would not be feasible without very large increases in cost. Orbital quarantine facilities, either automated or manned, would be very expensive, risky, and of limited use because of size limitations.

5) Orbital quarantine may be feasible if the sample is split, part of it sterilized and returned to the earth for study, and the remainder studied for pathogenicity in the automated mode as best we can in the limited space available in orbit. Ground studies of sterilized material plus "live" studies in orbit may convince us of the safety of returning the remaining sample to the earth under carefully prescribed conditions.

6) Additional unmanned, Viking-type missions to Mars can add considerably to our knowledge about a martian biota, or its absence, and thus increase the likelihood of being able to return an unaltered sample safely to the earth.

References and Notes

1. Space Science Board, National Academy of Sciences, *Potential Hazards of Back Contamination* (National Academy of Sciences, Washington, D.C., 1964).
2. Interagency Committee on Back Contamination, "Quarantine schemes for manual lunar missions," report to the National Aeronautics and Space Administration, Washington, D.C. (1967).
3. Lunar Sample Preliminary Examination Team, *Science* **165**, 1211 (1969); G. R. Taylor, J. K. Ferguson, C. P. Truby, *Appl. Microbiol.* **20**, 271 (1970); V. I. Oyama, E. L. Merek, M. P. Silverman, *Science* **167**, 773 (1970); C. H. Walkinshaw, H. C. Sweet, S. Venketeswaran, W. H. Horne, *BioScience* **20**, 1297 (1970).
4. Mariner 9 issue, *J. Geophys. Res.* **78** (1973).
5. L. E. Casida, *Appl. Microbiol.* **13**, 327 (1965).
6. Luna 16 issue, *Earth Planet. Sci. Lett.* **13** (1972); Luna 20 issue, *Geochim. Cosmochim. Acta* **37** (1973).
7. Viking 1975 issue, *Icarus* **16** (1972).
8. R. Radmer and B. Kok, *Science* **174**, 233 (1971); *Life Sci. Space Res.* **10**, 211 (1972).
9. Langley Research Center, Jet Propulsion Laboratory Study Team, *Mars Surface Sample Return Mission Study* (National Aeronautics and Space Administration, Washington, D.C., 1973).
10. G. Eglinton and S. Tonkin, paper presented at the 4th International Conference on the Origin of Life, Barcelona, Spain, 1973.
11. Potential sterilization regimes must be carefully considered because the exact conditions used may affect the scientific value of the sample markedly. It is assumed here that a plausible sterilization procedure might be dry heat at 200°C for about 24 hours. Sterilization by irradiation is another possibility that should be investigated. Although an irradiated sample may be more useful for biological and organic chemical analysis, other physical measurements (such as isotopic measurements and age dating) may be compromised. Other problems associated with this technique include self-shielding of the sample and heat generation.
12. For this discussion, we have to put aside attendant major problems such as: How sterile is sterile? Sterile compared to what? Is the sample sterilized on Mars, in Mars orbit, or during transit? These are important questions that must be addressed, but they are beyond the scope of this article. Instead, we focus on the general scientific value of a returned sample that has been, for example, treated by heat.
13. O. A. Shaeffer and J. Fahringer, *Potassium-Argon Dating* (Springer-Verlag, New York, 1966).
14. E. K. Gibson and S. M. Johnson, *Thermochim. Acta* **4**, 49 (1972).
15. R. L. Levy, M. A. Grayson, C. J. Wolf, *Geochim. Cosmochim. Acta* **37**, 467 (1973).

16. We thank K. A. Kvenvolden, J. M. Hayes, and E. A. King, Jr., for helpful discussions concerning the scientific value of sterilized versus unsterilized returned samples; R. Johnson, P. Deal, K. Souza, E. Merek, and W. Berry for analysis of sample sterilization procedures; and A. G. Marr for the idea of returning a sterilized culture of martian organisms.

Are Scientists Obsolete?

What is happening to their social role, and where are the future markets for their services?

Harvey Brooks

It is by now conventional wisdom that a profound transformation has occurred in the environment for the conduct of research in the natural sciences and engineering in the United States since about 1967. All agree that such a transformation has taken place, but consensus seems to disappear, even among scientists, when it comes to describing the nature of the change or assessing its significance for the future. Among natural scientists and engineers the prognostication is uniformly gloomy. We have just come through a period of more than two decades in which the scientific community, especially that composed of natural scientists and engineers, could afford to comport itself as a largely autonomous and inward-looking enterprise. This was true to a degree not likely to be realized again in the near future. During this period also we have brought up an unusually large cohort of bright and highly motivated young scientists in a euphoric atmosphere, and it is they who bear the brunt of any adjustments that have to be made to a different kind of future.

The situation in the social sciences since 1967 has been somewhat less bearish than in the natural sciences, although financial support and public understanding of theoretical work in the social sciences have not been much better than in the natural sciences. After a brief period of public belief in the promise of the social sciences for the solution of the social ills of the early 1960's, the climate for them also has deteriorated.

Yet I hasten to add that the title of this article is rhetorical. I do not believe that scientists are obsolete. In fact my theme will be that the demand as well as the need for science and for technically trained people will resume its long-term growth, though not at the dramatic rate of the period from 1955 to 1965. This growth may assume a somewhat different character from that of the past, and will involve science and scientists much more intimately as a component of general social and economic development than during the golden age of academic and basic science of the early 1960's. Indeed it is the academic and academically oriented parts of the scientific and engineering enterprise that will probably face the greatest uncertainties and adjustments.

Recent History

Over almost three centuries science has become adjusted to continuous growth. Even during the great depression, between 1930 and 1940, the overall funding of U.S. science grew in real terms at an average annual rate of 9

The author is professor of applied physics and dean of the Division of Engineering and Applied Physics at Harvard University, Cambridge, Massachusetts 02138. This article is adapted from the Second Donald Ross Hamilton Memorial Lecture, delivered at Princeton University 1 November 1973.

percent (*1*). Only in the depth of the depression, between 1932 and 1934, was there a decline in funding. Among all professional and technical employees in the economy, scientists and engineers constituted an increasing proportion throughout the decade of the 1930's.

In the postwar era the total national investment in research and development (R & D), private and public, reached its peak in 1966–67. In academic research, federal funding declined in real terms by 17 percent between 1967 and 1971 (*2*). This estimate is larger than some others because it tries to take into account the real cost of R & D per professional man-year, including institutional overhead, which has taken an increasing proportion of the research dollar as the volume of research has declined. Although the situation has somewhat eased since 1971, the level of academic research support projected for the fiscal year 1975 is still well below its 1967 peak in terms of research purchasing power, and is now being eroded at an accelerating rate by inflation. Moreover, this is occurring at a time when the numbers of university faculty and graduate students are considerably higher than in 1967.

Recent declines in financial support would appear less serious to the science community if it were not for the poor long-range outlook for academic employment of scientists, especially in the research-oriented universities. Although the advancement of knowledge has always been a major secondary purpose of the leading universities, the actual size of the faculty has been determined largely by the size of the undergraduate student body and to a lesser extent by the size of the graduate student body. If faculty-student ratios remain roughly constant in the future, the demand for faculty will be essentially at replacement rate, and this in turn will be abnormally small because of the skewed age distribution of present faculty resulting from the rapid growth that occurred in the 1960's in response to the unprecedented growth of the student population. In the early 1980's the college-age population will begin to decline. Furthermore, the decline in the employment prospects for college-trained people, and of the lifetime income differentials between college and high school graduates, may induce an even earlier and more marked decline in the size of the college student population (*3*). All this has been compounded by the increasingly precarious financial position of the major research universities, especially private universities, a condition that seems to be inherent in the economics of the service sector, as so graphically analyzed by Bowen (*4*). Thus every uncertainty in the projections for college faculty tends to point toward an even poorer employment market than now anticipated.

Hence it appears that university careers for scientists and engineers will only grow in number to the extent that applied research and public service functions of the universities are emphasized relative to their more traditional functions of education and scholarship. Research will be less coupled to the training of students. If evolution is to take place in this direction, it will require a change in the attitude of universities toward their own social role, and an even greater transformation in the attitudes of industry and government toward the potentials of university research to serve their long-term needs.

As support of academic science has declined and the demand for research-oriented academic faculty has dried up, there has occurred simultaneously a change in the attitude of industry and government toward "in-house" research, especially basic research and longer-range kinds of applied research. As one example one might cite the case of physicists in industry during the decade of the 1960's. Although the number of physics Ph.D.'s employed in industry increased very substantially from 1960 to 1970, the proportion employed in research (as opposed to development, sales, management, and related activities) declined by almost half. Those employed in basic research declined not only in percentage terms but also in absolute numbers (*5*). Some of this change was due to disenchantment with unrealistic expectations regarding the short-term direct payoff of research, some to its being no longer necessary to compete with universities by promising young scientists freedom to pursue their own scientific interests. Thus it became clear that basic research in industry had been partly a nonmonetary fringe benefit for technical employees rather than a directly productive investment.

Another factor has been that as the volume of basic research results produced by universities has expanded many nonacademic institutions decided that it was more efficient for them to monitor the general progress of academic research and rely less on their own internally generated results.

Still another influence may have been the increasing cost of money and an accompanying rise in the effective discount rate used by both industry and government in evaluating future returns from research investments. Admittedly this is speculative and is complicated by accelerated inflation. Nevertheless, there are several rational calculations that might lead business to postpone investments in R & D. During the decade of the 1960's costs of R & D were probably rising relative to those of physical capital, and by the end of the decade there was a prospect that, owing to the expanding supply of scientists and engineers, their salaries, and hence the costs of R & D, would go down relative to other costs.

In a sense scientific and technological progress may have undermined its own sources of support. By increasing the number of opportunities for profitable investment of capital, it may have contributed to the rising discount rate (*6*). In addition it is largely science that has revealed bad side effects of some kinds of industrial production and has thus increased the demand for various kinds of "defensive" investments such as antipollution equipment. In other words, what I am speculating is that the greater the results of research, the more it creates other opportunities or needs for the employment of capital which are directly competitive with research.

So far I have talked entirely about funds for science and about employment opportunities for scientists and engineers, and have said little about the output side of the enterprise. Indeed there is nothing really to contradict the argument that employment opportunities for scientists and engineers may be declining simply because the productivity of research and development has increased owing to more sophisticated and automated instrumentation, computers, and more powerful and general theories which enable us to generate and use information more efficiently. Thus a professional man-year of effort may represent more scientific output than it did a few years ago. Whether or not this is so is almost impossible to say because of another complicating factor, namely, that the "productivity" of research effort depends also upon the state of knowledge in a given field. When a virgin field of technology, such as computers or solid state electronics, opens up, it may be relatively easy to secure a high economic payoff with relatively modest effort as measured in professional man-years, but the marginal return tends to decline with maturity. There is no reason to suppose that virgin fields of technology with very high payoff appear in a regular way as science advances. On the contrary they may appear at random, with the result that the payoff potential of research in any one epoch may be subject to rather unpredictable fluctuations. Furthermore, this situation may simply be inherent in the particular overall state of scientific knowledge or the evolutionary stage of technology.

As long as the mechanism by which science is funded tends to be tied to some measure of the economy, such as gross national product (GNP), the relative demand for scientists may tend to lag behind that for other kinds of workers except when developments within science or technology result in an abnormally high payoff from research and development. This situation usually occurs only when the appearance of a new technological opportunity coincides with the appearance of an important social need or political push. Thus during the 1950's and the early 1960's there was the rapid buildup in strategic weapons, accompanied later by the buildup of the space program. From about 1954 to 1965 the military-space effort absorbed an increasing fraction of the GNP and of the federal budget, and during the same period more than 75 percent of the new employment in R & D in industry occurred in the aerospace industry and the electronics industry, the two industries most heavily funded through these high-priority government programs. Since 1967 the trend has been strongly in the opposite direction, and the continued growth of federally supported civilian technology and of self-financed industrial research (*7*) has been insufficient to offset the decline in the military-space effort, which, though small percentagewise, was large in absolute terms.

A somewhat similar coincidence of perceived social need with scientific opportunity occurred in the biomedical field and led to the spectacular takeoff of the programs of the National Institutes of Health after 1957. My principal argument is that it takes both the perception of a need and the "ripeness" of a scientific field for very rapid advance at relatively low cost to produce the kind of rapid takeoff that we have seen in these two examples.

It is possible that R & D for energy supply technologies may represent a new area of coincidence of perceived national need with technical opportunity, but it is too early to say whether this is so. The political thrust is apparent, but it is not yet so clear that the technical opportunity will lead to a high payoff rate.

Projections

The projection of future numerical demands for scientists and engineers has become a favorite indoor sport, but I do not propose to indulge in it here. Most projections are based on extrapolations of recent history, usually considering only first derivatives, with little or no attention to second derivatives, which cannot be accurately estimated anyway. In fact the projection type of exercise has more often than not contributed to the tendency of the technical manpower production system to overreact, building up alternate surpluses and deficits owing to the delayed response of the educational pipeline to the conditions in the market.

Rather I would like to try to identify some developing trends and problems in the overall social environment that are likely to affect the demand for science and technology and for technical people. Most of these trends, as I see it, are ones which will increase demand, but the effects are hard to quantify because of the difficulty of estimating the extent to which new technical activities will substitute for current ones and the extent to which they will constitute an add-on. If past experience is a guide, then we will probably see a mixture of add-on and displacement. For example, the buildup of the space program in the early 1960's probably stimulated government-financed R & D quite broadly but drew talent and resources away from research and innovation related to the private civilian sector and civilian public services (*8*). This occurred in part because of the glamor and challenge of space-related research but also because the space-defense effort increased the relative cost of innovation in general, as indicated by the rise in the salary position of scientists and engineers in comparison with other elements of the labor force and in comparison with the corresponding situation in western Europe and Japan. This of course made privately financed innovation more expensive at the same time.

By analogy with the space-defense buildup one may well question whether industrial effort on pollution control, product safety, occupational health and safety, and so on will to some extent displace innovative effort in industry directed at the development of new products and services for the consumer. Moreover, the future demand for scientists and engineers, especially in R & D, will depend sensitively on future trends in economic growth. Most industrial R & D is actually directed toward innovations in capital goods, not consumer products, and the market for capital goods is heavily conditioned by expectation of expansion in the economy. In addition, increasing concern about the environment and the depletion of resources will lead to "internalization" of the social cost of production, which will require new defensive investments. The result will be not necessarily a slowing of economic growth but a shift of the product mix to buy more environmental protection and less of other goods and services. The total demand for capital goods would be little affected.

New Factors Affecting Demand

Of course, it is easy to identify forthcoming social needs that would create a very large demand for scientists and engineers. Some scientists such as John Platt have expressed the opinion that the United States faces an emergency of tremendous proportions and that nothing short of a mobilization of the scientific community similar to that undertaken by the Office of Scientific Research and Development during World War II would suffice to deal with the problems posed by growing population, depleted resources, pollution, and an increasingly disorganized social environment (*9*). If Platt and those who agree with him had their way, the R & D effort of the country would be limited only by the availability of manpower of the necessary minimum competence to contribute to a highly organized and articulated applied research effort. Business as usual in self-motivated science would have to disappear.

Whether or not one agrees with Platt's estimate of the situation, his scheme does not seem to be in the cards politically, at least for the next decade. Resource and environmental problems have not reached a degree of urgency that would elicit public support for this kind of mobilization, and it is not likely that they will do so in the next decade or so. Society is not frightened enough to trust its destiny to scientists in the way it did (largely unbeknownst to itself) during World War II. Rather I assume that the degree of mobilization of science will be determined indirectly by economic forces and social priorities generated through the normal political process of compromise and consensus between conflicting advocates.

I also suspect that only a part of the future demand for scientific and technical effort will be created or organized directly by government specifically through government-financed R & D. A larger fraction will be generated indirectly through new constraints placed upon present industrial technology by government regulation. These constraints will require in many cases an increased pace of innovation if living with them is not to prove prohibitively costly. So long as all producers will be required to meet similar constraints, the usual inhibitions against increasing the proportion of sales spent on R & D may be less operative than at present. The cost can be passed on to the consumer with less effect on the competitive position of the individual firm, although it will produce some redistribution of sales as between classes of industry. This is admittedly speculative.

In thinking about the next decade I have assumed that the proportion of the federal budget and of the economy devoted to defense activities will continue to decline, as it has in the last several years. During the last 5 years federal support for civilian R&D programs has shown a steady growth of 9.1 percent a year, whereas space and national security R&D have, together, shown a slight decline. If the priority of military programs should change once more, the effect would likely be felt most strongly in the government R&D sector, but increased attention to national security could also mean less attention to environmental regulation and a relaxation of standards, which in turn would have repercussions on privately financed industrial R&D. However, it is too early to speculate intelligently on such questions, and what I have to say will be presented as though there had been no Middle Eastern crisis.

Let me, then, list the factors which I propose to discuss in more detail in the remainder of this article. These are energy supply and conservation; water and air pollution control; technology assessment; chemicals in the environment; the advent of a national health service; the world nutrition problem; the management of sophisticated public regulatory systems; the communications and information revolution; public sector productivity, especially at the state and municipal levels; urban mass transportation; and the U.S. comparative advantage in international trade.

Energy Supply and Conservation

Even prior to the Middle Eastern crisis the Administration, abetted by Senator Henry Jackson, was prepared to launch an energy R&D program to the tune of $2 billion a year for the next 10 years. This is about double what the federal government is investing at present (*10*). The utility industry, through its newly formed instrument EPRI (Electric Power Research Institute), is gearing up to spend large additional amounts on research related to utility systems. This is being achieved through what amounts to a self-imposed tax on electricity, paid ultimately by the consumer, since it is an allowable cost in rate setting. This investment is likely to increase with time.

The federal investment in energy R&D may prove to be just the tip of an iceberg. Industry consumes about 41 percent of all the energy used in the United States and constitutes the most cost-sensitive consuming sector. Indeed generating costs of electricity or production costs of fuel are a much more important component of the price of energy paid by large block users. Hence such users are more sensitive to energy prices than the individual consumer, for whom distribution costs constitute a much larger fraction of the price paid. The recent rise in fuel and electricity costs is likely to continue, if not accelerate, and this will almost certainly stimulate research and capital investment aimed at energy conservation or greater efficiency in energy utilization, especially in manufacturing. There are also likely to be new energy-oriented construction standards which will require R&D directly and also indirectly to develop test and evaluation procedures, including accelerated life testing. A recent study by the Conference Board, an industry-supported research organization, indicates that intensive planning for energy conservation has already begun in a number of industries, especially those that are large consumers of energy (*11*).

Some may argue that energy conservation will be effected largely through capital investment or through changes in manufacturing or management practices rather than through R & D. (Recently announced reductions in competitive long-distance airline schedules are a good example of this sort of change.) This is certainly true in the short term, but if the trend toward higher energy costs is a long-term one, which most now believe, R&D is likely to prove increasingly attractive as a measure for restraining energy costs. The savings from purely administrative measures are likely to be realized fairly quickly, and later savings can only come through technological changes brought about by research.

The electric utility industry has been growing at about twice the rate of the general economy, which means that it should have strong incentives for innovation. The small percentage of sales now spent by the utilities on research is deceptive, because much of the research is done by the suppliers of their capital equipment. Collectively financed systems research is now recognized as a necessity which the industry itself will have to take responsibility for, since the suppliers cannot appropriate the benefits. A negative influence is that, with fuel prices and environmental protection costs rising, the lag in the public rate-setting process may cause utility revenues to fall behind "fair return" and thus reduce the funds available for research compared with what they would be in a situation of stable or falling costs.

The Middle Eastern crisis and the ensuing price actions of the Organization of Petroleum Exporting Countries produced a shock to American political attitudes that is likely to sustain pressures for government-financed R&D on energy sources alternative to imported petroleum for years to come. It is estimated that new programs now projected may employ as many as 40,000 scientists and engineers, but this falls short of the demand produced by the space-defense thrust of the 1960's.

Pollution

Legislation on the books sets as a goal "zero discharge" of wastes into all waterways by 1985 and requires application of the "best state of the art" in pollution control during the intervening period (*12*). Many observers regard the long-range goals as unrealistic and unacceptably costly for the benefits obtained. Whether this will ultimately prove to be so will depend partly on public opinion but to an even larger extent on the capacity of new technology to meet these goals at reduced cost. The precise impact of this legislation on R&D is thus hard to forecast. Requiring immediate adoption of the "best available technology" may actually discourage innovation because it means that existing investments in pollution control equipment must be scrapped and replaced before they wear out. A firm that innovates gets no particular advantage over its competitors, since they are immediately forced to imitate it. An industry as a whole has a strong incentive to delay advances in antipollution technology, since any advance imposes new costs on the whole industry. On the other hand, if innovative equipment is largely developed by suppliers, the specification of best available technology tends to guarantee these suppliers a very large market. A system of effluent charges (taxes on polluters) would provide more incentives for innovation by the individual firm, especially in making process improvements that reduce pollution rather than procuring antipollution equipment.

The enforcement of pollution controls, whether by direct setting of standards on emissions or by effluent charges, will require growth in the technical capabilities of regulatory agencies in government, not only at the federal level but also at the state and local levels. Indeed one of the principal lessons of the last few years is the political and economic difficulties that occur when we are forced to establish standards of air and water quality on the basis of wholly inadequate scientific evidence as to their effects, especially on human health. The implementation of standards entails large economic costs which are difficult to justify without strong evidence, and scientific uncertainties provide leverage for agitation against their enforcement. The need for continual changes of standards in the light of new information is also economically and politically costly; hence great effort is warranted in obtaining the necessary information and understanding in advance of the establishment of regulations.

Increasingly stringent court interpretations of producers' liability for product safety and environmental protection will also provide a strong incentive for "defensive" research in industry, aimed at avoiding the risk of unexpected damage suits involving very large penalties.

Technology Assessment

Technology assessment is a very broad term which subsumes environmental impact but includes the secondary effects of the application of technology much more widely. Congress has established a new Office of Technology Assessment which is now developing an extensive program of studies. Given present public concerns, such an office is likely to grow fairly rapidly. The development of technology assessment (TA) by government will call forth matching capabilities in industry, if only as a defensive measure, as well as similar matching capabilities within many governmental agencies. Many industry-based professional groups already show a growing interest in TA.

In fact there may be a tendency for engineers and scientists in industry to take more forthright collective stands regarding their own responsibility as professionals for safety and environmental protection, being less willing to regard such responsibility as entirely the prerogative of management. If collective bargaining by technical people in industry develops, recognition of professional concern about the consequences of engineering products could become an issue. This will be especially true if TA is seen as an obligation of industry which will increase the job opportunities and policy influence of scientists and engineers, so that self-interest and the larger public interest are perceived as congruent.

In addition to all this there is likely to be an increased demand for sophisticated technocratic analysis in public decision-making. A symptom of this is the degree to which Congress is already turning to the National Academy of Sciences in search of objective advice about public decisions involving technical issues. Most of these requests are essentially for technology assessments. Despite some criticisms of the objectivity of the academy, it still appears as the best middle ground between self-serving industry pronouncements and dedicated environmental advocacy. At the present time there are dozens of bills in Congress which name the academy, directing that it make a report on this or that technical issue. For example, the academy is engaged in a comprehensive review of the health aspects of air standards for the main pollutants from automobiles.

What most such ad hoc studies reveal is the gaps in research and monitoring information and the need for more extended and continuous effort. Thus initial attempts at TA by the Office of Technology Assessment, the academy, and other groups are likely to spin off new research and analysis institutions to deal with the problem.

Chemicals and the Environment

There is likely soon to be a national law prohibiting the introduction of any new chemical compound into the environment without a prior assessment of its probable impact. Indeed the notion of impact statements has caught the fancy of legislators and public policy analysts, and one finds a proliferation of proposals for mandated impact statements with respect to a wide variety of public and private actions. At present thousands of new chemical compounds are introduced to the market by industry each year, and almost all of them could be thought to have a potential environmental impact. If a law of this sort were applied rigorously it would require an enormous amount of research, both defensive research on the part of industry and governmental research aimed at establishing criteria of acceptability. It seeems unlikely that all this research could or should actually be funded. Some kind of priorities would have to be set; otherwise, the effect of a new law might be more to discourage new chemical products than to stimulate research on their potential effects.

The potential benefits of chemical innovation are so great that they will justify great efforts to find better ways of assessing potential side effects. Present methods of empirical testing on animals will increasingly become prohibitively expensive as well as logistically impracticable as they have to be applied to more and more chemicals. New methods will have to be developed which permit the evaluation of the biological effects of whole classes of chemicals based on proven theories of the mechanisms of biological action. Experiments in vitro on tissue cultures of human and animal cells might be one technique for advancing this art. In fact a law requiring assessment of new chemicals would probably force a new scientific approach to the establishment of safety. Whether this will actually take place may depend on the attitudes of regulatory agencies, and on public realization of foregone benefits of many chemical innovations. My point is only that this is an area where stimulation of both basic and applied research may result from legislation—research in both the private and the public sectors.

National Health Service

Within 5 years the nation is virtually certain to have some form of compulsory national health insurance. When this comes, the present health care delivery system will reach a crisis (*13*). During recent years the rapid rise in health care costs has been a good deal more than 50 percent owing to simple inflation rather than to the extension of services to new populations or the increased sophistication of medical procedures. A national system is almost certain to result in a complete change in the modes of delivery of health care, depending on the incentives built into the system.

Although the initial innovations required will be social and administrative, such reforms are certain to bring in their train requirements for new biological and physical technologies and for concomitant advances in the natural sciences. It is true that national health systems in Europe have not resulted in much new technology other than computerized record keeping, but the situation may be different in the United States, where the cost of personal services is much higher. There is likely to be a large new demand for automated equipment for clinical tests, for new kinds of auxiliary personnel and organization in hospitals and outpatient clinics, and for much more centralized record keeping and record transfer. Many of these innovations will require the services of physicists, chemists, and engineers, as well as high-level technicians, in addition to the traditional medical personnel.

It is difficult to forecast what the net effect on the requirement for skilled technical and research personnel will be. On the one hand, there is probably a large amount of duplication and waste in the present system of health care delivery. There has been a tendency for every community or every hospital to acquire sophisticated capabilities which are underutilized by the population normally served. Hence a rationalization of the system could lead to a reallocation of technical resources more than to a requirement for new resources. On the other hand, reorganization of the health care system could absorb much new technology that would require R&D.

If new methods of financing medical care include sufficient incentives for greater efficiency and cost savings in the overall delivery system, pressures will be generated for research and development within the system. An increase of 1 percent in the proportion of health care costs devoted to research could create a demand for nearly 20,000 scientists and engineers. There should, and will, be much more emphasis in research on the elimination, rather than simply the management, of disease through better understanding of underlying biological mechanisms, and through the development of better techniques for predicting specific susceptibilities of particular populations and for early diagnosis.

World Nutrition

Realization is dawning that part of the world food problem arises from the fact that the developed countries as they become more affluent are preempting a larger fraction of the world's grain supply for conversion to animal protein. It is not true, as is sometimes said, that each individual can consume only so much food-producing resource and hence that demand for food is conditioned largely by population growth and is a problem only of underdeveloped countries. At the present time it is estimated that about two-thirds of growth in world demand for grain is due to population increase and the other third to growing affluence (*14*). Thus the developed countries, which are largely responsible for the latter component of demand growth, have a large responsibility for the world food crisis. As this is better apreciated, agricultural research in the industrial countries may become fashionable again. It may also become more profitable as world demand raises the prices of grain and animal feed relative to other commodities.

It is difficult to predict how much this might affect the demand for people in agricultural and food-related research and in the diffusion of agricultural technology. Projections from the recent past have been based on the assumption of burgeoning surpluses and subsidized agricultural inefficiency within each national economy. The new situation is likely to give quite a different complexion to agricultural technology. It will be more oriented toward production and less toward utilization. There will be more emphasis on nutrition and less on finding new uses for surplus products.

There will also be intensified effort to find replacements for chemical methods of pest control and for chemical fertilizers. Biological pest controls, being much more species-specific than chemical controls, will require more research to achieve a given level of protection. This is a good example of how constraints placed on technology by the requirements of environmental protection can actually increase the requirement for new technology and for research in support of it. Furthermore, the application of biological methods requires a much higher degree of fundamental understanding of the biological principles relevant to each situation.

Regulatory Systems

There is an increasing trend toward the use of performance rather than design standards in many industrial product areas. The automobile emission standards set as a result of the 1970 clean air amendments, and many of the safety standards recently set for automobiles, are examples of performance standards. So, in effect, are the regulations on drug efficacy and safety. In effect the government says it does not care what is in the black box so long as it has certain defined outputs which are precisely measurable through reproducible procedures. Such regulations encourage innovation to meet the performance specifications at lower cost. Their implementation is also more dependent on research knowledge than in the case of so-called design standards, typical of which are traditional building codes, where simple visual inspection is frequently sufficient to verify that a standard is being met. Scientific analysis and laboratory experimentation are required to design measurements which unambiguously verify that performance standards are being met, and scientific sophistication is required in interpreting the results of such tests. This should create a growing demand for technical people both in regulatory operations and in the research necessary to establish test procedures on a sound scientific basis.

Not all regulation will encourage innovation. The number of tests and verifications required may in some cases simply cause designs to be frozen. But I suspect the balance of increasing regulation will be toward requiring more and more supporting research and monitoring.

The Communications Revolution

The communications industry is in a process of rapid change such as has not been seen since the beginning of television. The classical monopoly of the common carriers in point-to-point communications is being broken down both by the advent of new technologies such as satellites, high channel capacity cable, and data transmission, and by apparent changes in the attitudes of regulatory agencies toward competition in the communications industry. With a wider menu of technologies available or potentially available, there is less certainty that telecommunications is a natural monopoly.

The effect of increased competition in communications on the rate of innovation and on the demand for technical people is hard to predict. One could argue that the monopolistic structure of the telecommunications industry and the oligopolistic structure of the data processing industry have favored the generation of excess revenues that can be and have been devoted to a vigorous and stable research program in these industries. Greater price competition may reduce the margin that can be invested in innovation, and especially in basic research. On the other hand, greater competition may open up new markets, greater differentiation of services, and a wider diversity of products. It would almost certainly lead to greater emphasis on development as opposed to research.

The growth potential of the information transmission and management industries is in any case very substantial over the long term. The end is not in sight for rapid decline in the unit cost of storage, transmission, or processing of a "bit" of information because of both advances in technology and economies of scale. The elasticity of demand for information services is high. More important, the relative costs of communications and transportation are likely to be increasingly in favor of communications as energy shortages and environmental problems plague the transportation field.

Almost all projections of the American economy stress the growth of services, public and private, relative to the processing of materials and the production of physical goods. One key to the efficient delivery of services is of course the capacity to handle large amounts of information, and this seems to make inevitable a continuing rapid growth in this sector of industry. A few service industries, such as banking, insurance, and marketing, have already shown spectacular increases in productivity as a result of the introduction of computers, and this trend is likely to continue, with perhaps more emphasis on small, special-purpose devices.

Public Sector Productivity

The public sector, which is of course a service sector, is believed to have lagged behind the private service sector. The more than doubling of employment between 1950 and 1970 in state and local government is an example of how employment growth in this sector has outpaced the general labor force. The cost of government has been rising much faster than the general price level and is often assigned an important share of the responsibility for the continuation of inflationary pressures in the economy. Government services are not under much competitive pressure; they cannot be readily imported and exported geographically. But public pressures on them—both the demand for more and better public services, and resistance to further cost increases—are steadily mounting.

At the same time the application of science and technology to the delivery of public services is minimal and confined to a few fields, such as the Internal Revenue Service, the Social Security Administration, and the Government Printing Office. In most areas of the public sector the introduction of new technology has been resisted. Where it has been tried, the results have been less than expected, usually owing to inadequate appreciation of the amount of adaptation required to incorporate new technology into a complex, ongoing sociotechnical system. There is widespread disillusionment with the computer as a tool of urban management, for example. This is due mostly not to the technical limitations of the computer per se but to failure to adapt organizations or work systems and the computer to each other. Moreover, general public disenchantment with governmental institutions has led to a somewhat ambivalent attitude toward governmental efficiency. The public, often rightly, tends to identify efficiency in government with impersonality and arbitrariness—a characteristic natural to bureaucracies which is often encouraged by the use of devices such as computers.

As in the case of health care delivery, the primary innovations needed for the public sector are probably social and administrative, but they are likely to bring with them a new market for the application of technological innovations, including new modes of analysis and rationalization of government tasks. As in any area where costs and manpower requirements are rising rapidly, the expenditure of a small fraction of operating costs on research and analysis to improve efficiency can have very large payoffs.

The long-range pressures for cost saving innovation in state and local government will win out. These sectors of government will be increasingly financed through federal revenue sharing. The federal government is unlikely to continue transferring large revenues to lesser jurisdictions without insisting on efficiency and productivity and developing standards of performance against which the utilization of federal funds by local jurisdictions can be measured. These pressures in the long run are likely to create a new source of demand for technical people at the state and local levels, as is already beginning to occur in some of the larger cities.

Urban Mass Transit

The obstacles to the use of the Highway Trust Fund for other modes of transportation seem about to be overcome, and this is likely to have a considerable impact on technological innovation in transportation. There will be a demand not only for people to develop and improve hardware but even more for people to analyze and plan transport systems, especially within urban complexes. There is likely to be great emphasis on energy conservation in transportation. If this is a new area of demand for technical people, it is likely to grow rather slowly at first. Except for highway design and construction, the United States has not been an international leader in ground transportation for at least a generation. It is not clear to what extent we will rely in the future on imported technology for other than highway and air transportation, but I think that in the long run this will be an important sector of demand for technical people.

Comparative Advantage of the United States in International Trade

Most commentators agree that since 1870 the United States has maintained a favorable balance of trade primarily by exporting products which were either unavailable abroad or so superior to corresponding foreign products as to be virtually new products (*15*). Most of these innovative products are capital goods, not consumer goods. Only briefly, during the periods after the great European wars when Europe was on its back, has the United States had a favorable trade balance in consumer goods. Indeed our export of capital goods and managerial skills has tended to help foreign competitors to catch up eventually in the consumer goods area. Thus there is a widespread belief among economists, though disputed by some, that the U.S. trade position in the world depends on its ability to innovate. To what extent this depends on our capacity in basic science is a matter of more dispute. Our superiority in capital goods technology considerably antedates the development of our commanding lead in basic science. However, this in part simply reflects the changing character of industrial technology in the direction of more science-based fields.

Since the early 1960's the growth of labor productivity in the United States has lagged behind that in Europe and even more behind Japan's, although in absolute terms our productivity is still greater. There are some who believe that our loss of trade position in the 1960's is significantly due to our concentration on space and defense technologies during this period, a concentration which deprived the civilian sector of the economy of our most innovative technical and managerial talent, as well as the most venturesome venture capital (*8*). It is significant that our strongest trade position is in areas such as jet aircraft, computers, and industrial controls which have benefited most from space and defense technology. Be that as it may, it seems likely that there will be a continuing thrust toward the use of technology to restore our international competitive position, and this will be a source of demand for technical people during the rest of this decade. At present there is no consensus as to the appropriate role for government in this effort, or on the relative value of direct subsidy of industrial R & D in comparison with indirect incentives for industrial innovation. Neither is there consensus as to whether we should exploit areas of technology in which we are already in an advantageous position or should exert efforts in areas in which we are lagging. Of all the factors I have discussed this could be the one which would lead to the largest demand for manpower, but it is also the one subject to the largest uncertainties.

Contrary to general belief, in industries other than those related to space and defense the number of scientists and engineers for a given number of employees is less in the United States than in many comparable industrial countries, notably Japan and the Netherlands (*16*).

Concluding Remarks

One of the questions left open by the preceding discussion is the future prospects for basic research. Much of the potential demand for technical manpower that I have suggested could be described as in highly applied areas, involving engineering rather than science, development rather than research. But this may be a somewhat deceptive effect of any projection based on social needs. Almost by definition it is difficult to foresee the social need for basic research. Moreover, basic research is really a form of overhead on the R & D effort determined by social goals, and in the long run is almost inevitably geared to the magnitude of the practical effort, as Alvin Weinberg has emphasized (*17*).

In one respect, however, the future is likely to demand more basic research in relation to development. This is simply because to the extent that there is a requirement for the assessment of new technology, along with its development, the supporting research required is more "basic." Much new technology can be developed on an empirical or trial-and-error basis, but to understand the potential side effects of a new technology requires a more fundamental understanding of its underlying scientific basis and of the environment in which it will operate. The relevant areas of knowledge cannot be foreseen with high confidence, and therefore a high level of intellectually guided research effort is required. The political problem will be to make sure that the public and the politicians appreciate this fact, and act accordingly.

In this paper I have had little to say about the support of science for its own sake, for its intrinsic social and cultural value. Although there is no question that the public has demonstrated its willingness to provide such support, I doubt whether the intrinsic cultural value of science could be used to justify to the public or to politicians more than a small fraction of the present support for basic science in the United States, or indeed in any other major country of the world (*18*). This does not mean that the public is unwilling to support some very abstract science of no apparent usefulness, but the most persuasive justification for this is likely to be that science is a seamless web, such that the "useful" parts cannot prosper unless the apparently "useless" parts are also well supported (*19*).

References

1. V. Bush, *Science, the Endless Frontier* (Government Printing Office, Washington, D.C., reprint, 1960), p. 86.
2. H. Brooks, in *Science and the Evolution of National Policy*, J. Shannon, Ed. (Rockefeller Univ. Press, New York, 1973), p. 105.
3. R. B. Freeman, "Manpower requirements and the skill composition of the U.S. work force," paper presented to the National Science Foundation Conference on Manpower Forecasting, Hot Springs, Va., 17 April 1974.
4. W. G. Bowen, *The Economics of the Major Private Universities* (Carnegie Commission on Higher Education, New York, 1969).
5. D. A. Bromley *et al.*, *Physics in Perspective* (National Academy of Sciences, Washington, D.C., 1972), vol. 1, p. 879.
6. H. Brooks *et al.*, *Science, Growth, and Society, a New Perspective* (Organization for Economic Cooperation and Development, Paris, 1971), p. 34.
7. H. Brooks, "Straws in the wind: Implications of the FY75 budget," *Public Sci.* **5** (No. 3), 3 (1974).
8. J. H. Hollomon and A. E. Harger, *Technol. Rev.* **73** (No. 9), 30 (1971).
9. J. Platt, *Science* **166**, 1115 (1969).
10. President's message to the Congress, 18 April 1973, *Compilation of Presidential Documents* (National Archive and Records Service, Washington, D.C.), vol. 9, pp. 389–406.
11. Conference Board, unpublished report to the Ford Foundation Energy Policy Project.
12. 1972 Amendment to the Water Pollution Control Act, Public Law 92-500.
13. D. D. Rutstein, *Blueprint for Medical Care* (MIT Press, Cambridge, Mass., 1974).
14. ———, statement to the Committee on Ways and Means, House of Representatives, 21 June 1974.
15. R. R. Nelson, *Minerva* **9**, 386 (1971); H. Brooks, *ibid.* **10**, 321 (1972).
16. M. Boretsky, *U.S. Technology: Trends and Policy Issues* (George Washington Univ., Washington, D.C., 1973).
17. A. M. Weinberg, *Reflections on Big Science* (MIT Press, Cambridge, Mass., 1967), pp. 97–100. For a general discussion of various justifications for the support of basic science, see H. Brooks, *The Government of Science* (MIT Press, Cambridge, Mass., 1968), pp. 54–80; *Public Admin. Rev.* **31**, 319 (1971).
18. H. Brooks, in *Basic Research and National Goals*, a report to the Committee on Science and Astronautics, U.S. House of Representatives (Government Printing Office, Washington, D.C., 1965), see especially pp. 84–87.
19. National Science Board, *The Physical Sciences* (NSB 70-1, National Science Foundation, Washington, D.C., 1970), p. 21.