Building R & D Policy from Strength

Roland W. Schmitt

About 5 years ago you could not open a news magazine without reading a title like "Vanishing innovation" or "Has America lost its edge?" or "The declining power of American innovation." Today you cannot open the same magazine without seeing the face of Steve Jobs of Apple, Dan Fylstra of VisiCorp, or Nolan Bushnell, who founded Atari and has already moved on through two other ventures. And when people from other countries, such as Adam Osborne of Britain or Jesse Awieda, who was born in the Middle East, or K. P. Hwang of Korea, want to start their own computer companies, they come to the United States (*1*).

Summary. Many proposals have been made for new initiatives in our nation's research and development system. But before rushing into untried approaches, we need to look to the foundations of the system that has worked so well for us in the past. We have a climate for venture capital that has never been better; the world's greatest research universities; an industrial base that is moving aggressively into high technology, spurred by competition; and a defense effort that can be a major asset to civilian R & D. We should build our future by understanding and using these existing strengths.

A great deal is said these days about the changes and new initiatives needed in this country's policies for stimulating high technology and industrial competitiveness. We hear about how the Japanese and Germans do it, about the need for large federally funded, industrial R & D programs, the need to unleash the national laboratories to perform R & D for industry, the need for new tax incentives for industrial R & D, and so on. All these represent changes in the way we go about pursuing technology development and industrial innovation (*2*).

But before we rush off into new and untried approaches, we need to look at the fundamentals of the system that has worked so well for the United States in the past. We need to make sure that these foundations are maintained in a healthy state and that any changes we make are built on them. In our preoccupation with foreign competition and our rush into new dimensions of policy for industrial innovation, we need to remind ourselves of our own sources of competitive advantage and our indigenous strengths.

A Supporting Environment

We have the building blocks for strong national leadership in innovation. I have already alluded to one of these building blocks—our ability to generate fast-growing high-technology firms. The climate the United States presents today to entrepreneurs is certainly one of our greatest strengths. So we should ask how to strengthen it further and how to build on it.

One answer that has been proposed is tax incentives for venture capitalists (*3*). But I question whether blanket incentives to increase the amount of venture capital are really needed. In total, there is a great deal of venture capital seeking opportunities in the United States today. East Coast venture capitalists establish offices on the West Coast, West Coast ones establish them on the East Coast, U.S. firms even establish offices in London and Paris—all looking for opportunities to invest. In addition, R & D limited partnerships, which are available to start-up companies as well as established ones, provide another source of venture capital. The overall availability of venture capital is not our chief limitation (*4*).

Rather, the limitation in many places is the absence of a strong climate for nurturing new ideas and entrepreneurship. This is a lesson we should have learned from the great successes of the past: Route 128 and Stanford's Silicon Valley. They demonstrate that growth of high-technology firms only occurs in the context of a supporting environment, an environment with a strong technical infrastructure and a general air of excitement about converting good ideas into successful businesses.

Awareness of this fact is spreading to many campuses, many states, and many localities. In fact, there is hardly a state in this country that is not putting in place programs to develop such supporting environments (*5*). New York State, for example, has taken new steps through its Science and Technology Foundation to activate and stimulate the many educational and financial resources within its borders. California, Massachusetts, North Carolina, and many other states also have organizations to stimulate high-technology economic development (*6*).

Skeptics argue that the states are overreacting, that they will begin to compete with each other for the relatively scarce people with ideas good enough to turn into new ventures. But I disagree. What is scarce is not the potential for good ideas, but the supporting environment. In my view, the many efforts by states and localities represent exactly the right approach.

One interesting initiative is the Incubator Program (*7*) at Rensselaer Polytechnic Institute (RPI). It is based on the premise that one of the main obstacles to the growth of small, high-technology firms is the lack of a supporting environment during the crucial period between conception of an idea and its development to the point where it can be taken to the venture capitalist. All too often, the potential entrepreneur is forced to work on his ideas during this period in his spare time in a garage or basement workshop. As a result, many good ideas are never developed.

The RPI program and others like it are intended to fill this gap and offer a supporting environment in which good ideas can be incubated. Potential entrepreneurs pay RPI a low rent, in return for which they receive office space on campus and access to the RPI technical environment, including its facilities and libraries. In addition, they are able to consult with the faculty, hire students to do support work, and obtain free assistance in putting together a business plan

The author is Senior Vice President, Corporate Research and Development, General Electric Company, Schenectady, New York 12301. This article is based on his talk at the AAAS Colloquium on R & D Policy, 25 March 1983.

and approaching venture capitalists. The program costs very little. But it is aimed at that stage of the innovation process in which small expenditures can make a big difference. It is an imaginative policy tool, and it is already at work.

Our Research University System

The incubator program also illustrates how, with a little imagination, we can find new ways to use a second major building block of R & D policy—and one of this nation's oldest and greatest strengths—our system of research universities. It is encouraging to see that all elements of the political spectrum recognize the importance of these research universities and are calling for the steps necessary to maintain their vitality, including large increases in federal budgets for R & D, such as the 18 percent increase proposed for the 1984 National Science Foundation (NSF) budget (*8*). But the needs of our research universities—better faculty salaries, new facilities and equipment, more funds for research and for graduate student and postdoctoral support—will not be met by a one-shot approach. It will not be easy to attract faculty members and graduate and postdoctoral students back into academia, especially in the engineering disciplines. It will require a sustained effort for many years.

One additional approach is to give universities high priority in the competition for federal funds for basic research. In particular, the universities should not be put in competition with the national laboratories for funding, as quite a number of universities now perceive themselves to be. When federal basic research funds flow to universities, several objectives are achieved simultaneously. The research is performed; graduate students are trained through their participation in the research; graduate departments are able to attract better faculty with the lure of large research projects; and the growing financial pressure on universities is eased somewhat, since part of the federal funds support overhead, faculty salaries, student stipends, and research instrumentation. If we are seriously concerned about the health of our universities, we should maximize the amount of federal funds for basic research that they receive.

Another approach to technology development that builds on resources already in place in the university system is the university-industry research arrangement. There has been a great deal of activity in this area in the past few years, and it is now hard to find a major university that does not have some sort of new institutional arrangement with industry (*9*). We have research parks, industry affiliate programs, industry-supported research institutes, and cooperative industrial associations that fund university research—a variety of arrangements that have grown in response to the competition from abroad and the need to strengthen our technological leadership. Again, the institutional arrangements are built from the bottom up. This trend has not been created through intervention by the federal government. It has existed for decades, although some of the ideas and arrangements are new. The United States already has a greater tradition of effective industry-university cooperation than any other nation.

Of late, this has sometimes been a troubled relation in the area of biotechnology. The contrast between the smooth university spin-offs in microelectronics and computer technology and the troubled ones in biotechnology puzzled me. But a venture capitalist friend, who has invested in some of the biotechnology start-ups, pointed out that these firms are still largely in the research stage and making their money on research contracts, not on specific product ideas like those that led to so many successful microelectronics ventures. So there are new issues in this type of industry-university relation that have to be addressed.

Industrial R & D Capability

Let us turn now to another of our strengths—our industrial R & D capability. In this area some of the most ambitious proposals for major new changes are being made. One set of proposals calls for strengthening the incentives for industrial R & D (*10*). We have already made significant gains in this area through the R & D tax credit and the provisions for faster capital cost recovery. But as we consider these and other changes, we ought to keep their potential benefit in perspective.

There already exists in this country an incentive for technological innovation that is far more effective than any incentives that might be created by new government policies. It is called competition in open markets—competition with the Japanese, competition with the Germans, competition among ourselves—and it is the most important incentive for investment by industry in R & D. It is the reason that any firm invests in R & D and the reason that R & D spending in industry has increased so rapidly that it now exceeds federal R & D spending.

That R & D is not going solely into the creation of new high-technology industries, as important as they are. It is also going into the use of advanced technology to revitalize our core and service industries—into the development of new integrated power semiconductors to make motors more efficient, robots to build appliances more productively, and computer-based expert systems to help repairmen do their job better. So as we consider tax incentives and changes in patent policy, we should keep in mind that the single most effective incentive for industrial R & D is market-driven competition.

Furthermore, when we consider the many proposals for federal intervention, such as federally funded industrial R & D centers, we should remember the failures of the past. In particular, we should avoid a repetition of the energy R & D syndrome of the 1970's, when we poured billions of dollars into the development of energy technologies intended for a market that could not absorb them. In successful industrial R & D laboratories, the greatest challenge is transferring technology from the laboratory into new or ongoing businesses, even when the laboratory and the business reside in the same firm. Transferring technologies between institutions from different sectors of the economy—from the government to industry, for example—is much harder (*11*).

So let me propose a very simple principle to guide our thinking about federally supported industrial R & D: the motivation for the work must come from the firms that would ultimately use the technology to be developed. Unless the federal government is itself the ultimate customer, it should support industrial R & D only when the firms that would use the results of that R & D have initiated the project, express a clear need for help, and back up that expression of need with substantial investment of their own funds.

As an example of what I mean by a clear expression of need, consider the recently formed consortium of electronics firms, the Microelectronics and Computer Technology Corporation (*12*). The consortium is not receiving federal funding, but it represents a case in which firms in an industry perceive an R & D need and commit themselves to meeting that need. Admiral Bobby Inman, the consortium's director, estimates that the first year's budget will be at least $75 million, and these funds will come from the member firms themselves. It is this kind of commitment that is required for successful technology transfer and that is often missing when the federal government rushes to fill a supposed gap in industrial R & D. If the intended recipients of the technology are not interested enough to provide a sizable portion of the funds, chances are that the R & D will not be transferred to industry.

Defense-Related R & D

There is one area, though, where government and industry have a good record of successful technology transfer: where the government itself is the prime customer. The leading example here is national defense, the last of the building blocks of technology policy that I will discuss. Large defense budgets are a fact of life, and the part of these expenditures that supports R & D could be a great asset to the commercial and industrial sectors of our economy.

Some Americans look with envy on Japan's cooperative government-sponsored program on very-large-scale integrated circuits. But we have a program that should make the Japanese envy us, if we use it well—the very-high-speed integrated circuit (VHSIC) program (*13*). It is aimed at the next generation of microelectronics and at making sure that the circuits created in that next generation can be widely used in military systems. Already contracts totaling $165 million have been granted to a dozen companies and one university, and the participants are matching each dollar they get from the government. By the time the program is finished, it could well involve total expenditures (public plus private) on the order of $1 billion.

The VHSIC program builds on a successful tradition in this country, one that began with aircraft engines, computers, and semiconductors. Defense dollars are used to develop generic technologies that have widespread, important civilian applications. Consider supercomputers, for example. The report of a recent NSF study of large-scale computing in science and engineering points out the growing possibility that the United States will lose the lead in supercomputers to Japan (*14*). It proposes as a national goal the development of a computer able to perform 100 to 1000 times as many calculations per second as today's fastest computer. And it indicates the wide range of fields, from quantum theory to computer-aided engineering, that would benefit in a major way from this capability.

Supercomputers are vital to such national security needs as cryptography and weapons system design. They would also enable industry to model things that cannot be modeled today. This could lead to new types of airfoils and aircraft with reduced drag, turbines and engines with sharply increased efficiency, improved oil exploration and better utilization of known resources, better understanding of crack initiation and propagation in alloys, new ways to design parts from plastics, new techniques in computer-aided engineering, advances in theoretical physics and chemistry, better weather prediction, perhaps dramatically improved materials designed from basic theoretical principles, and many more applications.

Supercomputers are a prime example of a technology in which defense can take the lead. They would clearly benefit the military, but at the same time they would give U.S. computer firms the opportunity to advance the state of the art in ways that most of them cannot afford at this point, because even though such computers are important, the civilian market for them is not large.

Dual-Use Technology

I realize that what I am advocating here appears to fly in the face of concern over loss of technology to the Eastern bloc, so let me address that issue. First, there is the question of so-called dual-use technology—technology with both civilian and military applications. The prevalence of this dual-use technology is usually cited as the reason for clamping down on civilian technology (*15*).

But the concept of dual-use technology is misleading: at a sufficiently fundamental level, all science and technology is dual-use. Certainly, there is widespread generic technology that has both civilian and military uses, but it must be extended and specialized for specific military applications. I believe that altogether adequate protection of military technology is available at the application-specific level. This should make it possible to protect the specific military use while leaving the underlying generic technology free for civilian use. For example, to counteract the Soviets' propensity to "reverse-engineer" microcircuits which they illegally acquire, I believe technology might be developed to permit a military form of microelectronics that would be virtually immune to back-engineering. Certainly, this is worth a serious look.

As another example, surely the technology for protecting military circuits against radiation damage can be classified and used exclusively for military applications without encumbering the underlying generic technology of microelectronics for advanced commercial applications. And there must be many more examples of ways in which dual-use generic technologies can be specialized for military applications while leaving the basic technologies relatively free. This strategy would be far more desirable than the alternative of interfering with our underlying ability to generate new technology.

That ability depends far more than nontechnologists understand on leaving technical groups and individuals as free as possible from bureaucratic controls of any sort—even those imposed for ostensible security reasons. The "protection" of technology implies its regulation, and regulation implies slowing down the generation of technology.

Why is the United States so good at developing the technology that the Soviets want, and why are the Soviets so poor at it? I submit that the answer has much to do with the oppressive bureaucracy with which the Soviet technologist has to deal. Do we now want to encumber our system in the same way? In particular, do we want to bring the part of our system that *is* working well to a halt without correcting the part of it—namely military-specific development and deployment—that may already be working less effectively than the Soviets'? It is ironic that one would even think it necessary to regulate the part of the system where we are clearly beating them in order to correct the part where they are threatening us.

Conclusions

On that note, let me sum up. We have today in America the basic building blocks we need to regain technological leadership. We have a climate for venture capital that has never been better; the world's greatest university system; an industrial base that is moving aggressively into high-technology areas, spurred by competition; and a defense effort that, in this era of dual-use technology, can be an enormous asset.

We need to become more aware of these strengths, to nurture the ones that are emerging, and to strengthen the ones that are full-grown and protect them against well-meaning but misguided assaults in the name of protecting domestic industry or in the name of military security. None of the policies I have heard talked about under the name technology policy can have nearly as much effect on the future as the strengths we already have. While being receptive to new ideas, we must not forget what we already have. We must build our future by identifying, understanding, and using our existing strengths.

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RESEARCH ARTICLE

Separation of Signal Transduction and Adaptation Functions of the Aspartate Receptor in Bacterial Sensing

Andrew F. Russo and Daniel E. Koshland, Jr.

Abstract. *In order to investigate the functions of stimulus recognition, signal transduction, and adaptation, the aspartate receptor gene for bacterial chemotaxis in* Salmonella typhimurium *has been sequenced and modified. A carboxyl-terminal truncated receptor was shown to bind aspartate and to transmit a signal to change motility behavior. However, the truncated receptor showed greatly reduced methyl-accepting capacity, and did not allow adaptation to the sensory stimulation. The separation of receptor functions by alteration of primary structure emphasizes that the receptor is directly involved in adaptation and is not solely a device for transmitting a signal across a membrane.*

Cells can respond to external stimuli by processes initiated upon binding of an effector to a membrane-bound receptor. In many sensory systems, the cells not only respond but also adapt to the stimulus. In at least two systems, bacterial chemotaxis (*1, 2*) and vision (*3*), this adaptation is associated with covalent modification of the receptor. In a third adaptive system, the acetylcholine receptor, phosphorylation has been observed, but its function is not yet known (*4*). Thus a receptor can transduce a signal from the outside to the inside of a cell and facilitate sensory adaptation through covalent modification during signal transduction.

To understand these processes, the aspartate receptor involved in bacterial chemotaxis offers a particularly useful system to study. The receptor gene has been cloned, and the purified protein has been reconstituted into artificial membranes (*5*). The gene has been mapped and identified as the *tar* gene (*6*). The protein is known to be multiply methylated (*7*) by a transferase (*8*), and demethylated by an esterase (*9*), both of which are encoded by chemotaxis genes. The degree of receptor methylation can be followed by means of in vivo and in vitro labeling techniques (*8, 10, 11*).

It seemed that altering this receptor might clarify the relationships between its structure and the functions of stimulus recognition, signal transduction, and adaptation. Our first step was to obtain the complete sequence of the aspartate receptor from *Salmonella typhimurium*. Having the sequence, we could systematically alter specific regions of the gene to generate new receptors for study both in vivo and in vitro. The first results of our investigation are reported here.

Sequence and properties of the aspartate receptor. The receptor gene has previously been localized within an Eco RI restriction fragment cloned into pBR322 (*12*). A subclone pRK41 containing the gene on a 2.35-kilobase Cla I fragment was used to obtain unique fragments for sequence determination. The method of Maxam and Gilbert (*13*), with minor modifications (*14*), was used for sequencing. A combination of 3′- and 5′-end labeling techniques allowed complete sequence determination on both strands.

The nucleotide sequence, and the amino acid sequence deduced from it, are shown in Fig. 1. The gene contains 1656 nucleotides and codes for a 59,416-dalton protein, which agrees with the molecular weight deduced from polyacrylamide gels (*1, 2*). Since the amino terminus is blocked, the NH_2-terminal amino acid sequence could not be determined directly (*15*). The terminus shown in Fig. 1 was deduced from correlation with the purified protein amino acid composition, especially the complete absence of cysteine residues (*15*). Furthermore, upstream from the assigned amino terminus, the nucleotide sequence (from −6 to −12) closely resembles the Shine-Dalgarno ribosome binding site (*16*).

The receptor has an average hydrophobicity index comparable to that of soluble proteins (*17*) [2.4 kJ per mole of residue, calculated as described by Gilson *et al.* (*17*)]. If the receptor sequence is further examined by the method of

A. F. Russo is a graduate student and D. E. Koshland, Jr., is a professor in the Department of Biochemistry, University of California, Berkeley 94720.