CBO PAPERS

LARGE NONDEFENSE R&D PROJECTS
IN THE BUDGET: 1980-1996

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PREFACE

The Congress has approved the initial funding of several large nondefense research and development projects that are expected to cost $23 billion in the period 1992 through 1996. The large size of these projects has caused some concern as to whether they may be funded at the expense of other R&D activities in the years ahead. At the request of the Senate Committee on the Budget, the Congressional Budget Office (CBO) undertook to examine the funding of large nondefense R&D projects in the past in an effort to determine whether such "megaprojects" tend to crowd out federal spending on smaller R&D programs and on other government-sponsored activities. In keeping with CBO's mandate to provide nonpartisan analysis, the paper makes no recommendations.

David Moore and Philip Webre of CBO's Natural Resources and Commerce Division wrote the paper under the supervision of Elliot Schwartz. The budget staffs of the Department of Energy and the National Science Foundation provided valuable assistance in compiling R&D project budgetary histories and forecasts. Thomas Lutton of CBO provided computational assistance. The authors wish to thank William Boesman, Daryl Chubin, Peter Fontaine, Leon Lederman, Frances Lussier, and other reviewers for their valuable suggestions.

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Director

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SUMMARY

The Administration's 1992 budget request calls for increases in federal support for nondefense research and development (R&D), and for the agencies and budget areas that fund these activities. These expenditures include funding for the National Aeronautic and Space Administration's space station and its Earth Observation System, and the Department of Energy's Superconducting Super Collider. Concern has arisen that these and other large R&D projects will be funded at the expense of smaller-scale activities, including many projects initiated by single investigators.

This study examines the budgetary history of large nondefense R&D projects during the 1980s, as a background to the Administration's proposal for the 1990s. Three specific questions are addressed:

- Are large nondefense science and technology projects currently consuming more budgetary resources, in either absolute or relative terms, than during the 1980s?

- Under the Administration's program, will large nondefense science and technology programs increase their share of science and other spending aggregates relative to current levels and to the trend during the 1980s?

- Are large nondefense science and technology projects funded at the expense of all other R&D spending (including "little science") or other types of spending?

BACKGROUND

Advances at the frontiers of science and technology have required ever more complex and expensive facilities, instruments, and experiments. The proliferation of these projects in the federal budget has raised a number of issues. Large R&D projects are expensive. Outlays on the space station and the Earth Observation System (EOS) could run to $35 billion and $17 billion, respectively, before the year 2000. The Superconducting Super Collider could require an investment of between $8 billion and $12 billion by the same year. Cost, of course, is not the only standard by which to judge an investment. Supporters of these large R&D projects believe they will deliver benefits that justify the expense, although not all share their confidence.

Large R&D projects are also risky. Their costs of development and operation are difficult to estimate, and it is also difficult to be certain of the capabilities of a system once developed, and the importance of its mission. Failure in a large R&D project may cause serious setbacks to scientific or technical projects that depended on its success. The very riskiness of large R&D projects, however, is an argument for federal support, since the government is the only institution able to bear the cost and the risk of these ventures.

Finally, some critics of large R&D projects raise a political concern: such projects, particularly in their development and construction phases, provide income for localities and businesses. Also, large projects increase the budgets of the federal agencies that sponsor them. These factors are not particularly important so long as they do not intrude heavily on the scientific and technical criteria used to make decisions about the mix of large and small projects. But if cost overruns or budget constraints require choosing between large and small projects, it would be against the national interest to support large projects at the expense of small ones for nonscientific and nontechnical reasons.

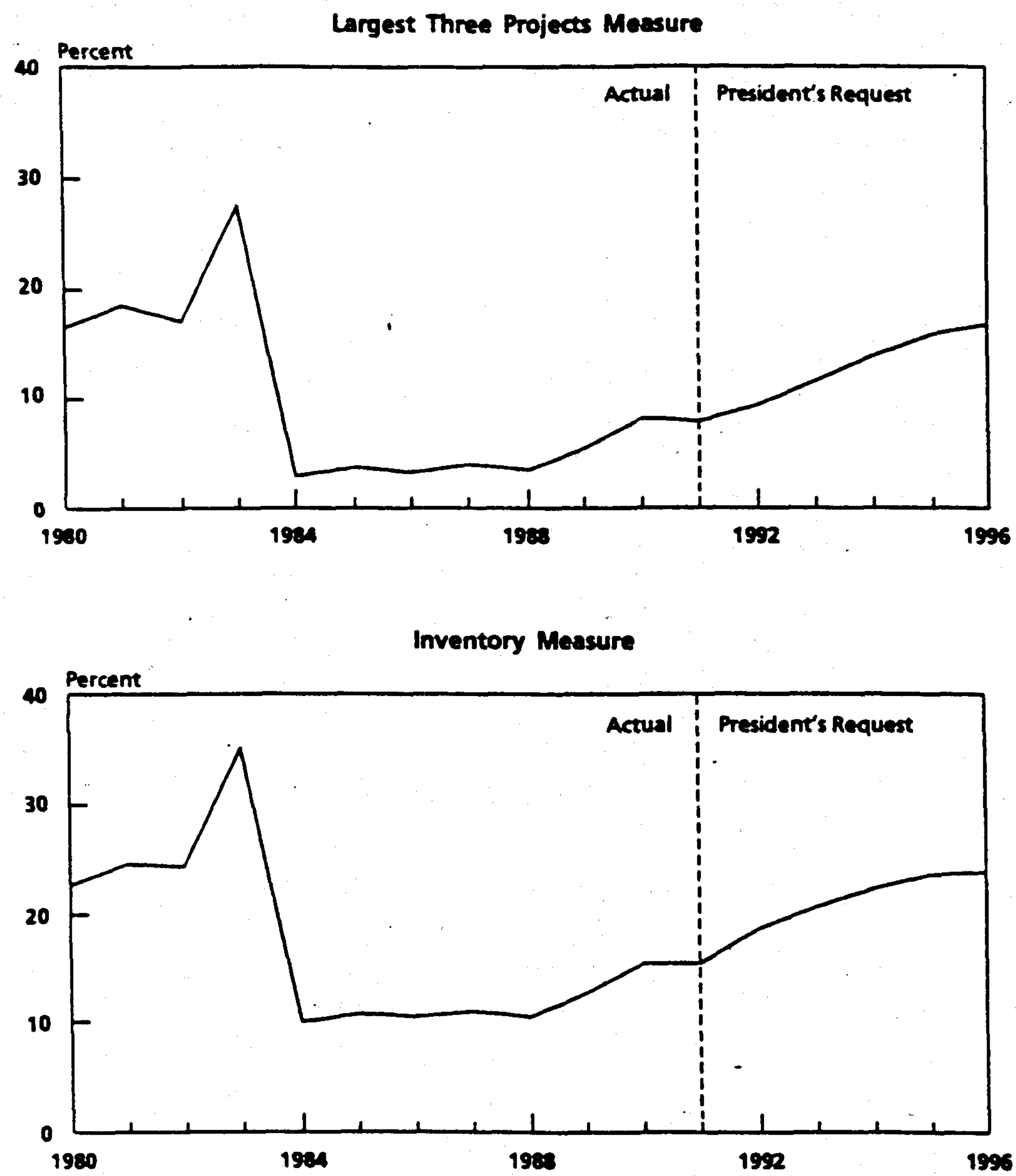
TRENDS IN SPENDING FOR LARGE R&D PROJECTS

After examining a variety of budgetary measures, CBO finds that the Administration's plan would increase the share of funding devoted to large nondefense R&D projects to levels not seen since the early 1980s. As Summary Figure 1 shows, the share of total nondefense R&D funding devoted to large nondefense R&D projects peaked sharply in the early 1980s, then fell in 1984 when spending for the development of the space shuttle ended. The share of nondefense R&D spending accounted for by an inventory of 80 large R&D projects and facilities rose from around 10 percent in the mid 1980s to over 15 percent by 1991 (the lower panel in Summary Figure 1). If the Administration's program was enacted, the share of large R&D projects would rise even more during the first half of the 1990s to 22 percent by 1996. The three largest projects in the inventory alone would double their share of nondefense R&D spending from the current level of 8 percent to 15 percent under the Administration's plan. The three largest projects would also increase their share of all domestic discretionary spending from 1.1 percent in 1990 to 2.8 percent by 1996.

The Administration's proposal calls for increases in overall R&D spending large enough to maintain the shares going to both "big science" and "little science." This approach would avoid the situation of the early 1980s when total spending in R&D-related budget functions remained flat or declined while large projects consumed a greater portion of the total.

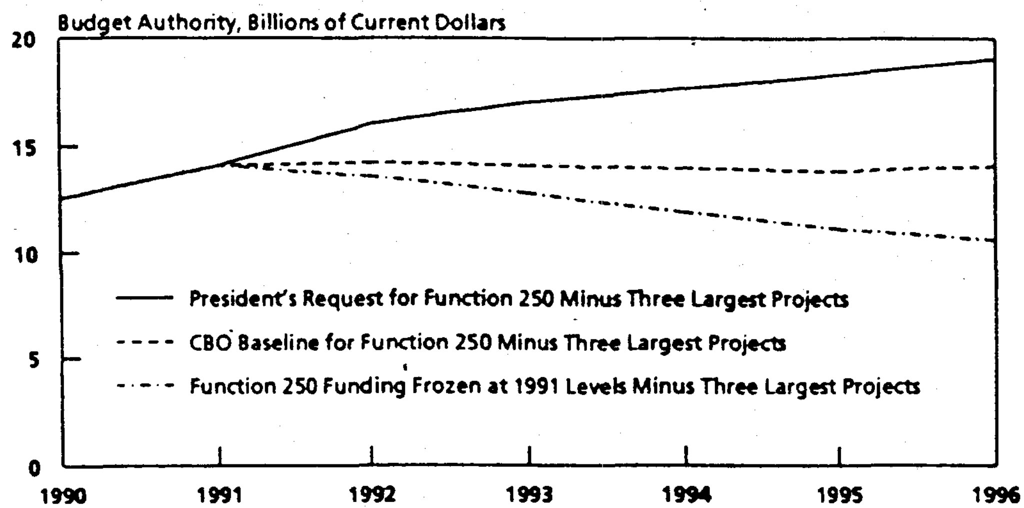
If the cost of large projects increases, or overall funding for general science and space turns out to be less than requested, the Congress could confront a choice between funding large R&D projects and other science and technology spending. Summary Figure 2 shows what could happen to spending on other science and technology if the very largest projects were funded as the Administration proposes, but the Congress placed constraints on overall space and science spending. If the largest three projects were funded as proposed and budget function 250 was permitted only to keep up with inflation--CBO's baseline projection--funds available to support other science and technology spending would be 25 percent below the

Summary Figure 1.
Spending on Large Research and Development Projects as a Percentage of Spending on All Nondefense Research and Development, Fiscal Years 1980-1996



SOURCE: Congressional Budget Office.

Summary Figure 2.
Alternative Projections of Spending for General Science, Space, and Technology Minus the President's Request for the Three Largest Projects, 1990-1996



SOURCE: Congressional Budget Office.

NOTE: Function 250 covers spending on general science, space, and technology.

Administration's plan. If spending for general science, space and technology (function 250) was frozen at the 1991 level through 1996, and the largest projects permitted to proceed as planned, other science spending would be reduced by 45 percent relative to the levels the Administration proposed. The National Science Foundation, a prominent source of funding for small R&D, would certainly be among the agencies considered for reductions from the Administration's plan under either scenario.

BUDGETARY OPTIONS

Current knowledge about the relative benefits of large projects as compared with smaller ones is not sufficient to provide much guidance as to how funds ought to be allocated between these types of activities. To keep better informed, the Congress may wish to initiate a biennial "cross-cutting review" of science and technology spending as suggested recently by the Office of Technology Assessment. The review would compare such spending by all agencies with broad national objectives and specific technological goals to see whether the distribution of current spending, including that between large and small R&D efforts, best meets these objectives and goals. Such a review could be useful even though it would partly duplicate the annual budget review several Congressional committees already conduct.

The Congress could also try to balance spending for large projects and spending for small projects by using multiyear appropriations and arbitrary annual spending caps. Multiyear appropriations might be effective in controlling the total cost of big projects by allowing agencies to proceed on an optimal schedule without tailoring their programs to fit annual budgetary requirements. But multiyear appropriations will not be effective in controlling cost if technical uncertainties lead to cost overruns. In defense programs, multiyear appropriations have been more successful in procurement projects than in developing technology.

Arbitrary annual caps could be placed on spending for large projects, set at levels that would assure adequate funds for other science spending. Caps offer the advantage of being in current use and easily understood, but they would raise the total costs of big projects.

Canceling one or more of the largest projects could offer immediate and sustained budgetary savings. Canceling the space station program, for example, could free up between $2.0 billion and $2.6 billion each year for other space and science projects, if Congress chose to appropriate funds for these purposes rather than other federal priorities.

Finally, the Congress may wish to pursue partnerships with other countries in large science and technology projects on a more equal basis than at present. Foreign partners would have more say in managing such projects in exchange for carrying a larger share of the costs. U. S. contractors would have to give up some of the procurement business, however. Multiyear appropriations could help to make more equal international partnerships effective. Thus, a secondary cost of these ventures could be the loss of Congressional oversight and funding flexibility granted by annual appropriations.

CHAPTER I
INTRODUCTION

Over the last several years, the Congress has been asked to fund a set of "big science" programs that will cost billions of dollars. These are large nondefense research and development projects in areas such as space exploration, high-energy physics, and geoscience. Outlays on such projects would reach a peak in the first half of the 1990s, at a time when budgetary constraints will be severe. This paper has assembled data to show the trend in funding large research and development (R&D) projects during recent years, together with projections of current plans through 1996. The aim is to assess the budgetary implications of such spending. The paper reviews only briefly more fundamental questions about the productivity of federal spending for large R&D projects as opposed to other R&D projects, other federal spending, or deficit reduction.[1]

The paper poses and seeks to answer three interrelated questions:

- Are large nondefense R&D projects currently consuming more budgetary resources, in either absolute or relative terms, than during the 1980s?

- Under the Administration's program as presented in the 1992 budget, will the share of spending devoted to large nondefense R&D projects increase relative to that of other programs?

- Are large nondefense R&D projects being funded at the expense of other science and technology programs (including "little science") or of other categories of spending?

CIVILIAN SCIENCE AND TECHNOLOGY IN THE FEDERAL BUDGET

The President's budgetary proposals for 1992 emphasize spending for civilian (that is, nondefense) science and technology. This emphasis is reflected in the proposed increases for the budget functions supporting civilian science spending and the major agencies that sponsor such programs, and in the cross-cutting budgetary aggregate of civilian research and development. Proposed nominal increases for civilian R&D include 9 percent for basic research and 10 percent for applied research and development. Another significant highlight of the budget is the increases it proposes for several specific projects and facilities: 7 percent for the space station, 82 percent for the Earth Observation System (EOS), 120 percent for the Superconducting Super Collider (SSC), and 25 percent for the Human Genome Project.

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1. The Office of Technology Assessment, in its Federally Funded Research: Decisions for a Decade (May 1991), poses a set of more fundamental questions than those addressed in this report.

In 1991 total federal support for all R&D was $67 billion, with nondefense programs accounting for $28 billion of the total.[2] Federally supported R&D represented about 45 percent of the national total. The federal role is even more pronounced when only basic research is considered, where federal support accounts for 70 percent of the national total.[3] The major components of federal spending for civilian R&D for 1991 are shown in Table 1. Spending is broken down by agency in Table 2.

The historical trend in federal spending for civilian R&D has a roller-coaster pattern, generated in part by the rise and decline of funding for large R&D projects (see Figure 1). The Apollo program accounted for a rise in federal R&D spending in the 1960s and its subsequent fall through the early 1970s. Increased spending for health research, for developing the space shuttle, and for energy programs pushed up civilian R&D through the early 1980s. Changing energy polices brought a decline in the first half of the 1980s, but since then increases in spending for space, general science, and health research have driven total civilian R&D up sharply.[4]

Federal support of science is based on a widely accepted rationale. Scientific knowledge is recognized to be a public good that many users can consume without diminishing its worth to other users. The private economy characteristically produces too little of this type of good. Government spending on pure science programs helps to correct this failing of the private economy by generating new scientific knowledge; it also assures the country's future scientific capability by investing in new facilities and training new scientists. Federal programs and policies that encourage private R&D likewise work to narrow the gap between the value to society of scientific activity and its value in the private market. Without these incentives, private firms might invest too little in R&D from society's point of view since the benefits of R&D do not always show up in the balance sheet. While this rationale for federal support is generally accepted, it offers little guidance as to how much the government should spend, and on what.

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2. Note that different data series use slightly different definitions because they are collected from different surveys for different purposes. Consequently, there may be slight discrepancies between data series. For instance, federal R&D spending for 1990 totals $63.8 billion, $66.08 billion, $68.5 billion, or $69.2 billion depending on the data series. (See Appendix for fuller discussion of data.)

3. For a review of the trends in federal support for research and development see Congressional Budget Office, *How Federal Spending for Infrastructure and Other Public Investments Affects the Economy (June 1991)*, chap. 4 and David C. Mowery and Nathan Rosenberg, *Technology and the Pursuit of Economic Growth* (Cambridge: Cambridge University Press, 1989), chapter 6.

4. Congressional Budget Office, *How Federal Spending for Infrastructure and Other Public Investments Affects the Economy* (June 1991).

TABLE 1. MAJOR COMPONENTS OF FEDERAL FUNDING FOR CIVILIAN R&D IN 1991 (In billions of dollars)

Health	9.8
Space	5.2
Energy	3.2
General Science	3.1
All Other	7.1
Total	28.4

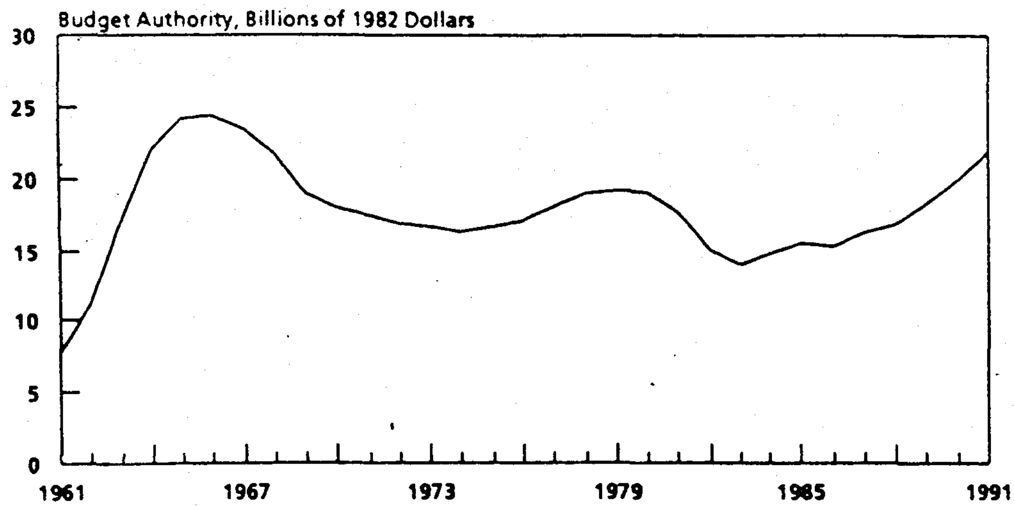
SOURCE: Congressional Budget Office based on American Association for the Advancement of Science, AAAS Report IVI Research and Development FY 1992, (1991) Table 1-4, p. 48

TABLE 2. R&D IN SELECTED AGENCIES FOR 1991 (In billions of dollars)

National Aeronautics and Space Administration	8.1
National Institutes of Health	7.9
Department of Energy	4.2
National Science Foundation	1.9
Other Health and Human Services	1.6
Department of Agriculture	1.4
Environmental Protection Agency	0.5
Department of Commerce	0.5
Geological Survey	0.4
Department of Education	0.2
Bureau of Mines	0.1
All Other	1.7

SOURCE: Congressional Budget Office based on American Association for the Advancement of Science, AAAS Report XVI Research and Development FY 1992, (1991) Table 1-7, p. 52.

Figure 1.
Funding for Nondefense Research and Development, 1961-1991



SOURCE: Congressional Budget Office based on National Science Foundation, *Federal R&D Funding by Budget Function* (various years) and National Science Foundation "Federal Funds for Research and Development; Detailed Historical Tables: Fiscal Years 1955-1990."

NOTE: Before 1979, data are in obligations.

LARGE AND SMALL R&D PROJECTS IN THE BUDGET

Many federally funded R&D projects tend to be very large. Their size is a reflection of scientific and technical progress: In many areas, progress requires increasingly expensive equipment and facilities as the advances permitted by the previous generation of equipment are exhausted. The federal government can undertake large projects because it has the ability to bear the risks and costs of such investments. At the same time, scientific and technical progress is continually opening new fields of inquiry that are arguably candidates for federal support. A conflict potentially arises between federal support of continuing progress in specific fields of inquiry and the equally important need to maintain a diversified science and technology base.

From a budgetary perspective, a large R&D project characteristically requires expensive and large-scale equipment that needs several years of funding to develop and build, and thereafter many years of operational support to deliver new scientific results. Large R&D projects typically begin with investment in engineering and construction activities. During this "ramp up" period, funding requirements increase rapidly. The benefits of this phase of activity flow to the local areas and contractors involved in the project. The major contribution of large R&D projects to scientific knowledge and technical achievement occurs later, during the operational phase. These projects typically have a core research agenda that the federal government develops and oversees.

In contrast, small R&D projects or "little science" tend to be initiated and conducted by a single investigator or a small team. The scientist plans them and the government funds them in a way that allows the investigator latitude as to the specific questions investigated and the methods employed. Small R&D projects typically use facilities and equipment that are currently available and seek to achieve results in the short term.

Federal support for small R&D provides the bulk of public funding of university-based research. Federal agencies supporting small R&D projects generally spend a high proportion of their funds on R&D conducted in universities. For example, in 1991 the National Science Foundation spent 71 percent of its R&D funds on university-conducted research; the corresponding figure for the National Institutes of Health was 54 percent. The National Aeronautics and Space Administration and the Department of Energy, which are the primary funders of large R&D projects, spent only 7 percent and 9 percent of their respective funds on university-conducted research in the same year.[5]

Concern about the relation between large R&D projects and smaller efforts arises on several fronts. Large R&D projects are expensive, both to build and to operate. In an era of tight budgets, committing resources to one program inevitably

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5. American Association for the Advancement of Science, AAA Report XVI: Research and Development FY. 1992 (1991), Table 1-7 and Table 1-9.

means that less will be available for others, including the smaller R&D efforts that maintain universities' scientific and technical base. If a large project is funded at the expense of many smaller ones, the large effort must deliver commensurately large benefits if it is to be justified as a sound public investment. The benefits large projects deliver beyond scientific and technical results may be decisive in this calculation. For example, large projects help to maintain the leading role of the United States in science and technology, and draw the attention of young people to careers in those fields--benefits that are difficult to measure.

Large R&D projects are risky. Their costs, capabilities, and schedules are subject to considerable uncertainty. For example, the four precursors of the proposed Superconducting Super Collider built in the 1980s exceeded their initial cost estimates by almost half, even after adjusting for inflation.[6] The ultimate capabilities of large R&D projects may be as uncertain as their cost. For example, the space shuttle was developed with the expectation of flying almost 60 times a year rather than the current flight rate of 6 to 8 launches each year. The long periods of time necessary to design, develop, and build large R&D projects expose them to the risk of technical obsolescence. While the possibility of failure is intrinsic to any risky scientific or technical enterprise, with large projects the cost is higher. However, the riskiness of large R&D projects also provides an argument for federal support: only the government is capable of bearing both the cost of creating large R&D projects and the risk of their failure.

Cost overruns are particularly vexing for large projects. Unanticipated funding demands force the Executive branch and the Congress to choose between several alternatives: funding the overrun, reducing the project's capabilities, delaying its completion, or perhaps combining all three. A decision to fund the overrun may force a decrease in spending for other R&D purposes, not as a consequence of well-formulated plans or policies but under the immediate pressure of meeting the annual budget constraint. The alternatives of reducing the project's capabilities or delaying it will exact their own price. The project's potential benefits will be decreased if its capabilities are reduced. If the project is delayed, total costs are likely to increase because the fixed costs of development will be incurred longer than necessary. Moreover, delay in achieving benefits also represents a cost, although the budget does not show it.

The Congress could avoid the potential conflict between funding for large projects and funding for other scientific and technical efforts by increasing overall spending on science and technology. Under the Budget Enforcement Act, however, caps have been placed on discretionary spending. The position of several large R&D projects in their "ramp up" phase, together with the spending caps by the Budget Enforcement Act created, may present the political system with essentially the same choices as a cost overrun: pay and crowd out other federal priorities, reduce

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6. Congressional Budget Office, Risks and Benefits of Building the Superconducting Super Collider (October 1988), pp. 44 - 48.

capabilities and future benefits, or delay projects and increase their total costs while deferring scientific and technical benefits.

APPROACHES TO MEASURING THE BUDGETARY IMPLICATIONS OF LARGE R&D PROJECTS

To what extent is concern about the productivity of large projects justified? Do large projects tend to crowd out smaller efforts? This paper develops measures that contribute to answering these questions by examining the extent to which large R&D projects dominate federal spending on both large and small R&D projects.

Yet, even this limited statement of the question is fraught with problems of definition and measurement. Stating the issue as big science versus small science gives the misleading impression that all large R&D projects are scientific in nature. They are not. Some large R&D projects focus on exploration or technology development rather than creating new scientific knowledge. Nevertheless, it would also be misleading to treat the R&D phases of large projects like the space shuttle or the proposed space station as federal activities with no special budgetary connection to science. Science projects, strictly defined, share the same agencies, budget functions, and appropriations jurisdictions with these large projects. For this reason, some of the measures of "big science" developed in the paper include all large civilian R&D projects--whether strictly science projects or not--so that the relation between spending for these purposes and spending on other science and technology can be explored.

Two additional questions concern the definition of "large R&D" and the relation between large and small projects in the budget. The paper makes no definitive claim to having a precise measure of large R&D. Instead, it presents several alternative budgetary measures of large R&D, none of which is completely satisfactory. The strategy of the paper is to apply different measures and look for common (or differing) trends.

The relationship between large and small R&D projects in the budget is problematic. Recently, concern has been expressed that large projects crowd out smaller ones particularly when budgets are tight overall. An alternative thesis is that large projects and small projects stand or fall together, with large projects often the critical ingredient in attracting attention to science and technology in general. A third theory might hold that the relationship between large and small R&D projects is not constant, but rather has changed over time. This paper makes no definitive statement about the past, since it cannot be stated with certainty that smaller projects would have fared better, for example, had NASA not embarked on its shuttle project.

CHAPTER II
MEASURING THE BUDGETARY EFFECTS OF LARGE R&D PROJECTS

Large R&D projects concentrate resources on developing and building sizeable facilities and instruments. During the operational phase of a project, institutions are created that govern the use of the facility or instruments, and in some cases steer an entire field of scientific or technical activity. It is difficult to capture all these aspects of large R&D projects in a single measure. Consequently, this chapter develops alternative measures of spending for large R&D projects. Three of the measures focus on construction and hardware. A fourth is broader, and includes all of the spending in fields of science and technology that are dominated by expensive instruments and facilities.

Standing alone, each of these measures is subject to conceptual problems, or to specific questions about why a particular project or group of projects was included or excluded. Alternative measures correct for the limitations of each. Also, they make the composite picture more accurate by establishing where the trend in each measure coincides with or differs from the other measures.

The impact of large R&D projects on the federal budget is examined by comparing the four measures of spending for large R&D projects with several aggregates of science and technology spending aggregates--for example, the share of large R&D projects in all civilian R&D. Finally, the four measures of spending for large R&D projects are compared with a time series of domestic discretionary spending.

MEASURES OF SPENDING FOR LARGE R&D PROJECTS IN THE BUDGET

The four different budgetary measures of large R&D projects are:

- An inventory of projects that includes all those defined as large by arbitrary criteria;

- A "largest projects" measure that includes only the three R&D projects receiving the most funding in a given year;

- A "fields of research" measure including all spending in scientific and technical fields dominated by large instruments;

- An "R&D structures" measure that includes only plant and equipment spending.

The four measures all rely, for the most part, on readily available sources of data. Table 3 presents the dollar value of each measure for 1980 through 1996. Three of the measures are in terms of budget authority, which is most directly under

TABLE 3. MEASURES OF SPENDING FOR LARGE CIVILIAN R&D PROJECTS
(Budget Authority, in billions of current dollars)

Year	Inventory of Large Projects[a]	Largest Three Projects[b]	Fields of Research[c]	R&D Plant[d]
1980	3.6	2.6	5.6	1.0
1981	4.0	3.0	6.0	0.9
1982	3.6	2.5	5.5	0.7
1983	5.0	4.0	4.7	0.6
1984	1.6	0.5	5.1	0.8
1985	1.9	0.6	5.4	0.9
1986	1.8	0.5	5.4	0.9
1987	2.1	0.7	5.7	1.0
1988	2.2	0.7	6.2	1.2
1989	2.9	1.2	7.5	1.3
1990	4.0	2.1	9.4	1.9
1991	4.6	2.4	10.9	1.8
1992	5.7[e]	2.9[e]		
1993	6.6[e]	3.7[e]		
1994	7.3[e]	4.6[e]		
1995	8.0[e]	5.4[e]		
1996	8.4[e]	5.9[e]		

SOURCE: Congressional Budget Office.

a. Includes nondefense science projects costing more than $25 million in 1984 dollars of budget authority.

b. Consists of the three largest projects in the inventory in any given year, measured in budget authority.

c. Includes areas of research dominated by large instruments, measured in budget authority.

d. Includes federal spending on structures and large equipment, measured in obligations.

e. Requested in the President's budget for 1992.

the control of policymakers, rather than outlays that reflect nonpolicy developments such as delays caused by technical and contractual factors. (The major exception is the R&D structures measure, for which data are available only in obligations.)

The CBO Inventory of Large Projects

CBO assembled a list of 80 large R&D projects and facilities that built upon a list made by William C. Boesman.[7] The Boesman inventory includes science and engineering research projects requiring complex and expensive equipment and costing over $25 million in 1984 dollars. It is based on research disciplines, such as astronomy or biology. By contrast, CBO's inventory is focused on the budget functions for General Science, Space and Technology (function 250) and Energy (function 270). These budget functions include most of the spending for science and technology by the Department of Energy (DOE), the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF). Health research, the largest part of civilian R&D not included in functions 250 and 270, is for the most part treated separately (see box).

Since the public debate is largely focused on the role of big projects in civilian R&D, CBO excluded big projects in both the Department of Defense and the defense-nuclear R&D portion of the DOE budget. CBO's inventory also differs from Boesman's in its treatment of NASA projects. To recognize the substantially higher cost of scientific and technical efforts in space, CBO's inventory includes the space shuttle in its development phase and only the largest or "facilities class" projects as NASA refers to them.

A drawback to the inventory approach is that it includes general-purpose equipment with wide applications--for example, supercomputers--that facilitate both large and small science and technology efforts. The threshold level of $25 million (in 1984 dollars) Boesman used, which was adopted for much of the CBO inventory, can also be criticized as too low and arbitrary. However, the three largest projects measure compensates for the threshold problem by excluding many R&D projects that are clearly recognized as large R&D efforts.

NSF Projects. The NSF projects include, but are not limited to, the Boesman inventory of big-science instruments. The annual data cover spending on these facilities during 1980 through 1995 and include both construction and operation costs. CBO projected spending on these projects forward to 1996 (see Table 4).

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7. William Boesman, *World Inventory of "Big Science" Research Instruments and Facilities*, Congressional Research Service (December 1986), reprinted in U.S. House of Representatives, Committee on Science and Technology, *Science Policy Study; Background Report No. 4 (1987).*

The Human Genome Project

The Human Genome Project (HGP) is a 15-year program to assemble the genetic master plan of human beings, carried on jointly by the National Institutes of Health (NIH) and the Department of Energy (DOE). NIH's rationale for participation is that the effort will provide "new strategies to diagnose, treat and possibly prevent human diseases." DOE's participation is consistent with its mission to study the effects of radiation on humans, and with the computational and technical capabilities of its laboratories.

This paper focuses on budget functions 250 and 270, while the HGP is funded under the budget subfunction for Health Research (552). The HGP is often included with the space station, the Earth Observation System, and the Superconducting Super Collider as one of the "big science" projects of the 1990s. Total cost of the project over 15 years is estimated at about $3 billion (in 1991 dollars), and over $4 billion when adjusted for anticipated increases in the cost of biomedical research. In 1991 the project was funded at a level of $135 million, with $87 million from NIH--an amount equal to 1 percent of its budget.

The HGP has some of the attributes of other large science efforts, most obviously its total cost and long life cycle. It also is a departure from the kind of investigator-initiated research more commonly supported by NIH funding. The project is more centrally coordinated, and some would argue more bureaucratic, than other NIH projects: a research agenda is specified from the top, and investigators are invited to respond. Funds will be allocated to multidisciplinary centers, although about half of the project's spending through 1995 will be directed to individual laboratories and single investigators in the typical manner of biomedical research. It will differ from other NIH projects in that a significant proportion of funds, over 10 percent, will be devoted to technology development. As with the SSC, some key project objectives will require anticipated, but as yet unachieved, technology development.

A major difference between the HGP and other large R&D projects is that the hardware and facilities play a relatively small role in accomplishing project objectives and accounting for project cost. The space station and the SSC require the development of hardware to achieve even minimum objectives. The mission of the SSC, for example, cannot be accomplished by building half of a particle accelerator. The HGP can proceed in a more piecemeal fashion even though the project aspires to a complete mapping and sequencing of the human genome. (The EOS is also a large-hardware project, although less so than the space station or the SSC.)

The HGP also differs from the typical large R&D project in that it will not necessarily dominate the field of research it supports. NIH will be devoting far more of its funds to research related to specific diseases, and genetic therapies are likely to be pursued in many of these programs. NIH spending on research for cancer and AIDS in 1991 was over five times greater in each case than that for the HGP. Even in its peak years anticipated spending for the HGP will not approach the share their agencies' funds accounted for by the three largest federally sponsored R&D projects. Under current plans, the space station and EOS would account for 10 percent and 7 percent of function 250 budget authority in 1995--$2.6 billion and 1.7 billion respectively--while the HGP would account for less than 2 percent of the subfunction 552 in the same year, an anticipated expenditure of $260 million.

The HGP has attributes of big science and some say it may be the precursor of a move toward big science in molecular biology. Yet it differs from the projects classified as big science in budget functions 250 and 270 more than it resembles them.

TABLE 4. NATIONAL SCIENCE FOUNDATION PROJECTS INCLUDED IN THE CBO INVENTORY

Physics

Cornell Electron Storage Ring

Coupled Superconducting Cyclotrons at National Superconducting Cyclotron Laboratory

Indiana University Cyclotron Facility

Long Interferometry Gravity Observatory

Computing Facilities

National Center for Atmospheric Research Scientific Computing Facility

Advanced Supercomputing Centers

NSFNet Computer Network

Magnet Laboratories

Bitter National Magnet Laboratory

Astronomy

National Astronomy and Ionosphere Center Observatories

National Optical Astronomy Observatory

National Radio Astronomy Observatories

Geosciences

Federal Oceanographic Research Fleet

Ocean Drilling Program

Source : Congressional Budget Office.

DOE Projects. Like those of the NSF, the DOE projects are not limited to projects in the Boesman inventory (see Table 5). Most notably, CBO's inventory includes spending for major projects, such as the Isabelle particle accelerator, that were never completed and that were excluded from the Boesman inventory. Also included are projects that are more technological than scientific (such as the Clinch River Breeder Reactor and the Clean Coal Technology Program). DOE provided annual data on its large R&D projects for the 1980-1996 period.

NASA Projects. NASA's large R&D projects dominate most data series measuring large R&D projects in the budget. This dominance holds even if technology projects--for example, the shuttle--are excluded from the inventory. As a group, NASA projects are more expensive than the projects sponsored by all other agencies combined (see Table 6). On a per project basis, average total development spending is almost $600 million for the NASA projects with two or more years of spending that are included in the CBO inventory for 1980 through 1992. For each project in the data set, costs are defined to include development and operations, but not the cost of federal employees, construction of facilities, or space launches.

The Three Largest Projects

This measure of large R&D in the budget includes only the very largest projects--sometimes called megaprojects. For the most part the list consists of the three largest projects funded in functions 250 and 270. In one comparison, however, a fourth project--the Human Genome--is added, to address directly the public concern that the Human Genome and several other very large projects--the space station, the Superconducting Super Collider and the Earth Observation System--will be funded at the expense of many smaller efforts.

The largest project measure is easily constructed, but suffers from several limitations. The same projects need not be the largest year after year. With the exception of the early 1980s, however, the list of largest projects exhibits a reasonable degree of consistency (see Table 7). A second limitation of the largest project measure is its failure to take account of size differences among the largest projects. A glance at the data shows that the multibillion-dollar space shuttle program during the early 1980s, and spending projected for the largest projects--by both NASA and DOE--during the first half of the 1990s, are in a different class from all other projects.

This measure was constructed for the 1980-1991 period using the data from the inventory described above. The series was projected forward through 1996 on the basis of forecasted costs for the three largest planned efforts--the space station, the Earth Observation System, and the Superconducting Super Collider.

The Space Station. The space station is currently the most expensive of the proposed large R&D projects. If the Congress accepts the President's request for 1992, total spending on the project will exceed $7.5 billion through 1992. Additional spending

TABLE 5. DEPARTMENT OF ENERGY PROJECTS INCLUDED IN THE CBO INVENTORY

High Energy Physics Facilities

Energy Saver	Tevatron I
Tevatron II	Collider Detector at Fermilab
D-Zero Detector at Fermilab	Stanford Linear Detector
Stanford Linear Accelerator Center	Isabelle Accelerator
Stanford Linear Collider	

Nuclear Physics Facilities

Tandem/AGS Heavy Ion Facility	Argonne Tandem/Linac Accelerator System
BEVALAC accelerator	88-inch Cyclotron
Los Alamos Meson Physics Facility	Holifield Heavy Ion Facility
Bates Linear Accelerator Center	Cyclotron Institute
Continuous Electron Beam Accelerator Facility	Relativistic Heavy Ion Colliding Beam Accelerator

Fusion Facilities

Princeton Large Torus	Princeton Beta Experiment
Tokamak Fusion Test Reactor	Burning Plasma Experiment
International Thermonuclear Experimental Reactor	Doublet III-D
ALCATOR-C	Tandem Mirror Experiment Upgrade
Mirror Fusion Test Facility	Advanced Toroidal Facility
International Fusion Superconducting Magnetic Test Facility	

Material Science and Engineering Facilities

Stanford Synchrotron Radiation Laboratory	High Flux Beam Reactor
High Flux Isotope Reactor	6-7 GEV Synchrotron Light Source
1-2 GEV Synchrotron Light Source	National Synchrotron Light Source

Supercomputer Facilities

National Energy Research Supercomputer Center	Los Alamos National Laboratories Computing and Communications Division (civil only)

Engineering Facilities

Fast Flux Test Facility	Experimental Breeder Reactor I
Loss-of-Fluid Test Facility	Transient Reactor Test Facility
Zero Power Plutonium Reactor	Calutrons Electromagnetic Isotope Separations Facility
Fuel and Material Examination Facility	Clinch River Breeder Reactor
Clean Coal Technology	

SOURCE: Congressional Budget Office.

TABLE 6. NATIONAL AERONAUTICS AND SPACE ADMINISTRATION PROJECTS INCLUDED IN THE CBO INVENTORY

Space Transportation and Orbital Facilities Development

Space Shuttle
Tethered Satellite
Space Lab
Space Station

Physics and Astronomy

Hubble Space Telescope
Advanced X-Ray Astrophysics Facility
Gamma Ray Observatory
High Energy Astronomy Observatory

Planetary and Solar Missions

Ulysses
Magellan
Pioneer
Galileo
Voyager
Mars Observer
Comet Rendezvous Asteroid Flyby/Cassini

Earth Science and Observation

Upper Atmospheric Research Satellite
Earth Observation System
Ocean Topographic Experiment
Landsat D

Communication

Advanced Communication Technology Satellites

SOURCE: Congressional Budget Office.

TABLE 7. THE THREE LARGEST PROJECTS, 1980 - 1996

1980	Space Shuttle	Clinch River Breeder Reactor	Galileo
1981	Space Shuttle	Clinch River Breeder Reactor	Spacelab
1982	Space Shuttle	Clinch River Breeder Reactor	Hubble Space Telescope
1983	Space Shuttle	Hubble Space Telescope	Clinch River Breeder Reactor
1984	Hubble Space Telescope	Clinch River Breeder Reactor	Spacelab
1985	Hubble Space Telescope	Gamma Ray Observatory	Space Station
1986	Hubble Space Telescope	Space Station	Upper Atmospheric Research Satellite
1987	Hubble Space Telescope	Space Station	Magellan
1988	Space Station	Hubble Space Telescope	Stanford Linear Accelerator Center
1989	Space Station	Hubble Space Telescope	Stanford Linear Accelerator Center
1990	Space Station	Hubble Space Telescope	Superconducting Super Collider
1991	Space Station	Hubble Space Telescope	Superconducting Super Collider
1992	Space Station	Superconducting Super Collider	Earth Observation System
1993	Space Station	Superconducting Super Collider	Earth Observation System
1994	Space Station	Superconducting Super Collider	Earth Observation System
1995	Space Station	Earth Observation System	Superconducting Super Collider
1996	Space Station	Earth Observation System	Superconducting Super Collider

SOURCE: Congressional Budget Office

of about $30 billion could be required through the end of the century, according to NASA's most recent plan for the project. One can argue that the station, like the shuttle system, is not science but a technology program that is only tangentially scientific.[8] It is included in the largest project group because it is directly relevant to other NASA science spending. This point has been made emphatically in current Congressional action on NASA's fiscal year 1992 appropriation, in which House action has funded the space station by freezing science spending in NASA.

The Earth Observation System (EOS). This system features a set of large space platforms, several smaller satellites, a ground-based information system, and a supporting research program. The system is part of a larger effort called Mission to Planet Earth, which adds to EOS a set of smaller satellites, called Earth Probes, and several medium-sized satellites already far along in development but not yet launched. The cost of the EOS is estimated to be $17 billion thorough fiscal year 2000, and as much as $30 billion over the life of the project. The Mission to Planet Earth is itself part of a larger budgetary aggregate called the Global Change Research Program, for which the 1992 budget request included a 24 percent increase to $1.2 billion. Only the funds for EOS proper are included in the largest project series.

The Superconducting Super Collider (SSC). The SSC is a particle accelerator to be built in Texas. The 54-mile racetrack-shaped facility is designed to allow high-energy physicists to discover unknown particles in their investigation of the fundamental structure of matter. Official estimates place its cost at $8.2 billion, but analysts both inside and outside DOE argue that the cost could approach $12 billion. Administration plans call for $5.9 billion to be spent on the SSC through 1996, with $534 million requested for 1992. The Administration currently estimates that nonfederal sources will finance $2.6 billion of the total costs. The state of Texas has committed $1 billion, of which a portion will be spent on in-state activities not included in the SSC total project costs. DOE has not been successful in getting commitments from other countries for more than a small fraction of the remainder. Because of the uncertainties as to the foreign contributions, CBO used the total estimated SSC costs of $8.2 billion, less the net Texas contribution, in its calculations.

Other largest-projects series were constructed for specific agencies to take account of similar resource concentrations within subsets of science and technology spending.

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8. Concerning the space station in particular, the claim that the project serves no scientific purpose is rejected by the defenders of the effort. For example, Richard Darman, director of the Office of Management and Budget, holds that the argument that space exploration and the space station are not of value to science is incorrect because it ignores the "extent to which exploration can enable, stimulate and inspire science." Statement by Richard Darman before the Committee on Science, Space and Technology of the House of Representatives, June 4, 1991.

Fields of Research

The fields-of-research measure of large R&D embraces all of the spending for a research field that is dominated by big instruments or facilities. For example, the cost of building and operating particle accelerators has dominated high-energy physics spending. Most of the research in this field relies on the results of experiments using accelerators that are included in the large R&D project inventory, even if funding of particular research is not directly tied to funding for a particle accelerator.[9] The rationale for the fields-of-research measure is that the institutions that control large instruments or facilities tend to drive the research in such fields. A strength of the measure is that it can reflect the position of fields that are small in budgetary terms yet dominated by large instruments. Its corresponding weakness is its failure to capture the interaction between areas of research--for example, the effects of developing the space shuttle on disciplinary funding in the NSF. An additional problem with the fields-of-research measure is that not all research in every funding category dominated by large instruments is related to these instruments. Consequently, it is by far the largest of the measures (see Table 3).

The R&D Plant Approach

A final measure of large R&D projects focuses on spending for the R&D plant--the building, equipping, and maintaining of facilities--as a defining characteristic of large R&D. This approach is potentially useful in examining the claim that spending for R&D is undertaken not only to further science and technology objectives, but also to provide the local and immediate benefits of construction. A drawback of the series is that it does not provide a consistent measure of large R&D projects: DOE's big projects, for instance, have a larger element of construction in them than do NASA's, which are dominated by development costs. DOE's plant share averages close to 15 percent of all its R&D, while NASA's average is no more than half that.[10] In addition, funds for maintenance as an activity, like funds for small R&D efforts, may be traded off against development funds for large projects if fiscal constraints are present.

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9. For instance, a theoretical physicist may take published reports of empirical work from a large accelerator, make theoretical refinements, and put forward a hypothesis that requires yet another large instrument to test. In some sense, the existence of an active field justifies spending on big instruments.

10. In addition, some DOE projects are covered by cooperative agreements with nonfederal entities. Such projects, most notably the Clinch River Breeder Reactor, are not included in the R&D plant series.

SPENDING AGGREGATES

CBO used two types of aggregate spending measures in its analysis of historical and projected trends in the various measures of large R&D projects; these are the denominators in the ratios discussed in the next chapter. The first type of aggregate includes three time series for science spending:

- All civilian R&D budget authority;
- Functions 250 and 270 budget authority; and
- Agency budget authority.

Two alternative projections of these aggregates are used for the period 1992 through 1996, one set based on the President's budget request and the other on the CBO baseline.[11] The second type of aggregate is a single measure of the broad class of spending of which science spending is a part: domestic discretionary spending.

All Civilian R&D

Civilian R&D is the conventional base against which to compare spending for large R&D projects. CBO's measures for the 1980s and early 1990s include both operations and construction. CBO estimated civilian R&D spending in the President's request for 1992 through 1996, based on the projected growth of the budget functions and agencies undertaking R&D that were included in the request.

Function 250 and 270 Budget Authority

Functions 250 and 270 account for most federal civilian R&D outside of the biomedical fields. Function 250 is the general science, space and technology function; 270 accounts for energy. These functions include the agencies that fund most of the R&D outside health and defense: the Department of Energy's civilian R&D, the National Aeronautics and Space Administration's nonaeronautical R&D; and all of the National Science Foundation's R&D. Most important, the major large instrument projects all are contained within these two functions, most of them within function 250. The major drawback of this series is that it contains many NASA and

11. The Administration and CBO projections of spending in these categories differ substantially. The Administration projections include funding for its menu of programs, whereas CBO's is a baseline projection that provides just enough additional funds to compensate for inflation, thus maintaining a fixed level of real resources committed to an area. In the case of function 250 (General Science, Space and Technology), by 1996 the Administration's program is 25 percent higher than CBO's baseline. In the case of the energy function (270), the Administration wants to shift resources out of these programs, and consequently its forecast for 270 is 25 percent lower than the CBO baseline.

DOE non-R&D operations. In fact, NASA non-R&D operations account for between a third and a half of the function 250 series.

Agency Budget Authority

Because agencies are in charge of administering these programs, a comparison of how the projects fare in terms of annual agency budgets over time can show their effect on agency priorities. The agencies examined in this paper are NSF, DOE, and NASA. In keeping with the paper's focus on civilian R&D, only DOE's civilian budget authority is presented. DOE budget authority is also presented in net terms, because some DOE activities generate receipts--for example, the power marketing authorities.

Domestic Discretionary Budget Authority

Finally, the paper compares spending for large R&D projects with domestic discretionary spending to show the relation between this and other types of federal spending in the past (and, for the Administration's proposed program, in the first half of the 1990s). Because a historical data series for domestic discretionary budget authority is not readily available, CBO used outlay data to estimate domestic discretionary budget authority for 1980 - 1990 (see Appendix). The projected series for 1992 through 1996 is CBO's reestimate of the President's budget request for domestic discretionary budget authority. This series conforms closely to the caps for domestic spending mandated under the Budget Enforcement Act of 1990 for fiscal years 1992 and 1993, and is consistent with the caps on all discretionary spending through 1995.[12]

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12. The Budget Enforcement Act of 1990 created three categories of discretionary spending: domestic, defense, and international. After 1993, the caps that the act imposed on each category separately will be merged into a unified cap for the three categories as a whole.

CHAPTER III
COMPARING PAST AND PROJECTED SPENDING ON LARGE CIVILIAN R&D PROJECTS

If the Congress adopts the Administration's spending plan for the 1990s, the share of civilian R&D accounted for by the three largest projects will double, rising to 15 percent by 1996. The three projects will increase their share of all domestic discretionary spending from 1.1 percent in 1990 to almost 3 percent by 1996. Under the Administration's plan, increased spending for large projects will be accompanied by real growth in other R&D spending. A comparable peak in spending on large R&D projects occurred in the early 1980s, but at that time other R&D spending did not increase. If the Congress does not fully fund the Administration's program, choices will have to be made once again between large R&D projects and all other R&D.

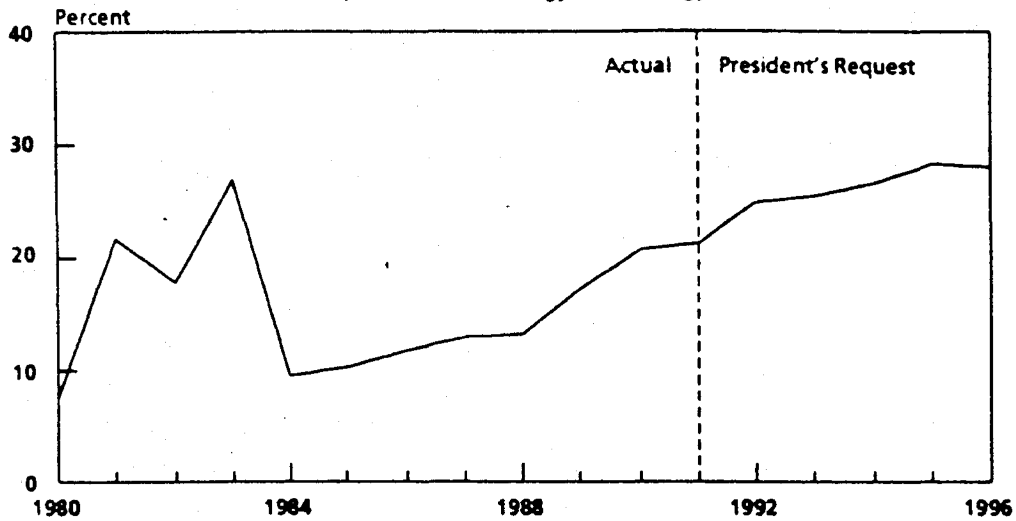
THE TREND IN THE 1980s

Spending on large civilian R&D projects, led by the NASA space shuttle, reached its peak in relation to all nondefense R&D project spending early in the 1980s. At its peak, the inventory of large R&D projects accounted for over a third of all civilian R&D spending (see Figure 2). The three largest projects received just over a quarter of the budget authority granted to civilian R&D (see Figure 3). The final years of R&D funding for the space shuttle during the early 1980s dominate both measures, accounting for over 95 percent of budget authority for the three largest projects. This peak occurred at a time when all civilian R&D was rising only slowly and when combined budget authority for functions 250 and 270 was falling (a consequence of the shift away from energy as a national priority).

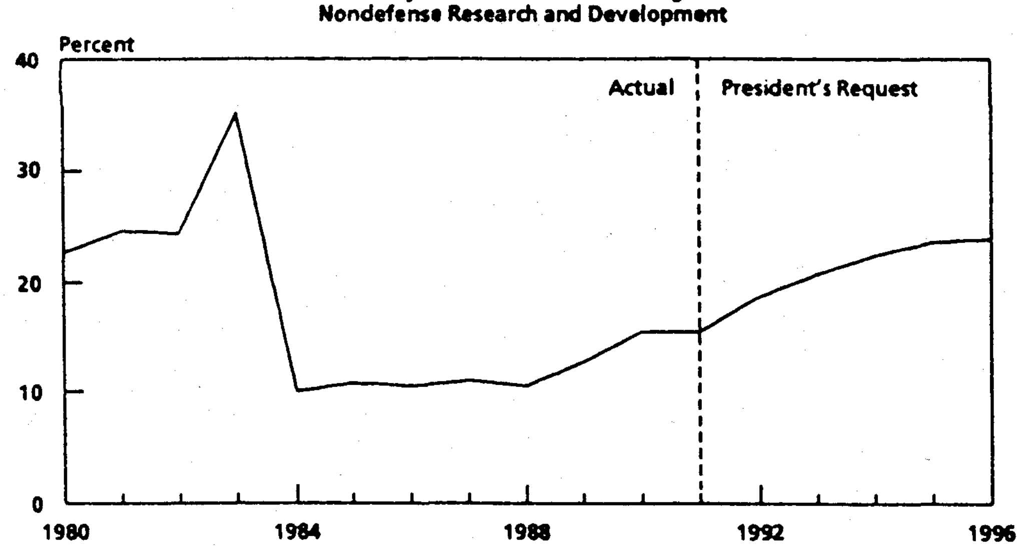
A somewhat different picture is presented if one removes spending on the space shuttle from the comparison. Recent data for R&D spending in the early 1980s no longer include the last several years of spending on development for the shuttle on the basis that the shuttle was not so much an R&D project as an engineering project and a capital investment in technology likely to serve defense and commercial interests as well as the scientific community. Removing the shuttle from the CBO inventory data series, as in Figure 4, results in a steady increase in the share of large R&D project spending throughout the 1980s, without a sharp spike early in the decade. The shuttle influence is present nevertheless; the increase is driven by NASA spacecraft development projects that proliferated and grew as the budgetary resources devoted to the shuttle stabilized. CBO retained spending on the shuttle in its measures of large R&D projects during the early 1980s, because development spending for the shuttle is comparable to that for the space station in the early 1990s, which is currently included in published R&D data series. Moreover, the shuttle is the large R&D project most prominently cited as having crowded out other activities.

Figure 2.
Spending on Large Research and Development Projects (Inventory Measure)as a Percentage of Budget Functions for General Science,Space and Technology, and Energy and of Nondefense Research and Development, 1980-1996

Inventory Measure as a Percentage of Budget Functions for General Science, Space and Technology, and Energy



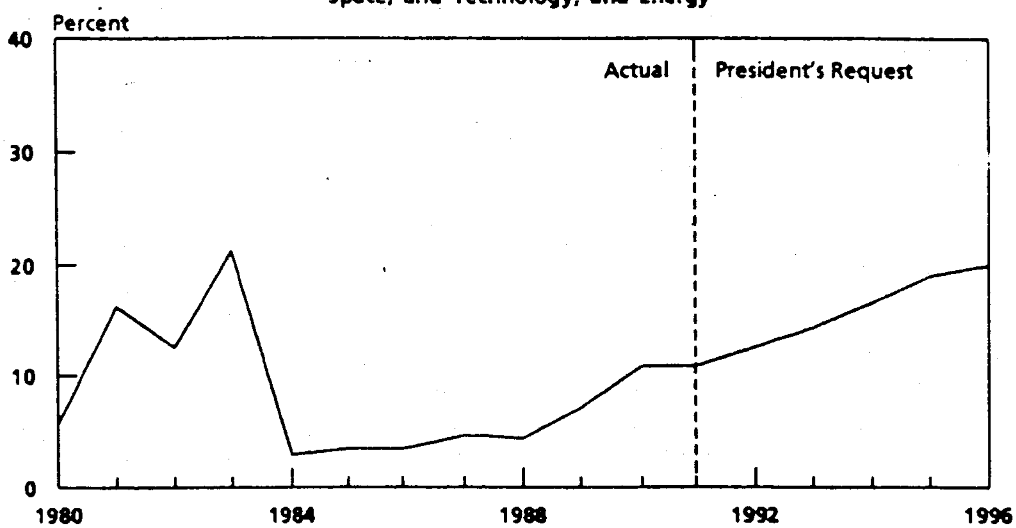
Inventory Measure as a Percentage of Nondefense Research and Development



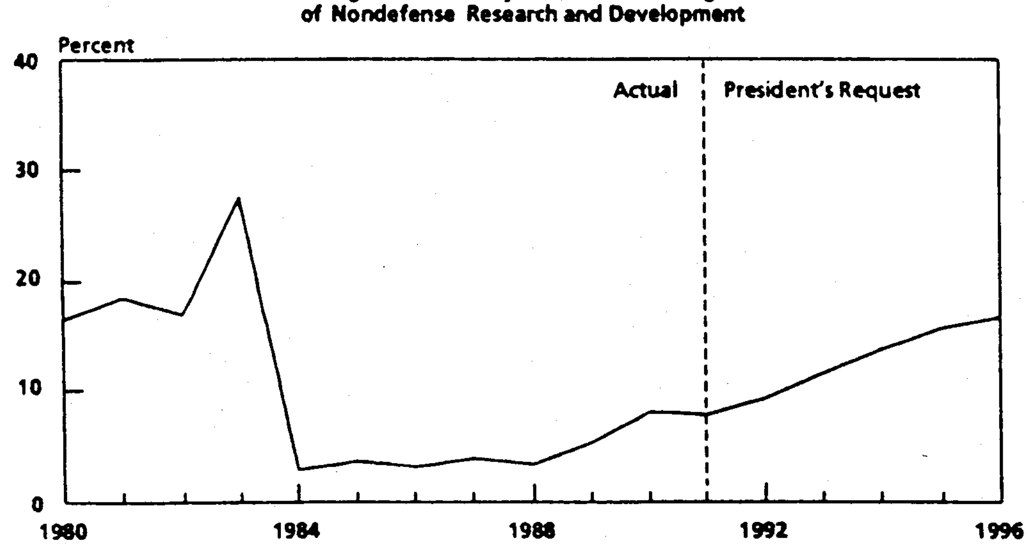
SOURCE: Congressional Budget Office.

Figure 3.
Spending on the Largest Three Research and Development Projects as a Percentage of Budget Functions for General Science, Space and Technology, and Energy and of Nondefense Research and Development, 1980-1996

Largest Three Projects as a Percentage of Budget Functions for General Science, Space, and Technology, and Energy

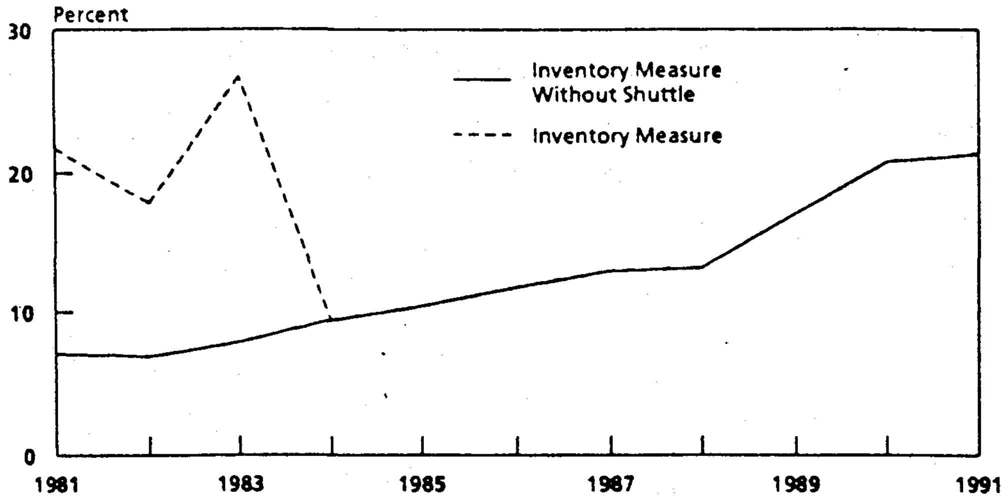


Largest Three Projects as a Percentage of Nondefense Research and Development



SOURCE: Congressional Budget Office.

Figure 4.
Effects of the Space Shuttle on the Inventory Measure of Large Research and Development Spending, 1981-1991



SOURCE: Congressional Budget Office.

Other measures of large R&D project spending tell the same story from a different perspective. In the first three years of the 1980s, the share of agency-level research and development accounted for by R&D plant fell for DOE, NASA, and NSF (see Figure 5). In NASA's case, the priority granted the shuttle probably explains this decline. In the case of DOE, the decline probably reflects downsizing of the overall national R&D effort in the energy field. Beginning in 1984, however, the share of each agency's R&D accounted for by plant began to move upward--a trend that has continued. The research field measure of large R&D project spending also ended the decade of the 1980s on the rise, but only after a longer period of decline than any of the other three measures (see Figure 6).

PROJECTIONS FOR THE 1990s

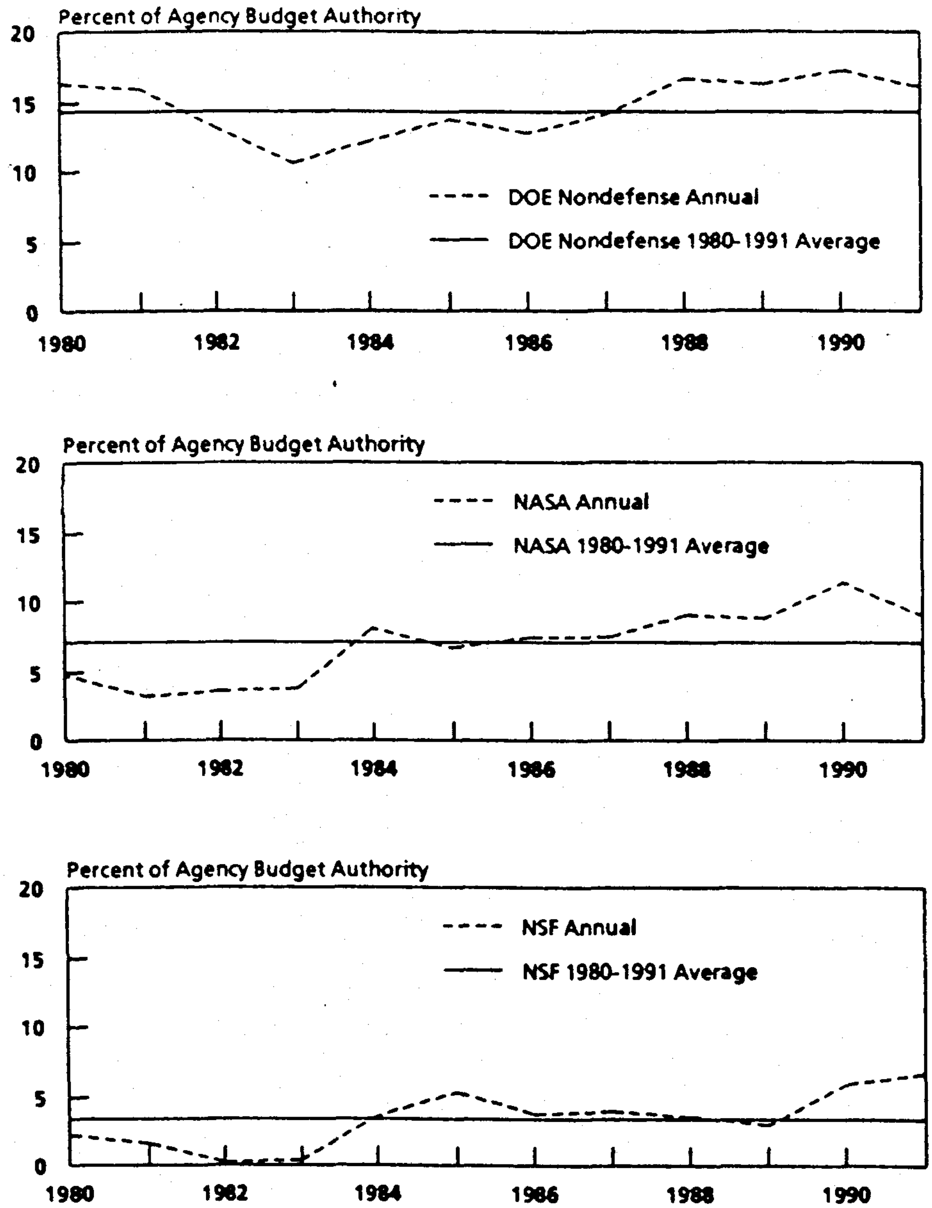
If the Administration's program is enacted, large R&D projects would consume an increasing share of domestic discretionary spending during the first half of the 1990s. By the inventory measure, the share of big R&D projects would increase from 2 percent of all domestic discretionary budget authority in 1990 to almost 4 percent of all such spending in 1996 (see Figure 7). The very largest projects would enjoy an even greater increase in their share: the three biggest science and technology projects would see their share more than double from 1.1 percent to 2.8 percent of all domestic discretionary spending.

The largest three projects would also see an increase in their share of civilian R&D, even though planned spending for civilian R&D would be rising overall (see Figure 8). In 1990, the three largest projects accounted for slightly more than 8 percent of civilian R&D, but by 1996 they would account for over 15 percent.[13] The inventory measure would experience a similar rise from 16 percent to 22 percent of civilian R&D. Equally dramatic as an indicator of the increasing share of large R&D projects in science and technology funding is the projected increase of the largest three projects' share of budget function 250 (General Science, Space and Technology) to 24 percent in 1996. The similarity of patterns among these different aggregates indicates strongly that under the Administration's program large R&D projects would occupy an increasing share of an increasing part of the budget.

On an agency basis, the large R&D projects are also projected to show an increase in their share of budget authority. The three largest NASA projects would take as much as a quarter of the agency's budget, though this would still be much less than in the early 1980s when the shuttle was being developed. At that time, large projects required half of NASA resources. The largest DOE projects, led by the SSC, would almost triple their share of DOE budget authority between 1990 and 1996,

13. If planned spending for the Human Genome project is added to that for the three largest projects in CBO's inventory, by 1996 the Human Genome, the space station, the Superconducting Super Collider, and the Earth Observation System would account for 16 percent of projected spending for civilian R&D.

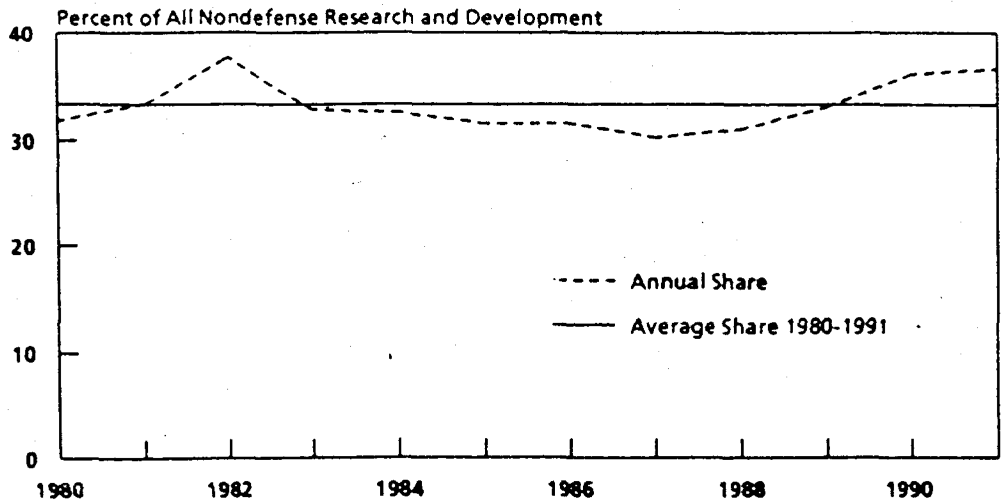
Figure 5.
Spending on Research and Development Plant
by Three Agencies, 1980-1991



SOURCE: Congressional Budget Office.

NOTE: DOE = Department of Energy; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation.

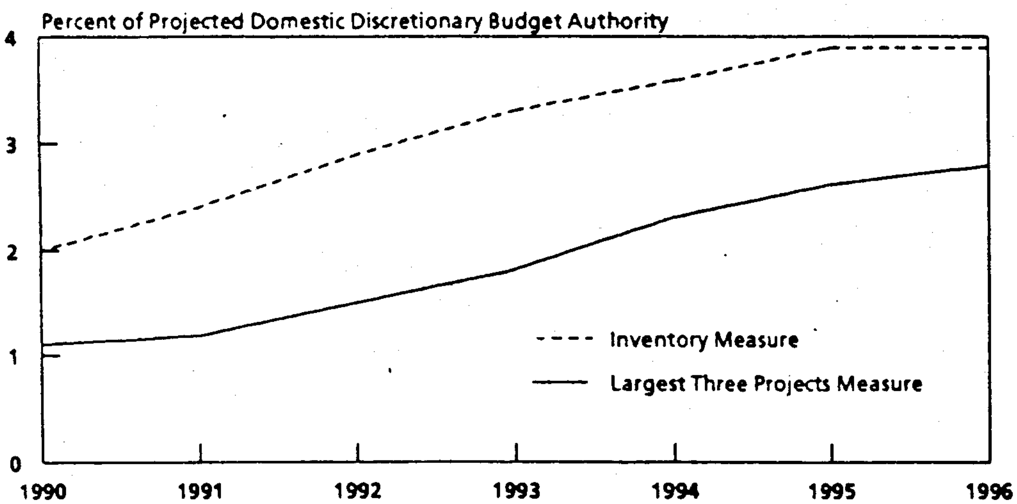
Figure 6.
Spending on Fields of Research Dominated by Large Instruments and Facilities as a Percentage of All Nondefense Research and Development, 1980-1991



SOURCE: Congressional Budget Office.

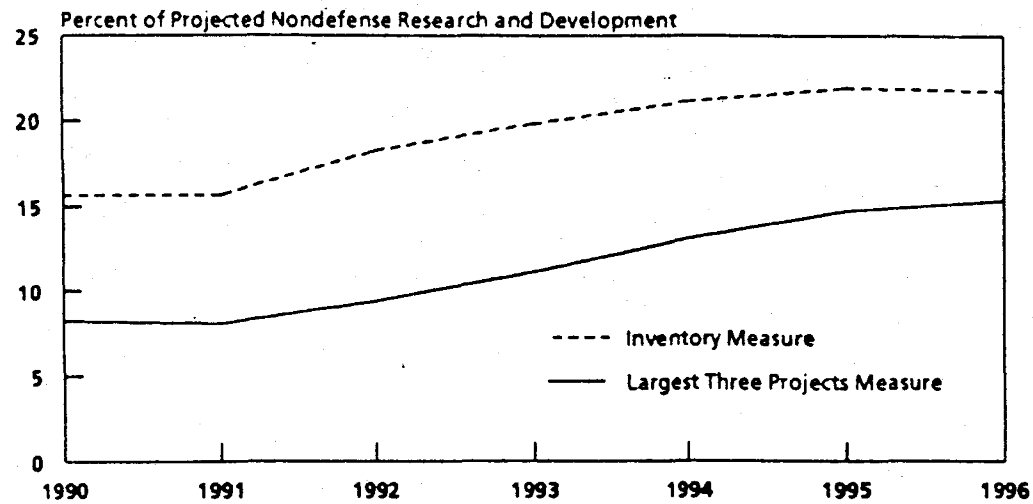
NOTE: The fields-of-research measure of large research and development embraces all of the spending for research fields dominated by big instruments or facilities.

Figure 7.
President's Request for Spending on Large Nondefense Research and Development Projects as a Percentage of Domestic Discretionary Budget Authority, 1990-1996



SOURCE: Congressional Budget Office.

Figure 8.
President's Request for Spending on Large Nondefense Research and Development Projects as a Percentage of All Nondefense Research and Development Spending, 1990-1996



SOURCE: Congressional Budget Office.

absorbing 28 percent of budget authority by 1996 (see Table 8). The share of NSF funds consumed by their inventory of large projects is projected to remain constant at roughly 15 percent.

The increase in the share of the biggest projects is partly accounted for by their growth in absolute terms. Budget authority for the largest three projects is projected to grow at an average rate of 14 percent a year through 1996 even after adjusting for inflation. The broader inventory measure registers a more modest 9 percent real growth a year during the 1990-1996 period (see Table 9).[14] Even at its height in 1996, however, the inflation-adjusted spending projected for the largest three programs would be less than what was spent on the largest three programs in 1983.

In absolute terms, the increases for the largest NASA projects would be much larger than those for DOE projects. NASA's three largest projects would increase in annual budget authority by $3.1 billion between 1990 and 1996, rising from $2:0 billion in 1990 to $5.1 billion in 1996. DOE's three largest projects would increase by less than one-third that amount, or $0.9 billion, to reach $1.4 billion in 1996. The more comprehensive DOE inventory of large projects would rise by roughly $1.2 billion over the same period.

CBO's budgetary measures of large R&D project spending use the cost forecasts the sponsoring agencies provide. Should these prove optimistic, then the Congress will face difficult choices. Under the Budget Enforcement Act, spending to cover overruns and maintain project schedules must come from reductions in other domestic spending. Reducing other domestic spending unrelated to science and technology would grant even higher priority to the area than that proposed by the Administration. Fully funding overruns so as to maintain project schedules for large R&D projects at the expense of other science spending would repeat what appears to have happened in the early 1980s. This would be the outcome most feared by those in the scientific community not directly associated with the largest projects. An internal DOE evaluation placing the total cost of the Superconducting Super Collider at almost 45 percent above the official estimate of $8.2 billion illustrates the possible magnitude of overruns in large projects.[15] Similarly, the General Accounting Office has questioned NASA's current cost estimate for its space station program.[16]

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14. Some part of the difference in inflation-adjusted growth rates is an artifact of CBO's choice of projects for the inventory. Upcoming projects may have been overlooked.

15. Department of Energy, Independent Cost Estimating Staff, "Independent Cost Estimate for the Superconducting Super Collider" (September 1990).

16. Statement of Charles A. Bowsher before the Subcommittee on Government Activities and Transportation of the House Committee on Government Operations, May 1, 1991.

TABLE 8. Large Civilian R&D Project Share of Agency Budgets (In percent)

	1990	1991	1992	1993	1994	1995	1996
Three Largest DOE Civilian Projects	10	9	17	22	25	25	28
Three Largest NASA Projects	16	16	17	19	22	24	25

SOURCE: Congressional Budget Office.

NOTE: DOE = Department of Energy
NASA = National Aeronautics and Space Administration

TABLE 9. Inflation-Adjusted Spending on Large Civilian R&D Projects (Budget Authority, in billions of 1990 dollars)

	1990	1991	1992	1993	1994	1995	1996
Inventory	4.0	4.4	5.3	5.8	6.3	6.7	6.8
Three Largest Projects	2.1	2.3	2.7	3.3	3.9	4.5	4.8

SOURCE: Congressional Budget Office.

A similar situation could develop if the Congress chooses to fund General Science, Space and Technology (function 250) at levels below the Administration's plan and, at the same time, funds the largest projects at their planned levels. For example, funding the largest projects as planned with function 250 restricted to the CBO baseline--the 1991 level increased for projected inflation only--reduces funds available for other science and technology activities to $5 billion below the Administration's plan by 1996 (see Figure 9). Were spending for function 250 even more restricted to a freeze at its 1991 level, and the largest projects funded as planned, the funds remaining for other activities within function 250 would be almost $9 billion less than the Administration has proposed for 1996. In the past such restrictions on spending might have been less likely. The Budget Enforcement Act, however, maintains discretionary spending at levels between a freeze and the CBO baseline through 1995, implying that at least some types of domestic spending will be frozen or actually decline over the period.

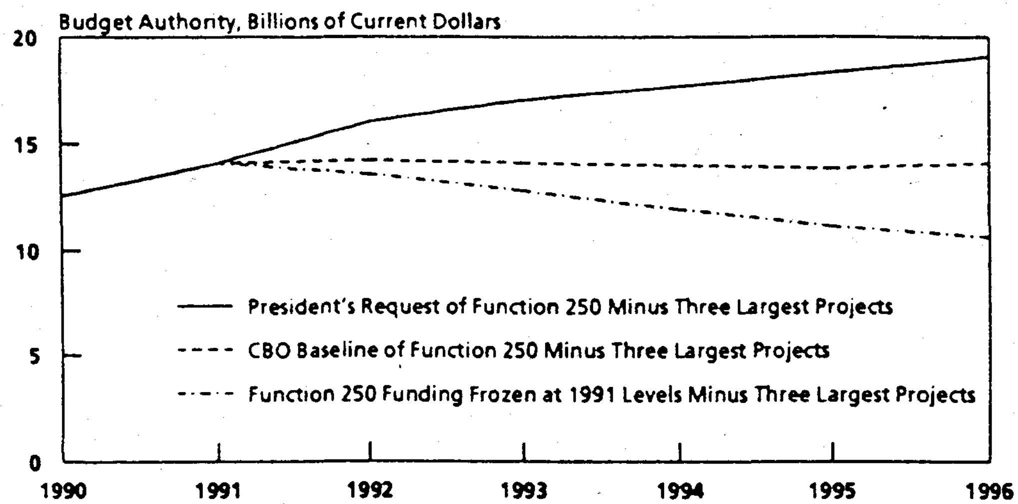
LARGE CIVILIAN R&D PROJECTS AND OTHER SPENDING

A comparison of large R&D project spending in the early 1980s with that projected for the middle 1990s shows differences in the relationship between funding for large projects and for other purposes. In the early 1980s, the data support the impression that the shuttle and other large R&D projects were funded at the expense of the remainder of R&D spending. Neither the budget functions supporting science and technology spending, nor the science and technology agencies' budgets, were on the increase in the first three years of the 1980s (see Table 10). Budget authority for domestic discretionary spending as a whole was essentially flat during the period. Thus, large R&D project spending, measured by the inventory and largest projects methods, took up for a larger share of the budget functions supporting science and technology at the same time that these functions were being allotted a smaller share of a roughly constant level of domestic discretionary spending.

The relationship between the space shuttle and other NASA projects is the most dramatic instance of a large R&D project crowding out other R&D spending in the 1980s. As the American Association for the Advancement of Science (AAAS) noted in its review of the R&D budget for 1983, "funding requirements for the space shuttle have been large and growing, but the rest of NASA's budget has been subjected to an increasingly tighter squeeze."[17] As the AAAS describes the situation, the Office of Management and Budget, when dealing with the unanticipated increases in the cost of the shuttle system in a tighter than expected fiscal environment, considered NASA's program as consisting of two parts--the shuttle and other spending. R&D for the shuttle grew in inflation-adjusted terms and other R&D did not, a decision in which the Congress concurred. There is no evidence that the shuttle funding problem spilled out of the NASA budget into other agencies, such

17. American Association for the Advancement of Science, *Research & Development AAAS report VII: Federal Budget-FY 1983 Impact and Challenge* (1982), pp. 31-35.

Figure 9.
Alternative Projections of Spending for General Science, Space, and Technology Minus the President's Request for the Three Largest Projects, 1990-1996



SOURCE: Congressional Budget Office.

NOTE: Function 250 covers spending on general science, space, and technology.

TABLE 10. Federal R&D-related Spending (Budget authority, in billions of dollars)

	Functions 250 & 270[a]	Civilian Research and Development[b]	Department of Energy (Civilian projects only)[c]	National Aeronautics and Space Administration[a]	National Science Foundation[a]
1981	18.4	18.0	7.6	5.6	1.1
1982	20.0	14.7	7.7	6.2	1.0
1983	18.8	14.4	6.2	7.1	1.1
1984	16.7	15.7	4.4	7.5	1.3
1985	17.9	17.1	5.3	7.6	1.5
1986	15.3	17.2	3.3	7.8	1.5
1987	16.0	18.9	2.6	10.9	1.6
1988	16.4	20.2	3.4	9.1	1.7
1989	17.0	22.8	3.6	11.0	1.9
1990	19.6	25.9	4.3	12.3	2.0
1991	21.7	29.6	4.5	14.0	2.3

SOURCE: Congressional Budget Office calculated from *Budget of the United States, Fiscal Year 1992*, Part Seven, pp. 54-59; and three publications of the National Science Foundation, Division of Science Resources Studies: *Federal R&D Funding by Budget Function*, various years; "Federal Funds for Research and Development, Detailed Historical Tables, Fiscal Years 1955-1990," no date, and "Selected Data on Federal Funds for Research and Development, Fiscal Years 1989, 1990, and 1991," December 1990.

a. Total budget authority.

b. Includes operations and construction.

c. Total budget authority less nuclear weapons budget authority.

as NSF. Indeed, the slower growth in other NASA efforts and other science and technology spending during the period is in part attributable to the overall economic and budgetary situation of the time. But the priority given the shuttle in part represents a choice of large R&D efforts over other science and technology spending within NASA's budget--a choice that some observers fear will be made again when the space station is being developed in the first half of the 1990s.

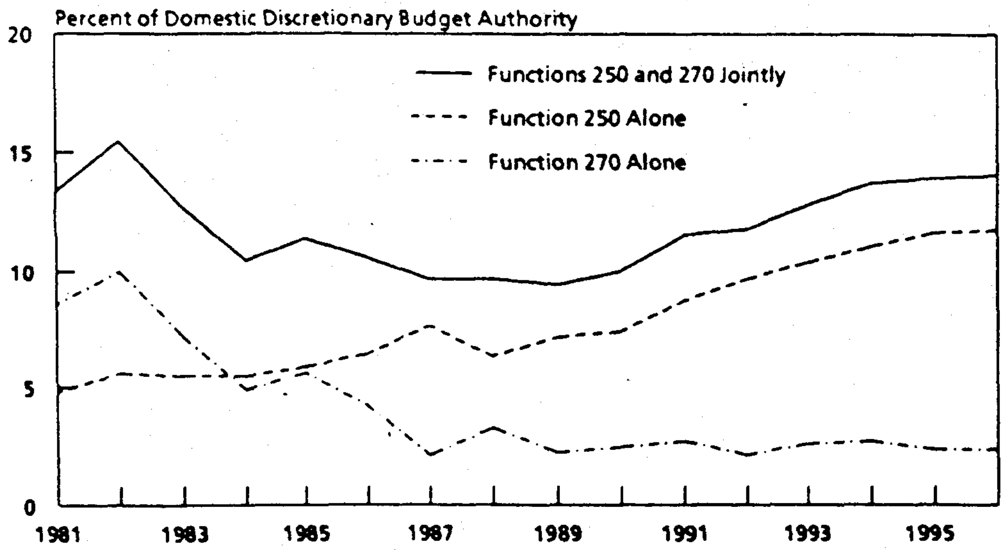
Projections of the same data for the mid-1990s present a different picture. The Administration's plan would increase the level of spending for budget functions and agencies supporting science and technology, while all domestic discretionary spending would be held roughly constant (see Figure 10). Increases in function 250 and 270 would be necessary for the very largest projects, but other R&D spending would also grow. A review of agency-level and R&D budgets supports this view. NASA's overall budget is planned to rise in the 1992 through 1996 period by 15 percent in real terms--not as rapidly as the largest projects but rapidly enough to allow small increases in other spending. NSF's budget for its inventory of large R&D projects is projected to grow only slightly more rapidly than NSF's total budget during the forecast period, although it may vary from year to year, but both would enjoy substantial increases.

The plan for DOE is different. Under the Administration's plan, DOE's funding for other missions decreases, while funding for large projects increases. Funding for DOE civilian programs other than the large R&D programs decreases by 30 percent after adjusting for inflation. Since part of the DOE nuclear facilities cleanup also must be paid out of these funds, DOE programs other than large R&D project and nuclear cleanup may find themselves under severe funding pressures.

These interpretations of the budgetary history of spending for large R&D projects, and of the Administration's program for the 1990s, should be treated with caution. Specifically, one cannot say with certainty that had big projects been funded at lower levels in the past, or not at all, smaller projects would have fared any better than they did. The counterclaim is often made that big R&D projects actually draw funds to agencies undertaking the projects, rather than crowding out other R&D spending. Actual budgetary results are in most cases the outcome of negotiations, so a fuller analysis of this process would be necessary before one could say definitively that the big R&D projects of the early 1980s actually crowded out other R&D spending.

As for the 1990s, the Congress may not accept the intent of the Administration. If the Executive's preference for increasing the priority afforded all R&D is not accepted, or if the cost of science and technology projects increases, then the issue of choosing between large projects and other R&D spending will be a matter for negotiation among the Office of Management and Budget, the Executive Branch line agencies, and the Congress and its committees.

Figure 10.
Spending in Budget Functions 250 and 270, 1981-1996



SOURCE: Congressional Budget Office.

NOTES: Function 250 covers spending on general science, space, and technology. Function 270 covers spending on energy.

Data for years 1992-1996 reflect the President's request.

CHAPTER IV
BUDGETARY OPTIONS

The prominence of large R&D projects in the budget raises questions as to whether their results justify their costs. Quantitative measures of the productivity of science and technology spending are crude. They provide little guidance as to how much to spend and how to distribute funds among projects. A useful principle in making difficult choices of this type is to diversify expenditures, because the level and timing of benefits produced by any particular project or area are uncertain.

In the effort to maintain a balance between spending for large R&D projects and other science spending, the Congress has several options. It could make a periodic review of federal spending on R&D, fund large projects on a multiyear rather than annual basis, set annual spending caps for large projects, cancel one or more of the largest projects, and establish new (and more equal) partnerships with other countries in funding the largest projects.

LARGE R&D PROJECTS AND PRODUCTIVITY

The federal agencies and scientists proposing large R&D projects hold that large R&D projects are productive. Advocates of the Superconducting Super Collider (SSC), or the space station maintain that the benefits of their projects exceed their costs, and are at least equal to those of other projects and programs, including that of reducing the federal deficit. No objective standard exists by which to gauge the of these claims.

The Case for Large R&D Projects

The case for large R&D projects as productive investments is twofold. First, in many areas of science and technology only larger, more expensive facilities can provide answers to fundamental questions. Moreover, only the government can bear the cost and risk of these enterprises and bring their benefits to society. For example, in making the case for the SSC, the Department of Energy and the community of experimental particle physicists argue that progress in experimental physics requires ever larger and more costly particle accelerators. Similarly, advocates of the human exploration of space hold that the space station program is the "next logical step" in a progression leading to human exploration of the solar system.

A second argument for large R&D projects is that large-scale facilities provide the foundation for productive small science. The progression of instruments and facilities in NASA's astronomy program illustrates the point: Supporters view the three large orbiting astronomical facilities included in the inventory of large R&D projects--the Hubble Space Telescope, the Gamma Ray Observatory, and the Advanced X-ray Astronomical Facility--as infrastructure that will support many users in the future. Unlike earlier efforts, which were carried out with short-lived satellites designed and directed by small teams of investigators, these new spacecraft will provide observation time to many investigators over a longer period of time. Longer operating life is not without cost, however. For example, NASA has requested $250 million in 1992 for the Hubble Space Telescope, to cover the cost of repair, refurbishment, maintenance, operation, and data analysis. Likewise, the Earth Observation System and the Advanced Photon Source, which are also envisioned as infrastructure open to many scientists, will require operating funds over a number of years.

These arguments provide qualitative justifications for investment in large science projects. They do not, however, enable one to evaluate the trade-off between large and small efforts within an area, or the best distribution of large and small efforts among scientific disciplines and technical fields. There is no standard by which to evaluate the benefits of federally supported science and technology. Much of the federal support is of projects that involve the production of public goods. Since public goods are not produced by private businesses, and are not traded in private markets, it is difficult to place a value on them. Even the "spillover" benefits to private business of advances in science and technology have proved difficult to measure.[18] Attempts have been made to measure the productivity of scientific programs indirectly on the basis of the number of publications produced by those who participate in them, but these have been inconclusive.[19] Sometimes the relative cost of a project becomes the de facto measure of its worth, and large projects are seen as being less valuable simply because they are more expensive.

The Case Against Large R&D Projects

The general arguments against large R&D projects are more numerous and varied than those for them, but ultimately no more subject to validation. In many respects, they resemble the criticisms brought against the development and production of major weapons systems. Like weapons, large R&D instruments and facilities are costly to develop, build, and operate. Estimates of their cost and capability are subject to great uncertainty. The failure of a large R&D project can be devastating to the research communities depending on it. For example, if NASA proves to be unsuccessful in correcting its communications problem with the Galileo mission to Jupiter, a single malfunction will have aborted a large effort by the planetary research community. Large R&D projects can also have long gestation periods, from conception to political acceptance, development, and eventual operation. During this

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18. Congressional Budget Office, *How Federal Spending for Infrastructure and Other Public Investments Affects the Economy*, Chapter IV (June 1991).

19. For a review of issues related to the value of science and technology spending, including bibliometric measures of output, see, Office of Technology Assessment, *Federally Funded Research: Decisions for a Decade* (May 1991), Chapter 2 and pp. 244 and 245.

time, advances in technology can render all or part of a large R&D project's hardware or mission obsolete.[20] The long gestation period of large R&D projects, particularly in space sciences, also handicaps Ph.D. candidates if their experimental field is overly dependent on the development of large instruments or facilities.

At the center of concern about large R&D projects is their potential to crowd out other R&D projects during the political process of making decisions about the distribution of funding for science and technology.[21] Executive agencies may prefer large projects to small projects, because the former provide budgetary support over a longer period. Large R&D projects offer an executive agency an opportunity to broaden its Congressional support, but along with this support goes a political commitment to keep funding large projects even if cost overruns or shortfalls in agency funding force cutbacks in other R&D spending. Large projects may be favored because of the economic benefits they bring to local communities. Once they are initiated, the momentum of large R&D projects gathers strength from the beneficiaries of project spending in both the public and private sectors.

These beneficiaries--both private corporations and not-for-profit scientific centers and institutes-enjoy an advantage relative to their small-science competitors because they have more resources at their disposal with which to influence the political process in support of their efforts. Recently, some concern has been expressed that spending for large science projects has more to do with bolstering agency budgets, supporting large private contractors, and generating local economic benefits than contributing to scientific and technical progress. Smaller R&D efforts, however, are not immune to this type of criticism. For example, the Office of Management and Budget held that in 1990 some $130 million in funding for small R&D projects was "earmarked" by the Congress for projects that might not have been funded on productivity grounds alone.[22]

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20. For example, recent discoveries using tabletop instruments have shed important light on the "technicolor" theory. Testing the theory has been among the scientific justifications for the SSC. See SSC Central Design Group, *Conceptual Design of the Superconducting Super Collider* (Berkeley, Cal.: SSC CDG, 1986), p. 29. For information on recent experiments, see Malcolm Browne, "Simple Device Produces Record-Breaking Cold," *New York Times*, May 28, 1991, p. C1.

21. See, for example, William J. Broad, "Big Science: Is it Worth the Price?" *New York Times*, May 27, May 29, June 5, June 10, June 19, September 4, October 9, and December 25, 1990; Robert Park, "Mega Science, Mega Bucks," *Washington Post*, October 21, 1990, p. C1; and Phil Kuntz, "Pie in the Sky Big Science is Ready to Blast off," *Congressional Quarterly*, April 28, 1990, pp. 1254-1260.

22. *Budget of the United States Government, Fiscal Year 1990*, p. 90.

The Congress could pursue several options if it wanted to assure a balance between large R&D projects and other R&D spending in the first half of the 1990s. These include undertaking additional legislative oversight of the entire science and technology budget, providing multiyear appropriations for large R&D projects, placing annual spending caps on large R&D projects, canceling or deferring the largest R&D projects, and entering into more-equal partnerships with other countries to fund, operate, and benefit from large R&D projects.

Adopt a Regular Cross-Cutting Policy Review

The Office of Technology Assessment has proposed that the Congress undertake a biennial review of overall science and technology spending.[23] Among the issues considered would be the interplay between large R&D projects and other science and technology spending. Hearings would be held to weigh priorities for federal spending on science. The hearings might assess the degree to which these programs correspond with broad national goals--for example, in education and human resources development--and with specific objectives such as increasing our understanding of global climate change or of superconducting materials. The review would cut across agency budgets in order to produce estimates of total federal support for various areas of science and technology, as well as less precise indicators of the contribution of federal R&D spending to more general purposes.

A cross-cutting review would clarify the extent to which the current distribution of R&D funding is consistent or inconsistent with national goals and objectives. If inconsistencies were revealed, corrective action could be undertaken to achieve a better distribution. The rationale for the review is that the question whether R&D funds are properly distributed hinges as much on an ignorance of the full implications of the current distribution as on a willingness to improve that distribution.

A cross-cutting review would duplicate aspects of the legislative process, particularly the annual budget process. Authorizing committees periodically review the overall national effort.[24] The budget committees consider both the goals and the trade-offs among different science activities in their annual review of function 250. For example, the committees have reviewed the three largest R&D projects proposed for the 1990s, and funding for the National Science Foundation, in each of the last several years. Funding for two of the three largest planned efforts for the 1990s, and NSF, is contained in the same appropriations bill. The existing legislative processes may fall short of the systematic, step-by-step review of goals and objectives

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23. Office of Technology Assessment, *Federally Funded Research: Decisions for a Decade*, p. 21.

24. See, for example, *American Science and Science Policy Issues*, Chairman's Report to the Committee on Science and Technology, House of Representatives, 99:2, December 1986.

envisioned for a cross-cutting review. The current process, however, offers the advantage of legal authority to take corrective actions.

A full review of all federal science and technology spending would nevertheless offer some advantages. It would enlighten the current process by providing a forum that transcended budget functions and agency jurisdictions, allowing the Congress to question overall resource allocation--including that between large and small projects. Moreover, as the Office of Technology Assessment notes, a cross-cutting review would allow the Congress to ask the Executive how it sets its spending priorities and justifies them in terms of broad national objectives. Requiring a biennial statement of both the priorities and the process of setting them from the President's Office of Science and Technology Policy and Office of Management and Budget would be consistent with this aspect of a cross-cutting review.

Multiyear Appropriations and Annual Spending Caps

Multiyear appropriations can be an effective means of controlling the total cost of a large project, if the technology of the project is well understood. With its funding assured, the sponsoring executive agency can minimize the total cost of a project by proceeding on an optimal schedule, rather than one dictated by the availability of funds on an annual basis. Predictability is a key ingredient in determining the success of multiyear appropriations. For example, in the defense area, assured funding has been found to be more successful in reducing total costs in the production of already developed weapons systems than in the development phase of new weapons where cost uncertainties are greater.[25] These findings suggest that multiyear appropriations may not necessarily be effective in controlling the total cost of large civilian R&D projects, which are more like weapons development then weapons production. But advocates of multiyear appropriations counter that Congressional actions requiring year-to-year changes in the funding profile for large R&D projects are themselves a cause of cost overruns and would be less of a problem were multiyear appropriations adopted.

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25. Several CBO studies of the Department of Defense's development and procurement of weapons systems shed light on the relation between program costs and multiyear appropriations. "Alternative Strategies for Increasing Multiyear Procurement," Staff Working Paper (July 1986), reports cost savings in production programs where multiyear funding commitments were used.

The point is reinforced in a second report, *Effects of Weapons Procurement Stretch-Outs on Costs and Schedules* (November 1987), that demonstrates the converse: program costs can be increased by stretch-outs and changes in available funding. Another report, *Concurrent Weapons Development and Production* (August 1988), demonstrates the effect that uncertainty can have on program costs in advancing the tentative conclusion that programs that moved forward into production, but still carried the uncertainties of the development phase, experienced substantial cost overruns.

From a legislative perspective, multiyear appropriations would mean losing the oversight and budgetary control provided by annual appropriations. This drawback becomes more important at a time when the Budget Enforcement Act has already limited spending options. For example, if the largest R&D projects were granted multiyear appropriations at a time when overall agency funding levels have been restricted, other R&D spending could suffer disproportionately.

Arbitrary annual spending caps on large projects are another option. They would help strike a balance between funding for large R&D projects and other R&D spending, given uncertainty as to the cost of projects and their ultimate benefits. While multiyear appropriations might aim at achieving the lowest total cost of developing a large R&D project, annual spending caps would explicitly sacrifice this advantage for predictable annual levels and to protect other R&D spending from being crowded out. Annual spending caps, in addition to raising total program costs, would impose an additional opportunity cost by delaying the delivery of the scientific benefits expected from a large R&D project.

Spending caps and similar arbitrary rules are already being used to control the effect of large R&D projects on other R&D spending. The 1991 Appropriations Conference Report limited the annual rate of growth for the space station program to 10 *percent*, and capped its total appropriation at $2.6 billion annually.[26] Within NASA's program, an informal rule holds that the largely unmanned space science and applications programs should receive funding equal to 20 percent of the agency's spending on research and development and space flight in order to assure that these programs are not underfunded as NASA pursues manned space flight programs. One can even see the Administration's stated policy of doubling NSF's 1987 budget by 1994 as an arbitrary device to assure balance.

Cancel Large R&D Projects

Canceling one or more of the largest R&D projects would be the ultimate form of budgetary control the Congress might choose to exercise in assuring that large projects do not crowd out smaller ones. If the Congress chose to fully fund the Administration's request, and the largest projects did not experience cost overruns, residual funding for other science and technology activities would increase during the next five years (see Figure 9). However, if fewer funds were made available and the largest projects fully funded as proposed, funding of others would be forced down. For example, were the Congress to fund function 250 for 1992 through 1996 at the level of a freeze, while fully funding the largest projects, spending on other science and technology would be more than $3.5 billion below the 1991 level by 1996. Canceling the space station in this circumstance, and retaining the funds within function 250, would soften the decline in funds available for other activities, leaving residual spending over $2.5 billion above what it would be if the station was funded,

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26. House of Representatives, Report 101-900, to Accompany H.R. 5158, 101:2 (1990), p.41.

but still $800 below the 1991 level. The situation would be less difficult if funding was provided for function 250 at the higher level of the CBO baseline. The boost provided to residual funds available for other science and technology activities would be less if either EOS or SSC was canceled since each of these projects is less costly than the space station.

The major direct cost of this option would be the loss of future benefits.[27] Moreover, in the case of two of the largest projects, the space station in particular, there would be an additional cost: a loss of international prestige, since the United States would have to break its current international commitments.

Increase International Cooperation

All three of the largest projects in the current U.S. inventory are planned to include international cooperation. In each project, however, the United States is in the role of senior partner and carries the bulk of the cost in exchange for retaining control and the benefits of national procurement necessary for building large instruments.

More equal international partnerships with Canada, Europe, Japan, and possibly the Soviet Union could potentially lower the cost to U.S. taxpayers of large R&D projects. The major costs of more equal international partnerships would be loss of the intangible benefits of U.S. predominance in a particular area and of operational control and procurement.[28] Partnerships of this type would work best were the Congress to provide multiyear appropriations, and hence a loss of legislative flexibility could also be among the costs of this option.

A disadvantage to the United States of increased cost sharing with other countries would be to reduce procurement benefits. For example, in high-energy physics, a new accelerator might be built in Europe rather than Texas. More important, procurement of the technical components (together with whatever potential for spinoffs those procurement contracts might entail) would be spread over a larger number of national contractors. This, in theory, might reduce the benefits coming from science to the U.S. industrial base.

27. CBO has reviewed the costs and benefits of the three largest projects in several different publications. For the space station and EOS, see Congressional Budget Office, *The NASA Program in the 1990s and Beyond* (May 1988) and *Reducing the Deficit: Spending and Revenue Options* (February 1990), pp. 219-223. For the SSC, see *Risks and Benefits of Building the Superconducting Super Collider* (October 1988).

28. For a discussion of the advantages and disadvantages of international cost sharing, see Congressional Budget Office, *Risks and Benefits of Building the Superconducting Super Collider* (October 1988), pp. 51-53 and 63-70.

To say that "big science" procurement contracts give U.S. firms monopoly benefits, however, is to overstate the case. Other industrialized nations also undertake large science projects, and the technical personnel often move around geographically. Furthermore, the specialized nature of many of the technical components of these large science instruments limits the ability of contractors to translate expertise in one contract into more general expertise. For example, the ability of a final contractor to build 15-meter superconducting magnets will not necessarily be of assistance in other areas because the superconducting magnets used in medicine and industry are typically much shorter than 15 meters.

APPENDIX
MEASURES OF "BIG SCIENCE" SPENDING AGGREGATES

This appendix details some of the methods and data that were used in developing measures of spending for the paper.

MEASURES OF "BIG SCIENCE"

The measures of spending for large R&D projects discussed here are:

- o The inventory of large projects measure;
- o The fields of research measure; and
- o The R&D plant measure.

The fourth measure used in the paper, spending on the three projects receiving the most funding in a given year, is a special use of the inventory and so is not discussed separately in the appendix.

The Inventory of Large Projects

The relevant agencies provided all the data for the inventory directly to CBO, or indirectly through their budget submissions (see Table A-1).

National Aeronautics and Space Administration Projects. The inventory developed by William C. Boesman is used as a starting point for the CBO inventory of NASA projects. Boesman's inventory excluded expenditures for developing the space shuttle and other investments in space transportation, but these are included in the CBO inventory. The Boesman inventory included all projects with a total cost of $25 million (in 1984 dollars) or more. The CBO inventory includes only major satellite and facilities class projects, as NASA refers to them.

Department of Energy Projects. DOE provided its data in budget authority, with one exception--the Clean Coal Technology Program, which provided its data in obligations. In the latter program, the Congress has already provided advance budget authority for five rounds of cooperative agreements. Because the authority is being obligated only as DOE enters cooperative agreements with its various partners, taking over 10 years in some cases, obligations were used as the best measure of program funding. Data for 11 large Clean Coal Technology projects that DOE had agreed to as of March 1991 were included.

TABLE A-1. MEASURES OF SPENDING FOR LARGE CIVILIAN R&D PROJECTS, BY AGENCY
(Budget authority, in millions of dollars)

Year	National Aeronautics and Space Administration: Inventory	National Aeronautics and Space Administration: Three Largest Projects	Department of Energy: Inventory	Department of Energy: Three Largest Projects	National Science Foundation: Inventory
1980	2,793	2,547	692	341	92
1981	3,166	2,932	701	337	106
1982	2,627	2,415	832	381	102
1983	4,138	3,902	792	379	119
1984	675	434	748	305	159
1985	1,005	623	655	252	195
1986	1,045	530	558	225	204
1987	1,224	736	631	247	226
1988	1,173	673	745	257	234
1989	1,823	1,185	806	304	288
1990	2,704	2,008	1,034	433	304
1991	3,141	2,307	1,188	420	292
1992	3,634	2,694	1,763	759	337
1993	4,135	3,322	2,027	1,071	399
1994	4,871	3,993	2,020	1,214	447
1995	5,541	4,764	2,029	1,239	473
1996	5,758	5,146	2,161	1,366	489

SOURCE: Congressional Budget Office.

National Science Foundation. The NSF provided data on annual outlays. CBO converted these data, which combine the construction and operation, into budget authority. The conversion formula was based on the historical relationship between NSF total R&D outlays and budget authority. Since the formula was based on the relationship between total R&D outlays and budget authority, it was applied to the sum of the facility series rather than to the experience of any single facility. The formula explained over 96 percent of the relationship between the two data series on which it was based.

The Fields of Research Measure of Science Spending

The fields and subfunctions included in this measure are:

DOE Energy Programs	Fission, Fossil, Fusion, Supporting Research, and Uranium Enrichment
DOE General Science Programs	Nuclear and High-Energy Physics, and the Superconducting Super Collider
NASA Programs	Space Transportation, Space and Terrestrial Applications, and Space Science

This measure does not include any activities of the National Science Foundation and the National Institutes of Health, because of the multidisciplinary nature of the subfunctions in the former and the small size of the instruments in the latter.

CBO constructed this measure from three data sources: NSF data on the conduct of R&D by function and field within agencies; NSF historical data on federal obligations for R&D plant by agency; and DOE budget submissions.[29] NSF data provide R&D spending broken down by budget function, subfunction, and agency for 1980-1991. The NSF R&D plant series was used for NSF and NASA facilities and large equipment, while DOE budget submissions allowed creation of a consistent series of DOE civilian facilities' spending.

29. National Science Foundation, *Federal R&D Funding by Budget Function* (various years). See also Division of Science Resource Studies, National Science Foundation, "Federal Funds for Research and Development; Detailed Historical Tables: Fiscal Years 1955-1990," no date, and "Selected Data on Federal Funds for Research and Development, Fiscal Years 1989, 1990, and 1991," December 1990. It should be noted that different National Science Foundation data series use slightly different definitions because they are collected from different surveys for different purposes. Consequently, there may be slight discrepancies between data series. For instance, federal R&D spending for 1990 totals $63.8 billion, $66.1 billion, $68.5 billion, or $69.2 billion depending on the NSF data series.

For example, DOE R&D is divided into energy spending (function 270) and general science (function 250).[30] Within energy R&D, spending is further divided into various program areas: fusion, fossil, fission, conservation, renewable, uranium enrichment (including only part of this category, much of which is considered production), environmental R&D, and supporting research technical analysis. NSF and NASA have a similar division by budget function and field.

The NSF published series on R&D by budget function purports to include only operating expenses. Consequently, it excludes construction projects, if they are defined as such. However, if the project is defined as a cooperative agreement, as was the Clinch River Breeder Reactor and as is most of clean coal technology, then spending on it is defined as operating expenses and is included in the series. The result is that the series is neither pure nor consistent (from an economic analyst's point of view) in that some capital projects are in and others are out, based on their legal, rather than economic, treatment.

For this reason, this measure of big science spending includes a constructed capital spending series for DOE civilian R&D for 1980-1991, based on budget submissions for the relevant years. The series includes construction and capital equipment budget authority at the subfunction level. For example it includes magnetic fusion construction and capital equipment, but the spending on any specific fusion project is not broken out. The series also excludes capital projects done under some cooperative arrangement, such as Clinch River. Thus, the series complements R&D data from NSF in that the projects fully paid for by DOE are in this series but not in the NSF series while those done under some cooperative arrangement are in the NSF series but not in the DOE series. Because the two data series complement each other, putting them together results in a consistent and complete series of DOE civilian spending on R&D.

The other major inconsistency in the data lies in NASA's redefinition of several hundred million dollars of annual spending from R&D to operations for 1978-1982. (Since the detailed analysis begins at 1981, some of this problem is mitigated.) Originally NASA labeled much of its shuttle spending as R&D, but after the shuttle became operational NASA retroactively redefined these same expenditures as operations. Thus, for these years the historical R&D data are high. Because CBO included the shuttle as an R&D project in the inventory, for the sake of consistency CBO has also used the historical data that include the shuttle.

30. DOE also has defense R&D activities, which are not relevant to a measure of civilian R&D.

R&D Plant

The NSF publishes historical data on obligations for R&D plant by agency. The definition of R&D plant includes facilities and fixed equipment and their acquisition, construction, alteration, or major repair.[31] This definition excludes predesign studies, office equipment, and movable equipment such as microscopes; NSF claims these should be in a parallel series called the conduct of R&D, discussed above.

SPENDING AGGREGATES

This section presents some of the methods used in creating the aggregates with which the measures of big science were compared. They correspond to the denominators of the ratios discussed in Chapter III. The aggregates are presented in Table A-2.

All Civilian R&D

This series measures all federal nonmilitary R&D spending. It contains both spending on the "conduct of R&D" and spending for plant and equipment, which are left out of many analyses of R&D spending. The data are the same as those used to create the fields-of-science and R&D plant measures discussed above. The data are in terms of budget authority, with the exception of the R&D plant series, which is in obligations.

At the functional level, the aggregate data match the historical budget function data relatively well. For instance, the constructed series combines DOE capital construction budget submission data with the NSF series on conduct of R&D and on R&D plant to create a general science and space function series. This constructed series generally matches the OMB function 250 General Science and Space series for 1980-1991. The average annual error is 2.6 percent.

At the subfunction level, the difference between the two series is sometimes greater: the OMB function 251 general science data series differs from the constructed series by more than 5 percent. By contrast, the constructed series on health research differs from the OMB historical data for function 552 by 1.6 percent for the 1980-1990 time frame, while the space series diverges by 2.2 percent.

The President's budget does not contain a forecast of civilian R&D through 1996. Consequently, CBO projected its civilian R&D series forward based on the President's forecast for the budget functions that account for the vast majority of civilian R&D, namely 250 (General Science and Space), 270 (Energy) and 552 (Health Research). These functions are forecast to grow by 5.5 percent annually

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31. See National Science Foundation, *Federal Funds for Research and Development: Fiscal Years 1987, 1988, 1989* (1989), p. ix.

TABLE A-2. R&D SPENDING AGGREGATES
(Budget Authority, in millions of current dollars)

Year	Office of Management and Budget Function 250	Office of Management and Budget Function 270	Office of Management and Budget Function 552	Congressional Budget Office Function 250	Congressional Budget Office Function 270	Congressional Budget Office Function 552	All Civilian R&D[a]
1980	6,251	40,320	3,642	6,251	40,320	3,642	17,667
1981	6,643	11,754	3,757	6,643	11,754	3,757	18,043
1982	7,219	12,770	3,844	7,219	12,770	3,844	14,711
1983	8,155	10,683	4,252	8,155	10,683	4,252	14,412
1984	8,822	7,865	4,773	8,822	7,865	4,773	15,710
1985	9,152	8,758	5,402	9,152	8,758	5,402	7,054
1986	9,286	6,047	5,552	9,286	6,047	5,552	17,188
1987	12,538	3,430	6,660	12,538	3,430	6,660	18,914
1988	10,864	5,526	7,018	10,864	5,526	7,018	20,232
1989	12,949	4,062	7,706	12,949	4,062	7,706	22,761
1990	14,644	4,926	8,324	14,644	4,926	8,324	25,947
1991	16,479	5,180	9,186	16,479	5,909	9,186	29,650
1992	18,934	4,129	9,670	17,096	5,537	9,588	31,281
1993	20,691	5,119	9,931	17,776	6,238	9,968	33,001
1994	22,202	5,509	10,288	18,479	6,489	10,361	34,816
1995	23,665	4,861	10,288	19,217	6,151	10,774	36,731
1996	25,057	4,956	10,288	19,975	6,535	11,197	38,751

SOURCES: Congressional Budget Office; Office of Management and Budget, *Budget of the United States Government, Fiscal Year 1992*, Part Seven, pp. 54-59; and three publications of the National Science Foundation, Division of Science Resources Studies: *Federal R&D Funding by Budget Function* (various years); "Federal Funds for Research and Development, Detailed Historical Tables, Fiscal Years 1955-1990," no date, and "Selected Data on Federal Funds for Research and Development, Fiscal Years 1989, 1990, and 1991," December 1990.

a. Constructed series, including both operations and facilities.

between 1991 and 1996.[32] By this forecast, civilian R&D would grow from 15.7 percent to 18.1 percent of domestic discretionary spending. This growth is indicative of the President's program of increasing the share of federal resources devoted to R&D.

Domestic Discretionary Budget Authority

In order to compare the historical data on domestic discretionary spending with the aggregates for big science discussed above, CBO estimated domestic discretionary budget authority based on historical data for outlays. This estimation was performed by using the historical relationships between budget authority and outlays for the major components of domestic discretionary spending. This relationship was then used for the series as a whole.

Time series data for the budget authority granted to all domestic discretionary activities are not readily available. CBO and OMB, however, have each issued an outlay series of domestic discretionary spending.[33] OMB also has issued time series data for the budget authority and outlays granted to budget functions and subfunctions, and for outlays for discretionary programs by budget function.[34]

The estimate of domestic discretionary budget authority for 1980 through 1990 used in this study is based on the relationship between outlays and authority in budget functions and subfunctions that are primarily composed of domestic discretionary programs, and on CBO's and OMB's total domestic discretionary outlay series. For each year, a ratio of budget authority to outlays was calculated for the total budget authority and outlays of the domestic discretionary budget functions and subfunctions. Total budget authority for domestic discretionary spending was estimated by multiplying both CBO's and OMB's total outlay data for each year by the corresponding year's ratio of budget authority to outlays of the budget functions and subfunctions identified as domestic discretionary.

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32. Calculated from *Budget of the United States Government, Fiscal Year 1992*, Part Seven, pp. 55 and 56.

33. *Budget of the United States Government, Fiscal Year 1992*, Table 8.1, Part Seven-78, and Congressional Budget Office, *The Economic and Budget Outlook: Fiscal Years 1992-1996* (January 1991), Table D-6, p.150.

34. *Budget of the United States Government, Fiscal Year 1992*, Table 3.2 and Table 5.1, Part Seven, and Table 8.3, Part Seven-84.

Budget functions and subfunctions identified as domestic discretionary were determined by comparing function and subfunction total outlays with discretionary outlays by function as presented in the budget.[35] On an outlay basis, the total for these functions and subfunctions for 1980 through 1990 accounted for between 55 percent and 60 percent of the data for total domestic discretionary outlays as presented by both CBO and OMB. The budget functions and subfunctions identified as dominantly domestic discretionary were:

250 General Science, Space and Technology
300 Natural Resources and Environment
400 Transportation
450 Community and Regional Development
501 Elementary, Secondary and Vocational Education
504 Training and Employment
550 Health Research
750 Administration of Justice

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35. *Budget of the United States Government, Fiscal Year 1992*, Table 8.3, Part Seven-84.