Speaking of Science

Science and Technology: The Next 50 Years

Science and technology in the United States are entering their adolescence—a period of self-doubt and of self-assessment. Society now demands that science be relevant to social needs and that technology assessment (broadly defined as "what else might happen besides what is intended") be an integral part of all new technology proposals. In contrast, quantitative predictions about the future have usually been upset by unexpected qualitative changes in the "rules of the game." Hence, instead of trying to plan the future through organized, directed research, it may be better to be prepared to manage the unforeseeable when it arrives, unplanned, by having a program of diversified basic research to fall back upon. Thus, the recurring conflict between basic research and applied research emerged, once again, from a "mini-symposium" on the future of science and technology over the next 50 years, part of the Navy-sponsored symposium "Perspectives in Science and Technology," held in October to celebrate the 50th anniversary of the Naval Research Laboratory (NRL), Washington, D.C.

The symposium featured a collection of world-famous scientists who reviewed the state of science (mainly physical science) from the outer reaches of the universe to the depths of the oceans. The problem of energy sources was also reviewed: one speaker said that an externally imposed curtailment of oil imports could occur in as short a time as 2 years and might finally cause the United States to deal with the energy shortage (a not unlikely prospect in view of the subsequent resumption of hostilities between Israel and the Arab nations.

Highlighting the entire symposium, however, was the look into the future of science and technology provided by the mini-symposium panel members, who clearly brought their imaginations with them to NRL. Philip Handler, president of the National Academy of Sciences and moderator of the panel, opened by observing that the antitechnology attitudes prevalent in recent years seem to have subsided [a contention apparently supported by at least one recent opinion poll to determine American attitudes about science (*Science*, 26 October, p. 369)]. However, despite the long-time American fascination with technology, social consequences will now be watched, and technology assessment will be demanded. Handler noted that, so far, technology assessments have never been made successfully. For example, he pointed out that few people, if any, anticipated that the introduction of cotton-picking machines in the South would lead to large-scale migration of the unemployed to Northern cities. He finished his comments by contending that, even today, no systematic discipline for technology assessment has been developed, but that such must be attempted.

The first panel member, Pierre Auger of the University of Paris, suggested that the important developments in the next 50 years will come in the life sciences. Speaking on what must surely be one of the most sensitive subjects in science today, and one in which technology assessment is highly appropriate, Auger then proceeded to consider the possibility of several advances in genetic engineering. Auger discussed injecting bits of DNA containing specific pieces of genetic information into cells in order to produce desired traits in plants and animals. He suggested cloning as a possible means of raising the cell containing the altered genetic information to become a mature specimen. He considered the possibility that aging, and even death, may be genetically controlled. Auger concluded by speculating on the possibility of doubling the number of neurons in the brain by genetic engineering, and hence increasing the brain capacity. He did not speculate on the consequences of such an experiment.

While moderator Handler, from all appearances, was having a time refraining from commenting, the second panelist, Freeman Dyson of the Institute for Advanced Study, Princeton, N.J., gave the audience time to recover from contemplating a doubled brain size by agreeing that the big surprises in the future would be in the biological sciences and that one could look forward to the kind of control over biological processes that now exists over physical ones. Dyson then continued the assault on the audience's credulousness by turning his attention to the possibility of outwitting the laws of economics by constructing self-reproducing automatons. Dyson related that the late mathematician and computer scientist John von Neumann had earlier deduced the basic components necessary for self-reproduction (before the molecular biologists experimentally found the equivalents in living cells): a factory, a printing shop, a blueprint of the factory, and a blueprint of the shop. Given these basic components, automatons could reproduce themselves indefinitely. Evolutionary change could be brought about by changing the blueprints. Next, it remained to determine how these equivalents of single-celled organisms could be made to evolve into complex, multicellular individuals. Once this was accomplished, however, the automatons could rapidly create wealth and eliminate most economic considerations.

Ultimately, Dyson foresaw, a complete economic development kit could be constructed which, if sent to an unindustrialized country, could begin reproducing itself, forming itself into factories and other components of an industrial society, and finally into a completely developed, industrial economy, all, apparently, with no investment beyond that needed for the kit itself. Unlike the preceding speaker, however, Dyson foresaw drastic consequences associated with the introduction of his hypothetical automaton, such as severe alienation and anxiety in the population of such a machine-developed society, despite the apparent miracle of the trivialization of the world's economic problems. Thus, in this heavy-handed allegory, Dyson outlined the problems inherent in the task of trying to organize science and technology dividual firms, the coefficients derived for any one sector represent an average over the production operations of firms which may differ greatly in size, efficiency of operations, and other factors. Thus the constant production coefficients may lead to inaccuracies when changes in final demand affect firms differently, as is often the case. In addition, because changes in technology are inevitable for the future, the use of constant base-year production coefficients for projections can also lead to major errors.

Moreover, in its nondynamic form the input-output model assumes the existence of unused capacity and resources, to allow for expansions when required. But often the sectors of a system may already be operating at capacity. In more recent and sophisticated models, however, capacity-building activities are being successfully introduced to help overcome this shortcoming.

An additional point concerns the applicability of input-output analysis for developing regions where little, if any, basis exists for collecting, processing, and borrowing data. How can the input-output method be used without the appropriate empirical base?

This incomplete list of criticisms, as well as others, can only be tempered by a recognition of what input-output analysis has accomplished, despite its shortcomings, and by a caveat as to how the model must be properly employed. First, we note that if nothing else, the input-output framework has been a tremendous boon to quantitative economics, in that it has required consistent, orderly, and comprehensive collection of economic data. The necessity for uniform accounting procedures and precise definitions of sectors and commodities has forced the many data collection agencies of a number of nations to coordinate their efforts, and the results have facilitated comparative studies across nations. Furthermore, input-output analysis is unequaled in its ability to describe the structure of an economy—to provide a comprehensive snapshot—for any given base year for which data have been systematically and properly collected.

When it comes to making projections and forecasting impacts, input-output analysis can still be extremely useful, despite its extensive use of constant production coefficients, provided it is supplemented with additional analyses and relevant data. It should be used by an analyst who has sufficient knowledge of the intricate workings of the economy being studied, so that he is able to modify production coefficients when necessary, such as in response to expected technological changes, or changes in input proportions because of changing relative prices, or in the light of the findings of other partial studies and data analyses which might be available.

In short, criticism of input-output work is criticism of work which has largely stemmed from the mechanical use of the model by those who fail to take account of the dynamics of a real-life situation. Input-output used as a computer plaything is a simple technique, requiring little more talent than a knowledge of intermediate algebra. Only a sophisticated analyst can do justice to the input-output model, by knowing how and where and when—and when not—to use it. Sophistication and skill will be even more crucial when we attack the problems of environmental management with the input-output model—which will inevitably happen, as it is the only technique we currently have or are likely to have in the near future for comprehensively probing the intricate interdependencies of the joint economic-ecologic system.

As plans go forward for the sixth International Conference on Input-Output Techniques in Vienna, cosponsored by the United Nations, it appears that input-output analysis is becoming a stable element of world culture. Like Adam Smith and *The Wealth of Nations*, Marshall and *Principles of Economics*, and Keynes and "The General Theory," Leontief and "Input-Output" are becoming permanent words in the economics vocabulary.

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References and Notes

1. W. Leontief, *Weltwirtsch. Arch.* **22** 338 (1925). It was subsequently translated as "The balance of the economy of the USSR" in *Foundations of Soviet Strategy for Economic Growth, Selected Short Soviet Essays 1924–1930*, N. Spulber, Ed. (Indiana Univ. Press, Bloomington, 1964), pp. 88–94.
2. F. Quesnay, *Tableau Économique* (1758).
3. W. Leontief and M. Hoffenberg, "The economic effects of disarmament," *Sci. Am.* **204** 34 (April 1961).
4. See, for example, W. Leontief, "Environmental repercussions and the economic structure: An input-output approach," *Rev. Econ. Stat.* **52**, 262 (1971).
5. Many of these coefficients are already being developed at the Regional Science Research Project, Center for Urban Development Research, Cornell University, Ithaca, N.Y.

merely to meet current social needs: the future is usually different from what it was once predicted to be, and only a broadly diversified science and technology will be ready to manage this kind of future.

The final panelist, Gerard Piel, publisher of *Scientific American*, implied that the economic development kit upon which Dyson speculated was already at hand in the form of the technology and resources available today from the developed countries, and he said it was time to use it. Piel contended that, at its present rate, the growth of the world's population would soon result in a population too large for the available resources to support a decent life for everyone. Moreover, he said that all the evidence appears to indicate that population growth slows only when the ratio of income per capita reaches a high value comparable to that in the industrialized countries. Finally, there is insufficient time left to permit the underdeveloped nations to progress at their own rate, because the world population will have become too large in the meantime. Hence, in order to attain the goal of a "human life for every human being," economic intervention is required on the part of the developed nations in the form of resources and technological know-how. Piel added that, while the resources and technology may be here, the wisdom to use them has yet to appear. But scientific, objective knowledge could be the source of such wisdom by making obvious, among other things, "the brotherhood of man."

Many people, of course, would not wish all aspects of heavily industrialized societies on anybody, and thus Dyson's warning may be at least partially applicable to Piel's plan for upgrading the world's standard of living. Auger may have been right after all: perhaps the best ways to use science and technology would become clearer, if everyone had double his present brain capacity.—ARTHUR L. ROBINSON