t-1}\right]$$

Phyllis Piotrow (19) documented the decisive impact upon the late 1960's policy of AID and the U.N.'s Fund for Population Activities that was exerted by the first of these models, created in 1958 by Ansley Coale and Edgar Hoover (20). Largely founded on the Coale-Hoover simulation, the belief that population growth in less-developed countries is bad for the world led the State Department to greatly increase its spending for fertility reduction in poor countries, hand-in-hand with relatively lower spending on mortality reduction and other health programs, as seen in Table 3 (21). Along with the hundreds of millions of dollars for fertility reduction, the United States has put pressure on foreign governments to adopt fertility reduction programs.

Response: At the heart of all these models is simply an arithmetical truth: When considering the ratio (total income)/persons and assuming the numerator (income) to be fixed, an increase in the denominator (persons) implies a decrease in income per capita. That is, an added child with all sharing a given amount of goods means there is less to go around. As Wilfred Beckerman remarked, the instant a calf is born, per capita income and wealth go up, but the instant a child is born, per capita income and wealth go down. This truth was well recognized by Coale and Hoover with respect to their model and findings: "The inauspicious showing of the high-fertility case . . . in levels of living is traceable entirely to the accelerated growth in the number of consumers" (20). The point was crystal-clear to Malthus even without a complex model. He noted that an increase in population "increases the number of people before the means of subsistence are increased. The food therefore which before supported eleven millions, must now be divided among eleven millions and a half" (22).

Once the children grow up, however, and become producers as well as consumers, their impact on per capita income reverses. Eventually the income of other people is higher because of the additional children, as my own technical work (14) has argued. But this takes more than the 25 or 30 years covered by the well-known models.

Another point of view: The main new element in my model for more-developed countries (MDC's) is the contribution of additional people to increasing productivity (14). This occurs partly through larger markets and economies of scale. But more important are an additional person's contributions to increased knowledge and technical progress. People bring not only mouths and hands into the world but also heads and brains. The source of improvements in productivity is the human mind, and the human mind is seldom found apart from the human body. This is an old idea, going back at least as far as William Petty (23):

As for the Arts of Delight and Ornament, they are best promoted by the greatest number of emulators. And it is more likely that one ingenious curious man may rather be found among 4 million than 400 persons. . . . And for the propagation and improvement of useful learning, the same may be said concerning it as above-said concerning . . . the Arts of Delight and Ornaments. . . .

Population growth and productivity increase are not independent forces running a race. Rather, additional persons cause technological advances by inventing, adapting, and diffusing new productive knowledge.

Technical progress, which is the main source of long-run economic growth in MDC's, arises partly from organized scientific R & D and partly from people who are not especially educated and do not work in science—the supermarket manager who finds a method to display more merchandise in a given space, the

supermarket clerk who develops a quicker way to stamp the prices on cans, the market researcher who experiments to learn more efficient and cheaper means of advertising the store's prices and sale items, and so on. This is the "learning by doing" phenomenon which has been all-important in raising our standard of living from what it was 20,000 years ago, 200 years ago, 20 years ago, to what it is now. The aggregate economic importance of the technological knowledge factor has clearly emerged in two well-known studies, one by Robert Solow and the other by Edward Denison (24).

I have added this effect of additional people on productivity to a standard economic model in several variants of Fig. 2. The result is that additional persons, instead of being a permanent drag, lead to an increase in per worker output starting 30 to 70 years after birth—that is, 10 to 50 years after entry into the labor force. (Economics can therefore be a cheerful science rather than the dismal science Malthus thought it to be.)

Babies do not create knowledge and improve productivity while still in their cradles. And though the family bears most of the cost, society must also unpurse to bring the baby to productive adulthood. This means that if you do not look as far ahead as the next 25 years, the knowledge benefits of someone else's baby born today do not interest you, and that baby therefore appears to be a poor social investment for your taxes. But if you feel some interest in, and obligation for, the longer-run future—perhaps because you yourself are today enjoying the fruits of the investment that someone paid for 25 or 50 or 100 years ago, or because you have children whose future is important to you—then you will view the knowledge produced by today's children as being of great benefit to you (25).

The mechanism is different in less-developed countries (LDC's). Offsetting the negative capital-dilution force of more people, there are the positive forces of increased work done by parents, extra stimulus to agricultural and industrial investment, increased social infrastructure, and other economies of scale. When all these forces are combined into my LDC simulation model, an additional child comes to have a positive net effect on the general standard of living after the better part of a century. But this positive net effect is much larger than the negative net effect early on (14). Once again, most of the cost is borne by the immediate family rather than the rest of society. And the immediate family apparently feels that the benefits from

the additional child outweigh the costs in the early years, because they choose to bear the children and the expenses.

In short, economic theory that includes key elements left out of previous models, together with the empirical data, suggests that additional children have positive long-run effects upon the standard of living.

It is true that the long run—30 to 70 years—is far from now, and therefore is of less importance to us than is the short run. But our long run will be someone else's short run, just as our short run was someone else's long run. Some measure of unselfishness should impel us to keep this in mind as we make our decisions about population policy.

Statement: Urban sprawl is paving over the United States, including much "prime agricultural land" and recreational areas.

Fact: All the land used for urban areas plus roadways totals less than 3 percent of the area of the United States. And the increase over the half-century starting in 1920 was only 0.00025 percent of total land annually (26). The U.S. Department of Agriculture says "we are in no danger of running out of farmland" (27).

Each year 1.25 million acres are converted to efficient cropland by draining swamps and irrigating deserts, while 0.9 million acres are converted to urban and transportation use. The rest of the 2.2 million acres of rural land which goes out of use yearly is abandoned not because of "paving over" but because it has "low soil fertility and a terrain unsuited to efficient use of modern machinery" (28). A million acres yearly goes into additional wilderness recreation areas and wildlife refuges, and another 300,000 acres goes for reservoirs and flood control (27). The danger to agriculture from "paving over" is another bogeyman.

About wildlife areas, state and national parks: these increased from 8 million acres in 1920 to 73 million acres in 1974 and are still increasing (26). The number of visits to these recreation areas has risen sharply because of improved transportation and increased income. From 1946 to 1960, for example, visits increased from 780 to 2184 per thousand people yearly.

Statement: We are running out of natural resources and raw materials. "Entering an age of scarcity" is such a commonplace that it is simply assumed and asserted in public discussion by people ranging from B. F. Skinner to Solzhenitsyn (29).

Response: The only meaningful measure of scarcity in peacetime is the cost of the good in question (30). The cost

trends of almost every natural resource—whether measured in labor time required to produce the energy, in production costs, in the proportion of our incomes spent for energy, or even in the price relative to other consumer goods—have been downward over the course of recorded history.

An hour's work in the United States has bought increasingly more of copper, wheat, and oil (representative and important raw materials) from 1800 to the present. And the same trend has almost surely held throughout human history. Calculations of expenditures for raw materials as a proportion of total family budgets make the same point even more strongly. These trends imply that the raw materials have been getting increasingly available and less scarce relative to the most important and most fundamental element of life, human work time. The prices of raw materials have even been falling relative to consumer goods and the Consumer Price Index. All the items in the Consumer Price Index have been produced with increasing efficiency in terms of labor and capital over the years, but the decrease in cost of raw materials has been even greater than that of other goods, a very strong demonstration of progressively decreasing scarcity and increasing availability of raw materials.

The relative fall in the prices of raw materials understates the positive trend, because as consumers we are interested in the services we get from the raw materials rather than the raw materials themselves. And we have learned to use less of given raw materials for given purposes, as well as to substitute cheaper materials to get the same services. Consider a long-ago copper pot for cooking. The consumer is interested in a container which can be put over heat. After iron and aluminum were discovered, quite satisfactory cooking pots—almost as good as, or perhaps better than, pots of copper—could be made of those materials. The cost that interests us is the cost of providing the cooking service, rather than the cost of copper.

A dramatic example of how the service that copper renders can be supplied much more cheaply by a substitute process: A single communications satellite in space provides intercontinental telephone connections that would otherwise require thousands of tons of copper.

Statement: Energy is getting scarcer.

Response: The facts about the cost of energy are much the same as the facts about other raw materials. The new strength of the OPEC cartel to control oil price obscures the cost of production. But the production cost of a barrel of oil

has not risen, and probably has fallen, in deflated dollars; even after the "oil crisis" of 1973 it was still \$0.05 to \$0.15 per barrel in the Persian Gulf, which was perhaps a hundredth of the market price (31). It is reasonable to expect that eventually the price of oil will again return nearer its economic cost of production, and the long-run downward trend in the price of oil will resume its course.

The price of electricity is an interesting measure of the consumer cost of energy, and it is largely unaffected by cartels and politics (though the price of electricity did rise after 1973 because all energy sources, including coal and uranium, jumped in price when the price of oil went up, on account of the improved market power of coal and uranium suppliers). But the long-run cost of electricity clearly has been downward.

In short, the data show that energy has not been getting scarcer in basic economic terms, but rather has been getting more plentiful.

Statement: The supplies of natural resources are finite. This apparently self-evident proposition is the starting point and the all-determining assumption of such models as *The Limits to Growth* and of much popular discussion.

Response: Incredible as it may seem at first, the term "finite" is not only inappropriate but is downright misleading in the context of natural resources, from both the practical and the philosophical points of view. As with so many of the important arguments in this world, this one is "just semantic." Yet the semantics of resource scarcity muddle public discussion and bring about wrongheaded policy decisions.

A definition of resource quantity must be operational to be useful. It must tell us how the quantity of the resource that might be available in the future could be calculated. But the future quantities of a natural resource such as copper cannot be calculated even in principle, because of new lodes, new methods of mining copper, and variations in grades of copper lodes; because copper can be made from other metals; and because of the vagueness of the boundaries within which copper might be found—including the sea, and other planets. Even less possible is a reasonable calculation of the amount of future services of the sort we are now accustomed to get from copper, because of recycling and because of the substitution of other materials for copper, as in the case of the communications satellite.

Even the total weight of the earth is not a theoretical limit to the amount of copper that might be available to earth-

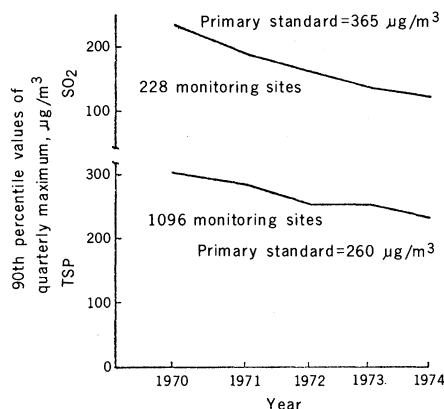


Fig. 3. Overall national trends in daily observed levels of sulfur dioxide (upper curve) and total suspended particulates (lower curve). [Reproduced from (33, p. 226); data from U.S. Environmental Protection Agency]

lings in the future. Only the total weight of the universe—if that term has a useful meaning here—would be such a theoretical limit, and I don't think anyone would like to argue the meaningfulness of "finite" in that context.

With respect to energy, it is particularly obvious that the earth does not bound the quantity available to us; our sun (and perhaps other suns) is our basic source of energy in the long run, from vegetation (including fossilized vegetation) as well as from solar energy. As to the practical finiteness and scarcity of resources—that brings us back to cost and price, and by these measures history shows progressively decreasing rather than increasing scarcity.

Why does the word "finite" catch us up? That is an interesting question in psychology, education, and philosophy; unfortunately there is no space to explore it here.

In summary, because we find new lodes, invent better production methods, and discover new substitutes, the ultimate constraint upon our capacity to enjoy unlimited raw materials at acceptable prices is knowledge. And the source of knowledge is the human mind. Ultimately, then, the key constraint is human imagination and the exercise of educated skills. Hence an increase of human beings constitutes an addition to the crucial stock of resources, along with causing additional consumption of resources.

Statement: The old trends no longer apply. We are at a moment of discontinuity now.

Response: One cannot logically dispute assertions about present or impending discontinuity. And one can find mathematical techniques suggesting discontinuities that will be consistent with any trend data. We can say scientifically,

however, that if in the past one had acted on the belief that the long-run price trend was upward rather than downward, one would have lost money on the average.

Statement: The nation's "overall environmental well-being" is declining, according to the Environmental Quality Index (EQI).

Fact: This widely reported index is, according to the National Wildlife Federation, which prepares and disseminates it, "a subjective analysis . . . judgment [which] represents collective thinking of the editors of the National Wildlife Federation Staff." That is, the EQI represents casual observation rather than hard statistical facts. It includes such subjective judgments as that the trend of "living space" is "down . . . vast stretches of America are lost to development yearly" (32). But the objective statistical facts indicate that the environment is getting better. Earlier we saw that "living space" is not declining, and recreational areas are increasing rapidly. The official data of the Council on Environmental Quality concerning major air pollutants show sharp improvements in the last decade (Fig. 3). With respect to water, "major improvements have been documented" (33, p. 285) (see Fig. 4). The fish catch in Lake Erie, long ago said to be "dead" by Barry Commoner, has been increasing. The most important indicator of environmental quality is life expectancy; it continues to rise, and at an increasing rate: a gain of 2.1 years from 1970 to 1976, compared with a gain of only 0.8 year in the entire decade of the 1960's (34).

Statement: "[E]ven if the family size drops gradually—to the two-child average—there will be no year in the next two decades in which the absolute number of births will be less than in 1970," said the President's Commission on Population Growth, 1972 (35).

Fact: In 1971—the year before this forecast by the President's Commission was transmitted to the President and then published—the absolute number of births (not only the birth rate) was less than in 1970. By 1975, the absolute number of births was barely higher than in 1920, and the number of white births was actually lower than in most years from 1914 to 1924. This scientific fiasco shows how flimsy are the demographic forecasts upon which arguments about growth policy are based. In this case the Commission did not even "backcast" correctly, let alone forecast well.

Another peculiar forecasting episode: Between 1969 and 1978, U.N. and other

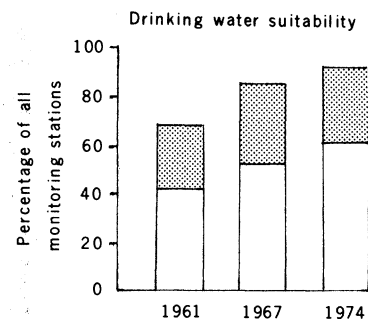


Fig. 4. Summary of water quality observations related to drinking-water suitability, 1961, 1967, and 1974. Unshaded, "good"; dotted, "fair." [Adapted from (39); data from U.S. Geological Survey]

standard estimates of the world's population in the year 2000 fell from around 7.5 billion to around 5.5 billion. This is a difference of 2 billion people—equal to about half the world's present population—for a date only 30 years or less in the future. There is also grave disagreement even among estimates of current magnitudes. An important example is the population growth rate of China, a fifth of the entire world population: 2.4 percent per year according to the Environmental Fund, 0.8 percent per year according to AID, these estimates correspond to doubling times of about 30 years and about 90 years respectively, estimates with entirely different implications (36).

Why Do We Hear Phony Bad News?

Why do false statements of bad news dominate public discussion of these topics? Here are some speculations.

1) There is a funding incentive for scholars and institutions to produce bad news about population, resources, and the environment. The AID and the U.N.'s Fund for Population Activities disburse more than a hundred million dollars each year to bring about fertility decline. Much of this money goes to studies and publications that show why fertility decline is a good thing. There are no organizations that fund studies having the opposite aim.

2) Bad news sells books, newspapers, and magazines; good news is not half so interesting. Is it a wonder that there are lots of bad-news best-sellers warning about pollution, population growth, and natural-resource depletion but none telling us the facts about improvement?

3) There are a host of possible psychological explanations for this phenomenon about which I am reluctant to speculate. But these two seem reasonably sure: (i) Many people have a propensity

to compare the present and the future with an ideal state of affairs rather than with the past or with some other feasible state; the present and future inevitably look bad in such a comparison. (ii) The cumulative nature of exponential growth models has the power to seduce and bewitch.

4) Some publicize dire predictions in the idealistic belief that such warnings can mobilize institutions and individuals to make things even better; they think that nothing bad can come of such prophecies. But we should not shrug off false bad news as harmless exaggeration. There will be a loss of credibility for real threats as they arise, and loss of public trust in public communication. As Philip Handler, president of the National Academy of Sciences, testified to congressmen in the midst of the environmental panic of 1970: "The nations of the world may yet pay a dreadful price for the public behavior of scientists who depart from . . . fact to indulge . . . in hyperbole" (37).

The question, then, is: Who will tell us the good-and-true news? How will it be published for people to learn?

References and Notes

1. *Newsweek*, 19 September 1977, p. 80.
2. Associated Press, in *Champaign-Urbana News Gazette*, 10 January 1978, p. A-5.
3. H. Ware, personal communication, 20 March 1978.
4. J. Caldwell, in *Drought in Africa No. 2 (African Environment Special Report No. 6)*, D. Dalby, R. J. H. Church, F. Bezzaz, Eds. (UNEP-IDEP-SIDA, London, 1977), pp. 93-100. For a full and judicious assessment of the situation and the area see Caldwell's *The Sahelian Drought and Its Demographic Implications* (Overseas Liaison Committee, American Council on Education, Washington, D.C., 1975).
5. *New York Times*, 28 August 1977, p. 1.
6. E. P. Eckholm, *Losing Ground: Environmental Stress and World Food Prospects* (Norton, New York, 1976).
7. J. Kumar, *Population and Land in World Agriculture* (Univ. of California Press, Berkeley, 1973).
8. *FAO Production Yearbook* (United Nations, New York, 1975), vol. 29, p. 3; *Foreign Agricultural Economic Report No. 98* (Department of Agriculture, Washington, D.C., 1974).
9. When I submitted a letter to the editor containing these facts, *Newsweek* did not print it but replied: "Dear Mr. Simon: We can only say that, in preparing the Sept. 19, 1977 story to which you refer, we used what we thought were the best available sources. The different figures you have obtained are of course disturbing. But all we can say at this point is that we will add this information to our files and take it into account in future stories. We appreciate the concern that prompted you to write to *Newsweek*."
10. W. Stys, *Popul. Stud.* 11, 136 (1957); R. H. Myers, *The Chinese Peasant Economy* (Harvard Univ. Press, Cambridge, Mass., 1970), originally from J. L. Buck, *Land Utilization in China Statistical Supplement* (Nanking Univ. Press, Nanking, 1937), p. 288.
11. P. Ehrlich, *The Population Bomb* (Ballantine, New York, 1968), p. xi.
12. *Newsweek*, 11 November 1974, p. 16.
13. P. Paddock, *Famine—1975!* (Little, Brown, Boston, 1967), p. 222.
14. J. L. Simon, *The Economics of Population Growth* (Princeton Univ. Press, Princeton, N.J., 1977).
15. Associated Press, 12 February 1975.
16. D. G. Johnson, *Am. Stat.* 28, 89 (1974). For more details, see Johnson's article "Famine" in the *Encyclopaedia Britannica*, 1973 edition.
17. "The effect of population density upon infrastructure: The case of roadbuilding," *Econ. Dev. Cultural Change* 23, No. 3 (1975).
18. Summarized in (14, pp. 139-140). To ensure that earlier studies were not flawed by employing only population growth as an independent variable, R. Gobin and I regressed the economic growth rate in various cross-sections of less-developed countries from 1950 to 1970 on population density and population size together with population growth. Population growth continued to show no effect. Interestingly, however, population density shows a pronounced positive influence on economic growth. See J. L. Simon and R. Gobin, in *Research in Population Economics*, J. Simon and J. DeVanzo, Eds. (JAI Press, Greenwich, Conn., 1979), vol. 2.
19. P. Piotrow, *World Population Crisis: The United States Response* (Praeger, New York, 1973).
20. A. J. Coale and E. M. Hoover, *Population Growth and Economic Development in Low-Income Countries* (Princeton Univ. Press, Princeton, N.J., 1958).
21. Ehrlich caught the spirit of this policy thus: "... we should see that the majority of federal support of bio-medical research goes into the broad areas of population regulation, environmental sciences and behavioral sciences, rather than into short-sighted programs of death control" [P. Ehrlich, *Reader's Dig.* 94, 137 (1969)]. Or as an economist then of the Coale-Hoover school put it, "To diminish mortality and morbidity . . . where underemployment of labor is the critical characteristic . . . serves markedly to retard rates of general economic growth" [quoted in W. Petersen, *Population* (Macmillan, New York, ed. 2, 1969), p. 572].
22. T. R. Malthus, *An Essay on the Principle of Population, or a View of its Past and Present Effects on Human Happiness* (J. Johnson, London, "A new edition," 1803).
23. W. Petty, "Another Essay in Political Arithmetic" (1682), reprinted in *The Economic Writings of Sir William Petty*, C. H. Hull, Ed. (Cambridge Univ. Press, Cambridge, 1899), p. 474.
24. R. Solow, *Rev. Econ. Stat.* 39, 312 (1957); E. F. Denison, *The Sources of Economic Growth in the United States and the Alternatives Before Us* (Committee for Economic Development, New York, 1962).
25. For a comprehensive discussion, see H. J. Barnett, *Econ. Dev. Cultural Change* 19, 545 (1971).
26. R. Barlowe, *Land Resource Economics: The Economics of Real Property* (Prentice-Hall, Englewood Cliffs, N.J., 1978), p. 50.
27. *Our Land and Water Resources: Current and Prospective Supplies and Uses* (Miscellaneous Publication No. 1290, Economic Research Service, Department of Agriculture, Washington, D.C., 1974), p. vi; H. T. Frey "Cropland for Today and Tomorrow" (USDA Economic Report No. 291, Washington, D.C., 1975); "Major Uses of Land in the United States: Summary for 1969" (USDA Economic Report No. 247, Washington, D.C., 1973).
28. M. L. Cotner, M. D. Skold, O. Krause, *Farm-land: Will There Be Enough?* (Economic Research Service, Department of Agriculture, Washington, D.C., 1975), p. 10.
29. G. Homans, *Harv. Mag.* July-August 1977, p. 58; A. Solzhenitsyn, quoted in *Newsweek*, 18 March 1974, p. 122.
30. H. J. Barnett and C. Morse [Scarcity and Growth (Johns Hopkins Press, Baltimore, 1963)] give the classic argument for this point of view, accompanied by a wealth of data. My discussion was inspired by their treatment and follows in their spirit, which in turn has roots in the Paley Commission of the early 1950's and in J. S. Davis, *J. Polit. Econ.* 61, 369 (1953). The data in *Scarcity and Growth* cover 1870 to 1957. Barnett has recently extended his analysis from 1957 to 1970 and found that the downward trends in real costs of extractive materials continue [H. J. Barnett, in *Scarcity and Growth Reconsidered*, V. K. Smith, Ed. (Resources for the Future, Washington, D.C., in press)]. A provocative but convincing technologically based argument for continuation of these downward cost trends for minerals is H. E. Goeller and Alvin M. Weinberg, *Science* 191, 683 (1976).
31. *Jerusalem Post*, 3 January 1978, p. 5; M. Zonis, *Univ. Chicago Mag.*, March 1976, p. 14.
32. "Environmental quality index," *Natl. Wildlife* 15 (No. 2) (1977).
33. *Environmental Quality—1976*, seventh annual report of the Council on Environmental Quality, Washington, D.C., p. 285.
34. *Stat. Bull. Metrop. Life Insur. Co.* 58, 9 (May 1977).
35. E. R. Morse and R. H. Reed, Eds., *Economic Aspects of Population Change* (Government Printing Office, Washington, D.C., 1972), p. 4 [as quoted by Larry Neal, *Ill. Bus. Rev.* 35, No. 2 (1978)].
36. R. Kramer and S. Baum, "Comparison of recent estimates of world population growth," presented at a meeting of the Population Association of America, 1978.
37. P. Handler, interview in *U.S. News World Rep.*, 18 January 1971, p. 30.
38. S. Kuznets, *Economic Growth of Nations* (Norton, New York, 1971), pp. 11-14.
39. *Sixth Annual Report* (Council on Environmental Quality, Washington, D.C., 1975), p. 352.
40. *FAO Production Yearbook* (United Nations, New York, 1968, 1975, 1976).
41. L. E. Bradshaw, D. Pitty, C. P. Green, *Popul. Rep. Ser. J* (1977), p. J272.
42. This article is drawn from the author's forthcoming book, *The Ultimate Shortage* (Princeton Univ. Press, Princeton, N.J., in press). I thank S. Friedman, E. Satinoff, and R. Simon for their useful comments. D. Love assisted me ably.