PCAST Panel on Federal Investment in S&T and its National Benefits

Draft Report
Assessing the U.S. R&D Investment

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1. Summary

The PCAST report Federal Investment in R&D[1] clearly shows action needed in the following areas of the country's R&D strategy:

- *Shifting R&D Budget Allocations*: The increase in private sector R&D funding over that of the federal government is causing, if not issues, certainly concerns, as is the reallocation of funds among certain disciplines which has resulted in an unbalanced research portfolio that is detrimental in the long run to all of the disciplines.

- *Science and Engineering (S&E) human resources* are a major issue, especially with the increased security provisions some federal labs and defense companies must implement.

- *Organizational issues* caused by the multiplicity of research agencies and appropriation committees that deal with R&D have always caused coordination and management problems. These are exacrbated by increasingly multi-disciplinary research requirements.

- *R&D investments, priorities, and effectiveness* are three issues that deserve more of our attention.

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[1] Elisa Eiseman, Kei Koizumi, and Donna Fossum, *Federal Investment in R&D*, Rand Science and Technology Policy Institute, Project Memorandum PM-1336-OSTP, Arlington, VA, July 2002.

- *Competition and Cooperation*: More countries are becoming involved in R&D and more countries have a sizable research infrastructure. Awareness of other countries' activities and possible collaborations are becoming more important.

2. Work of the Panel

PCAST's Panel on Federal Investment in Science and Technology and its National Benefits has the assignment to review the federal government's research portfolio and make recommendations on areas where programs should be expanded, curtailed or maintained. It was obvious from the outset that any review of the federal R&D budget needs to address the total U.S. R&D budget, including private sector R&D funding as well as that of the states, in order to judge the full impact of the government's investment and its effect on the national well-being.

The total federal budget - and especially the R&D budget - not only reflects the activities of government agencies and their contractors, but to a great extent also reflects the Administration's and Congress' changes in policy. These policies have varied widely as the political and international environment has changed, as the country's problems, responsibilities and opportunities have evolved, as science and technology have developed, and as all these changes have affected the economy, leisure and work. A broad long range view was therefore in order, and the time frame chosen was 25 years. We recognize that many of today's realities are outgrowths of activities over this time interval. In addition, the data for the last 25 years does exist, is available and has integrity.

The RAND Corporation, in conjunction with AAAS, was asked to create a report from the large amount of data available that could provide the needed facts and figures from which insights and conclusions could be drawn. The report, entitled Federal Investment in R&D[2], deals specifically with five topics:

Federal R&D. Major changes in federal R&D policy and spending over the last 25 years.

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[2] Ibid.

Non-federal R&D. Major changes in private sector R&D, state R&D and other major non-federal R&D efforts.

R&D Balance. Changes in the allocation of R&D funding among fields of science and engineering.

Education. Changes in U.S. science and engineering graduate education and the U.S. technical workforce.

International Comparison. Comparison of U.S. R&D spending with spending by other major R&D performing countries.

These topics are extensively discussed and documented in the report and the conclusions are highlighted in the Foreword to the report but not repeated here.

The analytical survey was augmented by a series of hearings. A number of experts testified on various issues regarding the federal R&D budget. They included:

- o executives from the more salient R&D departments and agencies;
- o representatives of companies and universities;
- o representatives of industry and professional associations.

Appendix A (attached) lists the hearings' agendas and participants and includes summaries of the discussions.

These activities and the deliberations and expert judgment of the members of the Panel resulted in the observations and recommendations that make up the remainder of this report.

3. Findings and Proposed Actions

We want to highlight a number of areas that were identified as especially deserving PCAST's attention and suggest appropriate action that the Administration should take over a period of time, particularly in the next budget submission to Congress. We will refer to the previously referenced report, Federal Investment in R&D[3], observations from our discussions, and other reports and data that are available in the literature and elsewhere.

[3] Ibid.

Shifting Allocations

There have been considerable shifts in the sources of funds for U.S. R&D. In FY 2000, private sector R&D was 67% of total U.S. R&D, federal funding a mere 30%. This compares to an even split in 1976[4] between these two sources of R&D funding and a higher federal R&D budget compared to that of industry in the years prior to 1975.

There are two issues that PCAST believes need to be addressed. The first is the tendency of industrial R&D funding levels to vary with the business cycle. Since R&D is an expense on the balance sheet, as profits decline R&D is often curtailed. But research, in particular as compared to development, requires a longer gestation period. The staying power of industrial investment in R&D is therefore becoming more of a factor for the U.S.

An equally serious concern is the fact that industry understandably focuses heavily on development and government on basic and applied research. Thus the shift towards the predominance of industry R&D will cause basic and applied research as a percent of total R&D to drop. This raises the question whether the level of basic and applied research will be adequate to fuel the nation's future development needs. One should realize that the time scales over which basic and applied research investments bring about results are quite different, measured in decades in the case of basic research and in years in the case of development. Furthermore, if there is no or too little investment in basic and applied research, there will be no significant advances in new products, services, defense or health twenty years from now and we will become importers rather than exporters of most goods and services.

The second issue for PCAST is the rather large changes in disciplinary areas supported by R&D funding over the last 25 years. There are not only changes between defense and civilian R&D caused by changes in the international political climate, but also rather large shifts in funding among science and engineering disciplines, such as the physical and life sciences. As a base point: in FY1970, support for the three major areas of research, namely physical and environmental sciences, life sciences and engineering was equally balanced.

[4] Ibid., Fig. 2-1, p. 15.

Today, the life sciences receive 48% of federal R&D funding compared to the physical sciences' 11% and engineering's 15%.[5] Even if Physical Sciences, Environmental Sciences, Math and Computer Sciences are combined, their total share is only 18%.

It can be reasonably argued that the increase in funding for the life sciences does not necessarily indicate an underfunding of the physical and other sciences. After all, a major revolution is occurring in the biosciences requiring a major build-up of infrastructure and other resources.

However, thelack of funding in these other disciplines is a cause of concern for a number of reasons:

- Both full-time graduate and Ph.D. students in most physical sciences, math, and engineering are decreasing while those in the life sciences are increasing.[6]
- Facilities and infrastructure in general for the physical sciences are becoming less than adequate for the needs of today's research problems.
- It is widely understood and acknowledged that the interdependencies of the various disciplines require that all advance together. Dr. Harold Varmus, former Director of the National Institutes of Health, eloquently noted that "scientists can wage an effective war on disease only if we – as a nation and as a scientific community – harness the energies of many disciplines, not just biology and medicine."

For all these reasons it is valid to question whether the unequal support of certain disciplines jeopardizes progress in others in a significant way. As a consequence, is the U.S. position in R&D at stake? It needs to be stressed that these imbalances are not easily rectified, especially not in a constrained budgetary situation. Given the decreases in the physical sciences over the past decade, the focus must be to achieve a rebalance by increasing these disciplines and not by decreasing the life sciences.

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[5] Ibid., Figs. 3-1 and 3-2, pp. 21 ff.
[6] Ibid., Figs. 4-2 and 4-3, pp. 34 and 35.

With the drop in support for certain disciplines comes a drop-off in students and faculty entering these fields. We have seen this happening; the number of engineering, physical and environmental science degrees has been falling since the early 1990s.

This issue of shifting allocations is a concern to the Senate VA-HUD Appropriations Committee which asked the Science Advisor, in conjunction with PCAST, to develop an action plan to address this issue as a part of the fiscal year 2004 budget proposal.

We recommend:

- the R&D budget be adjusted upward for the physical sciences and engineering, bringing them collectively to parity with the life sciences over the next 5 budget cycles;
- OSTP monitor basic and applied research expenditures to ensure they do not fall below present levels as a percent of total U.S. R&D;
- responsibilities for key disciplines be assigned to those agencies that support the majority of R&D in a particular field to increase understanding of the strength of each major field in terms of human resources, R&D and other key parameters. As examples, Life Sciences could be assigned to NIH, Environmental Sciences to NASA, Physics to DOE and Mathematics/Computer Science and Social Sciences to NSF.

Human Resources

The adequacy of human resources in science and engineering (S&E) is a chronic issue in the U.S. The number of full-time graduate students in most fields of science and engineering has either declined or been stagnant, as already pointed out above**.** The number of S&E doctorates awarded increased since 1985, primarily because of the high influx of foreign-born students. Of late, even this trend has leveled off as some foreign countries have expanded their institutional capacity for S&E graduate programs and doctoral education.[7] . We also need to take into account the changing demographics of the U.S. White males, the traditional major source of scientists and engineers are not entering or graduating from college at the same rate as women. Hispanics and

[7] Ibid., Fig. 4-5, p. 37.

African Americans, who will constitute a larger percentage of the workforce, have traditionally been and are still underrepresented in these fields of study.

Compared to other countries, on a per capita basis the U.S. is at the low end in terms of the 24-year olds we are attracting to the natural sciences and engineering; in 1975 we were at the high end.[8] While these statistics apply to four year graduate degrees and above, a similar problem exists at the technical/community college level of training.

Since a large fraction of the federal investment in research supports academic research and therefore the training of scientists and engineers, the shifts in spending that have occurred during the past two decades have limited the supply of S&E human resources in the physical sciences and engineering. The steps to restore balance between biomedical and physical sciences and engineering in the federal R&D budget that we advocate could also begin to expand the number of U.S. citizens entering these fields, a goal that has grown significantly in importance since the tragic events of 9/11 and their sequelae.

Increasingly, graduate students from foreign countries are coming to the United States to earn their degrees – these students represent the best and the brightest. Nearly half of the students earning doctorates in S&E fields in the United States are foreign born, and nearly 35% of those earning Masters degrees are as well.[9] Approximately a quarter of these students plan to return home immediately after finishing their studies – in the long run, an even greater number return home. Foreign graduate students enrich our universities and provide tremendous value to this country, but it is important to understand the implications should there be a decrease in this educated workforce. We must ensure that immigration and other policies that affect immigration by highly skilled individuals are designed to encourage them to stay. The competition for these students is much more intense than in the past. As investment in semiconductor and related IT businesses migrates overseas, sometimes for business reasons and other times

[8] National Science Board, *Science and Engineering. Indicators - 2002*, Arlington, VA, National Science Foundation, 2002, NSB-02-01, Fig. 2-27, p. 2-39.

[9] Ibid, Fig. 2-20, p. 2-33.

because of readily available technical talent, opportunities for these students to return home to high paying jobs is far greater than ever before.

Our economy is increasingly dependent on high technology in all sectors from manufacturing and services to government. This demands that we have at our disposal a technical workforce of adequate size. In the discussions we had with managers of institutions, agencies,enterprises, and industry no subject was as often discussed as this one. The participants pointed out that professionals with background in the physical sciences and engineering are especially in demand in high technology industries. An example is IBM where over 95% of the Ph.D.'s who compose its nanotechnology research staff have degrees in the physical sciences, including solid state physics, physics, chemistry, physical chemistry, inorganic chemistry and electrical engineering. The training these people receive is largely sponsored by the federal government and is highly dependent on the research support for the disciplines that attract these students..

It also needs to be noted that The Senate Appropriations Committee for OSTP is "...urging OSTP to develop a comprehensive strategy to increase the number of students pursuing degrees in science and engineering."

What is missing from the whole debate is an authoritative "demand profile" for our technical workforce. This has been attempted in the past, creating debates but no clarity. Obviously, demand is a function of the state of the economy and varies, therefore, over short time periods. These variations many times occur on a shorter time base than the educational cycle for graduate students, especially Ph.D.'s.

We strongly urge that:

- NSF in conjunction with the Department of Commerce be tasked to assess biannually the adequacy of the nation's S&E human resources, utilizing surveys combined with the most appropriate statistical approaches, taking into account the changing demographics in the U.S. and abroad. We clearly realize the complexity of this task, but few other inquiries are as important and far-reaching as this one.
- OSTP as part of its responsibility for a coherent R&D strategy analyze yearly on a consolidated basis the various undergraduate and graduate programs that support students through stipends, employment in universities and the federal government and other means and form an opinion as to the adequacy of the various agencies' participation in these programs and also as to the adequacy of the financial support offered.
- The departments and agencies that assume responsibility for certain disciplines and fields as we suggested above also be monitors of the human resource issue in their assigned fields and take action as needed.

Organizational Issues

Responsibilities for the R&D budget are distributed among many departments and agencies of the federal government. This stove piping is not conducive to the research required in this increasingly interdisciplinary world. Also, some multi-disciplinary programs are distributed among multiple agencies. The Nanotechnology program, being the latest such example, encompasses in one form or another probably most agencies involved in R&D. This multi-agency involvement demands careful coordination of these programs among the responsible parties and a management structure that needs to be more active and intrusive than was necessary in the past, although the IT Directorate that existed in the mid-90's might be an interesting example of a workable model. We need to add that within OMB the above described stove piping is continued.

A similar diffusion of responsibility exists in Congress. Among the thirteen appropriations subcommittees that have jurisdiction over the federal budget there are at least ten subcommittees[10], each responsible for a portion of the

[10] Eiseman, Koizumi and Fossum, op.cit. Table 8, p. 77.

R&D budget. The decisions that determine the content of the individual appropriations bills are for the most part uncoordinated, and the trade-offs are many times with programs unrelated to R&D.

This situation will not change; therefore, it is important that OSTP and OMB put forth to Congress crosscutting issues and their associated budgets for special emphasis. We understand that there are only a limited number of special emphasis areas that can be highlighted in a particular budget, but we feel strongly that these special emphasis areas need not be confined to programmatic areas but can and should also be policy areas that are fundamental to the conduct of R&D.

We suggest especially the following crosscutting non-project special emphasis areas for the FY2004 budget:

- Disciplinary allocation of R&D funds. We have given the reason for being concerned about this issue above and will not repeat the arguments here;

- Goal oriented human resource programs across all R&D agencies to assure an ample supply of domestic science and engineering professionals and a higher component of U.S. cotozens in trhe professional student cohort..

<u>Investments, Priorities, Effectiveness</u>

A frequently asked question is what the country gets for its investment in R&D. A similar difficult-to-answer question is, are we spending enough on R&D or when is enough enough. As a response to these questions the Academies, OMB, OSTP and the research agencies themselves have over time expended some effort on this general issue of investment and payback and it is a center of focus today. Without duplicating what has been done and avoiding a project by project analysis, PCAST needs to shed some light on this subject.

The three issues we want to address are: assessing the R&D investment, judging the priority focus and the effectiveness of the R&D effort.

Assessing the R&D Investment

There is no easy way to view the R&D investment of the country, except by the standard R&D classifications (Basic, Applied, Development), by academic disciplines (Physics, Life sciences, Engineering, etc.) or by organizational funders or performers. The questions that are seldom answered regard R&D investment's purpose from the perspective of social benefit. The public and Congress certainly search for such a comprehensive answer.

One suggested set of classifications that could be utilized and should be satisfactory for analysis as well as for goal setting are as follows:

- Economic Impact Investments: consisting of the part of our R&D geared to the advancement of our economic well-being.
- R&D Infrastructure: building, instrumentation, equipment needed in pursuit of R&D.
- Human Resource Development: student support through R&D programs, government stipends, support of educational institutions in the R&D budget, research into education.
- Anti-terrorism and Defense: a linkage of these two subject matters, since in the R&D arena there are many common areas of interest.
- Societal Improvements: The life sciences and social sciences can claim large activities and expenditures that affect the health and well-being of society directly.
- Knowledge Generation: this area comprises undirected research, curiosity driven research and other basic research activities that cannot be tied to a particular outcome. The fear that being specific about this category could lead to the abolishment of important programs is more paranoia, rather than a reflection of actual experiences.

We suggest that the OSTP require
the R&D agencies to provide this or a similar classification scheme in addition to the data set that is required todayso that over time OSTP and OMB can form an opinion as to the optimum distribution of R&D investments among these classifications.

Priority Focus

The same set of classifications discussed above can be used to justify and assess both re-programming and new money allocations by the agencies.

Effectiveness of U.S. R&D

Papers and data that judge the effectiveness of R&D have been extensive and widespread. We included much data in the paper on Investment in Federal R&D.[11] Other output parameters that have been evaluated and scrutinized are

- Intellectual property and patents generated
- Students educated and degree production
- CRADAs and joint studies
- Trade balance of intellectual property
- High technology exports

We suggest strongly that OMB and OSTP in their current drive to assess the quality and productivity of R&D on a project basis do not lose sight of the overall health of the U.S. R&D enterprise. To that point, certainly the works of Solow, Stieglitz, Denning and others are authoritative attempts to judge R&D in a macro way. Some newer work by Michael Porter and the Council on Competitiveness is not as exploited as it deserves to be. Dale Jorgenson and the Bureau of Economic Analysis have also studied the role of IT-related technology advances on increased productivity and GDP. As an action we suggest that

- PCAST or the NRC undertake the task of summarizing the general studies on R&D effectiveness, critique the approaches and derive a set of Macro Output Parameters that should be tracked.

Competition and Cooperation

How does the U.S. compare to other countries - especially those that are prominent in R&D - is a recurring question. An equally recurring issue is our cooperation in international R&D programs.

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[11] Eiseman, Koizumi and Fossum, op.cit.

Comparing ourselves to other countries with regard to R&D is not a simple task. We need to examine not only proportional spending comparisons for important insights, but also look at which activities are being given priority. The Federal Investment in R&D[12] study provides some of the answers, e.g., U.S. federal R&D spending goes primarily to Defense; Japan, Germany, and Italy spend their government R&D on "Advancement of Knowledge". Another indicator of importance is the R&D to GNP ratio of a country. While we are fourth in this comparison, it is smaller countries that are exceeding or equaling our performance.

This leads to another point: we need to pay attention to developments that can give a country a leading edge in one particular area, even though they lack the breadth of activities that the U.S. or other leading countries can afford to undertake. India is an example of this approach with its leading edge in software development, Switzerland in pharmaceuticals, and Israel in chip design and layout.

The NRC has proposed and occasionally tested comparing ourselves to other countries in various and important disciplinary areas to shed light on the question of what role science and technology should play in the existing social system and what national goals need to be established for science. We support this initiative and further suggest that benchmarking by leading experts be undertaken to establish relative performance in a particular field (e.g., mathematics) between the U.S. and other nations. The consequence of this evaluation would be suggestions on the allocation of funds and resources to fields that need bolstering or reductions from areas that have been more than adequately funded. This approach has not aroused enough support to see it implemented on a grand scale.

The second initiative we propose, namely our participation in international R&D programs, has in the past suffered from the U.S. being late in its involvement, not being a dependable partner and not being transparent in our intent. The examples are well known and are many.

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[12] Ibid.

PCAST recommends that:

- OSTP together with the R&D agencies put in place a strategy for the U.S. to lead or participate in large scale international R&D programs, and get congressional agreement on the long term participation and funding of these programs.
- OSTP, in conjunction with the State Department and NSF with their international divisions and listening posts in Europe and Asia, keep a closer watch on R&D developments across the globe and provide a bi-yearly assessment of the impact of those developments on our science and technology.

Erich Bloch
August 22, 2002