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Science and Technology

THE CHALLENGES OF THE FUTURE

Science and Technology: The Challenges of the Future

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Abstract

Challenges to science and technology in the 1980s are discussed in a series of six lectures by distinguished speakers of national and international reputation. In the first lecture, Dr. Lewis Branscomb, Vice President and Chief Scientist of IBM, discusses the roles of the Department of Commerce and the National Science Foundation in the future. Dr. Branscomb draws heavily on the experiences of the Japanese industrial community. Mr. William Carey, Executive Officer, AAAS, follows with his views on the interrelationships between Government, science and the society in the 80s. Carey emphasizes that science will play a key role in the future and that the scientific community must not be passive, but rather must accept responsibility for the impact its technology will produce. Dr. Arthur Bueche, Senior Vice President, General Electric Company, focuses specifically on Government-Industry relationships in the 1980s. A hypothetical "earthworm crisis" is used by Bueche to illustrate his view of the future. In the next lecture, Dr. Arno Penzias of Bell Laboratories shares his thoughts and ideas about managing research in a changing environment. Penzias emphasizes selection of the right people and providing them with an environment to succeed. Mr. William Miller, President and Chief Executive Officer of SRI International, then discusses the national technological edge that the United States possesses in computer software. He traces software development in the United States and discusses our ability to capitalize on this technological advantage in the future. In the last lecture, Professor Richard Nelson of Yale University relates technological advantages to productivity and growth from an economical point of view. Professor Nelson delineates a sharply defined and rather narrow role for Government in industrial research and development.

Key words: fundamental research; Government-industry relationships; industrial technology; NBS 80th Anniversary; productivity; science; software edge.

Preface

On its 80th anniversary, the National Bureau of Standards hosted a series of lectures by six distinguished speakers of national and international note who discussed the challenges facing science and technology and, thus, the Bureau in the coming years. This publication contains the texts of these presentations, along with transcripts of the question-and-answer sessions following the presentations. The lecture series was organized by Dr. Donald R. Johnson of NBS with the very able assistance of Mrs. Carol Shipley in making arrangements for speakers and handling the manuscripts. The staff of the NML Text Editing Facility are acknowledged for their substantial contributions of typing and editing support.

Contents

Dr. Lewis M. Branscomb, vice president and chief scientist of International Business Machines Corporation, is responsible for guiding the Corporation's scientific and technical programs to ensure that they meet long-term needs. He joined IBM in May 1972.

A noted physicist, Dr. Branscomb was appointed director of the National Bureau of Standards by the President in 1969 after a research career at the Bureau since 1951.

Dr. Branscomb was graduated from Duke University summa cum laude in 1945. He was awarded M.S. and Ph.D. degrees in physics by Harvard University in 1947 and 1949.

Among his affiliations, Dr. Branscomb has been a member of the President's Commission for the Medal of Science and the President's Science Advisory Committee. He is a member of both the National Academy of Engineering and the National Academy of Sciences. In 1979 he was appointed by the President to the National Science Board, and in May 1980, he was elected chairman. A fellow of the Royal Society of the Arts, Dr. Branscomb was the 1979 president of the American Physical Society. He is a director of both Mobil Corporation and General Foods Corporation.

The Competitive Challenge to U.S. Industrial Technology R&D Responsibilities of Government Agencies, Universities, and Industry

As the American public focuses its attention on the state of our economy, now challenged around the world by technically competent, progressive competitors, calls for Government action and changes in Government's role are increasingly heard. In the civil sector the attention focuses on new roles for the Department of Commerce and the National Science Foundation, as exemplified by the proposal for a National Technology Foundation. Defining the proper responsibilities of these agencies, establishing the needed resources and managing them properly will constitute a major challenge before the Administration and Congress in the next few years.

Not long ago, I read in the *Washington Star* how a subcommittee of the House of Representatives had concluded that, in trade terms, America is "Japan's plantation," supplying wood and crops to Tokyo in return for high technology products.

Those of us in the scientific and industrial communities have been debating the importance of science to the economy for 30 years. But it was not until the Japanese showed us how to do very well the things we thought we were best at, that the whole country decided to take this issue seriously.

This concern has generated lots of presidential commissions and studies about innovation, productivity, basic research, engineering and technology, and a number of bills intended to promote all of them.

Some Americans want us to copy the Japanese, and turn the Department of Commerce into MITI. And some Japanese tell us what they think we want to hear. For example, I recently asked a Japanese colleague what was the greatest strength of his computer development group. "Our people are very innovative," he said. "What do you mean by 'innovative'?" I asked. "Each engineer is innovative every day." he replied. "He comes to work knowing precisely his goal for that day, and doesn't go home until it is achieved."

That is the kind of innovation we all respect. Hard work, personal savings, and concerted national action have brought the Japanese from the ashes of World War II to the most technologically ambitious economy in the world today. Meanwhile, the United States has allowed itself to get inefficient, self-indulgent, short-sighted, and unsure of its future.

There are almost as many views as to how the United States got itself into this fix, and proposed solutions, as there are economists who espouse them. Every expert has a pet villain, and most of them are probably right. Lester Thurow, a distinguished MIT economist, calls it "death by a thousand cuts."

Perhaps the cruelest cut of all is that many people believe America has somehow lost its knack for innovation. Government attention has focused on innovation ever since the Charpie report, put forward by the Commerce Technical Advisory Board 2 decades ago. People tend to think of new products when you mention innovation. But our economic problems are at least as much or more related to sluggish productivity growth as to lagging product innovation. Where the Japanese show their strength is in process and manufacturing innovation, and very quick adoption—often with superior engineering design for manufacturability—of the product innovations of others.

Professor Thurow, whom I quoted earlier, has recently published a book called "The Zero-Sum Society." He notes that Americans save only 10 percent of their GNP, compared to 15 percent in West Germany and 20 percent in Japan. This shortfall in capital formation contributes importantly to obsolete factories and forms a barrier to the introduction of new technology.

Thurow estimates that to bring American savings up to even the German percentage would require a diversion of $114 billion in consumption to savings and capital investment. That calls for a formidable amount of self-restraint in a society that has become too self-indulgent.

What about our technology base? We Americans have become accustomed to a new experience, we now expect leading-edge technology in Japanese and some other foreign products. We expect quality and sophistication where once we looked to foreign suppliers for the cheap and imitative.

Even in computers, an area in which the U.S. still is world leader, the Japanese have declared their determination to achieve a position of technological parity, if not leadership, whatever the resources and however long it may take. The skill and determination they bring to this effort does not exceed that of the U.S. companies with which they compete. But the commitment of the entire citizenry, and of the government as well, to the achievement of this goal is very impressive.

Let us take a more detailed look at the computer industry and the Japanese challenge. In comparison with the historical performance of other industrial sectors, by every measure these are extraordinarily healthy and successful industries. Gleams in the scientist's eye as recently as 30 years ago, the U.S. data processing industries produce $70 billion dollars of revenue for our economy here and abroad, exhibit a long-term growth rate of 13 percent, employ 700,000 workers in their American operations and are generating new jobs at roughly the rate of 50,000 per year. They are industries whose profitability has financed much of their own growth and at the same time attracted a substantial amount of equity capital, financing hundreds of new business entries into the industry every year. They are therefore extraordinarily competitive industries, as measured both by new entries and by rapidly falling prices in conjunction with performance and functional improvements, and they exhibit a remarkable rate of introduction of new technologies and new products.

Any industry exhibiting this kind of technological and business dynamism is always in a state of change, and there are always challenges to be faced. As we move into the next generation of microelectronics technology, we will find the cost of entering the microelectronics business rising because of the great complexity and cost of production tooling. End-user product manufacturers will find the technical complexity of designing products in the most advanced technologies a substantial challenge. We therefore see many companies moving towards a vertically-integrated capability; that is, the ability to make both microelectronic components and to deliver end-user products incorporating them.

Another measure of the state of health of this industry is the extraordinary attention being paid by the governments of other nations to developing their own competitive capability. These competitive challenges testify to the success of an industry whose roots lie within American ingenuity and business leadership.

The Japanese certainly are our most rapidly advancing competitors. At the present time, their penetration of U.S. computer sales is modest, but they enjoy enormous success in consumer electronics broadly. They are just beginning to be a significant factor in the U.S. semiconductor industry. They do have a way to go, and there is no reason to panic. In Japan itself, only last year did a Japanese company exceed IBM's wholly-owned Japanese subsidiary in domestic gross revenue.

There is no reason for complacency, however, for the Japanese rate of technical progress is truly impressive. In terms of integrated circuit components, the fundamental devices on which computer and consumer electronic products are based, Japanese shipments increased from 19 percent of the worldwide volume in 1977 to 24 percent in 1979 while exhibiting an average absolute compound growth rate of 56 percent. In the same period, Japanese investment in integrated circuit research and development has increased from $120 million in 1977 to $258 million in 1979, an average compound growth rate of 46 percent.

At the present time, IBM is the only company shipping 64,000 bit-per-chip memory devices in large volume, but I believe all of us are impressed by the quality of Japanese 16,000-bit products, by their costs, and—most importantly—by the technology base they are building with which to challenge us both in components and in computers and other products in the mid-80s. There is little question that their rate of progress represents a serious challenge to the U.S.-based industry.

This extraordinary rate of progress in Japan has many sources, of which I believe the following are most important:

a. Japan focuses its priorities on sources of economic strength—not weakness (as our government often seems to do). There is a national consensus in Japan that the information industry is to be one of the strategic industries on which the Japanese base their future. Every Japanese worker, government employee, and citizen understands that. They act accordingly.

b. Both government and industry in Japan focus on competition in technological terms. The Japanese seem to be able to forego near-term profitability in the quest for long-term strategic industrial position. Japanese managements understand the key leverage of technology, and their investors and bankers back them up.

c. The involvement of the Japanese government in the development of their key industries, in designing favorable tax and other financial arrangements for strategic industries, and in taking a very aggressive position supporting their companies' trade activities.

d. By no means least important in this list is the quality and dedication of Japanese workers and management, the quality of their educational system and its production of engineers (twice ours), and the prestige which manufacturing technology and factory performance enjoy in the Japanese technical community.

These four areas of strength have little to do with research capability or scientific attainment. But it would be very wrong to imagine that U.S. scientific and engineering capability do not merit priority attention by government as well as the private sector as we seek to generate our national strategy for economic revitalization. To clarify the issues, let us look again at our computer and microelectronics industries and ask the chicken-and-egg question: Is the health of the U.S. microelectronics industry driven by technological progress or by market opportunity? The answer to this often-asked question is "both." Neither factor alone can keep the industry healthy. Scientific and technological progress has permitted the production cost of a given electronic function to fall annually by more than 26 percent, on the average, for 25 years. This falling cost, reflected in a highly competitive industry by prices falling at the same rate, both permits and requires volume growth in electronic shipments. This aggregate volume of shipments has grown faster than unit costs have fallen. That is, the demand elasticity for electronic and computer products has exceeded the technology's productivity gains and has led to very large growth in the physical volumes of manufactured goods and to net revenue growth in the industry. An industry with revenues growing at 13 percent which enjoys a technology price/performance improvement trend of 27 percent, is thus delivering 40 percent more computational power or other electronic capability to its customers every year, reduced perhaps to 30 percent by inflation.

Thus, the U.S. computer industry as a whole is exhibiting a real growth of more than 13 percent per year, minus the penalty of inflation. Unless this real growth continues, the demand will not be sufficient to generate the revenues that permit the reinvestment in technology that will continue the price/performance trend.

Thus, this very strong sector of the U.S. economy could fall on hard times if there should occur a failure of the upward spiral of growth, in which customer demand more than compensates for the ability of technology to reduce prices. This upward spiral could turn into a downward spiral, in which volume growth fails to produce revenue to cover falling prices. Then, companies would only be able to hold the profit margin needed to keep the technology going by cutting back on employment, and revenues would fail to generate capital to buy the tools to exploit the technology. Such a failure could occur for any of the following reasons:

a. Failure of the technology to continue to advance sufficiently rapidly.
b. Appearance of obstacles to demand-growth, such as government regulatory restrictions or a shortage of key science and engineering skills.
c. Factors that unreasonably escalate costs (such as inflation, cost of capital, or tax increases).
d. Failure to compete internationally, for whatever reason.

How can we avoid these four pitfalls? The new administration is set on a course to address the regulatory and economic factors that can stifle demand growth, unreasonably escalate costs and restrict access to capital to finance growth. I assume the administration will also continue to pursue a fair and free trade policy based on the provisions of the GATT, which became effective in January 1981. These are indispensable steps toward a significant stimulus to private investment in growth industries. Companies can be expected to raise the needed funds to invest in product development and manufacturing technology, if inflation moderates, the cost of capital falls and investment is encouraged.

But what about the wellsprings of that technology, and the training of the technically skilled people to ensure continued advances in the technology in the face of fierce international competition?

The right kinds of governmental investments in science and technology are not only welcome; they are urgently necessary. But when the American Government seeks to stimulate industrial science and technology by direct action, it often runs into difficulties.

The Bureau of Standards has seen such attempts made off and on for three quarters of a century. Old timers will remember the Civil Industrial Technology program, which proved a lightning rod for private sector objections to being helped by government technologists. The history of the AEC's encouragement to the commercial nuclear power industry is—in retrospect—no model for the government/private relationship. For out of the government's own conflicted role as both regulator and promoter of nuclear power came the legacy of lost public confidence that throttles the industry today.

The most recent and ambitious venture into public financing of private technology is the Synthetic Fuels Corporation. In this case it is clear that the government has undertaken to accept responsibility for making investment decisions for the oil industry, having captured the revenue for high risk investments through the "windfall profits" tax.

The Reagan Administration is likely to back away from these forms of direct intervention. The Administration will still have to decide what forms of indirect science and engineering support are justified.

One form of indirect support attempts to identify "generic" technologies for federal support, such as those authorized in the Stevenson-Wydler Act, enacted last year. The idea of generic technology centers would not be bad if they focused on nonproprietary, publishable research, generally known to be useful by the broad community of industrial scientists and engineers. The difficulty arises when the word "technology" is invoked, since it is difficult to pursue technology in the absence of economic tests and market requirements.

If government-sponsored programs move closer to economic and market criteria for success, the political complications grow, for it becomes necessary to put the direction of such laboratories under the influence of industrial competitors. A host of difficulties may then ensue, ranging from competitively biased technical judgments to antitrust problems. On the other hand, if such laboratories attempt to work on commercial technology without the guidance of those aware of the economic and market requirements, a good deal of technical effort and money can be wasted.

I do not intend a blanket rejection of such proposals. Indeed, IBM participates in several university-operated and government-sponsored applied research programs in which a number of companies take part. I only observe that it is not easy for government to invest effectively in commercially important technology, without encountering political complications.

A classic example is the attempt of the Carter Administration to bolster the competitiveness of the beleaguered U.S. automotive industry by federally sponsored research. Caught between Congressional exhortations to "re-invent the automobile" and skepticism about a government agency's ability to manage an automotive technology effort, the Carter Administration adopted a plan for basic automotive research. The Department of Transportation would ask NSF to manage a program in fields of potential importance to automotive technology.

This project, acronymed CARP, was one of the first to be struck down by the incoming administration. It was indeed a wholly unobjectionable project as far as research content was concerned. But it was very vulnerable to the objection that the public expectation for results would not be matched by the project's reality. A "basic research" program to "re-invent" the automobile is a contradiction in terms.[1]

Thus, I believe there is general recognition of the need for restraint in government initiated attempts to engage in commercial research, while there is growing conviction that a growing share of the federal research investment should be made, with ultimate use by the private sector in mind. Yet there is confusion in how these seemingly contradictory principles can be accommodated. This confusion has part of its origin in differing perceptions about basic, applied, and engineering research.

We have arrived at a point—in the evolution of technology policy—where the thrust is "back to basics" and common sense must be allowed to prevail. We will no longer deceive ourselves that a government agency can do a better job than private industry at evaluating the economic and market potential of alternative technologies. But I believe this administration must and will accord a high priority to strengthening the science and engineering research base on which private investments can build.

This brings me, then, to the question of research and education strategies for NSF and the Department of Commerce. The time is at hand to focus federal energies on the central government's unique responsibility for the nation's scientific and technical infrastructure. Key to this view of policy is:

a. a more sophisticated view of the common distinctions between "pure" and "applied" research;

[1] Lewis M. Branscomb, "Opportunities for Cooperation Between Government, Industry and the University," *Annals of the New York Academy of Sciences,* Vol. 334 (December 14, 1979), 221-227.

b. a focus of federal concern on engineering capability as well as scientific excellence;
c. development of stronger ties between university and industrial research;
d. federal investments to ameliorate serious shortages in key technical skills; and
e. attention to the knowledge and services with greatest potential to increase research and development effectiveness.

Let me speak to each of these points. I have long believed that the NSF's distinction between basic and applied research has confused public policy in a most detrimental way. I have expanded on this view at length in a recent paper at The American Physical Society's New York Meeting.[2] I will summarize the point by noting that the NSF definition rests on the motives of the investigator. (Am I exploring the unknown driven by curiosity? (basic research) or am I looking for an answer to someone else's question? (applied research).) Useful as this may be to sociologists of science, it is not very helpful to investors in research, including the Federal Government. What matters to the investor is, what is the likelihood that this research will lead to ideas or information of great significance or value?

There are, in fact, two classes of applied research funded by government. One is what I like to call useful or applicable research—known to be productive of ideas and answers that can be put to good use. This useful science is really not distinguishable from the conventional notion of "basic" research, except that a fraction, actually a very small fraction, of basic research deals with notions unlikely to find application very soon.

The second kind of applied research is what I call "problem-focused" research, which purports to address and even provide solutions to identified societal problems. There is nothing wrong with investing federal money in such problem focused research. It is the primary activity of the "mission-oriented" agencies. But in most cases it is not the right way to use either universities or national laboratories, for problem-focused research should be carried out in institutions able to solve the problem when the research is done. Usually this will be the private sector unless the problem lies within the sphere of governmental responsibility.

In 1969, within a month of becoming Director of NBS, I sought a meeting with Dr. William McElroy, then Director of NSF, to solicit his interest and cooperation with NBS in what I called the "useful sciences." After a few months, I was given the opportunity to address the NSF senior staff. I confess my ideas fell then on infertile soil. But today there is a more sophisticated view of science and engineering and their dimensions of value to American society.

[2] Lewis M. Branscomb, "Physics—Used and Unused," *Physics Today,* March 1981.

The NBS has encouraged and endorsed the policy of the NSF to integrate basic and applied science in all its research directorates. This provides the opportunity to pursue research of high value and significance in all the science and engineering disciplines. The NSF will continue to focus on investigator-initiated, competitively evaluated research but it will be in a much stronger position to respond to opportunities and urgent needs and to explain to its publics the value of its total investment in research.

This should put NSF in a stronger position to help university investigators to explore the excellent and useful areas of scientific and engineering work such as those pursued at the National Bureau of Standards. By the same token, I hope NBS will continue to make seminal contributions to science, taking full advantage of the Bureau's measurement skills to open new doors to discovery.

The second issue requiring attention is the status of engineering capability in the U.S. There is no doubting the crisis in American engineering. The Japanese, with a smaller population, outproduce us in engineers two to one. Our engineering faculties are depleted. Two thousand tenure track faculty posts stand vacant. Instructional equipment is so outdated, many engineers must start their technical education anew after they are employed in industry. And, even in a recession, recruiting is especially fierce for electrical, computer, and chemical engineers. Fifty to 60 percent of the engineering graduate students are foreigners, and the ratio continues to rise as the fall-off in the number of engineering Ph.D. candidates—a fall of 30 percent in 10 years—is almost entirely restricted to the U.S. citizens.

The NSF's primary role is to support research in the engineering disciplines. To this end an Engineering Directorate is being created with the intention of strengthening research in these fields. Secondly, NSF has renamed its education directorate "Science and Engineering Education" reflecting new priority we intend to accord to ameliorating the crisis in engineering education.

The NBS does not believe that these responsibilities should be removed from the NSF and relegated to a new National Technology Foundation. They are our proper job, and we intend to seek the resources to do it. But the tasks proposed for the Technology Foundation are important and most of them do belong properly, in my view, to the Department of Commerce and to the NSF.

I believe the Commerce Department should share with others concern for the quality and availability of professional engineers and technicians, as well as the retraining of engineers in midcareer. The Department should be knowledgeable about the strong and weak components of the technology in different industrial sectors, and seek to focus national policy toward support for areas of strength and opportunity.

Most important, the Department should focus attention on the factory as an institution deserving respect and offering rewarding technical challenge. The prestige of manufacturing engineering needs to be restored by an infusion of the most advanced technical ideas and talent. Modern engineering design, production control, process technology, materials strategies—all these are areas of technology which the DOC should understand and whose health in various sectors can be assessed. I do not propose DOC should finance the needed improvement in industry, but DOC might well finance, in collaboration with industry, some of the needed upgrading of our engineering schools' capabilities, particularly those capabilities that could rapidly upgrade the productivity and technical agility of our manufacturing institutions. Indeed, much can be accomplished without substantial federal expenditures by encouraging research collaboration between university and industry laboratories.

The National Science Foundation has a substantial program, which is being expanded, of grants to such collaborating partners. The funds may flow to either partner; the work is reviewed by technical peers and evaluated; and the results are expected to be published.

The real benefits from such a program go well beyond the specific research it finances, however. The most effective mechanism for ensuring that our technology properly stimulates our science, and that the science illuminates and sparks new technology, is to maintain the highest degree of cooperation and interchange within the professional, engineering and scientific communities that cut across university, industry, and government research enterprises.

An alternative approach to encouraging this interchange with universities also merits serious study, in my view. Congressman Charles Vanik of Ohio introduced a proposal last year (the Research Revitalization Act of 1980) to permit companies a 25 percent tax credit, in addition to the normal business deduction, for contributions to university-conducted research.

This, in effect, allows the government to underwrite the cost of university research that has been undertaken as the result of agreements entertained by the university and a company, without government's direct involvement in those discussions and agreements. This approach has the virtue of minimizing the overhead expense and the bureaucracy attendant to receiving a direct grant of government money.

It puts the responsibility for deciding what university research is of greatest interest to industry in the hands of industrial scientists and engineers. It puts the responsibility for determining what industrial research needs are appropriately responded to by universities squarely in the hands of the university faculties. And it permits microdecisions on both issues to be made in the context of specific relationships.

I have already spoken to the issue of key technical skills. This is an area where the administration has yet to define a clear view of federal responsibilities. I am convinced that however diligently the states attempt to bolster science and engineering education, the effort will fall short without a federal leadership. Industrial philanthropy today meets 2.6 percent of the operating costs of our research universities, public and private. Even a major expansion of industrial support will not relieve the Federal Government of its leading role.

Finally, let me turn to the technical information and other services, offered on a national level, to promote the objectivity, efficiency and progress of both public and private research and development activities. Looking back over all the decades, there has been controversy from time to time about the extent to which the NBS should focus on help to specific industries or the amount of investigator defined basic research the NBS could afford. But, there has never been any doubt about the value of the Bureau's work in measurement science, materials characterization, test methods, and properties of natural matter and useful materials. To be sure, the Bureau has never claimed exclusive jurisdiction over these services. Nor has the Bureau failed to recognize that the information industry has an important role in providing access to this great body of useful information.

But now that the view of government in a limited, helpful role has the endorsement of the electorate, the time is ripe for recognition of the extraordinary value to industry and to science of the basic NBS services. The Bureau's work in measurement science belongs in the priority core of the Nation's science investments. This work is invaluable to industry, but is so widely shared it will not be performed or paid for by industry. And its value to the effective progress of science is just as unique as is its value to the efficiency of industrial research and development. Here too, categorization of work into "basic" and "applied" is mischievous and not helpful in making research investment decisions.

How can these four ideas be applied to microelectronics technology? Regarding "basic" and "applied" research, the problem is bypassed by the totally new and dynamic character of the fields engaged in it, from applied mathematics to solid state physics, ceramics, polymers and metallurgy, computer science, electrical engineering, production control, automated design, development and test.

University-industry collaboration has arisen quite spontaneously, and with very little federal stimulation or support. In California, North Carolina, and Minnesota, the Governors have personally led the call for state investment in university-operated microelectronics science and engineering. Companies have invested hundreds of thousands of dollars in programs at schools such as Cal Tech, Stanford, Berkeley, Purdue, Minnesota, Duke/UNC/NC State, and Cornell. But sooner or later, the Federal Government will have to come forward with substantial, continuing support.

Finally, the technical base for this technology touches about every area of NBS interest and competence. The NBS Very Large

Scale Integrated circuit initiative can be very helpful by helping establish a firm foundation of meaningful and practical measurements on which all productivity gains must rest.

We all owe a debt of gratitude to Congressman George Brown for generating a national discussion of these issues through his National Technology Foundation proposal. And I have already indicated concern about the separation of science from engineering that is implied in the proposal. But there still remains the primary and highly desirable goal of Congressman Brown's proposal: putting together the package of efforts in both NSF and DOC agencies to bolster the technological base for economic revitalization of this country.

This goal can still be achieved by the cooperative efforts of NSF and other scientific agencies, most especially NBS. Our roles are complimentary, but our purposes are similar—ensure that the scientific and technical capabilities of the USA are developed to the highest level.

I believe our leading engineers and scientists must make common cause. We must recognize that scientific leadership is indispensable to industrial leadership, as the Japanese are finding. We also must recognize that engineering skills guide reduction of scientific ideas to practice, and manufacturing engineering determines the productivity industrial workers achieve. If we are to compete successfully in growth industries, we Americans need to pull up our socks and take an optimistic view of what our brainpower can do to make our economy the world pace-setter it should be. Let us recall what Rudyard Kipling once wrote:

> "They copied all they could follow, but they
> couldn't copy my mind, and I left 'em sweating
> and stealing a year and a half behind."

Discussion

Q. My question is related to your comments on the shortage of engineers. Can you tell me what an engineer working in the semiconductor industry with just a bachelor's degree would expect to earn coming right out of college without any experience and also, an engineer with a master's degree and no experience?

A. My impression is that the answer to the first question is in the range of $18,000 to $24,000, and the answer to the second question is from $21,000 to $27,000. But that depends a good bit on whether or not the individual is a person with some very specific skill in a shortage area. People with any training in logic design for example are in very short supply.

Let me make the observation that the fact that salaries are not astronomical does not necessarily mean there is not a shortage.

The problem is that everybody already has a full complement of people that are paid what they are paid, and if you hire people in at 50 percent more than what they used to get you have got to raise everybody in your organization or you have a lot of trouble. So, there are factors that tend to keep that in balance even with the shortage of skills.

Q. Would you like to comment on the standards of present United States management, with some exceptions: the Harvard Business School, for example, where it seems that the manager can manage anything without any knowledge of what he is managing.

A. I was in the Navy in World War II and I have always referred to that as the Navy approach to management. Without casting aspersions, Navy had a good reason to want to manage that way. The concept in the Navy is that if you have a star on your sleeve and you are a line officer, whatever your rank, and everybody more senior to you gets killed, you can take command of the vessel. You are fully equipped and prepared to do so. It is a good principle because in the Navy you may have that situation in which the superior officers are all dead and you have got to cope.

I believe that the modern theory of American management is to recognize that managing a complex operation requires more knowledge and judgment than any one person can reasonably be expected to have. By this theory, the biggest mistake you can make is to exercise too much personal opinion, which has a danger of keeping an organization on a course too long, or taking it down a wrong path from which it is hard to get back. Therefore, the style of management that is very common in this country is a deliberate maintenance of a high degree of turbulence; that is, the encouragement of internal institutional change.

Now, many countries suffer a terrible lack of the ability to accommodate change, especially within big organizations. I think we are better at adapting to change than most, although we have a few spectacular industrial examples where that has precisely been the shortcoming. Nevertheless, I think that if you look at case examples of great growth achievements, they have in almost every case been company founders or sons of company founders who had a very powerful grip on the management, a very strong personal style. They made judgments about technical as well as market issues and carried the companies into areas prior to the time that it was obvious by analysis that those markets were ripe for exploitation.

Small innovative enterprises are still very much alive in the spirit of this country. There is a tremendous amount of desire on the part of individuals to have that kind of personal achievement. There are a lot of investors who are looking for those kind of companies to invest in. The Jack Rabinows of this world are not dead yet.

Q. I think it is a disease in the United States. Would you like to comment about the conglomerate business, which unfortunately our country gets involved with, like where 200 people manage 500 different kinds of companies.

A. Well, I think it is a fairly logical consequence of the style of management that I just described. First of all, it is a way of diversifying your risk. If your management does not have a personal dream and conviction of what the right business is to be in, the right answer is get in six businesses and find out. Sell the ones that do not work, and buy more if they do. I am not sure there is a big difference between a diversified holding company and a big investment bank which quietly and behind the scenes does the same thing. But they have to understand that what they are doing is financial management of capital, and not deceive themselves into believing that they are running companies. It often happens that they slip over into that latter mode and ruin the companies they acquire. I think one of the proofs of your point is the vigor with which the best managed middle-sized but rapidly growing companies fight being acquired, even though the average ratio of offered price of stock in acquisitions is 1.85 times the market price.

Q. The Institute of Molecular Science in Okazaki—would you like to comment on analogous institutions in Japan in relation to the Bureau?

A. Unhappily, I have not visited any Japanese institutions that are analogous to the Bureau. The institutions that I know in Japan are all manufacturing enterprises with which we have one kind of business relationship or another. I am very impressed with the personal knowledge, conviction and vision of the chief executives with respect to the technology they are trying to master. They really do see things in technological terms. They see things in a much longer time-frame than we do here. That is partly because our industrial managers face more uncertainty in an economy that is deliberately highly competitive, fractured, and contentious. Japan is a pretty close and homogeneous society and they work hard at knowing where they are going to be in 15 years without getting sidetracked.

Q. You commented on the quality of the Japanese efforts. We are indebted to an American for that: W. Edwards Deming, who is a friend of mine. Immediately after the war, he went to Japan and gave a lecture on quality control, and he received a medal of effort. Each year one Japanese is given this award because of their accomplishments in quality control.

A. The Deming Award is the highest valued prize in Japan short of the Emperor's medal. There are a lot of things in Japan of the sort that he has stimulated that are truly impressive. They are not unknown in this country. It is just extraordinary the extent to which you find them everywhere in Japan. For example, in this country it is very common for quality control to be thought of as a set of tests made in the course of production to figure out which of the products are bad. These bad products are then disposed of in order to avoid shipping them to the customers and thus reduce the shipped product defect level. That is not what quality control should be for at all, as you pointed out.

Quality control is for the purpose of making sure that the process you are running stays in control. If the quality control measurements are part of that process control loop, the process stays in control and all of the product is good. The right outcome from a properly quality-assurance controlled production line is 100 percent good.

Another impressive thing that you see in Japan is the personal dedication and interest of the workers and how they relate to the production process. I remember seeing the production line for videodisc players, which are produced in a joint venture between a partnership that we are in with the Pioneer Corporation in Japan. The key part of this videodisc player is the optical laser servo mechanism. To assemble these players, they have a conventional looking production line worked mostly by young girls. There is a conveyor, but the conveyor is not driven by an external time scale. Each worker completes the work at her station and pushes the work on to the next worker. But there is a detour in the middle of this line where that optical servo is assembled. That is in another room, next door, with a glass wall between the rooms. It is a clean room, and the first thing you notice is all the workers are about 15 years older in there than they are in the first line. Clearly, a picked team. Again mostly women, but obviously experienced, mature, trained people. The second thing you notice is that the production line is still a conveyor, but in this case it is all hot assembly. At each work station, the first thing they do is put the thing in a jig and plug it in. The laser is on and the electricity is on while they are adding the mirrors and other devices. They assemble, adjust, and test all in a single operation, unplug it and pass it on to the next worker who plugs it in again and adds more pieces. The result is they make that very complicated videodisc player for a few hundred dollars.

Q. What do you see as the future of small companies in the computer field?

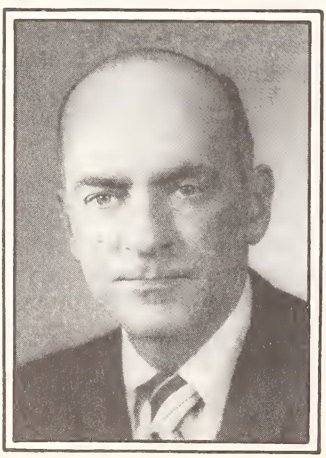
A. A microprocessor obviously has been yesterday's answer to the small company's problem. There they get the logic very cheaply, and then they put the other circuits in and the costs are not so bad that they cannot compete very well indeed. Software will be a profitable business in the 1990s, with the 80s as the transition. But, I think we will see the evolution of what has been analogous to the microprocessor in the past. I think the whole CPU will become an OEM product that is built to standard interfaces, manufactured in large volume. Small companies will now buy an entire CPU and integrate it with the disk files, the printers, the communications gear and what not. Increasingly, the systems configuration of the software and the user interface will be the ultimate competitive advantage.

William D. Carey is executive officer of the American Association for the Advancement of Science and publisher of Science and Science 80 magazines. Carey joined the Association following 6 years at Arthur D. Little, Inc., where he was vice president in charge of public affairs. Prior to joining Arthur D. Little, Inc., Mr. Carey was assistant director of the U.S. Bureau of the Budget, Executive Office of the President.

He was graduated from Columbia University with a Phi Beta Kappa in 1940, received the M.A. in public law and government in 1941 from Columbia, and the M.P.A. in public administration from Harvard in 1942 while a Littauer Fellow.

He is chairman of the U.S. side of the bilateral group in science policy of the U.S./U.S.S.R. Joint Commission on Scientific and Technological Cooperation. Chairman of the NBS Statutory Visiting Committee, he also serves as a member of Brookings Institution's Advisory Committee on Government Programs.

Mr. Carey is a member of the Board of Trustees of the MITRE Corporation and the Russell Sage Foundation, and he is on the Board of Governors of the Center for Creative Leadership. In addition, Mr. Carey is a member of the National Academy of Public Administration, the American Political Science Association, and the American Society for Public Administration.



Government, Science, and Society in the 80s

I suppose the gentlest rebuke to all would-be prophets was administered 30 or more years ago by Samuel Eliot Morrison in his preface to a very good book, *Admiral of the Ocean Sea*, the account of Columbus' voyages of discovery. Morrison was locating the story he would tell in the particular cultural environment of Columbus' own times—which is what I shall have to do here very shortly, too. Morrison did it by quoting from the *Nuremberg Chronicle* of July 14, 1493, a chronicle claiming to report "the events most worthy of notice from the beginning of the world to the calamity of our time." I quote Morrison to you: "Lest any reader feel an unjustified optimism, the Nuremberg chroniclers place 1493 in the Sixth or Penultimate Age of the world, leaving just six blank pages to record events from the date of printing to the Day of Judgment. Then begins a prophecy of the Seventh and final age—and quoting directly from the *Chronicle*—"in comparison with which our age, in which iniquity and evil have increased to the highest pitch, may be regarded as happy and almost golden: there will be no faith, no law, no justice, no humanity, no shame, and no truth." But as Morrison observes while the chroniclers were scripting that awful and imminent future, a Spanish caravel named NINA was running before a gale into Lisbon with news of a discovery that was to give the old world another chance.

There is a lot of the chronicler's spirit loose in western society today, including our own very young society. I have found it exceedingly useful to travel abroad with my eyes open, because it makes me very glad to come home where, against just about any yardstick of comparative well-being and promise, we have the good society. It is out of shape, but it is good. Its present troubled condition perhaps was prophetically foreseen a hundred years ago by Thomas Huxley on his first visit, when after marveling at America's immensity, he said: "Size is not greatness, and territory does not make a nation. The true question is: What are you going to do with all this? What is to be the end of which this is the means?"

His questions still beg for answers. And the answers lie hidden within the ambivalence of a society so blessed with choices, yet so unsettled in its values, that it lurches in one direction and then, reversing itself, goes in another. In the space of three brief decades we have traveled the course from global altruism to self-interest, from joyous self-expression to petulance, from arrogance to humiliation and—just possibly—back to arrogance. We have celebrated our form of governance and groveled in its failings; we have preened our human rights and lectured others, while ignoring the three-fourths of humanity who cling miserably to the edge of our lovely blue and white planet. What matters is the prime rate, the CPI, and superior quality control in Japanese consumer industries. How shall we answer Huxley? What are we going to do about all this? What is to be the end of which these things are to be the means?

Three weeks ago, the President told us on television that in the past 20 years our government has spent over $5 trillion, and he asked "how much better off are we for it?" In his opinion we are much worse off, because what he sees is a trillion-dollar national debt and stubborn inflation. I would have supposed the mistake was not in spending the money, but in the failure to adjust the tax base and the rate schedules to cover the spending, or to hold down the spending to the ability and willingness of the society to pay. But by implication, the President was saying that we threw it all away. What did we spend money for that we should not have? A mistaken war might head the list, but the going gets tough after that. The big ticket items, after all, were welfare, medicare, social security, national defense, revenue sharing, space, and grants to States and cities for everything from mental health to roads and law enforcement. California, I believe, got its share. If we are not better off for it, how do we know? Did we, or did not we, give another chance to the poor? Did we, or did not we, cushion the elderly against the costs of major illness? Did we, or did not we, get something of value from the Apollo mission? I do not for a moment doubt the President's figures. The government probably did spend $5 trillion in the last 20 years. While government was doing that, the private sector was spending $15 trillion. How much better off are we for that? Were the choices wiser, more cost effective, more fiscally or morally responsible?

Perhaps, but for other reasons, we are not better off. We are a nation of quantifiers. Quads, mpg, CPI, GNP, throw weights, the population clock, the capacity of the newest micro chip, the pocket calculator nuzzled up against our hearts. But the other evening I watched a PBS film on Auschwitz. There it was, 35 years later, a hundred acres of grass, barbed wire, and the shells of buildings. But I saw no people, no visitors, no pilgrims as far as the camera's eye could reach. Something had been quantified there, too, some part of 6 million. The very silence screamed. But the people in that corner of our overcrowded planet all were busy elsewhere, turning out

VW's and hi fi sets and cameras. Even the heartless Russians show some humanity. If you doubt it, visit the war cemetery in Leningrad sometime. You'll see streams of people coming and going, in good and bad weather, old men with ribbons and medals, and children holding a few grubby flowers. I do not know if they pray, but I can tell you that they care, after 35 years. Last summer I was in Vienna with my young daughter, and one day I could not find her. She came back to the hotel quite late and very pale. It was a while before I found out that, without a word to me, she had taken a morning train to visit the relics of a Nazi concentration camp and to feel the horror of her century. I do not think that we will find answers to Huxley's questions by quantifying. If we find them at all, it will be in the tragedy and the exultation of our human experience. Where else? Perhaps a child will have to teach us that.

My blurred view of society in the 80s is one that you may not find entirely appetizing. I think that the function of thought is going to be delegated more and more to the print and electronic seers and prophets, and that the most powerful centers of policy analysis and interpretation likewise will be media-based. I am not suggesting, not quite, that the silicon chip is destined to be the Master of the Universe, but I feel very sure that for as far ahead as I care to look the media and communications technology will wield transcending authority in shaping the quality of national choices and the public's grasp of the meanings of change. I submit that this new power is not, nor can it be, neutral to the value environment which sustains it. Indeed, the possibility exists that as respect for our political and economic institutions recedes, respect for the authority of the media will advance. I sense that this transfer of trust is already well-advanced, though still not at high tide, and we have not faced up to the problem it poses for a society designed for checks and balances. The First Amendment is a great guarantor of citizen freedoms, but its assumptions are fundamentally transformed in an age of communications power that encroaches progressively on constitutional architecture and preempts those processes of group negotiation and conflict, the processes of evolutionary social growth, conciliation, and change on which everything thus far has depended.

(Just after I wrote those lines for today's talk, I read in the *Washington Star*—a paper owned by *Time, Inc.*—that "in a unique effort, all of the magazines published by *Time, Inc.* are joining this month in a common editorial undertaking to explore a single theme: American Renewal." And in an accompanying article, the Chief Editor of *Time, Inc.* stated "the need for renewal ranges well beyond economics, politics, and defense: it encompasses ethics, moral, social and spiritual values . . . We have not worried about what seems politically feasible, but about what seems right." I think this comes very close to illustrating the point I have been making. We see a very powerful information conglomerate in what is called the "independent sector" massing its capabilities to come down hard on public attitudes and opinions not with news but with proposals for America's renewal not just in those areas of public policy confusion like economics, politics and defense, but in the very personal and private areas of conscience associated with ethics, social, and spiritual values. One can look at this in different ways: as a magnificent public service on the part of the independent press, or as a questionable intrusion into the democratic process under the shelter of the First Amendment. I tend to see it as both, and as bearing out my sense that a transfer of social authority is under way.)

I am giving you a problem, not a solution because I do not have one. I will remind you, though, that in just six years we will be celebrating the bicentennial of our Constitution, and I hope that beyond the parades and fireworks this fortunate nation will take the time to search its history, its intentions and its institutions, and come a step or two closer to knowing what we are going to do with all these things.

What seems to be going through our society, as we head into the 80s, is a passion for dieting, an urge to shed weight. What weight? To start with, the weight of complexity. The problems of our national economy baffle and enrage us. The metastasis of authoritarianism throughout the world—and very close to our own continent—confounds us. The apparent hopelessness of the arms race paralyzes us. The sense that the world is closing in on the English-speaking peoples, as the century turns, raises the spectre of a historic defeat. So we are weary of complexity and ache for simplification. We reach for deregulation, tax relief, getting the poor off our backs, dislike of government, impatience with the third world, and confrontation politics. How much "better off" will we be when we have done all this? It is a desperately dangerous state of mind for the 80s because it mistakes the whole quality of our self-interest, which does not lie in military and technological clout but in creative democracy at home and in economic and political reconciliation with the developing nations. It is in that latter zone of turmoil that the fuses are smoking. It is the zone of maximum instability, and for the United States to discount it and allow a vacuum of leadership to open would be a historic blunder from which our recovery would be very chancy. This, I believe, is the salient problem of choice that bears on our future. It is pertinent to the whole litany of catastrophe scenarios that you are familiar with, starting with the "Global 2000" Report—overpopulation, exhaustion of natural resources, terrorism, mass hunger, and the rest. Simplification is a nonstarter, and stability will not come cheap. Understanding this is the essence of American self-interest.

The paradox is that the curve of our national expectations is again on the rise. This is an important political change, representing at best a long-lasting social consensus or, at worst, a temporary fever. It has been borne in on a lucky society that it is capable of fumbling its advantage and committing large mistakes. What is good about this is that it occurred at the high crest of America's power and wealth, and it taught us to be careful. That is a useful lesson to go along with power, even in a democracy. And as we get back on the track of rising expectations it just may occur to us that our expectations are locked into an interdependent global society, one in which the voting majorities will have to be given a seat at the table. If they are not given the seat, they will take it for the not-so-simple reason that the resources, the sea lanes, the air space, and the markets on which our expectations depend will be theirs to dispose of, at a price. The simplicities of the past—protectionism, the nuclear shield, scientific and technical preeminence, managerial superiority, the Pax Americana—are not going to help. There is no way that we can go it alone and reach the higher ground that is implicit in the present resurgence of expectations. We cannot just draw the curtains. (I am reminded of a remark I came across in a book by the Polish writer Kuniczak: "With the curtains drawn, it is possible to close our eyes to the present, ignore the future, and regard the past with hope and confidence.")

Whether the American political technology is adequate to the stresses of the 80s has a bearing on all this. It is a necessary question as we think ahead to 1987. The essence of our political technology is in the separation of powers, the federal system, checks and balances, and the familiar constitutional guarantees as interpreted through jurisprudence. It is not a straight-line system for getting things done, nor was it meant to be. And this basic political technology has been affected deeply by the American experience of national development, economic growth, the progress and applications of science, and the new global realities. It is a system that has permitted remarkable experimentation and innovation, yet it is built very close to the ground, and its institutional properties—apart from size and leverage—still reflect its beginnings rather than a vision of what will have to be anticipated and dealt with.

I shall not go into that subject clinically today, except to say that our political technology needs to be calibrated in terms of its abilities to manage surprise. It is the play of surprise upon our system that reveals its limitations and defines the risks. I am speaking of the class of surprises, chiefly of external origins, that inflicts shock and trauma on the institutional structure. Surprise of that kind deranges, even concusses, the consciousness centers of a large and relatively immobile political system. It is not possible for us to hide from surprise, and we have had enough recent experiences to realize that we are easy marks for it. It is not all that hard to envision the budding surprises that could be waiting for us in the doorways and blind corners of the 80s and 90s. They may be detected in the monetary system, in superpower miscalculations, in terrorism, in insurgency, in the pressure cooker of incendiary frustrations and hatreds, and even in religious fanaticism. History has a way of replaying its tapes.

Our political technology, our statecraft if you prefer, has a blind side. It treats surprise as aberration, as abnormal. It had better learn to expect it and defuse it. We heard and read a good deal during the last presidential race about the need to follow a consistent, stable course in our economic policies, energy policies, fiscal policies, and foreign and defense policies. As scientists, we also often plead for stable and consistent science policies. It strikes me that a better prescription is for imagination, flexibility, and vision. We are not going to live in a surprise-free environment, and there is no chance that others will subscribe to our preferences for stability and consistency when those words are equated with a $2 trillion national economy going for the third and fourth trillion. The limits to growth do not lie in resource constraints but in the world of rising expectations and the function of surprise in the play of rogue forces that will not hesitate to test and stress an overloaded and unresponding Western system.

If our political technology is to learn how to manage surprise, it will have to shed many of its historical prejudices and created new capacities for assessing the sources and the meanings of the turmoil of the 80s. It will have to convert the stale routines of diplomacy to a new science of negotiation and bargaining. And to support all this, we will need a public consensual process built on the understanding of the inherent instability of our position, a process that is more straight-line than we have been used to; a policy process that is not traumatized by surprise when it comes; a process that is not intimidated by the selfasserted authority of the media; and, finally, a political technology that never takes its eyes off the time constants. A process, if you please, with a thick skin.

To imagine the texture of science in the next decade, when the NBS will be ninety, I think we must first locate its place in the record of the 3 postwar decades. What happened then was that American science was first idealized, then politicized, then internationalized, and finally secularized. Science hung on to its first principles, even so. But is was a heady passage and a narrow one, and the sides of the vessel inevitably were scraped and scarred. Bush's vision of a sweet social contract under which scholarship, learning, and discovery would advance with independence along with a type of federal support that would be condition-free, proved to be a fragile vision. Science indeed advanced, at a pace and with a variety that deserves to be celebrated, honoring both itself and the national policy that made it possible. My friend Jean Mayer identifies no fewer than four great postwar "revolutions" based on science or technology: releasing the energy of the atom; man's escape from earth's gravitation; multiplication of the powers of the brain through computers; and seizing control of evolution through genetics. But these achievements quickly and progressively brought government and politics into the life of science, even as it drew science ever more closely into the web of government, and from there into social controversy. With scale came dependence on government, and dependence led to oversight and accountability.

So, as science prospered its environment changed. We have come now to the fourth postwar decade, to the economics of constraint, a lively appreciation of risk, the politics of tension, the dilemmas of ethical responsibility, and to brimming possibilities for the humane uses of science.

How will America's science treat humanity in the 80s? Today, the U.S. has 6 percent of the world's population. Twenty years from now, it will have only 4 percent. If we accept, for example, that we are now in an exponential phase of biotechnology, what will we do with it and what will be the ends to which our knowledge will be put? The high likelihood exists that within a couple of years biotechnology will produce a vaccine for hepatitis, a disease that impacts 50 percent of the people in developing countries. I have heard it said that this works out to afflicting 500 million Chinese for the 2-year duration of Hepatitis-B, an effect that adds up to social costs almost beyond calculating. The approaching opportunities through biotechnology to attack the pestilences that harass the lesser developed countries are enormous, and it means that our scientific promise can be a very high card in American diplomacy, and a new avenue for outreach and reconciliation. But at the same time, biotechnology has potential military applications, especially by letting loose pathogens which have been pacified by evolution, to attack targeted strains of agricultural crops—in other words, biotechnology can scale up the feasibility of using starvation as an ultimate offensive weapon. Thus, science brings both light and shadow to the future.

So ours is a decade of contradictions. When so much could happen from the first postwar decades to the threshold of a fourth, then what lies ahead for the fifth and the sixth? I think it depends on how America looks out on the world, how it defines its responsibilities and goals—how, if you will, it answers Huxley's questions. In all this, science must not be passive, willing to march without asking or caring what road it marches on. My own concern for the decade is that confusion of purposes may be overtaken by ideology and dogmatism, which are what confusion tends to breed. And if science ever has to stand and fight, ideology is its natural enemy.

My hope is that, in the 80's, science will land on its feet and decide its own identity. Through one lens we see science and technology as cogs in the production economy. Through another, we see them honing the edges of military technology. From a third window, they are high cards in global diplomacy. And a fourth representation brings us back to science as a frontier of wonder and discovery, a continuum over the reaches of time. How do we deal with this multiple persona? Can a distinctively American policy for science be found that does justice to this versatility, to a process and a structure that is at once political and apolitical, at once anchored to government and yet a buffer against government, at once an expression of national purposes and a bridge across the mean differences of national ideologies? If such a policy will ever come to be, science itself must think it out.

Science's hopes and fortunes will go well or badly as government and society go. It is, unfortunately, not the other way round. But there is this, also to be said: Science has a conscience that is shaped by its accumulated insights into the relationship between man and the universe, a conscience that draws from prehistory and looks ahead beyond the human scale of time. Science knows very well, for example, that ours has not been a pretty century. Its quality is etched in the repeated violence that man has inflicted on his brothers. For that, the conscience of science has reasons to be troubled, for science is writ large in the chronicle of our century. And for the 80s, I would like to look to the conscience of science to keep alive a reverence for life, for the human struggle, and for the wonder that is also part of our shared experience. If you hope I will say that I see years of achievement and a growing American love for knowledge through science, I will tell you that it is probable, but not sufficient. Science is bound to be fiercely concerned with the right uses of knowledge, fiercely independent in championing them, and fiercely honest with itself—because as a reflective friend of mine would say, though science has not yet made the good society, it has caught an unforgettable glimpse of it.

Discussion

Q. I was very much moved by your speech, especially with reference to what is left over from the holocaust and to science's social concerns. I wonder if you have an opinion as to whether science would be able to devise a means of preventing such violence again.

A. I would say that if science, viewed as an interdisciplinary process, were given the chance it could do a great deal. I look, for example, at the potential of science. Today we do not seem to make our decisions about the uses of science, or the areas of investment in science, in terms of potential: lost potential, unused potential, open capacity. I look at the possibilities and the potential of space science and technology where I think that the opportunities exist in satellite technology linked to communication and information could bring a great deal to a rational world order, much more indeed, than equivalent expenditures to improve the edge of our military superiority. Yes, I believe that science with technology could do a great deal if it were given the chance and if we chose to go that way.

Q. Mr. Carey, we are rapidly gaining the ability to transmit a tremendous amount of harmful misinformation throughout the society. With the functional literacy and other communication problems of the upcoming younger generations, who may be technologically quite sophisticated but unable to communicate with simple sentences and spell properly, are you optimistic or pessimistic about our ability to cope with this crisis?

A. Well, I think you are dealing with an example of neglect and decay in an otherwise very prosperous society. I think that the young people certainly know more about more than we did in our time. I think that there is a qualitative difference in that what we thought we knew, we held on to, we considered, we digested, and we retained. Today's kids, as I see it, catch information on the wing. There is not time, no leisure, no spacing in which to digest, reflect, and interpret. If the education system in this country is going to be allowed to go downhill, to become third- or fourth-rate, when everywhere else in the world, except in the third world, it is given pre-eminent importance, I think this is one of the great tragedies of contemporary times in this country. The value of learning is well understood in other societies that operate differently from ours. I see no sense, whatsoever, of national priority being directed toward the quality of education, the quality of learning. All the national priorities seem to be addressed to the production side of our economy and to military prowess, and something very important is being lost. I do not think at all that the present state of semi-illiteracy in many areas is irreversible. And in our small way at AAAS we are trying to do something about this, as you know, with a magazine called Science 81. We are getting on the radio, we are trying to develop a critical function relative to the performance of the media—it is a tough business. I do not think that scientists can stand aside and simply passively watch these malfunctions settle into our system. That is why I said what I did, that science in the 80's must not be passive and it has got to know when it is time to fight back.

Q. Mr. Carey, the trend technologically speaking with regard to the LDCs, is for the rich to continue to get richer and the poor to get poorer, and with our budget cuts in aid, for example, we are certainly not reversing that trend. Can you think of two or three general ways one might work on reversing that trend?

A. Well, when a country that is rich and spoiled has to make choices, as its leadership defines those choices, it can either bring about a greater understanding relative to the third world, or it can lead us to recede in those areas. I ride a bus home from downtown, and on the way home last night I happened to be reading the Johns Hopkins Alumni Magazine. I came across an item relative to the research they are doing on Vitamin A. It was a report of a finding that for a particular destructive malady that effects hundreds of thousands of people in the tropical areas, a 2 cent oral dose of Vitamin A followed by two more doses at 2 cents each would reverse the impact of that disease and put hundreds of thousands, if not millions, of people who suffer that tropical disease on a path to a comparatively healthy and decent life. Well, 6 cents per person, if there are 500,000 people out there, sounds like about $30,000. I have a feeling that there is a great deal that we can do through science at the micro level, while we hope and use whatever influence we have as scientists to alter the macro scale or priorities. Let's get the Vitamin A out there. Thank you all very much.

Dr. Arthur M. Bueche* is General Electric's principal technical officer and a member of the company's Corporate Policy Board. He received a B.S. degree in 1943 from the University of Michigan and a Ph.D. in 1947 from Cornell University, where he served as a research associate until joining the General Electric Research Laboratory in 1950. He held a number of technical and managerial positions prior to his appointment as vice president for research and development in 1965. He assumed his present position in 1978.

A key spokesman for the technical community, Dr. Bueche served in President Reagan's transition organization as head of the Science and Technology Policy Team, Office of Policy Coordination. He was a consultant to the Department of Commerce in its recent Domestic Policy Review of Industrial Innovation.

Dr. Bueche is a member of the Executive Committee of the Council of the National Academy of Engineering and of the Academy Forum Advisory Committee of the National Academy of Sciences. He is past president of the Industrial Research Institute and present chairman of its Federal Science & Technology Committee, past chairman of the Gordon Research Conferences, and past chairman of The Metal Properties Council. He holds or has held many other positions of leadership for the American Chemical Society, American Physical Society, and the American Institute of Physics.

* Dr. Bueche died on October 22, 1981.

Government-Industry Relationships in the 1980s

If I could sing, which I cannot, I would invite you to join in a rousing chorus of "Happy Birthday, NBS." But I can wish you many happy returns on your 80th anniversary and thank you, most sincerely, for inviting me to share in this celebration.

The year 1901 was quite a year . . . although, any rumors to the contrary, I do not speak from personal experience. It was the year when the most quoted comment out of Washington was, "Speak softly and carry a big stick." It was the year the Victorian Era ended. The first Nobel Prizes were awarded, although not for instant coffee, the electric vacuum cleaner, Mercedes cars, mercury lights, or Quaker Oats, all of which were introduced during "ought-one."

The favorite song of 1901 was "I Love You Truly." But I will not sing that, either, even though I do have the very highest regard for the National Bureau of Standards.

I have been privileged to work closely with the NBS for many years, there are many good friends in this room, and I like to consider myself a great booster of the fine work the National Bureau of Standards performs for our nation's government, for its industry, and for its people. I congratulate you, one and all.

As noted, I do not intend to sing. Nor do I intend to deliver a sermon. But I do have a "text" for today's message, and to get it I had to go back not 80 years, to 1901, but 100 years—exactly 100 years—to 1881 and the writings of a still-in-the-news scientist-philosopher named Charles Darwin.

Darwin wrote: "The plough is one of the most ancient and most valuable of man's inventions; but long before he existed, the land was in fact regularly ploughed, and still continues to be ploughed, by earthworms. It may be doubted whether there are many other animals which have played so important a part in the history of the world as have these lowly organized creatures."

Darwin was not alone in noting the importance of earthworms. Nor was he the first. Cleopatra was so impressed by the work of earthworms in creating the fertility of the Nile valley that she decreed the earthworm to be a sacred animal to be revered and protected by all her subjects. Later, a French researcher named André Voisin went so far as to say that civilization itself could not have developed without the earthworm's help.

Now I am not about to stand here and try to describe to you, in clinical detail, what it is that earthworms do to make themselves so effective, or so numerous. But let us just say that they are untiring contributors to fertile soil and extremely efficient converters of organic wastes into valuable resources. One agricultural expert has shown that earthworms in poor soil can boost the yield of herbal plants by more than 10 times. Worms control pH; they transport minerals and nutrients from beneath the soil up to where they can help plants grow; they improve the composition of the soil; they can increase the rate at which soil can absorb water by 3 or 4 times.

You may properly wonder, along about now, just why a speaker whose assigned subject is "government-industry relations" is devoting all this attention to what some people would classify among God's lowliest creatures. But I beg you to be patient. The worm will eventually turn . . . to the subject.

Earthworms, my friends, might well become a big business; and as a large industry they surely will invite the attention of government.

Any entrepreneur looking at earthworms should be impressed by these statistics: Americans produce well over 100 million tons of residential and commercial trash each year—and two *billion* tons of agricultural by-products. As one of the nation's leading experts on earthworms, Steven Bridgens, puts it, "If earthworms were allowed to turn the organic part of these 'wastes' into valuable castings (that's the polite word for what earthworms leave behind), the stress on America's already overburdened solid-waste disposal system would greatly ease."

Bridgens goes on, "By mixing organic wastes from human consumption with sewer sludge and animal manure, the earthworms can really get down to work. In one California experiment, 18,400 pounds of biodegradable refuse, composed of materials ranging from phone books to grass clippings, was 50 percent consumed in 38 days and 80 percent consumed in 68 days."

Meanwhile, a lot of people are considering earthworms as a source of food. Dried earthworms consist of up to 72 percent protein by weight. Nutritionally, earthworm-burgers would probably be far superior in many respects to beef—or even peanut butter. It has even been reported that several newspapers have held contests for recipes using earthworms.

And, if this does not appeal to you, you can still use them to catch fish, which is why they were called angleworms in the first place.

Presently, this nation has some 100,000 earthworm ranches, many of them quite profitable. But this is only the beginning. Many people see the growing of earthworms, for animal (and maybe even human) food, and for applications in the processing of waste products, as a potentially major business.

Well, up to now, I have been dealing in fact. Let us now turn our imaginations loose and try to envision what *might* happen when earthworms blossom into a highly competitive multi-billion-dollar-a-year industry.

The first thing that will happen when it becomes apparent that earthworms have such great commercial value is that someone will figure out how to tax them. Depreciation schedules are likely to be quite slippery, and a large number of research contracts will probably be necessary to establish the required classifications.

Truth-in-labeling will obviously be a problem; in fact, it may be difficult to label the product at all. Import and export regulations will have to be established, and as American genius learns more about earthworm science we surely will have to devise some new rules regarding the export of earthworm technology and know-how.

The movement of earthworms across state lines, especially burrowing for reproductive purposes, could have serious ramifications. As it is recognized that earthworms have great environmental value, it will surely be necessary to place limitations on their wasteful use in recreational, as opposed to commercial, fishing. This, in turn, would be a blow to the nation's eager, young entrepreneurs who would thus demand, and receive, some kind of road-stand subsidy.

I should not be surprised if you folks in the National Bureau of Standards are asked by a Congressional committee to determine the optimum length and girth for all 1,800 of the presently recognized species of terrestrial worms of the class Oligochaeta.

We may have to consider import quotas on such competitive threats as the Australian species of earthworm that can grow as long as 11 feet. The licensing of compost-bins can be expected to become increasingly complex, as will the required environmental impact statement for large-scale systems for handling commercial wastes. It may take years to work out the necessary compromises among the various special interest groups that might be impacted by a Pure Food and Worm Act.

But the truly *serious* technological and environmental crisis of the future can be expected to come after the tremendous value of earthworms has been demonstrated . . . and after the *major threat* to this invaluable natural resource starts getting full media attention. It is bound to become Public Issue #1, and the rallying point for movie and rock stars you have not even heard of yet.

This major threat, of course is the vast expanse of concrete, tarmac, and other artificial surfaces placed across the nation in the interests of various kinds of transportation and recreation. Every inch of the nation's vast highway system, every landing strip, every parking lot, every sidewalk, every tennis court, every driveway . . . the inexorable march of concrete-laying and the related paving technologies across the face of the nation . . . all of these have created a literal deathtrap for our invaluable earthworms. Every night, millions—perhaps billions—are killed by the lethal tread of vehicle tires and the careless tramping of feet. After rainstorms, the carnage is even more disastrous.

When the potential seriousness of the Earthworm Crisis is first made clear, Congress will surely entertain ideas for installing permanent spray systems along the edge of all streets, highways, and runways, so that a regularly timed flood of water can gently wash errant earthworms back to welcoming soil. However, a series of ever-larger pilot plant and full-scale studies will surely show that such an approach, while effective for the earthworms—and helpful in creating new wetlands to protect—causes other national problems, such as metropolitan drought and catastrophic national debt.

So we can imagine that a simpler system will be enacted by law: the drilling of worm-relief holes at appropriate intervals in all major expanses of hard-surface areas from coast-to-coast. The size and spacing of these holes may well become a major campaign issue, splitting even those political segments which are otherwise the most cohesive. Obviously, there will be charges that big, fat worms are being protected at the expense of the billions of thinner and more needy species.

An EPA—that is an Earthworm Protection Agency—could well become one of the largest of government bureaucracies, especially with the need for literally thousands of full-time inspectors policing their respective national districts to make certain that states, communities, and private property owners, if any, are keeping their worm-relief holes unplugged and passable.

Initially, the cost of all this will be borne, according to some early estimates at least, by a wormfall profits tax on a certain group of entrepreneurial companies that have managed to corner the market on those 11-foot-long worms from Australia. But eventually, in an inevitable new cycle of national politics, we can expect a new leader to come along and suggest that the nation is spending too much on things like earthworm protection, that the earthworm business might do at least as well without the requirements for labeling the product, and that maybe something ought to be done. I can hear it now: "It's time to get the government off the earthworm's back!"

Well, when that happens, I am sure the new leadership is going to augment its wisdom by undertaking the cutbacks and the new approaches and the simplification of rules only after reviewing all the good advice it can get from people *who know something about the earthworm business*.

And what, at long last, after this lengthy flight-of-fancy about worms, is the moral of this story? As we seek a new era of understanding about technological relationships—technological relationships between government and industry—and between government, industry, and the universities, too—it is obviously of very great importance to have the best possible advice for the people who must call the shots.

And this, of course, is why so many of us who have been asked to consult with the new administration have stressed the need for a top-notch President's Science and Technology Adviser. We believe the role of the Science and Technology Adviser is *not* to be an advocate for science and technology—not if by "advocate" you mean someone representing a specialized constituency in its desire to obtain a larger share of the budget for research and development. We *do* believe that the Adviser should provide a critical area of expertise, and objective judgment, in helping the hard trade-offs that must be made.

We think a strong Science and Technology Adviser can help avoid surprises that come from lack of awareness of the facts—and of emerging issues—and we believe he can do a great deal to help identify opportunities for using science and technology to solve the nation's problems, and achieve its goals.

Just take a look at the challenges facing the new administration—facing all of us. We want higher productivity, increased employment, reduced inflation, greater competitiveness in world markets. We want to cut the costs of government. We want sensible environmental protection. We want opportunities for young people and improved health for all citizens. Above all, we want to make sure of our national security so we have the option to work toward those other goals.

Attaining every single one of those objectives is dependent, highly dependent—on *technological leadership*. Putting new vigor into American science and technology is essential to the health and well-being of our people, to our national security, and to our economic survival.

Technology is a tool . . . the best tool we have for achieving many of our national goals.

Knowing what technology can do—and what it cannot do—is certainly a key factor in making a lot of the big decisions necessary for cutting unnecessary government expense, for determining the necessary tradeoffs, for helping set the priorities.

I am sure we all agree that cuts should be made by people who understand what they are cutting. And I am sure we all agree that we ought to reduce many of the suffocating regulations that have grown like barnacles on our social system over recent years . . . and that changing or reducing these regulations ought to be done by people having not only some firsthand knowledge about what the regulation was originally intended to do but also about the scientific data-base—and measurement capabilities—for making them practical.

As for cost-cutting, I believe having high-level technical advice is quite in keeping with the desire to achieve a balanced budget. I think a sure way to reduce the costs of government is through the two-pronged approach of providing better management of government-sponsored science and technology, plus greater reliance on a private-sector freed from some of the obstacles that have kept it from doing what it can do best.

For both parts of this job, those of us who have been studying and advising in this area are therefore in agreement that the President needs a strong science adviser, a person he can trust to help provide leadership as well as advice.

The technological strengths available to the President from within the government include diverse contributions from many departments and agencies, not the least of them right here, the National Bureau of Standards. These strengths include also the wealth of engineering and science strengths of private industry and the universities. The President surely will benefit from having a close adviser who can secure, coordinate, consolidate, and interpret the scientific and engineering impacts from the many sources.

The short- and long-term health of engineering and science, and their rates of development, are vital to the quality of these many impacts. The Science and Technology Adviser must be responsible broadly to advise the President on the state of this health, and to help him maximize it through many forms of governmental support, not just financial aid but legislative and regulatory as well. And, I might add, through *moral* support!

The Adviser should represent the President in many science and engineering activities within the government, to private industry, and to the universities, both here and abroad. The President's Science and Technology Adviser should be especially alert to the progress of science and engineering to inform the President of the promise and implications of advancements in these fields. He also should monitor the quality and quantity of the nation's technological manpower and physical resources.

That is a lengthy list of assignments, and, I firmly believe, a list of essential tasks to be accomplished.

Good advice on technology, at high levels, will be helpful to the maintenance of those government-sponsored laboratories, like the National Bureau of Standards, that have proved their worth over the years.

Good advice on technology, at high levels, is also important to those of us in industry looking toward the improvement of government-industry relationships in the 80s.

It is the consensus of virtually every "study group" and Task Force I have been associated with in recent years and months that the private sector of our economy needs to be encouraged to increase its innovative activities . . . and that this growth must occur throughout the entire chain leading from basic research in the laboratory to products and services for the marketplace.

Let me touch on three general opportunities for government to provide help and encouragement to private institutions seeking to share a larger part of the nation's technical job:

First, properly balanced *tax structures*:

Second, sensible *regulation*:

And finally, an overall *attitude* that emphasizes cooperation rather than adversarial confrontation.

Without presuming to provide specific prescriptions in each of these areas, I would like to spend just a few minutes describing some of the issues involved.

Sensible modifications in federal tax codes that would encourage innovation and private investment in R&D include, for example:

a. Providing for faster depreciation of facilities and equipment. The development and diffusion of new technology in the manufacturing sector is vitally dependent on new investment in more modern facilities, and this change would help speed up the process.

b. Allowing flexibility in write-off periods for research-related facilities and equipment, as well as externally-acquired technology. Such assets are critical to maintaining a forefront research effort,—and to efficient utilization of technology—and they may become obsolete very quickly.

c. Providing business—and maybe even individuals—with greater incentives for contributing to university science and engineering programs. We have critical shortages of certain types of trained scientists and engineers. Faculties in these fields are being drained. And we need to stimulate closer collaboration between industry and universities.

These modifications are not suggested only as encouragement to large institutions with large laboratories, of course. Significant attention also needs to be directed toward federal tax policies that will recognize the special problems of *small* technology-based businesses . . . the special problems of attracting equity capital.

Whether discussing small businesses or large, we are constantly reminded about the importance of the *attitudes* of government policy-makers. It is absolutely essential for these key people to understand the true effects of their decisions—or indecisions—on the economy, on business management, and thus on the health of the nation's leadership position in science and technology.

Now what about regulations?

Frankly, this anniversary celebration here today does not seem like quite the appropriate time to open the Pandora's box of government regulation . . . regulation for safety, health, and environmental protection. So, let us just take a quick peek inside.

The issue here is not the *need* for regulation. I think we will all agree: protecting public health and safety *is* an obvious job for government.

However, discussions of the details of regulation invariably become exercises in frustration. As one of my colleagues has put it, "Nothing is more frustrating than a traffic light that says 'stop' more than it says 'go'."

Besides urging new attitudes for cooperation and respect between the regulators and those being regulated, the most cogent advice that technologists seem to have for regulators is this: in all areas of regulation, a priority for government must be the independent establishing—and assuring the use of—*adequate scientific baseline data* for decision-making. One way to say this is that federal regulators ought to be making better use of the skills and experience of the National Bureau of Standards.

Other suggestions in this area include improving the methods of estimating costs, benefits, and risks in comparing alternative choices for proposed regulations; better coordination where different agencies have responsibility over similar areas; applying "performance standards" rather than "specifications" to allow those being regulated greater freedom in determining the optimum technical approach; and using economic incentives to encourage innovation.

Earlier I commented that one way for the government to help achieve and maintain the technical strength it so urgently needs would be through the adoption of "an overall *attitude* that emphasizes cooperation rather than adversarial confrontation."

This just may be the most important point of all . . . and it may be the change we have the best opportunity to make during this period of national introspection and new directions.

"Cooperation instead of confrontation" is a challenge for all of us as individuals . . . as representatives of our own organizations, public or private . . . as practitioners of our own professions . . . as citizens.

Let me put it just as plainly as I can. This nation's government and this nation's private institutions do *not* have different basic goals. We all recognize that our country has problems. We certainly cannot afford to waste time or energy arguing about whether these problems ought to be solved. And, above all else, everybody involved has got to wake up to the reality that *we are all on the same side.*

On balance, science and technology have contributed immeasurably to the health and happiness of humankind in the past. If we all work together, they can certainly do so in the future.

New ideas, science, invention, technological skill . . . these are prime national assets to be treasured, protected, and—above all—used for the common good.

And beyond the apparent, tangible benefits to be gained from revitalizing scientific research and its applications, new emphasis on technological leadership can provide an urgently needed lift for the national spirit.

Just as it was 200 years ago when the nation was founded . . . just as it was at the turn of a great new century when this Bureau was founded . . . America's destiny can still be one of pioneering example, of willingness to explore frontiers with faith instead of fear, of dedication to helping show people everywhere how individual human skills, given freedom to achieve, can make life for so many so much more worth living.

In short, my friends, there is very little wrong with this country that good new ideas, hard work, respect for the past, cooperation, and confidence in the future cannot fix.

As for the role of science and technology in all of this, I will probably never be able to squirm my way out of the earthworm allegory with which I started these comments, so I will close them simply by saying that a lot of digging—night and day—can be a very good thing, as long as those who are digging leave behind something that is useful to others.

Discussion

Q. There were rumors coming out of the White House that the Science Adviser's position might be moved from the White House staff, and I believe that the New York Times quoted you directly as calling that inconceivable. Is there any further word on the likelihood of that happening?

A. I do not really know what is going on, frankly. I escaped on January 20th and I have only been in telephone contact with people since then. The rumor I have had is that the whole White House staff situation is being reevaluated. Whether or not that is true, I do not know. I do know that most of the technically based positions in the government have not been filled. Just look across the departments and agencies; we do not have people in those. It could well be, and I have been told that this is so, that the whole manpower selection and approval process in the White House is now so bogged down that it is difficult to get anything through. I hope they do not downgrade the Office of Science and Technology Policy because as I said in the talk I think it is absolutely essential. I also think that the President and his staff recognize this. You know the budget for OSTP is $4 million and any person worth his salt can show them how to save $400 million in the first week and do it in such a way that it will make sense to most of the people who look at the way you save money. And $400 million is just the beginning. You could probably do that in two days if you know anything about what is going on.

Q. Could you say a few things about long-term research? The tendency of private industry in recent years is for short-term research and a quicker return. Could you say what the role of government in terms of tax incentives would be to help rectify this?

A. First, I agree that there has been this trend in a good number of companies. Industry has really been strapped for good investment opportunities that it thinks it can get a good rate of return from. That rate of return is made very dubious by our high inflation rate, and of course, also by our high interest rates. These high interest rates make people look for quick payoff things, because if they have to borrow money to do any of these things, it is horribly expensive. They do not want to borrow it for very long, they want to get their money back out again under these conditions.

I think the proposals that Mr. Reagan and his administration have are a step in the right direction. They are going to try to reduce inflation, they are going to cut government expenditures which is one piece of it, presumably, if you believe the theory under which they are operating. They are going to reduce taxes which will presumably increase savings and make more investment money available, and at the same time, increase consumption of goods and services by Americans and hence stimulate production and make more jobs. I hope that all works. I happen to believe it will, although economic theory is not my strong suit, and I gather from what I have read, hardly anybody's strong suit. So, I think they are making steps in the right direction. I think the intent of at least streamlining the regulatory process is an important one because there is an awful lot of very good R&D work going on in industry which, in terms of goods to export or services and goods to people in the United States, is just not productive. It is there to fix up something, or to make sure that the regulator does not crawl down your throat. I am happy to see that regulations will be streamlined. There will be more emphasis on cost benefit analysis and I think that is awfully important.

I am not one who thinks that there should be a special tax incentive for donations by industry or by private individuals to universities. I think that most private individuals, and certainly most responsible industries, if they have the money, and if they really understood the problems of the universities, which many do, would increase their contributions. Contributions come in many forms: sponsoring programs, endowing professorship chairs, hiring faculty and students for the summer, donating equipment—all sorts of things. A tax action to stimulate that probably is not the thing to do at this moment. I think if you get everything healthy and going, the universities will prosper.

Government can help, too. During the transition period, I had an opportunity to look at what government laboratories do—and we did not look at the Bureau of Standards, so there is nothing personal in this. But we did look at the Department of Energy laboratories and asked what is it that they do that might better be done in universities or in private industry. If you do it in universities, you do that work and at the same time train students and provide equipment for the university. If you do it in industry then you can worry less about technology transfer.

A good number of the government laboratories with which I am familiar are now asking, "How can we transfer our technology to industry?" Well, the simple answer would be to send all the people to industry. If the government wants to spend that money, spend it in industry and then you will have transferred that technology to someone who can utilize it and follow-up on it. I think we could do an awful lot to help the universities, to lengthen our perspective on research, if we actually do more of the things that might better be done in the universities rather than doing them in government laboratories.

You got me on my soap box on that one. If there are more questions or comments I will try to be a little more brief.

Q. I know that Proctor and Gamble has a scientist here in Washington who has a title like Associate Director for Company/Government Cooperation. Do other companies have scientists like this?

A. I do not know. Proctor and Gamble, you must realize, is a rather special company. I do not think I would be wrong in describing them as pretty much consumer-oriented and having very little interaction with the government in terms of taking government money to do things such as R&D. They and other companies, for example, Monsanto, Merck, drug companies, chemical companies, and so on, do have a lot of people in Washington whose job it is to get to know the regulators. These people try to anticipate what the regulators are thinking and try to help them and if they have questions, to feed them information. So, I do not know of exactly a parallel position, but I suspect there are people in almost all companies who perform that function.

There is another set of companies that are both in the strictly commercial, consumer type businesses, and at the same time, in defense and space related businesses, energy projects, and so on, such as the one for which I work. There we have lots of people in Washington, trying not only to get government/ industry cooperation, but a good number of these people are trying to get government money to fund that cooperation. That works pretty well, by the way. I think the DOD has had a marvelous record for getting the help of industry in planning early in the project, and carrying things out to where the DOD can use them. There are all sorts of these.

Q. One of the things that has been reported is that many technical organizations are now being led by people who do not themselves have a technical background, and who are, therefore, less inclined to put new technology into their product. Would you care to comment upon that?

A. It was alleged that many corporations are now being led by people who do not have strong technological backgrounds and, hence, are hesitant to invest in the development and marketing of high-technology products. I guess it is only partly true. I can think of industries where, much to my disgust, rather than spending the money to modernize their factories and bring in new techniques, or come out with new high-technology products, they increase the dividends to the share owners. And I think for a business that is short on money, that is not a very good way to operate. On the other hand, I look at General Electric, and I am a great admirer of Mr. Jones, our leader, who is a financial type. He is the strongest friend science and technology ever had in General Electric. He believes in it. Even during the 1974-1975 downturn he saw that the advanced technical work grew rather than cut it like a lot of other things. So it is a highly personal thing, I think it is a highly variable thing.

If you want to make a point with at least some of these businessmen, you should draw their attention to exports. If you look at the U.S. exports, it is a collection of high-technology products, including wheat and corn. Agriculture is certainly a high-technology occupation today. Without the fertilizers and the modern machinery, our productivity would be very low and we would not be exporting grain to feed the rest of the world. But if you look at the other things—airplanes, jet engines, nuclear power plants, steam turbines, gas turbines, electronic gear, computers, drugs—these things that we do export are all high-technology products. My personal experience would be that if your product is equal to the product in country X to which you hope to export, you had better forget it, because they will keep you out of that market just as much as they can. The only way they are going to buy your stuff and provide jobs and profits to the United States, is if our products are better and unique, and they cannot be obtained at anywhere near the price in those countries that they can be obtained from the United States. You just have to have exports and I think that is a powerful argument for most of these businesses.

Q. Since you mentioned DOD, the figures that seem to be coming out on support for basic research show that government funding will be shifting more toward defense related problems and away from civilian sector problems. Could you comment on the importance of that trend in light of the comments you made about the need for innovation and increases in productivity.

A. I do not see anything wrong with it, in fact, I think that there are some very interesting possibilities. I am aware of a number of programs which already have been funded by the DOD that are aimed directly at increasing productivity. There is a big computerized "Factory of the Future" program that DOD is supporting and I think is just marvelous. It goes all the way from information handling and software, the kinds of things you think of in connection with computers, to new machining methods and new ways of forming metals and plastics, to new ways of inspection and insuring higher quality. It goes through the whole cycle. That is an example of something, which, once it starts out because of DOD fiat, is going to spread throughout American industry and will increase productivity and stimulate innovation. I think you only have to look at some of the things that happened after World War II where, because of forced draft by DOD, American industry did a lot of things. But the most important thing it did was increase its technological base, with the help of universities, with the help of the Bureau of Standards, with the help of a lot of people. It sucked more out of the literature and science efforts that had gone on years before than it had in quite awhile. And after that, then you begin to get the widespread use of computers, modern electronics, test gear, you name it. I think it is not bad. I really am a believer in what they call the "trickle" down theory of technology. If you start someplace, it will spread out as time goes on, particularly if they have the money with which to invest, and hopefully, the tax changes will make that available.

Q. General Electric is one of the most well known names in American industry, but I am surprised at the number of products by G.E. which have their origin in some other country. Now I am wondering if all of American industry gets these favorable tax breaks, will that money in turn be applied to R&D in some other country such that our balance of payments will not be any better off than they are now?

A. I do not know, of course. I guess that a prime example of forcing R&D overseas is in an industry with which I am not all that familiar, because I am not directly involved but have heard a lot of people talk about it, and that is the drug industry. It is apparently much easier to develop and test new drugs in other countries than it is in the U.S. As a result, the citizens of those countries have new drugs available much earlier than we have in the United States. As somebody said, if you have ailment X for heavens sake do not get it here, go to Germany or France or someplace else to get it, they will cure you in a hurry. Now of course, that is probably overstating. I do not see a major thrust to do R&D outside the United States just because one has more money.

Where you do R&D has been looked at by a lot of people, and the answer to that question is dependent on a lot of factors. First, it is dependent on the extent of the activities overseas. For instance, if we have a sales office in Germany to sell products, we are certainly not going to put R&D there because the information flow is just too difficult. We would have people flying across the ocean, interacting with the engineers and scientists on this side and, by the way, it used to be cheaper to do the work over there and now it is not, it is cheaper to do it here. If you had a large factory, however, that was making things that resembled pretty much the things that you also made in the United States, then you could very well have, let us call it a strong engineering function there, that would help redesign the models to take advantage of local preferences and local materials and methods. This happens in some industries but does not really detract from what you do in the United States because most of the early work is done in the States.

You would not have that market at all if you did not do the engineering work over there to adapt the product to local customs and needs.

There is a second reason why you might do work overseas, and that is where the governments insist on it—and we are seeing a lot of that now. They are saying that if you are going to sell stuff in our country, then you are going to do some of the R&D in our country, and they make it pretty sticky if you do not. Our good neighbor to the north is pretty much in that direction, Brazil is heading in that direction, and I am not sure if I am up to date on Mexico or not, but if they are not, they will in the near future because they are training technical people. They understand the importance of starting out with R&D to develop high technology businesses, innovations that lead to high-technology businesses, and they want a piece of that pie as their countries become more sophisticated and as they grow. So, we are seeing a lot of that. Where you do R&D is a complicated question. If you just make the decision on a financial basis, and you are a United States based company with history in the United States, you will do almost all of it in the United States, but there are some other circumstances to be considered.

Q. In the government/industry relationships, we seem to have a growing new emphasis on the military. Unfortunately, the government relationship with the military in research and technology has not been noted as being the most efficient place to do that sort of thing. Can you say anything about the new—administration—are they coming up with any more efficient management techniques, or so forth, from the government that would more effectively utilize these people? Otherwise, it appears that we are drawing away from the private sector the very research and technology that we need to increase productivity in the United States?

A. I really do not know what DOD has in mind for the efficiency of doing R&D or productivity, if you will. The President pointed out yesterday, that Weinberger used to have a nickname that made him feel pretty secure in his insisting on higher productivity and cutting waste—it was "Cap the Knife" I think. I am not sure it is all so bad. I know there are an awful lot of bureaucratic delays sometimes in procurement and things of this sort, but from what I have found in government generally, the technical people are competent, they are very dedicated, they work hard, and try to do things just as efficiently and of as high a quality as possible—and you are no exception here. True, you have some bureaucratic delays, whether you are in private industry or government, or universities, where they tell me, it is still worse. But I am not disturbed because the DOD will have more R&D money. Being an optimist, if I were in a university or industry that relies on government money for a certain number of its activities, I would go where the money is. I would be plowing DOD today, tomorrow and forever until things changed and my friends in universities are doing that.

Let me just say in closing, that I think this a great institution. It is 80 years old, but it has really established a wonderful reputation. I used to have a vision for this institution as being the corporate research laboratory for the federal government. And to a certain extent I think it is. It has good people; hopefully it will continue to have good people. I understand your equipment situation is better than it has ever been. I know your management is good. I know you have a lot of supporters out there in industry, and I just want to wish you Happy Birthday and many happy returns.

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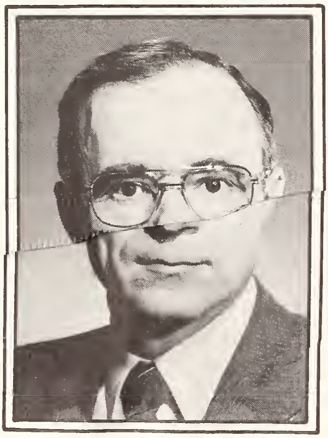
In 1978, Dr. Penzias and Robert Wilson, another Bell Labs research scientist, shared the Nobel Prize in Physics for their 1964 discovery of evidence to support the big-bang theory of the origin of the universe.

Dr. Penzias received his B.S. from the City College of New York and M.S. and Ph.D. degrees from Columbia University. He has received a number of honorary degrees and is the only American to hold the degree of Docteur Honoris Causa from the Observatoire de Paris.

Among his affiliations, Dr. Penzias is a member of the National Academy of Sciences and a fellow of both the American Academy of Arts and Sciences and the American Physical Society. He is also visiting lecturer in Astrophysical Sciences at Princeton University, adjunct professor of Earth and Space Science at the State University of New York at Stony Brook, and research associate at the Harvard College Observatory.



Managing Research in a Changing Environment

I cannot claim to represent all of industry or even all of Bell Laboratories; what I would like to do instead is to share with you some personal thoughts on how to carry out research.

I have a bunch of notes in my pocket, I did prepare a talk, but I will leave them in my pocket for the time being. Instead, let me begin by expanding on what I was talking about over coffee with a few of the people from the Bureau a few minutes ago. It had to do with jokes about a Guru on a mountaintop. The idea, with only minor variations, is that somebody walks up the mountain to ask a question. The punch line usually hangs on the Guru saying something obvious. The difference between that joke and reality is only one of rather subtle degree. You are here to listen to an "expert," but you probably already know the answer. What we have to do, in order to do the job that technology has traditionally done in the modern world, how to do that job better, and have that job be perceived as being better.

I said I was going to speak specifically about myself and the organization that I know the most about, Bell Labs. Basically, the way we do research at Bell Laboratories, the way we have been successful, follows three very simple rules. You get bright people, you point them in the right direction and you get out of their way.

Let me start with the first one. How do you get bright people? One of the best ways to start is to look at yourselves. Conventional wisdom says that first-rate people look for people brighter than they are, and second-rate people look for people who are dumber than they are. We ought to ask ourselves what the difference is. What is the break point? At what level does it happen that people feel threatened by talent? It has to do with the amount of anxiety that exists in an organization. I will talk some more about anxiety later, but for the moment let me leave the point with the observation that nothing can destroy the quality of an organization faster than placing hiring decisions in the hands of people who regard new employees as potential competition.

A second hiring pitfall has to do with preconceived stereotypes. One of the great philosophers of our time, Art

Buchwald, made a very interesting military observation. He pointed out that in modern times every single war has been won by the army with the less good-looking uniforms. There is some information there we ought to think about. People wear uniforms to look alike. When people look alike, they act alike and they think alike. When all the people are thinking alike, all but one of the brains are unnecessary. I suppose years ago when soldiers lined themselves up in rows with muskets and fired at the other side until one side had more dead people than the other, uniform thinking may have worked. I do not know if it ever really did. This country was born on the fact that our side did not form into a line but hid behind the stone walls near Concord Bridge. So thinking for yourself worked even in those days. It certainly works today.

Today, we want organizations in which people do not all look alike. We need organizations that encourage diversity. What are the odds that the small fraction of the population from which you normally hire has all the available intelligence within it? Furthermore, hiring from a look-alike group would not only be unfair to the people who you have not let in, but would also be unfair to those within because there would be none of the diversity people need to avoid the pitfalls of group thinking.

I do not think there is much disagreement about the need to enlarge the group of people, the kinds of people, from which we hire. In doing this, you have to go after the very best people, but you have to understand what that means. It does not mean just going after grade point averages. Ask yourselves what sort of questions you ask the candidates you see. When you ask about their school work, do you ask about the facts that they know? Or, do you try to find out if they can think? My son is an electrical engineering graduate this year. He talked to me about one interview he had in a place where he would really like to work. The engineer in charge asked him, "How many barbers are there in the United States?" What would you do if somebody asked you that question? If your reaction is that it is unfair because you have not looked it up, then you are not thinking. There are many ways of doing that problem. You can estimate how many people in the country have hair that is cut by a barber, how often they go, how many haircuts does a barber give in a day and how many days does he work? Or, what fraction of stores are barbershops? There are many ways of looking at the problem, they all depend on your ability to think. Are you hiring people who know how to think, or are you hiring people who have just swallowed the things which exist in textbooks and brought them back up in examinations?

There are lots of places in this country to look for bright people. To send a few more recruiters to MIT does not do as much good as looking around in non-traditional places, including your own organization. There are many secretaries who are doing very competent work in a variety of difficult tasks, but too many secretaries are invisible when one searches for people to fill higher level openings. Non-traditional hires must, of course, be coupled with a broad and flexible in-house educational program, one which encourages growth in your existing staff as well as new people.

What I would like to talk about next is pointing people in the right direction. People often beat on organizations like Ford for having invented the Edsel. I think that almost every organization has its own mistakes, whenever people deal with problems by asking their boss what to do. In an organization that hopefully works, it is the task of the management to encourage the people in that organization to look for the right direction, then see to it that the organization is going in that direction.

This means organization thinking in a deep way, not in a buried way. The power of science in isolating phenomena by removing them from their extraneous surroundings is a key element in the scientific progress we have made in the last couple of centuries. No one has ever seen a single atom hanging in space with nothing near it. It is an abstraction, but a very useful abstraction. One must remember, however, that having removed the extraneous items to achieve a result, it is at least as important to bring this result back into context. The alternative is concentrating on less and less, and learning more and more about it. Fundamental should not be synonymous with irrelevant. The larger context must be used to provide the "right direction" I just spoke of.

However fundamental a scientist you may be, however much you manage to isolate yourself in the society in which you live—ultimately somebody pays you. Therefore, unless you are the modern equivalent of some 18th or 19th Century nobleman keeping his spare time occupied, the problems you ought to be working on ought to involve bringing your own expertise to a larger task, looking at context—not looking inward but looking outward. Select a tractable piece of a significant problem rather than an area in which there has not been publication yet.

In providing guidance in these matters at Bell Labs, I do not attempt to stay abreast of the detailed scientific literature. The people concerned are far better acquainted with it than I would be. Instead, I begin by asking the broadest, most elementary question. Take computers, for example. By asking what responses an "unsophisticated" individual might want from the computer, we can begin an ongoing discussion among the people in our group which serves to guide our research program in computers. This usually means involving computers to solve a problem, computers as tools rather than as toys. On the other hand, some people seem to enjoy working with computers for their own sake, leaving it to others to make use of their discoveries.

A manager of research ought to focus on objectives rather than process. What are the uses? What are the applications? What is it we are trying to do? What we are often trying to do is to organize information in some useful way. People talk about this being the information age. Information today is a valuable commodity; as you know, valuable things are usually scarce. There is plenty of data around, but much less information. Ultimately, information involves the brain of some human being. People prefer to talk, rather than write. They like having information available in written form, a piece of paper with all the information. When someone approaches us saying "I'd like to tell you about . . . ." The usual response is "why not write it up?" even though you are probably not going to read the whole thing you have asked for. You are going to read the introduction, look for a few conclusions and then make up your mind. You want to be able to skim over the parts that do not concern you. One challenge to communications research is to provide an appropriate interface between the speaker and the reader.

We must aim the goals of our research to fulfill a variety of tasks. This is far more complicated in the world we live in today because the previously dominant imperatives associated with economy of scale appear to conflict with another societal imperative, to give the individuals more control over their own lives. We have to allow for individual needs and desires while not sacrificing the gains we have made in the past. At the same time, we must deal with shortages of resources. We must make fewer resources suffice for our present and future tasks, learning how to do them more efficiently.

In such an environment we can scarcely afford the overhead associated with layers of specialists involved in the accomplishment of a complex task. Instead we must learn how to make relevant information available, in concise and usable forms, directly to the initiator of the task. In such an environment for example, computer aids in the design of integrated circuits become a necessity because the person who ought to be designing the integrated circuit has no time to learn about the integrated circuits themselves. All the intervening steps, all the additional information required to carry out these processes from beginning to end—how to organize memory, how close and how thin can you make the lines, how much heat dissipation you can have on the chip—all those things have to be done by an appropriately programmed machine. Thus the same person can maintain control over this large set of responsibilities.

Divided responsibilities worked in the past, they will not serve us well in the future. The commitment of the greatest nation on earth, to public transportation is evident to its visitors when you come to National Airport. Its new and very expensive Metro station is almost unreachable from the terminal. It would be a joke if it were not a symptom of a larger disease entitled, "my project stops here, his project starts there." To contain the spread of this disease in the research environment we must aim for what a friend of mine calls "tall, thin people." People who are able to reach from one level to another, to place the results of their work into a higher context.

Under these circumstances, one is able to find the right direction because it is the end user who works on the entire process. One fills the entire set of levels of understanding with a single human being or in an organized group of human beings, not with layers of narrow specialization. The challenge to the organization of basic research is to supply the tools necessary to make that process a reality.

Finally, how should management act in order to "get out of the way?" after hiring better people and getting them to go into the right direction. What are the organizational obstacles to doing things that I talked about? Are our organizations structured to manage tasks or just to manage organizations If you put somebody in charge of "energy," say, and build a Department of Energy, you often find it growing until you can do little else but kill it altogether. You might have ended up with something very different if you had originally given the same person the job of reducing energy use. The manager of a group is a success as long as the group grows or at least stays the same. The manager of a project is a success when the group works itself out of business because the project is finished. Two very different approaches. Two things which seem to be the same but are not. One of the diseases of management is that every time we need to have a project done, instead of putting together a team or a group to work on a project, we put together a group and then give the group the project. A group, almost by definition, never gets finished.

It is not only the organization that gets in the way of progress, it is the individuals in the organization who are all-too-often really in their own way. I talked a few minutes ago with someone, who I respect very highly, about his smoking habit. He was telling me that one of the nice things for him in meetings is lighting a pipe and then having extra time to think before having to answer. I asked him, "are you so dumb that you would not be able to answer questions as fast as everyone else at the meeting." It might seem pretty insulting for me to say that, but I did not have much time, and I wanted to get a piece of information across. I have the feeling most people have the impression that everyone around them is brighter than they are, that "other people" seem to understand things more quickly and in the more fundamental way than you do. The evidence for this circumstance is that everytime that you are ready to ask a question, nobody else is asking one. They must all know the answer, and the only way you can keep up with them is to keep quiet yourself. The few things that you do know yourself must be easy to understand because, however hard it was for you to learn them, when you start explaining they immediately nod their heads; they appear to understand right away. So what happens is you stop explaining and no one asks questions. Any organization, and the atmosphere in which it lives, is really made up of the attitudes of the individual people. As people, you can wish for a more enlightened boss or you can create a more enlightened boss. You create a more enlightened boss, co-worker or subordinate by taking him or her a little more into your confidence.

Somebody has to be the first one to start asking questions. Somebody, at some point, has to say "stop, I don't understand."

I was talking to a high school student a few weeks ago. She was asking me some questions about cosmology. She apparently had a particularly primitive science teacher who was making all sorts of arrogant statements about the "stupidity" of religion, which I felt were untrue. I got mildly excited about the short-sightedness of the science teacher. The student was just repeating the science teacher's questions, but I was responding with arguments instead of answers. Fortunately, she had the courage and the maturity to say "you are making me feel stupid" which changed the tone of the rest of our conversation. Somehow, she had been lucky enough to go to a school which had not totally destroyed her ability to ask questions and to tell somebody when she felt stupid, when she did not understand. I hope and pray that she manages to get through another 10 years of education with much of that same self-respect intact. The rest of us, unfortunately, have to strive to learn it again, to be able to say "I don't understand," "I need more help," "you are not explaining it clearly," "I'm going to explain this at the level which I learned it."

Doing research means asking questions of Nature. It is hard to imagine that we can learn to ask the right questions in that sphere if we cannot first learn to ask questions among ourselves.

Having touched on the main points of managing the inner aspect of a research organization let me now turn to the outer aspect, the interaction between science and the society it serves.

If as scientists, engineers, and technical people, we would like society to treat us more like human beings, we have to do two things: We have to start acting more like human beings and secondly we have to give up some of our "perks." The kind of fears that we have and the kind of intimidation that goes on around us make us reluctant to throw away those societal advantages that our degrees and our limited expertise give us. We too often are ready to dismiss as nonsense the statements of a sociologist who wants to know, "how come you guys are always talking about handling nuclear waste, and I am thinking about solar energy." It may be frustrating to try to communicate with somebody who mistrusts people not wearing blue jeans. Whatever the answer is, we cannot afford the kinds of barriers that now exist and the kinds of distorted perception that go with it. As technical people, it is not enough to do our job, we have to be perceived to be doing our job. In order to have that perception permeate in the larger society, people have to understand what we are doing. In order for them to understand what you are doing, you have to understand it yourself well enough to explain its larger context and implication an exercise which is not wasted motion by any means.

Even if we could, I do not think we ought to return to the days of the late 50s and early 60s, when to be a scientist, or engineer, was to be a hero; when all one had to tell the public after a few billion dollars had been spent was "we learned some real interesting things about the craters on the moon." We certainly kept any discussion of whether or not we were asking the right questions very much to ourselves. And now, when we have more interesting questions to ask, the resources are not there any more. Because after all, the public does get wise. Maybe they get wise to us faster than we get wise to ourselves.

It seems to me that if our society appears to be down on its luck right now, we ought to start seeing about how to get luckier. That great expert on luck, Branch Rickey, said "luck is the residuum of planning." We ought to start planning to be lucky, to use the best of our ingenuity to control our destiny. The only kind of civilization that I want to live in is a high technology society. The Greeks had most of the intellectual advantages that we do. Their architecture, philosophy, geometry, literature, plays, music, and poetry, were created without the benefits of technology. All they needed was a plentiful supply of human slaves. I do not think we can go back to a society in which some fraction of people expect other people to do their dirty work for them. The only alternative to a sub-subsistence standard of living is to have machines to do things that people no longer can do, or no longer ought to do, like the replacing of porters with a subway system that goes right inside the airport as it does in Zurich.

If we want our society to be lucky, technology must play a vital role. It cannot be technology developed in a vacuum, handed down as it were, as if people doing the technological work were somehow on a higher level. The tasks before us are so hard, the problems so difficult, that we cannot succeed without help, without coupling to the larger society and using the best that human intelligence has to offer. If we do couple to that larger society, and get our own act together in ways such as those that I have suggested this morning, we will be perceived to be doing a good job because we are doing a good job.

William F. Miller, president and chief executive officer of SRI International, was educated at Purdue University (B.S., 1949; M.S., 1951; Ph.D., 1956). He began his career in atomic and molecular physics studying the effects of high-energy radiation before turning to the computer sciences. As director of the Applied Mathematics Division of Argonne National Laboratories (1958 to 1965), he made significant contributions to the development of computer systems.

He was the first holder of the Herbert Hoover Professorship in the Stanford Graduate School of Business and a professor of computer sciences. At Stanford, he also served as professor and head of the Computation Group at the Linear Accelerator Center, vice president for research and vice president and provost.

Dr. Miller is a member of the American Physical Society, the American Mathematical Society for Industrial and Applied Mathematics, the American Association for the Advancement of Science, the American Management Association, Sigma Xi, and is a fellow of the Institute of Electrical and Electronic Engineers and the American Academy of Arts and Sciences. He has been a visiting scholar at the Center for Advanced Studies in the Behavioral Sciences and at the International Institute for Applied Systems Analysis in Laxenburg, Austria. He also serves on several national advisory councils to government agencies and private foundations.

The Software Edge

With the United States under great economic challenge from other nations it is important for us to look for our strengths as well as our weaknesses. We need to look for our weaknesses in order to see what corrective actions can be taken. We need to look for our strengths in order to build on them.

One of our great national assets is our human resource in the area of software for computers and for microelectronics. In the area of computers and microelectronics the name of the game has become software.

Heretofore, it has been principally a U.S. game—of course, not exclusively a U.S. game—but principally a U.S. game in the sense that the major volume of software work had been done in the U.S. We have not done all the lead research and we certainly have not done all of the production. Overall, however, in terms of software for computer systems, and especially in terms of applications in business and industry, the U.S. has been a very clear leader. That situation is changing.

My main thesis is that for the present time the U.S. has a margin of advantage in software production. We ought not only to maintain that margin, but we also ought to capitalize on that margin vis-a-vis global competition. We do not have a monopoly. No country can expect a monopoly. But we do have a comparative advantage on which to build. Executives from foreign electronics companies seeking to locate in America have told me that the availability of software talent is one of their principal reasons for coming here.

Other countries are developing software talent and techniques, trying to narrow that margin of advantage the U.S. has. I believe in competition. I believe that there should be competition. The very fact that other countries are catching up with us in many areas, and even moving more rapidly in some, means that we have to revitalize ourselves to maintain a competitive position. Software can be a very big factor in the revitalization of America.

I am talking today about software, and its impact and its role in the revitalization of America. Although I think software talent is a national asset, I am not so naive as to suggest that any one issue or any one technology will alone have a major impact on revitalization. Many changes are needed in both public and private policy before the U.S. can regain its economic momentum.

Many industries believe that they cannot invest sufficiently in research and new technologies because of the burdens of government—both regulation and taxes. Additionally, many of the developed industries believe that labor must come to an understanding of and accommodation to the need for automation and increased productivity in order to meet foreign competition. This whole area of the socioeconomic impacts of new technologies and changes in public and private policy to accompany revitalization is an important one I shall not go into today.

Turning back to our main subject, let us look for a moment at the total impact of the information society on the U.S., and move from there to the impact of software and the scope of the software industry. Finally, let us look at some strategy for America's efforts in maintaining the software edge.

Even for those of us who 25 years ago were true believers and were forecasting "The Rise of Digital Man," most of us are still greatly surprised by the breadth and pervasive impact of the information society on our industrial development. The effect is similar to the transition from the agricultural to the industrial society. In the early days of the industrial revolution, farmers, plantation owners, and owners of estates and trading companies associated with the agricultural industry resisted the industrial revolution. They resisted its advent in every way possible. Those with vested interests in the agrarian society looked at industrial development simply as a companion activity to the agrarian activities, and as a source of competition. They did not see those industrial activities as being directly applicable to agriculture.

About the middle of the 19th century it became clear that science and technology could have a direct impact on agricultural productivity. In the United States this led to the establishment of the land grant colleges for "agriculture and the mechanical arts," to the development of agricultural research stations, and to the development of the county agent system. The county agents were carriers of change, bringing research to farms, ranches, and plantations. Agriculture had indeed embraced the industrial society.

Correspondingly, in the early days of the development of the information revolution many industries and businesses viewed the information business simply as a companion business. They did not see it as having a very direct or pervasive impact on their businesses. Today, there are few businesses or industries who can ignore the direct impact of the information society, although most of them do not yet recognize the central role of software in current developments. They do not recognize it, that is, until they have to try hiring programmers. Computers and electronics for both data processing and communication have affected not only the hardware industries and the engineering industries, but they have virtually permeated every conceivable industry, even invading the home.

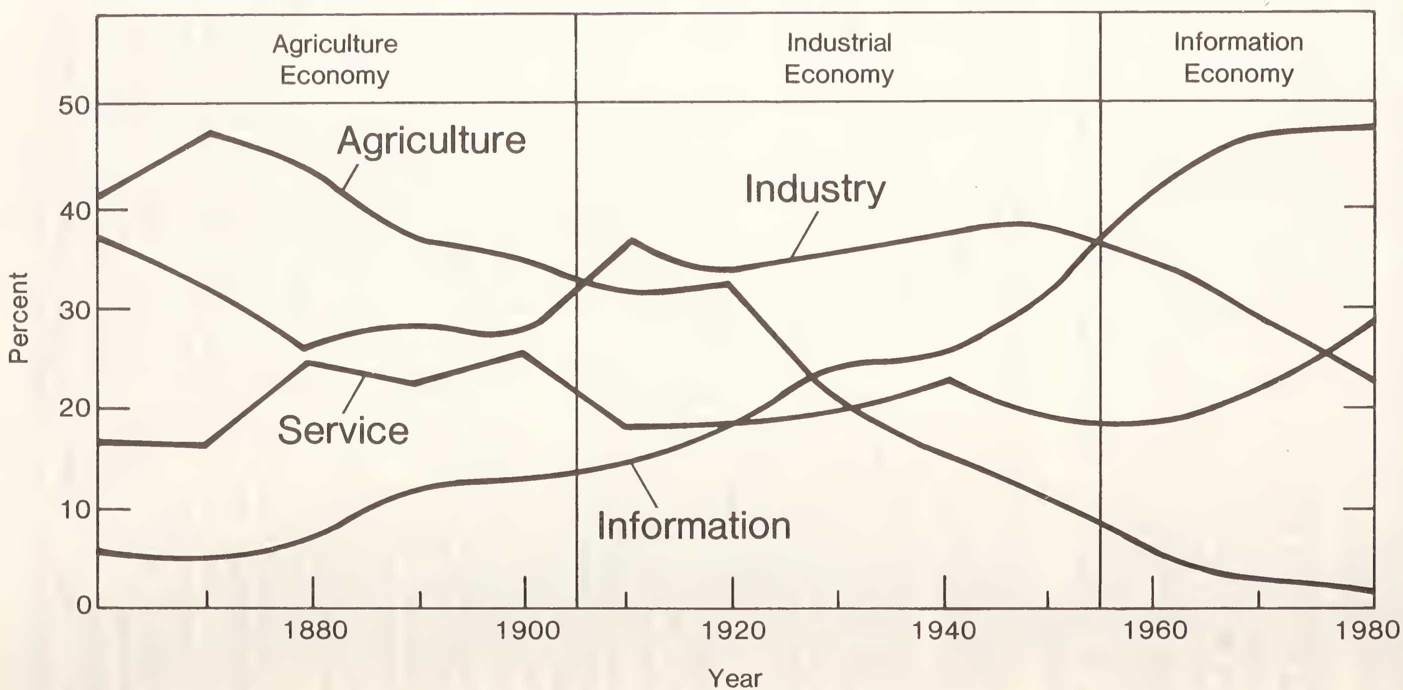
One way to get a sense of the massive effect of the information revolution in the U.S. is by examining the changes in the work force over the last few years. Figure 1 shows the transition of the work force from the middle of the 19th century to 1980. This figure reflects a tremendous restructuring of the U.S. economy, especially in the last 25 years, due to the impact of the information society. If anything, figure 1 understates the impact. This shows the part of the work force that is directly involved in the information society. Not included in this representation are student use, home use, or business and industrial use by teachers, managers, or other specialists.

The information society's impact in other countries is extensive. In a few areas of application there are countries ahead of the United States. We have much to learn from them, but across the board the impact has not been as pervasive as in the U.S. In particular, the industry's development of the software component and the impact of software in other sectors of industrial development is greater in the U.S. than abroad. U.S. business and industry have embraced the information society in much the same way that agriculture embraced the industrial society about the middle of the 19th century.

In figure 2 we will look at the scope of the software industry. Already by the early 1970s the cost of software had exceeded the cost of hardware when in-house software development and maintenance is included. By the end of the 1970s many changes occurred including the unbundling of software. Both computer manufacturers and computer systems houses recognized that the growth part of the industry was in the software arena and were turning to that area to sustain their growth. Perhaps it is too soon to recognize how the various hardware manufacturers will play the game between software and hardware, given the extent of unbundling. There is little doubt that software will play a major role in the growth companies that have, heretofore, been principally hardware companies. For example, Hewlett-Packard, a company principally in the scientific instrument and computer business, now invests very heavily in software and computer science.

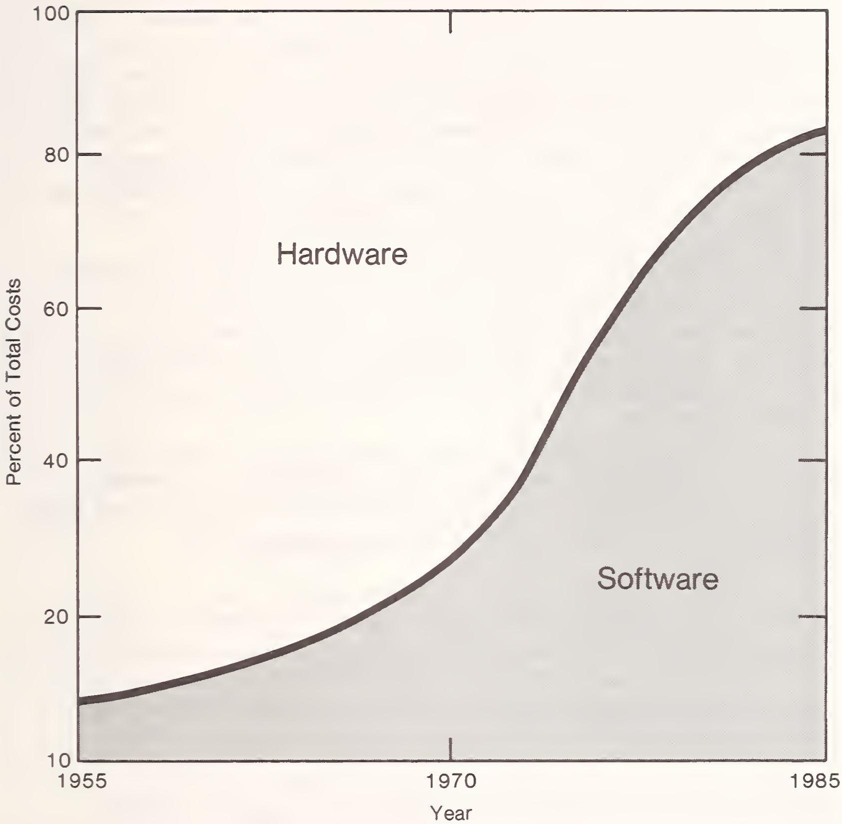
Companies in the service market area, such as forecasting, and companies that perform problem solving through the use of sophisticated or generalized business applications are expected to grow at a phenomenal rate in the next 5 years—perhaps as much as 20 percent a year. These companies are principally in the business of selling access to computer models and data bases. Previously, the principal targets for these agencies have been other businesses. In the future, one of the large target markets will be the direct consumer. Already one can get various financial services and financial reports either by acquisition of casettes for home

Figure 1.—Distribution of U.S. Work Force, 1860-1980



Source: Porat.

Figure 2.—Growth of Software Costs



computers or through remote access. The independent software market is also expected to grow very dramatically, perhaps tripling over the next 5 years.

If we assume both the business and consumer public, which acquire these services, are making wise decisions, then the impact of the information society on business, industry, and the individual is going to continue at a rapid pace. Of course, we may not trust the judgment of these people who are acquiring all of these services, but I tend to accept the marketplace as an efficient process. I believe, in these days of heavy emphasis on economy and productivity, that most purchases will have a very reasonable expectation of being effective.

Let us now examine more briefly the major sectors of software development in the U.S. Up to this time, one of the largest areas of software development has been in support of large-scale computing systems including timesharing and multiprocessing systems. An even larger area of support has been in the applications carried out on those systems: very large-scale design calculations, large data base operations, and financial services. Over the last few years, systems support for microprocessors has become a very active area of software development and gives promise of continuing to be an active area for years to come. That must be followed by applications of microprocessors including the software used in those applications. Communications is becoming a significant user of software, not only is electronic mail becoming more widely available, it is even available on a commercial basis at this time. The linkage of computers, especially microprocessors, with the other aspects of the communications industry and television in particular has given rise to a hybrid business that also has promise of developing very rapidly. And of course, the continued development of data bases currently referred to for diagnosis, sales information, financial information, and technical design considerations will continue to be a very active part of the software business.

The large chemical industries' data base and the Lexis system for bibliographic legal searches—all will have increasing importance in the future. Those industries having access to key data bases will have a large comparative advantage over their competitors.

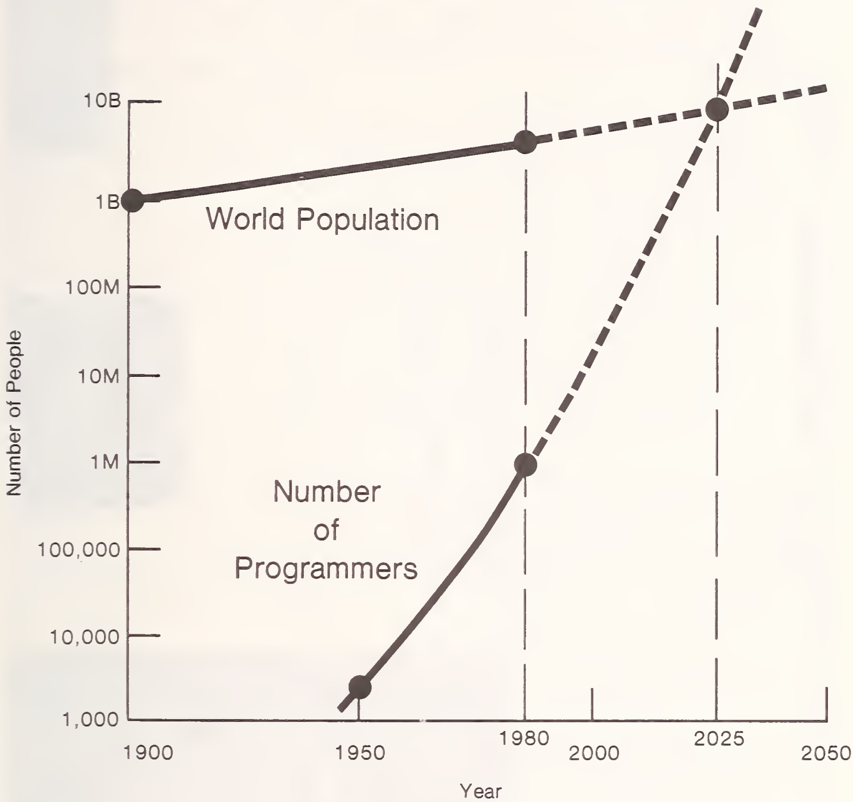
Finally, education and training are going to see continued emphasis on software development, the development of both learning programs and the data bases for education and research.

How can we continue to capitalize on this software edge? How can we maintain this edge? First, we need to produce more computer scientists. Even though they are coming out of the universities in very large numbers, the demand still exceeds the supply by a considerable amount. Between 1979 and 1980 the increase in overall demand for computer specialists of all kinds is estimated from 30 to 50 percent. Given the rate of increase in demand, we are by no means keeping up. The National Center for Education Statistics estimates that the number of students obtaining bachelor's degrees in computer science will increase by about 35 percent in the next 5 years. There are, of course, other sources for computer specialists. Immigration provides a source as well as retraining professionals from other fields, or upgrading staff workers with a company. Nevertheless, it is abundantly evident that the supply is by no means going to match the demand.

One of my colleagues humorously displayed the problem on the following graph, (fig. 3) which suggests that by the year 2025, if we follow simple projections, we will all be programmers. And why not!

This leads to the next important issue in maintaining our software edge in the United States. Programming has to become more efficient and more reliable. This means business, government (both state and federal), and private universities should continue to support software technology.

Figure 3.—Population of Programmers

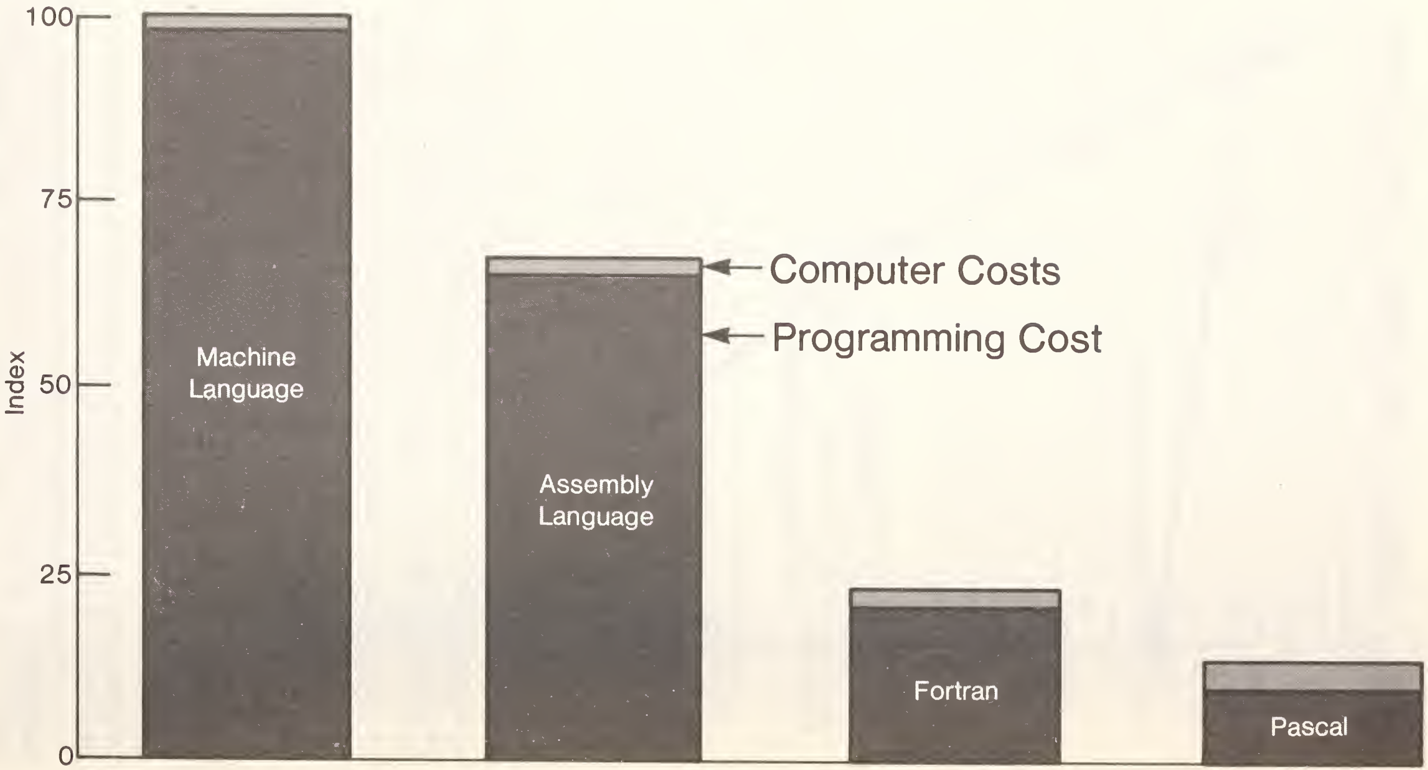


SRI does research in computer science and software sciences, including software technology. We also do a great deal of work in applications of large computer systems, helping both governments and corporations develop their computer systems and products. We know the need for more research on efficiency of programming and reliability of software from our own application experiences.

This is old hat to many. We know that many industry people have been calling for more efficient programming for a good number of years. But I am happy to say that much is happening. Programming is becoming more efficient and more reliable. There is a dramatic increase in the use of programming tools and aids for computing. This is especially so in the area of microprocessors. The growth in the development of programming tools for microprocessors is matching the growth that we experienced for large-scale systems 10 years ago.

Figure 4 illustrates the net cost of a typical program development using more sophisticated programming techniques. You can see that in going from machine language programming to

Figure 4.—Net Cost of Typical Program Development - 1978



the use of PASCAL, the net program development cost decreased by almost a factor of 5. Every system does not have such sophisticated programming tools and one cannot suggest that all programming costs can come down by this full factor of 5, but this measurement does indicate that efficient programming tools can contribute greatly to programming productivity.

In addition to more efficient programming, we must have more reliable programs. Efficient programming tools contribute to reliability. In addition, the development of fault-tolerant computers and verification schemes have tremendous economic and technical payoff to the products that critically depend on computations. In products where the value added to hardware is primarily the software, well engineered, reliable, and efficient running software becomes a must. Moreover, it is absolutely essential that we develop these tools for efficiency and reliability, and put them in the hands of educators for their students, those students who will become the professionals "carrying the ball" in the software development area of the future.

What is so unique about software thinking? My thesis is that software thinking is quite different from hardware thinking. Software thinking is much more a problem solving type of thinking. Of course, in good products and good instruments software and hardware must function together in a supportive and compatible way. The designer of an instrument or a machine should think about the software at the same time as the hardware. I have frequently watched the development of instruments and products by engineers who had no training in software and compare that with comparable developments where a great deal of software thinking was present. In the former case, the designer generally looked to see what could be measured or controlled, and eventually thought about the data analysis or control system that should be attached. In the latter case, where a lot of software thinking was present, the designer thought in terms of the problems to be solved and what software and hardware were available and necessary to solve those problems. In the latter case, one had more effective data analysis and control, and certainly more flexibility in the design.

The new robots that are being developed by U.S. companies, and that are in early use for assembly line production of heavy equipment, are programmable robots with sophisticated software. They reflect some excellent software thinking. I suspect that the lead in robotics will shift back to the United States because of the level of software thinking that has gone into U.S. robotics.

I was recently shown through a heavy industry manufacturing plant in a foreign country by the general manager who told me he had designed the automation equipment. This factory is highly automated by anyone's standards today. One could clearly see the presence of good hardware engineering and good hardware thinking. But there was not software thinking in the development of that system. The system works very effectively at this time, but when it becomes necessary to modify the production line to different products or major components, the line will have to be completely disassembled and reassembled. It is like rewiring the program. In the future, a bit of software thinking in the design of the whole factory would permit a more flexible and more rapid changeover. I am not suggesting that one could have a factory so automatic that one simply reprograms the whole factory, but there are critical points that could be reprogrammed more handily than is the current case, thereby saving enormous amounts of cost and time in the changeover.

This concept may be less important in very large-scale production plants than it would be in high technology production. Design automation is getting a great deal of attention now for application in the VLSI industry. Design automation is principally a software game. In thinking about the problems that have to be solved in designing efficient circuits one has to think of the software issues first. Here we see great potential for modern computer science research in problem solving and in artificial intelligence to be applied in manufacturing. Artificial intelligence is one of the areas of computer science that is being actively pursued by many companies in the electronics industry today.

Software is a way of thinking. I can illustrate this by an anecdote from my early days in computing when I was a graduate student working in the summer at the Argonne National Laboratory. During the construction and programming of two Princeton-type computers which were built there, namely the Avidic and the Oracle, one being built for the Argonne National Lab, the other for the Oak Ridge National Lab, I noticed that several of the staff were busily converting decimal numbers to binary form for input to the computer. I asked, "Why don't you let the machine do the conversion?" They replied, "We wouldn't want to waste machine time on such trivial tasks." How things have changed! Most of you find that very amusing. Incidentally, the numbers were being read in on the paper tape through a mechanical paper tape reader. Since I simply could not stand that attitude, I generated a character-by-character converter that did the conversion calculation in the time interval between readings of the characters by the mechanical paper tape reader. This process did not waste any machine time since machines were not multiprogrammed in those days. Also, since it did not waste any machine time it was an easy conversion to sell. But the main point here is this represented a different way of thinking. The machine was there to serve the total activity of the scientist, not simply selected parts.

There is one area where software thinking will play a tremendous role and is already playing a tremendous role—in the area of office automation. Almost all the value added to the hardware that will be provided in office automation is going to be software in the most general sense: software programs within the computers and procedures external to the computer for using the office automation. As long as the planners of office automation systems think in terms of applying hardware to specific tasks they will fail to get the major impact of office automation. To get the full impact it will be necessary to consider the integration of various office systems being used or that have to be used in the future. That design should precede the selection of the hardware to handle the problem. Office automation does provide a real opportunity for increasing our productivity. In addition to an integrated system design, it is going to require a thorough education and employee involvement in the development of systems, in addition to continuing education. In the first place, office automation must not be viewed as a threat to office workers. Participation in the development helps remove some of the threats. Additionally, most office workers are not going to understand the impediments to productivity. Each has his or her pet idea, but most of these are untested and the design of the system needs to allow for change and improvement. That, of course, speaks heavily for an effective software effort.

Let us turn now to an important issue for American industry—an issue that is especially important for the computer, and especially the software industry. That is the management of human resources. A great deal of attention is being given to human resource management. A business week article on the reindustrialization of America made a major point of the renewed emphasis on human resources.

We especially need to learn how to manage innovation. America has a very strong reservoir of individuals trained with excellent management skills in the technical sense, that need to be augmented by training in managing human resources. Recently, I have been thinking a great deal about the revitalization of American industry vis-a-vis global competition. This caused me to reflect upon J. J. Servan-Schreiber's book, *The American Challenge,* written in 1967. In that book, Servan-Schreiber underlined the need for France and Europe to learn management, American style. "The Americans are coming, the Americans are coming!" was his theme. Americans are better at organizing, production control, and marketing. If they were going to meet this American challenge, they were going to have to learn those skills. Let me tell you that they have learned all that, and much more. Our foreign competitors are very effective in their management today.

In searching through the book for clues that would suggest how we could revive our industrial activities to bring forth a second American challenge, I ran across a quotation I missed on the first reading. Servan-Schreiber was saying in this particular quotation why the Americans were so good at management. He said, "All cliches to the contrary, American society wagers much more on human intelligence than it wastes on gadgets." That is the part I missed. There is the part that most people missed on reading Servan-Schreiber. What is he saying to us? He is saying, "invest in education and R&D; invest in intelligence." That is why America has done so well, and because of that we came on strong with the first "American Challenge." That is still the right message. We have forgotten it. The message should be not simply to exercise those skills that we had developed previously, but to find new ones and exercise those in the management of our industry. Find our new strengths as well as our weaknesses.

There are some wonderful examples of what can be done with proper human resources management. One fine example is that of the Dana Corporation in Toledo, Ohio. The chairman of the corporation, Ren McPherson, is now Dean of the Graduate School of Business at Stanford University. McPherson, while chairman of Dana, doubled the (per capita) productivity of the corporation in 7 years. In effect, he doubled his company without capital investments. Dana Corporation paid attention to the skills, to the work habits, to the ambitions, to the enthusiasms, and to the criticisms of their employees. This is an important lesson for all of American industry, and an important lesson for us in the computer industry and the software business.

I want to close with a number of messages for America—six of them in total. First, think software. Software thinking is problem-solving thinking. Think of software in design of our computer systems, in design of our office systems, in design of instruments and products. We have a greater capacity than any other country and a considerable comparative advantage in software development on which to capitalize. We certainly do not have a monopoly, but in today's world one cannot expect a monopoly, only a margin. Put software in our products. Do not let them leave home without it. The next round of industrial development can be ours.

Secondly, we should continue to invest in the development of our human resources through education, training, and management of their capabilities. We should remember what J. J. Servan-Schreiber said about the great advantage that America had in the first American challenge.

Third, we should invest heavily in software R&D, both within the industry and in the public sector. Software research and development will contribute not only more efficient programming and more efficient products, but more reliable and more flexible products.

Fourth, software is a major key to increases in productivity, manufacturing, and in the office. We know relatively little about the principal factors in white collar productivity. We need to be experimental in our development. Software in the system permits an experimentation, a variation, a flexibility for us to discover the key factors of productivity and optimize those once we have discovered them.

Fifth, we need to place more emphasis on the control of the manufacturing process of software. Software on a chip is now feasible and practical, providing a means of controlling the manufacturing process, ultimately putting higher value on the software itself. I believe that we have been selling our software too cheaply. When software was viewed as an adjunct to hardware, buyers wanted to pay as little as necessary. In the extreme, they looked at it as an operations manual for the hardware. When you think of software as the key ingredient in the system, the part of the system that contains the intelligence of the system, it begins to look much more valuable. Now that we have discovered that it is a valuable commodity, we need to begin to price it accordingly. I am reminded of the underdeveloped countries selling their resources to colonial powers when they did not really understand the value of those resources, be they minerals or oil. They more or less took what they could get for them. As time goes on, the importance of good software and the means of measuring and identifying good software will increase its value. Being able to put software on a chip will give the means to control the manufacturing process, an essential ingredient in pricing for value.

The sixth message is that, through software and in software, we should play the innovation game and capitalize on the innovative qualities of our computer scientists and specialists. At this stage of global development we have more computer specialists trained to be innovative than is the case among our competitors. One of the reasons for our lead is that we encourage innovation in our students. We encourage our students to play—serious play, but play—on computers. As more home computers become available we will find even more of this playing on the computer. In many countries when the professor gives the student a problem and the student approaches the machine, the suggestions of the professor are followed as accurately as possible in order to get the solution right, using very little machine time. In the case where our students have sufficient machine time to play around, or when they have home computers on which they can experiment, they will try any solution but the professor's first in order to try to outdo the professor. They only use the professor's scheme as a last resort or when they are in a great hurry. This creates a more experimental and innovative attitude on the part of our students. It may create less discipline, so we need to adjoin to this innovative spirit sufficient recognition of the need for discipline in turning out products. On the other hand, we have an outstanding, innovative human resource. We need to learn to manage it well. The innovation game is our game. We need to capitalize on it while we revitalize America.

Discussion

Q. Because of the high demand, many students are going to work immediately after receiving a bachelor's degree rather than go on to do research and work toward the Ph.D. Is this not destroying some of our capability?

A. I think competition does have certain destructive aspects—it always will. You can also look at it as giving rise to stronger entrepreneural spirit. Nine of my students have become professors and three have become millionaires, and I think the dichotomy is very sharp. Some people ask me, was not the very fact that there were so many instant millionaires in Valley having a destructive effect. There was a concern about the competition between industries there and partly drawing people out of the universities. I had a different view of it. I believe that has given rise to a renewal of an entrepreneural spirit which is very important to innovative industry. That is the price you pay. We need to encourage more research, we need to support research, and when its a lot of fun, people still go into it. There are people who still believe in the certain element of delayed gratification. SRI is a wonderful example of people who are very happy at what we often call a halfway house, that is, halfway between a university and an industry. We have a lot of people who would like to share some of the benefits, namely money, from industries and who would at the same time like an academic setting. They cannot get both of these if they go either to the university or to the industry. But we try to provide them opportunities. For example we changed our patent policy to share the royalty with them a little more, to make it more attractive to stay rather than to have to go to industry to capitalize on that. So I think we have to address this problem and try to keep more people in research, but I am not fearful that this is going to destroy the industry.

Q. I am wondering if your comments on the need for emphasis on education and intelligence on the one hand and your emphasis on the need for hardware and software to become flexible enough to allow for experimentation on the other hand does not apply to conflicting trends in the way people think in the future. In particular with research, what I am asking is do you think research will become more imperical as opposed to theoretical in the future because of the easy access to both hardware and software?

A. There are lots of ways to approach theory. Some of the finest theoretical research I know is based on imperical work. People had to experiment a great deal in numerical analysis. It applies in the experimental area of mathematics as well as in physics and other areas. I do not find introducing empirical research in problems, which are ultimately theoretical problems a disadvantage. I am thinking of one of my friends, Felix Block who is a theoretician. He conducted experiments first before he developed his theory, so somehow your concern does not bother me. If you are worried that people will fail to follow up with developing a theoretical understanding, that could become a problem, but people are inquisitive and that is why it does not worry me very much. Now I think the availability of theory in areas we really do not know much about, such as office automation and productivity, everybody has a little pet theory, is very slight; I think experimentation there will be very valuable.

Q. A number of years ago the Philosophical Society of Washington had a talk on computers by Emanuel Piore who was then head of research at IBM. I asked him a question at that time relating to numbers in base 10 or in base 2. What number would be the most efficient? And he said the debate was dead, end of comment. He did not explain why.

A. I never did understand that answer. Back to the opportunity to do empirical work. Experimental work impacts theoretical work. I remember in the early days when there were an awful lot of people who simply did not want to have floating point arithmetic on their computers. That is always very important for the mathematician to understand every time you are going through a program floating point operation. Actually it turned out that the advent of floating point hardware created some terrific research on the part of Jim Wilkinson; he really did some wonderful error analysis. Nobody today would think of not wanting floating point hardware unless it is a matter of cost.

Q. I firmly believe in software, yet one reads now that software industry is like a little cottage. I wonder if you would like to comment on what you see as the future trends of software.

A. I do not find a cottage industry unattractive. I think that is wonderful, actually. I know of a case of a woman who had children and found it difficult to also have a full-time job, so she started a little business specializing on one company's machine and doing one kind of business software. Last year she booked ten million dollars out of her house. It is a nice cottage industry. There is nothing wrong with a cottage industry, I think it serves a very good purpose. I had it presented to me that these people are similar to the county agents in the agricultural areas. They are some of the carriers of change and one might make a reasonable argument for that. There are a lot of places where there is a strong concentration, however, of software science and software technology research, so I do not think that is being neglected. I mentioned Hewlett-Packard and others. We say that because people are raiding our software talent and our artificial intelligence group have four of them taken out to another major company to work on artificial intelligence for them. So I think there are strong pockets of development there that will get a lot of the research done, a lot of the advance work done. I am encouraged rather than discouraged by that. It is kind of nice to have a cottage industry and that is actually contributing to what Talford calls the Third Wave. You find right now many more people working at home because of the work on terminals, work with their offices and that is going to create some of these changes.

Q. You indicated that we must pay more attention to the Nation's investment in R&D. How can a Nation forget the lessons of the past and how can we go about reinvesting?

A. Well we started forgetting about 1970. In another speech I give from time to time, I have a slide that shows the percentage of our GNP going into research and development. We had forgotten what Servan-Schreiber told about us about investing in human intelligence. Starting about 1970, actually, our R&D as a percent of GNP was going down in the U.S. whereas Japan and Germany were starting their drive and they were coming up. I am happy to note that in 1979 there was a slight upturn. Now there is good news and bad news in it. There is a slight upturn in the percentage of our GNP going to R&D and I think that is very good. The bad news is it was not because of the increased R&D it is because the GNP did not go up as fast as it was supposed to. This is the source of a big debate in this country. I think in many ways now people are reminded that they had forgotten what Servan-Schreiber was pointing to. I am encouraged by that and hope that it continues. I think we see it in industry and a lot of the drive in the industry-government relationship now is to make it affordable for industry to invest in R&D. But we did forget.

Q. Could you expand a little further on your comment on the pricing of U.S. software?

A. I think one could be selective about what are the interesting things that people begin to see as monolithic in an industry or a product—but they are not monolithic. Software is not monolithic either. There is some software that is valuable and there is some that is not, there are some areas where it is especially valuable. I suspect, and I have good reason to know through various proprietary activities, that there are companies that are going to put very high value now on good software in robots because they are still recognizing people in this country who have some very good software in robots. And the people who sell that to them ought to take that into account and jack the price up. If they do not they are missing an opportunity.

Q. Most of your comments apply to the private sector. Can you suggest anything that Government itself can do in terms of policy or in terms of research?

A. In referring to my talk as I mentioned before, I often talk about what I call the positive forces of Government as well as the negative forces. There is a great deal of concern now, which I think there should be, in clearing out some of the underbrush and allowing the private sector to accomplish some of the things that it can accomplish. I am very supportive of that. My association of the NBS and Commerce is a very theoretical one—it goes all the way back to Herbert Hoover. I once held a professorship in his name and I had to learn something about Herbert Hoover. Herbert Hoover believed that . . . I am oversimplifying this immensely . . . but he believed that the Government should have the major responsibility, not all, but a major responsibility for the infrastructure. My argument is that R&D is a part of the infrastructure of a highly technological society, and so positive thrusts in this area are very important. One of many wonderful examples of this is agriculture. I think that we should not neglect those positive thrusts. R&D is my principal message, but I think looking at regulation that will stimulate R&D and so forth is also very important. Artificial intelligence can be taken as an example of something that just would not have happened without the federal government. Farsighted people in certain areas like ARPA understood the importance of artificial intelligence, but no commercial business would have supported artificial intelligence. In fact, they scorned it. It was not attractive at all, it had a bad name. But now the problem solving capabilities that have been generated in artificial intelligence research are being used in design automation. I think that is a very strong message in the manpower development and in R&D. There are others. I have a concern, I do not know how big a concern because we are rather abysmally ignorant in this area, but as we try to introduce more automation in both the office and in industry, we do not know what can and should be proper response of labor. And I do not necessarily mean labor unions. I mean the working force. For example, we do not know the demographics in different areas well enough to know whether attrition will handle the problem or whether as is in the case of the electronics industry, you simply withdraw your offshore labor. We do not know what can happen, and I think there are some very important kinds of studies that ought to be done and are not likely to get done unless somebody coordinates among several agencies, and this is one of them.

Q. You spoke a lot about the efficiency of software, but you did not say anything about the transportability of software. Would you like to comment on that?

A. Well, the question which Ernie is raising is about the transportability of software. The more it is written in the higher language the more transportable it becomes. The reliability, efficiency, and transportability are in many ways wrapped together because you achieve a lot of that through use of structured languages and structured programming to generate the application programs. That does not make it automatic but it certainly makes it far easier to transfer from one machine to another. I believe that many of the early office automation machines, word processing machines, had their own little languages in them so that application programs were not transportable. But as we are now getting more of these tools into those microprocessors, that problem is being resolved in the favor of higher languages for even the office automation application software. And I think that will contribute a great deal to the portability.

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In addition to these positions, Dr. Nelson has served as a consultant and panelist to a number of government agencies including the Bureau of the Budget, Council of Economic Advisors, Office of Science and Technology, National Science Foundation, National Academy of Sciences, and the President's Science Advisory Committee.

Technological Advance and Productivity Growth: The Roles of Business and Government

Interest in government policies to spur industrial innovation waxes and wanes. Only a short time ago the domestic policy review was all the rage. Observers may differ as to whether or not what it brought forth was a mouse, but if it was a mouse it was a lively one. Generic technology programs, the cooperative automobile research program, new mechanisms to facilitate industry-university interaction in research, and more were proposed and introduced. While the view on these matters of the new administration is not yet fully apparent from what we have heard that view is likely to be a skeptical squint. Industrial innovation is the realm of business. By and large government should stay out.

I do not think we have heard the last word on this topic, even within this administration. In the early days of the Kennedy administration there was considerable interest in a civilian technology program. The interest faded. The fire was rekindled under the Nixon administration, but then petered out. Carter started the fires again, and now again they are damped. They will flare up again.

Let me state my own position. I believe that active government policies have, in a number of industries, been very successful in stimulating industrial innovation. In the concluding section of this paper I will discuss some cases. But first, I want to set the stage by surveying some of the things that are known, and not known, about the role of technological advance (read industrial innovation) in productivity growth, and about research and development as a source of technological innovation. Next, I want to consider the economic incentives and mechanisms that stimulate and guide industrial innovation. This will set the stage for a consideration of the diverse, but often influential, roles the U.S. Government has played in the generation of new technology.

Technological Advance, Productivity Growth, and Research and Development

My focus in this section will be on what economists have learned about the sources of productivity growth in their researches on that topic, conducted largely over the past 2 decades. The late 1950s marks both the resurgence of interest by economists in productivity growth and technological advance and the establishment of a particular methodology for studying the relevant questions. However, the interest of economists in technological advance and productivity growth goes back much farther. Chapter I of Adam Smith's *The Wealth of Nations* is mostly about those topics. An important portion of the writings of the great 19th-century economists was concerned with long run economic growth, and virtually all recognized technological advance as the central source of growth.

Somewhere around the turn of the century the formal theoretical work of economists began to concentrate on equilibrium conditions and steady states. As a result, empirical research on long-run economic growth gradually came to be separated from the theoretical mainstream. This is a condition which, in economics as in any other field of inquiry, reduces the coherency of research in the empirical field, and leads ultimately to a falling away of interest in it, no matter how intrinsically important the topic might seem to be, when viewed through lay eyes. Thus, during the 1930s, 1940s, and early 1950s not much research was done by economists on long-run economic growth. Part of the reason was that the problems of depression, of wartime mobilization, and of postwar demobilization naturally were drawing the most attention. But part of the reason, I suggest, was that economic growth was not then a topic of much theoretical interest.

During the 1950s, however, for a variety of reasons there was a surge of empirical research by economists on long run growth. An important empirical finding began to claim attention, and soon received a pregnant theoretical interpretation that rekindled widespread interest among economists in the subject. The empirical finding was that growth of output in the United States had been proceeding much faster than growth of (an index of) inputs. The theoretical interpretation was that the excess of output growth over that which could be explained by input growth was a measure of technological advance. This simple proposition (together with some techniques for estimating how much output growth input growth can explain) gave theoretical standing to research on productivity growth and technological advance.

The labeling of the part of productivity growth unexplained by input growth as "technological advance" was quite like the practice of physicists in preserving certain balance relationships by hypothesizing (then) unobserved particles, like neutrinos. It is a holding tactic, to preserve a prevailing theoretical stucture with minimal change. Ultimately, the acceptability of the revised formulation must depend on being able to observe technological advance (neutrinos) more directly. Further, there is a presumption that direct evidence about the presently unobserved variable, when ultimately collected, will turn out to be consistent with the interpretation of that variable within the prevailing theory. Otherwise, some major reconstruction of that theory might be in order. I gather that recent findings about neutrinos are making physicists do some basic rethinking. As I shall explain in a minute, with respect to "technological advance" things also have turned out to be more complicated than originally had been expected.

During the 1960s and 1970s a number of economists pursued knowledge about technological advance working roughly within the theoretical framework sketched above. Some of this research has been called "growth accounting." Here the strategy is to make a finer and more complete listing of factors of production and devise better methods to estimate the contribution to output growth of their increase. The "residual" is the measure of technological advance. Other scholars have used multiple regression techniques, with output regressed against inputs, and time; the coefficient on time has been interpreted as a measure of technological advance. Still other scholars have hypothesized that technological advance ought to be related to research and development spending. Some of this work has employed multiple regression techniques with the estimated contribution to output growth of R&D interpreted as the contribution of technological advance.

Studies of this sort have been undertaken to try to explain the relative roles of different "sources" of growth over time in a country, like the United States. In virtually all of these studies, of other countries as well as the United States, the contribution of technological advance, defined as a residual, or a time trend, turns out to be large. Time series evidence on the role of R&D in productivity growth, at a macro level, is less conclusive. While the 1960s were marked by both rapid productivity growth and a high ratio of R&D to GNP, and in the 1970s both fell, the evidence that the fall off in R&D caused the productivity growth slowdown is not persuasive. There are too many other factors distinguishing the 1960s from the 1970s for correlation to be interpretable as causation.

Other studies have tried to explain differences across countries in productivity levels at a given time, and productivity growth rates over time, by similar techniques. Here, differences in technology levels turn out to be a large part of the explanation for differences in productivity levels, and differences in rates of technological advance, as measured by the residual, are the lion's share of the differential productivity growth story. However, here too, research and development does not come out too well as an explanatory variable. There is not much of a correlation between a nation's total R&D spending, or R&D spending as a fraction of GNP, and its productivity growth rate. This should not be surprising. Throughout the postwar era, until recently at least, productivity in the United States stood significantly above productivity levels in the other trilateral countries. Undoubtedly much of their productivity growth, since the mid 1950s, is associated with their adoption, and modification, of American methods. While their R&D efforts significantly facilitated this process, one would not expect the connection here to lead to any tight correlation between a nation's R&D efforts and its productivity growth. Except when one is in the forefront of technology, technological knowledge is sufficiently public and international for a relatively modest R&D effort to permit a nation to exploit, with a lag, the technological developments created in other nations. At the forefront, of course, the situation is different. Perhaps the R&D effort of the United States has been more important in its productivity growth than the R&D efforts in other countries have been to theirs. And now that there are a cluster of nations at the forefront, and the United States no longer stands alone, R&D may be increasingly important in establishing, or preserving, the competitive edge in rapidly progressing industries.

Several studies have identified and tried to explain significant differences across industries in measured rates of productivity growth. Much of that work has been concerned with differential productivity growth among industries in the United States. Here R&D is an important part of the story. Industries experiencing the most rapid productivity growth have tended to be those in which the firms themselves spent a considerable amount on R&D (like electronics, pharmaceuticals, and chemicals) or industries in which the equipment or material suppliers spent a considerable amount on R&D (airline services). In contrast, industries where little is spent on R&D either by firms in the industry, or by supplying firms, have tended to experience slow productivity growth.

The studies described above have usually been done at an economy or industry wide level, using published economic statistics. There also have been a number of studies in which the effect on productivity of particular technological advances (for example hybrid corn) has been assessed. The contribution to productivity of some of these advances has been spectacular. Where data is available on total R&D spending on a technological advance, as well as on the productivity growth permitted and the extent of use of the new technology, it is possible to estimate rates of return. These estimates have tended to be very high.

Economic Incentives and Mechanisms, and Industrial Innovation

At the same time that some economists were exploring the role of technological advance in productivity growth, and research and development expenditure in technological advance, other economists were studying the economic incentives and mechanisms that stimulate and guide industrial innovation. Some of that research was concerned with identifying the factors that influence the kinds of inventions and innovations that occur over time. Economists, historians of technology, and other scholars, recognized two different classes of influence. On the one hand, it was apparent that the inventions of an era are heavily influenced by what is scientifically and technologically feasible at the time. On the other hand, it also is clear that invention and innovation is strongly influenced by what inventors and innovators think will be profitable—that is by perceptions of the state of the market.

For some time scholars of these questions argued with each other regarding which of the two kinds of influence was the most important. Ultimately, it became obvious that both were important, but that their roles were played in somewhat different ways.

Research has pinned down persuasively that changes over time in the pattern of demand for goods and services tend to be followed by changes, in the same direction, in the pattern of inventive activity, as measured by patents applied for and granted. The rise of the auto industry and the decline in use of horses, is reflected in a change in the composition of patenting in the same direction. The high cost, during the 19th century, of American labor relative to British led to particularly strong efforts in the United States to devise methods that would conserve on labor, even if these methods were costly in terms of materials used. Conversely, the high cost of materials in Britain and the low cost of labor led to inventions which conserved on materials. The recent rise in the price of energy has led to a sharp intensification of efforts to devise techniques to save on energy. Thus, the effect of market conditions on invention and innovation is well documented.

At the same time, it is clear that while market conditions may signal that a technological advance, if achieved, would be desirable and profitable, that advance is not going to be achieved unless technological and scientific capabilities permit. Technological and scientific prospects for success not only limit what can be achieved, they also may limit the amount of effort that goes into trying to advance particular technologies. Thus, the surge of research and development in the field of computation during the 1950s and 1960s surely reflected not only the strong market, but also the awareness that major technological advances had become possible (largely as a result of the revolution in semiconductors).

The slim available evidence suggests, however, that effects of changes in the pattern of demand for products, and changes in scientific and technological capabilities, are not symmetric. Increases in the payoff for certain kinds of invention lead to increases in resources allocated to achieving them, and through that mechanism, to a faster pace of technological progress. Changes in scientific and technological capabilities, on the other hand, lead to changes in the character and quality of the technological advances, but not necessarily to any significant increase in R&D efforts aimed at advancing the technology.

Other economists focused their research on the nature of the economic institutions which generate inventions. Economists, and other scholars, documented significant change over the 20th century in the role of organized R&D efforts in business firms, relative to private free-lance inventors, in the generation of inventions. There has been a significant increase in the fraction of patents assigned to companies, and a parallel decrease in patents assigned to individual inventors. However, there are some interesting differences between industries and fields.

Other scholars focused on the changing roles of different sizes of business firms in invention and innovation. Much of that work was guided by what might be called the "Schumpeterian" hypothesis that, by the mid-20th century, large firms with organized R&D efforts had become the principal source of major new technologies. Suffice it to say that, in its boldly stated form, the Schumpeterian hypothesis is much too simple. There indeed are some industries in which R&D on the core systems now is very expensive, and only very large companies can and do afford to do that work. This is the case with respect to large airliners since World War II, pharmaceuticals since the 1960s and probably large computer systems since that time. However, in a number of technologically progressive industries new or small established firms have made significant contributions, even in the post-World War II era. Small firms were important sources of technological advancement in the early days of the semiconductor industry, for example. Several scholars have put forth the hypothesis that, when a technology is new, new entrants and small firms tend to be the most important sources of new ideas, and new designs. As the technology matures, experience accumulates, and becomes more important, as economies of scale are progressively exploited in production, greater resources are required to do effective R&D, and large firms become more important. One wonders if this is what is going on in the semiconductor industry.

Other scholars have focused on the nature of competition in industries where technological advance is rapid. One outcome of this research has been to cast doubt on the theory behind the productivity growth studies. In particular, the basic logic of technological advance in capitalist economies implies that, even within an industry, firms are going to differ in the technologies they use. Indeed, product and process innovation is the prime competitive weapon in technologically progressive industries, and in such industries the gap in technology between the leader and the lagger is what yields the return on R&D to the former. This essential diversity among firms is repressed in models which are based on the idea of an industry or economy-wide production function, which shifts as a result of technological advancement. Absorbing this "neutrino" into the corpus of economic theory is likely to require considerably more modification of that theory than economists earlier thought, or than many now admit.

The view of the technological change process that gradually has emerged from these, and other studies, is one that highlights very considerable uncertainty at any time regarding which technological options are going to be the most fruitful ones to pursue, and usually considerable disagreement among knowledgeable individuals regarding that matter. As a consequence, in broad fields where successful innovation is profitable, one observes a considerable diversity of R&D efforts by firms. Some lay their bets one way, some lay their bets another way. Some win, some lose. A variety of studies have shown that successfully innovating firms are more profitable, and grow faster, than their rivals.

The processes going on have a number of features akin to evolutionary processes in biology. There are some key differences, of course. In the first place, inventive activity is much more purposefully directed than is mutation, but invention does share with mutation a significant stochastic element. In the second place, selection forces work not only by means of expansion of the fitter (firms with the better technologies) but also through conscious imitation by other firms. Taking account the differences, as well as the similarities, it would seem fruitful to try to model technological advancement and productivity growth as an evolutionary process. Several economists now are at work developing models of this sort.

It should be apparent that the basic conceptions behind these evolutionary models are at tension with those behind the mid-1950s models of productivity growth and technological advancement which regenerated economists interests in those subjects. Like the analogy in physics, the economists' effort to pin down and observe the neutrino of technological advancement have led to recognition of deep difficulties with the original theoretical formulation. It will take some time to work these out.

From an evolutionary perspective, and consistent with virtually all of the historical studies of technological advancement in various industries, technological advancement is an experimental process and, with the vision of hindsight, a wasteful one. Many of the alternatives explored turn out to be dead ends; it surely would have been more efficient to have early in the game found the routes that turned out to be the most fruitful ones and have concentrated on them. The competitive processes which stimulate R&D and industrial innovation also contribute to the inefficiencies involved. In some cases there are races among firms to reach a technology first, races which surely both involve the wastes of duplicate efforts, and the wastes of undue haste. The property rights associated with patents, and with industrial secrecy, which in some industries provide much of the spur to innovation, also lead to incentives for firms to try to develop new technologies which are unlikely to be better than the best available technologies, if the latter are blocked by patents or secrecy.

The inefficiencies in the current system are easier to see, and analyze, than to resolve. While the best way may be easy to observe after the fact, before the fact the uncertainties are real, and a diversified portfolio is called for. While the diversified portfolio generated by competition among business firms is far from a planner's ideal, given what is known about comprehensive planning systems, market pluralism may be our best available protector of diversity.

The discussion above by no means implies that the Federal Government cannot and should not play a significant role in industrial innovation. It can, and it has. I turn now to reviewing some of that experience.

The Role of Government in Industrial R&D

As I remarked at the beginning of this paper, the last few years have been marked by a wide ranging discussion about the fruitful roles that the government might play in stimulating industrial innovation. The next few years are likely to see a drawing back, an attempt to delineate quite narrowly what governments should do, and what should be left largely or totally to business initiative. A narrowly constructed governmental mandate likely would follow the following lines.

First, the government certainly ought to assure a general business climate, and a legal framework, within which innovation by business is profitable and is stimulated. Care should be taken that tax and patent law and policy, and antitrust policy, be supportive, not hindering, of innovation. Under this general banner also march the arguments that inflation and heavy-handed regulation are major enemies of industrial innovation. Second, the government has a mandate for the support of basic scientific research. Such research is not proprietary and in general it is not profitable for business firms to undertake much of it. Third, the government also must support, or draw forth from the private sector, R&D relevant to public sector needs. Aside from these three basic roles, the government should stay out of the industrial innovation business.

It sounds clean, but it is too simple. No clean line can be drawn between special tax treatment of business R&D, and subsidy of R&D. Is a sheltered market part of a supportive environment for R&D? If so, how is that to be distinguished from preferential procurement or R&D subsidy? The attempt to fence off government R&D funding responsibilities into one field called basic research and another field called public sector R&D provides less guidance than one would think because the boundaries of those fields are so shady. Those who work at the National Bureau of Standards certainly recognize the haziness of the line between the kind of research which is rightly treated as public, publishable, and to be supported by government, and that which can be treated as proprietary, and outside the appropriate realm of government funding. Research on the properties of materials falls squarely in the shady region. A central fact is that, where we draw the line between public research, and proprietary research, is a matter of policy, not something dictated by the nature of the matter. Similarly, the lines between public and private sector needs are impossible to draw cleanly. The standard case is overlap. Aircraft, computers, medicine, buildings, are inputs into both private and public sector activities.

The narrow view of government's role sketched above also seems to rest on the belief that where government has gone beyond those narrow limits, and engaged itself in active support of stimulus of industrial R&D, it has botched the job. That simply is not so. I want to call attention to the fact that, historically at least, active federal direct and indirect support of R&D in a particular industry often has been very effective. In what follows, I shall be reporting from a collection of industry case studies of the evolution of technology and the role of government policy. The studies were done under the auspices of the Center for Science and Technology Policy at New York University, and were supported by NASA.

In agriculture (or rather farming), since the third quarter of the 19th century, the Federal Government has played an important role in supporting R&D. Much of this work has been done at experimental stations of the land grant colleges and universities, with federal funds complemented by state funds. In general, public monies and university R&D efforts have not gone into areas where a strong private commercial design or R&D capability existed. Thus, the university engineering departments and experimentation stations have not tried to preempt tractor or farm implement development. In some cases, a division of labor between the university effort and commercial effort has been worked out, as in the case of hybrid seeds, with the universities doing the more basic work and the private companies doing the proprietary work. Various studies have shown public R&D in agriculture to have been an important contributor to the rapid productivity growth experienced there, and to have yielded a very high rate of return.

Another area where a reasonably well established division of labor between universities, financed by government, and private commercial R&D has been worked out is pharmaceuticals. Here the National Institutes of Health has concentrated on the basic biological studies. However it also has engaged in more applied work, including the development of pharmaceuticals, for disease categories where the markets are not deemed large enough to attract sufficient commercial interest. Cancer chemotherapy is a prominent example. There is some disagreement about the relative importance of the publicly supported work, and the work of the large pharmaceutical companies. But just about everybody agrees that over the long run the basic research support of the National Institutes of Health to enable better understanding of disease, and health, and of how various chemicals and other substances work in the body, is going to be extremely important to the evolution of the next generation of pharmaceuticals.

The Federal Government's role in the evolution of civil aviation is another interesting story. In my judgment at least, the aborted effort of the Federal Government to subsidize the development of a supersonic transport was a serious mistake, and a good example of federal R&D support gone wrong. In contrast, the program supported under the National Advisory Commission on Aeronautics during the 1920s and 1930s, which provided significantly increased understanding of airplane design principles, was right on the mark. Several studies have testified as to the importance of this federal program in the evolution of the modern commercial airliner during the 1930s. And, of course, the modern jetliner owes considerably to Department of Defense R&D support and procurement of military aircraft.

Technology in semiconductors, and computers, also was strongly influenced by the federal interest in these technologies in their early days, including R&D support, and (later) procurement. In both of these industries, the government in effect "made" the early market. As these industries and technologies matured, the civilian part of the business ultimately grew sufficiently so that the companies' own efforts began to pick up the lion's share of the R&D burden. Of course the future federal role in the evolution of semiconductor technology is right now a hot issue.

As the foregoing discussion indicates, it simply is not true that the Federal Government always has been clumsy when it has tried to support the evolution of a technology. There have been unfortunate instances. The supersonic transport episode was one. Project Breakthrough (aimed at improving technology in residential construction) also clearly was a failure. However, the reading of that case I draw from the study in our collection is that the problems there, to a considerable extent, were administrative and political, and that no real test was made of the proposition that federal support could significantly improve housing technology. In agriculture, pharmaceuticals, civil aviation, computers, and semiconductors, the government's role has been powerful, and fruitful.

What are the circumstances under which government R&D support can be fruitful? Let me, drawing on past experience, suggest three different kinds of conditions.

First, the government can play an effective role in supporting, or even undertaking, R&D in industries where the firms are small, not in rivalrous competition with each other, and there is not a set of supplying industries with vested interests in particular ways of doing things. This description fits agriculture. It fits housing worse, largely because of the presence of a variety of supplying industries with particular parochial interests. As suggested above, however, my reading of the Project Breakthrough fiasco is that government ineptness, more than supplier resistance, caused the trouble.

Government R&D support can be fruitful where it is possible to establish a line (however shady) between proprietary R&D, and nonproprietary R&D, and important knowledge can be gained from the latter. This has been the situation regarding pharmaceuticals. The recently established cooperative automotive research program was a new attempt along these lines. And, of course, this is an area where the National Bureau of Standards long has worked.

Third, where there is a widely recognized legitimate public interest in the evolution of a particular technology, for example a national security interest, then the government can be aggressive, informed, and effective regarding applied research and development aimed at public objectives. As the experiences regarding computers and semiconductors indicate, what companies learn through their public sector oriented R&D efforts can greatly strengthen their civilian technology capabilities.

I make these suggestions not in advocacy of any particular policies, or to suggest that the apparent instinct of the Reagan administration is to back off from the new departures of the past few years, is necessarily a bad thing. But, I do think it important to clear the air of the belief that the record of the Federal Government in its effort to stimulate industrial innovation is, uniformly, a bad one. There are many clear examples of considerable success. Furthermore, in looking at the successes and failures, it is possible to identify the kinds of conditions, and the kinds of programs, where government efforts have proved effective. This should be useful information when, sometime in the near future, the climate turns most favorable towards active government policies.

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