Research and Competitiveness: The Problems of a New Rationale

John A. Armstrong

The following text is based on the plenary address given at the 1992 MRS Fall Meeting in Boston, November 30.

I cannot think of a better group than MRS with whom to discuss the issues now faced by research institutions around the world. Your membership is from universities, industry, and government labs and is international. You include both basic and applied researchers, and you have a reputation for being a vigorous and interdisciplinary organization.

My thesis this evening is this: it is both timely and appropriate to re-examine the rationale for the support of research. Concerning this topic, there are two questions: Why does the public support research in universities and national labs with tax dollars, and why do industrial firms support research with shareholder dollars? These two questions should get everyone's attention.

It may seem superfluous to ask these questions, but my recent experience in talking to colleagues at IBM and other companies, and my experience as a member of the NSB Special Commission of the Future of NSF, lead me to believe that there is an urgent need to raise and discuss these issues, in part because most scientists have not thought much about them.

The marvelous research institutions we have created in this country are under unprecedented stress. I am convinced that to survive this stress and emerge as a healthy institution, the research establishment must carefully re-examine the rationale for its support.

Whether we are researchers in the university, in industry, or in government labs, it is time to scrutinize the justification for support of our research because many of our supporters' situations have changed. The three major changes in their situations are: the end of the Cold War, the greatly increased international competition among national economies, and the qualitative changes in some industries, brought about by decades of exponential quantitative improvement in technology.

My remarks will follow this outline: First, I propose to review in more depth why it is timely and appropriate to make such a re-examination. Second, I will review what I believe has been, for the past 45 years, the rationale for research support, both public and private. Third, assuming that support for economic competitiveness will figure largely in public thinking and rationale, I want to consider what may be some of the consequences, both good and bad, of such a change. I will advance several areas of possible action and evolution on the part of research universities that may help in dealing with these problems. And finally, I want to list some important considerations to keep in mind when reacting to changes in industrial research investments. My hope is to stimulate discussion in the community at large, rather than to "give the answers." Now, back to how the situation of those who support us has changed.

The end of the Cold War, coupled with U.S. fiscal problems, makes it likely that the amount of money spent on research in support of defense will steadily decrease over the next few years. In addition, for the first time in decades, we are nervous as a nation about our ability to generate the wealth that can lead to a sustained improvement in our standard of living. Hence, there is a great interest in reallocating defense-related research support to the civilian sector despite any clear indications that such a redirection is possible in any efficient and effective way.

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Consider what has been the rationale for government support for basic research. Economic theory holds that the rationale is provided by the expectation of a substantial "societal return" on the government investment in basic research. It is expected that there will be a return to society in jobs, a higher standard of living, and better health. More precisely, the economic rationale is that government should invest in research because the societal return will be greater than the private return that could be captured by private firms making the same investments. Our experience as a nation during the 1950 to 1985 period seemed to confirm the validity of this "greater societal return" rationale, even though government support for research was not based on its contribution to the standard of living; rather, 90–95% was based on contributions to defense. Of course, during most of that period, our economy was dominant and essentially isolated.

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Incidentally, little thought was given to whether greater "societal return" meant (a) an integrated long-term return that exceeds a possible alternative integrated private return, or (b) a societal annual rate of return that exceeds the alternative private annual rate of return at a particular point in time. As long as the U.S. economy was both dominant and essentially isolated with respect to the rest of the world, this distinction did not matter. It was possible that public investments in research would have integrated positive societal benefits even though a similar investment by private parties would have shown no integrated net return, and would even have had a negative rate of return.

However, the globalization of technological and economic institutions generally has made us rethink this previously valid "societal return" rationale. What matters now is not only whether there is a substan-

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tial integrated societal return on the public's investment, but also how soon that return will be realized. Thus, the rationale for government support of university research—if it is to be based on a contribution to national competitiveness—must focus on whether the rate of societal return would be greater if investments were made by private parties, *or by governments or private parties in other countries.* It is no longer clear that the citizen who pays for research is the citizen who gets the benefit. The consequences of this change are the main subject of this talk.

What is new in much of the high technology economy is the rapid succession of technology generations, and the rapid decrease of prices over time within each generation. Thus it becomes increasingly obvious that only the firm (or country) that is first into the market in a given technology generation has a chance of obtaining an aggregate return that is attractive. Those who are late may never recoup either their private or, in the case of government, their public investments. The semiconductor industry has proven that time and time again.

A version of the old rationale was given in *Science—The Endless Frontier* by Vannevar Bush, a report written for President Roosevelt at the end of the Second World War. Bush argued that science is the proper concern of government because the health, standard of living, and security of the nation's citizens are the proper concern of government and because long experience has shown that basic research contributes—sooner or later—to all these goals. Vannevar Bush did not use the economic jargon that "the societal return exceeds the private return," but that was his argument.

Even though Vannevar Bush asserted that contributing to economic well-being was a major reason for supporting basic research, it has not been the case, up to now, that Congress and the taxpayer have funded nonmedical basic and applied research because they understood its relation to improved productivity and new products. Government has funded research primarily because of the impact of earlier research on radar, bombs, missiles, and other defense-related technologies during and after World War II. We have little experience using government-funded research to improve the civilian economy.

So, with cutbacks in defense-related R&D likely, the question is, What *will* be the new rationale, implicit or explicit, for supporting the research infrastructure in the nation's universities and in the national laboratories? What will government and society find as a complement to the defense rationale?

Parenthetically, in *Science—The Endless Frontier*, Bush did not make the argument that government should support research because scientific knowledge was of intrinsic value, independent of its applications. Doubtless he believed (as I do) that man's spiritual horizons are extended, and his appreciation of the wonders of nature improved by scientific research. But he did not advance that as a rationale for government support. In that, he was much wiser than many prominent scientists of today who use the cultural argument without realizing that it justifies the same level of national support as is accorded to painting or music or theater—all areas supported by governments, but at levels 100 times below the levels of support that science enjoys.

> We should help Western culture rid itself...of the intellectual hierarchy in which "pure" is somehow better than "applied," physics is better than chemistry, both are better than engineering, and the ...intellectual content of manufacturing is valued hardly at all.

The discussion up to now has been primarily about publicly supported research—done mainly in universities and national labs. But much of the industrial research establishment is also under stress, and I want to comment on the context for them as well.

First, the rationale. Why do stockholders and senior company management support research (when they do)? It is with the expectation of a competitive advantage for the firm. Moreover, this expectation of competitive advantage clearly influences choices about which fields of science are likely to be sources of advantage. For example, electronics, computer, and telecommunications companies work on solid-state materials science, but do very little research on recombinant DNA—not because that's not an exciting field, but because there is little likelihood of leverage on the semiconductor or telephone business from new DNA science. This may seem too obvious to mention, but it is useful for the next stage of the discussion—when to expect and even welcome substantial changes in industrial R&D.

Consider the implications of following well-known developments in the semiconductor industry. The cost of a new, leading-edge factory is growing at a rate 2.5 times the compound rate of growth of industry revenue. A year or so ago, worldwide, the industry's revenue was about $60 billion and they could afford to build roughly 50 new factories per year; 10 years from now, when revenues have grown to $110 billion, that revenue will not justify the building or retooling of more than 18 to 20 fabs (leading-edge manufacturing facilities) worldwide for the leading-edge technology generations.

What has happened is that the leverage of semiconductor technology to generate attractive (or even acceptable) returns on investments has dramatically decreased, compared to 20, 10, or only five years ago. This is due, in part, to past technical success, and in part to the fact that what many corporations can do is not a good source of comparative advantage for any one of them. If the economic facts are as I have suggested, would it be responsible for an electronics firm to invest the same amount in semiconductor materials and process research as made good sense 10 years ago? If there is a decreasing advantage, the enlightened industrial R&D policy would be to move some part of the firm's research investments into fields where the leverage is greater: into the design of subsystems, for example, as compared to hardware technology.

Now let us return to considering possible outcomes of a reassessment of the rationale for the public support of research. On careful re-examination of the nation's needs, it might be concluded that the situation as it has been over the past 45 years is the correct balance between military and civilian targets, and that all that needs to be done to cope with changes in the Department of Defense budgets and other fiscal realities is to do considerably less research, but continue to distribute it among fields in the same way.

Despite the unsatisfactory nature of such a conclusion in principle, it is likely that because of inertia, inability to forge a new national consensus, and natural timidity in the face of change, this arrangement will be given to us as the default solution. I am somewhat more sanguine, since the election, that we will have a new national consensus.

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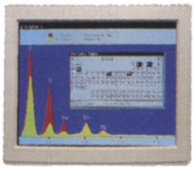

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examination of the rationale for public support of research might be that we decide to shift emphasis in a major way to support for the competitiveness of our economy. One of the reasons the research establishment has been so enormously effective in the past 40 years is that not only was government the sponsor for much of the work, it was also the customer for what was produced. As people in industry know, having to satisfy the customer does wonderful things for your ability to stick to plans and goals. The government was the definitive customer for technology going into military systems. It is not now remotely close to being the definitive customer for the civilian economy.

When talking about technology competitiveness, we should keep in mind that the lion's share of the responsibility for deficiencies in our industrial performance rests with failures in the private sector: failures of strategy, investment, and training... failures, in short, of management. These will not be cured, or even helped, by more research, whether publicly or privately supported. Trying to cure poor industrial performance in the short term by more university research is like asking for helpers when pushing on a rope.

Industry's problems stem from poor management decisions, lack of attention to quality and low cost in manufacturing, lack of proper investment strategies, high interest rates due to structural economic factors that make it difficult to get the return on investment expected by U.S. financial markets, poorly educated workers, and many other factors.

Although it is an issue, and deserves attention, poor "technology transfer" from the university or national labs to industry has not been a major cause of our competitiveness problem. And at any rate, there are only a few sectors—for example, software development and perhaps biotechnology—where rapid technology transfer from university labs can have both a long- and a short-term effect. This is because universities do not, in general, develop technologies; they generate new knowledge and new possibilities. Companies develop technologies.

The most effective "technology transfer" from universities, in the short term, is well-trained technical and scientific workers at many levels of sophistication and knowledge.

Indeed, most of the public concern with "technology transfer" from universities grows out of mistaking what is necessary for what is sufficient. Healthy and vigorous institutions supporting scientific and engineering research and education are necessary for a productive and growing economy in the long term. They are by no means sufficient. "Sufficiency" requires excellent manufacturing, low costs, rapid cycle times, farsighted marketing strategies, a sound macroeconomic climate, and so on.

One of the mistakes we often make in the research community, both in industry and in universities, is tending to overestimate the importance of what we do as it relates to the whole chain of events required for economic success.

But now to return to the likely impact on universities of this new rationale for support of research. Should we be concerned about our universities adopting improved industrial competitiveness as a rallying cry? I believe that we should, and let me explain why.

Among the problems I see with using increased competitiveness as a rationale for funding of university research are,

- The amount of funding available, and the priorities for its application are likely to shift; that is, the amount of research that is supported is likely to change when competitiveness is a main part of the rationale.
- Where research is supported is likely to change in ways that further reduce the ability of universities to assemble and sustain a critical mass for research.

There is some danger that both society at large and those in the universities overstate what universities can contribute (because they are trying to maximize support!)

Another unpleasant consequence is that as people articulate the rationale that we support research because it contributes to commercial competitiveness, there will be tremendous pressure for universities to behave as if they believe that they can and should be contributing to competitiveness in the short term.

But I think it is both fair and accurate to say that university scientists lack deep understanding of products or markets, have no responsibility for development or manufacturing, and tend to overestimate the importance of science in technological competitiveness; they may also underappreciate the value of incremental engineering improvements. Improved understanding in all these areas is prerequisite to universities playing a more effective role in contributing to civilian technology competitiveness.

Two unpleasant consequences of a shift toward increasing competitiveness as the rationale for research may be struggles over where we support research, and how much support is appropriate.

Consider this question: Where should government support research if the motivation is to help industrial and economic competitiveness? In the universities, of course. But now there's a claim that much of the budget of the government laboratories should go toward this purpose. This is an extremely dubious proposition, in my view. However, in a society in which overall support is diminishing, having new claimants for this support will place substantial stress on the universities. Of course, our national labs are under stress as well.

When the implicit rationale for supporting university research was based primarily on contributions to a superior defense, one could argue that it was all right for most of the money to go to a small number of research universities. But if we support basic research primarily because of its boost to the competitiveness of our economy, then many will argue that this investment ought to be more or less uniformly spread around the United States because no region has a superior claim on help for its economic competitiveness.

Trying to cure poor industrial performance in the short term by more university research is like asking for helpers when pushing on a rope.

This will reinforce a growing tendency over the last few years of awarding research grants and contracts by various measures of geographical or political equity or as "scientific pork," as opposed to the results of peer review or other determinations of technical merit. A likely consequence of this trend is that, at a time when the scientific infrastructure in the universities is under serious financial strain, they will face further constraints as a fixed amount of money is spread much more widely and uniformly. We will be fooling ourselves as a society if, on the one hand, we want university research to help us compete in a world where the merit—i.e., the quality—of products is key, but on the other hand, we are not as a society willing to use merit as the major basis for allocation of research support.

Finally, in my recitation of pitfalls and problems, I believe there will be a renewed focus on how much research is the right amount. Consider the following issues:

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1. When the Cold War was the rationale, the "right amount" of research was "whatever it takes." But we do not have a national consensus to take that attitude vis-a-vis competitiveness, nor do we know what it would mean to do so.

2. Often observed in academic circles is the strong feeling that anyone who can do research (as evidenced by the ability to obtain a PhD and get an appointment in a university) should be supported to do research. Can this possibly be correct? It is analogous to the notion that a company should do as much research as it could possibly afford, rather than an amount which is consistent with other corporate goals and priorities and its ability to drive competitive advantage. This is the unmentionable problem of "scientific birth control."

3. The "right amount" of academic research may have much more to do now than it did in the past with training the needed number of scientists and engineers. It may require different academic views about career paths, prestige, etc. It may require much greater focus on research topics relevant to manufacturing.

These questions urgently need to be debated, but I am not sanguine that our community of scientific and engineering research has either the mechanisms or the will to achieve a consensus, although I was impressed by the outpouring of over 850 letters that were sent to the members of the Special Commission on the Future of NSF. We are unwilling in the research community to discuss, or even to think about the question, How much research is enough in my field? Do we, for reasons of national policy, need to be world class in every subfield of science? (A hopeless wish, in any case!) And once we are "world class" in an important field, do we need to be "three times world class," which is the usual argument that is made, if only implicitly.

What will probably happen if the scientific community cannot deal with the question, How much is enough in this field? is that the political process, in the form of Congressional committees and the OMB, will decide how much research is done in universities and in which ones. If there were a coherent, comprehensive national science and technology policy, then the political process might lead to a happy result; since we have no such policy yet (at least in the depth required), we are unlikely to get a good result. Perhaps the new Administration will be willing to produce a coherent, wide-ranging science and technology policy.

I suggest that there are a number of ways in which we can improve the rate of return on society's investment in university research, without fundamentally harming the ability of universities to create new knowledge and explore new pathways. But these changes must be made in the context of a *wholly improved* process for moving rapidly from new knowledge to new products—albeit an improved process where most of the "improving" has to be done in the private sector.

Among the areas where constructive change is both possible and, in my view, desirable are: (a) improvements in the training of scientists and engineers that enable them to be more effective and enthusiastic participants in the process of R&D exploitation, including a heightened interest in and respect for the intellectual challenges of manufacturing, and (b) innovation in the modes of interaction between universities and industry. Let me now talk briefly about each of these two subjects.

First, I'll address the topic of training scientists and engineers with the idea that many of them will need to be enthusiastic participants in an improved process of commercialization of new knowledge. This will occur in a world where the speed of that process is crucial to success, and where there is no sustained payoff until and unless manufacturing is competitive.

Prerequisite, in my view, to this broader training is cultural change in the university. We need to work on abolishing the academic "pecking order," that I and others perceive as a serious impediment to the rapid application of new knowledge. We should help Western culture rid itself once and for all of the intellectual hierarchy in which "pure" is somehow better than "applied," physics is better than chemistry, both are better than engineering, and the discipline and intellectual content of manufacturing is valued hardly at all.

> Poor "technology transfer" from the university or national labs to industry has not been a major cause of our competitiveness problem.

The truth is that Nature knows nothing of these distinctions. And they interfere mightily with the utilization of knowledge to solve problems that arise in making new products and processes work. We need to produce graduates with a broader view of what is a respectable and exciting career.

In addition to a re-examination of the results of training that is given in our research universities, there is room—on both the university and the industry sides—to improve the quantity and the quality of the interaction between us.

There are, of course, sabbaticals, adjunct professorships, summer visits, and other such programs already in place. But it is still the case that a PhD engineer with five years experience in industry has a much better grasp of the two worlds, university and industry, than does his or her thesis professor. This asymmetry may be explainable, even understandable, but it works against a national ability to progress swiftly from concept to product.

Indeed, I believe major benefits to competitiveness would flow from a national program aimed at greatly increasing the flow of university faculty and industrial scientists and engineers in and out of each others' institutions. As you know, there are small numbers of such opportunities today—sabbaticals in industry, and adjunct appointments in the university. My distinct impression, however, is that these existing opportunities are undersubscribed on both sides, and for the same reason.

Namely, that any close acquaintance with the "other" community is believed to be time wasted as far as one's "real career" is concerned. The industrial culture does not think that its success is enhanced by having its best people on assignments to universities. Conversely, young academics do not believe that a year's stay in industry helps much, either with tenure or with obtaining research grants and contracts.

As things stand now, both parties are correct and behaving rationally in their local cultures. What we need to work on as a country is understanding that the success of our separate communities, industrial and academic, is dependent in part on our collective success. A sense of urgency about this interdependence is what might well make possible the institutional changes on both sides that would make greatly increased interaction possible.

Perhaps a "national initiative" to stimulate such a rethinking would be a good idea. It ought to be analogous in prestige to the Presidential Young Investigator program, although different in content in obvious ways. The program should be one in which costs are shared between the university and the industrial partner, with partial support coming from various federal and state funding agencies as well as from industry consortia. (The multiple sources of support would help ensure the highest quality of participation in exchanges. Provision probably must be made for ongoing guidance and support of graduate and postdoc students of participating faculty members.)

I would now like to summarize briefly the points I have raised in this article, emphasizing that both my analysis and my suggestions for action are certainly in need of the correction, improvement, and amplification that will come from further discussion in our community of researchers and policy makers.

It has been my thesis in this paper that it is both timely and appropriate to re-examine the rationale for society's support of research.

Even though Vannevar Bush asserted 47 years ago that contributing to economic well-being was a major reason for supporting basic research, it has not been the case in practice that Congress and the taxpayer fund basic research because they understood its relation to improved productivity and new products.

The likely outcome of a re-examination of the rationale for public support of research is that we decide to shift emphasis in a major way toward support for the competitiveness of our economy. Given the intrinsic merit of the idea, and given the current concern about American technological competitiveness, it is not surprising that many people are seizing on the idea that university research should lead to increased international technological competitiveness.

The internationalization of technological competition has had the consequence that it is no longer sufficient for university research to generate a societal return that exceeds possible private returns. What is now required is that the societal return must exceed not only the private rate of return in the U.S., but also the private returns in the most competitive countries overseas. Moreover, this can only be accomplished if the whole process, from invention to low-cost manufacture and marketing, moves much more rapidly.

However, since most of the responsibility for competitiveness rests not with universities but with industry, a too zealous emphasis on competitiveness as a rationale for supporting universities may have undesirable consequences. Among them are,

1. The amount of funding available, and the priorities for its application are likely to shift; that is, how much research is supported is likely to change, when competitiveness is a main part of the rationale.

2. Where research is supported is likely to change in ways that further reduce the ability of universities to assemble and sustain a critical mass for research.

3. As a possible consequence of bad assumptions on the part of policymakers, and attempts by universities to do the impossible in matters of technology transfer, the role of universities may be distorted.

There are, however, a number of things—not likely to be harmful—that universities might do to improve the speed and efficiency of part of the process.

Among the areas where constructive change is both possible, and in my view desirable, are (a) improvements in the training of scientists and engineers which enable them to be more enthusiastic and effective participants in the process of R&D exploitation, and (b) greatly increased professional interactions between university and industrial scientists and engineers.

Finally, I would like to close with a quote from the Report of the Special Commission on the Future of the NSF.* These paragraphs are from the section called General Recommendations.

1. The United States should have a stronger and more coherent policy wherein science and engineering can contribute more fully to America's strength.

The (National Science) Board is encouraged to work with the President, his Science Advisor, and the Federal Coordinating Council on Science, Engineering and Technology to assess the health of science and engineering broadly and to generate a stronger policy into which the NSF mission fits. This thesis is amplified in the conclusion of the report.

2. Society's voice is welcome and needed. Society's support for the NSF and for university research is based on the confident expectation that the generation of new knowledge, and the education of a skilled workforce are necessary (though not sufficient) investments to achieve our national goals of a high quality of life in a productive and growing economy. In accepting society's support, the scientific community naturally assumes an obligation to be both responsive to national needs voiced by society as well as the intellectual priorities solely initiated by the scientist or engineer.

Concern over technology application and competitiveness sometimes conjures the idea that budgeting decisions are based on the criteria of either pleasing the scientists or serving the public need. In reality these criteria and interests are congruent.

The history of science and its uses suggests that the NSF should have two goals in the allocation of its resources. One is to support first-rate research at many points on the frontiers of knowledge, identified and defined by the best researchers. The second goal is a balanced allocation of resources in strategic research areas in response to scientific opportunities to meet national goals.

It is in the national interest to pursue both goals with vigor and in a balanced way. The allocation of resources should be reviewed regularly with these two goals in mind. Positive responses to both will enhance the standing of science.

3. The Commission strongly supports the initiation of proposals by investigators and selection of those to be funded by merit review carried out by experts. This method has proved to be the best way of tapping into the creativity of research scientists and engineers. Periodic examination of how to improve the functioning of the system is in order. The system, of course, must assure the selection of work of the highest quality and promise.

4. The NSB, the NSF, and the science and engineering community must come to better grips with the reality that many fields not covered by traditional disciplines offer challenges for new knowledge and opportunities for creative, investigative research worthy of the most gifted scholar. These fields should be valid candidates for support and may both yield key knowledge and enable timely response to national goals.

5. Since the private sector plays the major role in the translation of knowledge into new products and services, and since the speed and efficiency of this process is an important factor in a productive and growing economy, it is appropriate that the NSB involve the private sector more fully than heretofore in the decisions that affect the classes of research allocation as well as some evaluation of the effectiveness of the expenditures. It is more than incidentally significant that the scientific advances are as likely to be driven by advances in technology as the reverse and the interplay between parties who are conversant in both fields holds the promise of synergy.

*The Special Commission on the Future of NSF released its report on November 20, 1992. See *MRS Bulletin* issues XVII (11) 1992, p. 34 and XVIII (1) 1993 p. 19.

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