CBO STAFF MEMORANDUM

A REVIEW OF EDWIN MANSFIELD'S ESTIMATE OF THE RATE OF RETURN FROM ACADEMIC RESEARCH AND ITS RELEVANCE TO THE FEDERAL BUDGET PROCESS

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This staff memorandum was prepared in response to a request from the House Committee on Science, Space, and Technology. The Committee asked the Congressional Budget Office to comment on the policy relevance and statistical accuracy of Edwin Mansfield's estimates of the social rate of return from academic research.

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SUMMARY

In the last few years, Edwin Mansfield, a respected economist at the University of Pennsylvania, has produced a series of studies on the relationship between academic research and industrial innovation. Among the most widely cited findings of these studies is that the rate of return to society from the funds invested in academic research is an estimated 28 percent. This Congressional Budget Office (CBO) memorandum examines his studies, with an eye to answering two questions:

- How relevant is the 28 percent rate-of-return estimate to federal science policy and the federal budget process?

- How precise is the 28 percent estimate; that is, how big is the margin of error?

How Relevant Is Mansfield's Result to Federal Science and Budget Policy?

Although Mansfield's methodology and insights into the role of academic research in economic productivity are innovative, his findings offer only general guidance for determining the annual federal science budget. His estimate suggests that social expenditures for academic research--over half of which is federally funded--have yielded handsome returns. This finding

implies that federal money for academic research has been invested well. Such a result contrasts with the case of research and development (R&D) conducted under federal contract--the half of the federal R&D budget whose economic return can most readily be measured. Such R&D has generally been estimated to yield very low or even negative returns in strictly economic terms.

Beyond finding that the economic returns from academic research are high, however, Mansfield's results cannot shed much light on the details of federal science or budget policy. First, as Mansfield notes, his estimate is "the rate of return from the entire investment in academic research, not the rate of return from an extra dollar spent on academic research."[1] More specifically, it is not an analysis of the return from changes in federal funding of academic R&D. Thus, it is not very useful in making incremental budgetary decisions. In addition, the type of research most likely to yield commercially valuable breakthroughs in the future can best be determined not by economists who study historical data, but by researchers and industrialists who study the state of technology. Finally, considerations other than strictly commercial ones motivate most federal R&D funding--for example, for defense, space, or the environment. For these reasons, Mansfield's findings cannot be translated into policy rules to

1. Edwin Mansfield, "Academic Research and Industrial Innovation," *Research Policy* (February 1991), p. 6.

determine either the appropriate level or the distribution of federal research funding by agency, discipline, mission, or performer.

Nevertheless, a high estimated rate of return from academic research provides broad justification for budget allocations to such programs as a whole, in economic as well as scientific terms. By contrast, the low return typically found in connection with large federal technology-oriented programs, such as the space shuttle, would suggest that such programs usually cannot be well justified on strictly economic grounds. They must be evaluated on their intrinsic merits.

How Precise Is Mansfield's Estimate?

Mansfield's estimate probably establishes a reasonable order of magnitude, but the actual figure may be significantly higher or lower. For example, the figure could be higher because Mansfield counted as benefits only what U.S. firms realized from academic research, but counted as costs the spending on academic research both in the United States and abroad. The figure could be lower because the findings of academic research may themselves depend on other research funding--for example, by the national laboratories or industry. Not including the cost of such research increases the calculated return. Many other sources of uncertainty in the estimate exist. These uncertainties stem from the nature of the problem rather than from Mansfield's method, which tries to be conservative and generally seems reasonable.

MANSFIELD'S METHODOLOGY

Mansfield's estimate attributes a high rate of return to academic R&D, most of which is publicly funded. Outside of a few specific areas, such as agriculture and medicine, broad studies of federally sponsored R&D have not shown a strong link between such R&D and economic growth.[2] Because of Mansfield's unique findings, the Bush Administration used his estimate in both its 1992 and 1993 budget submissions as part of its justification for increasing federal funding of basic research.[3] Mansfield himself noted, however, that his estimate could provide only very limited guidance to policymakers, in large part for reasons that are discussed below.

This section reviews the methodology used in three of Mansfield's studies. The first two present his method for estimating the social rate of

2. For a review of this literature, see Congressional Budget Office, *How Federal Spending for Infrastructure and Other Public Investments Affects the Economy* (July 1991), pp. 89-101.

3. *Budget of the United States Government, Fiscal Year 1992*, part 2, p. 42; and *Budget of the United States Government, Fiscal Year 1993*, part 1, p. 117.

return from investment in academic research. The third, follow-up, study analyzed the characteristics and funding sources of that academic research.[4]

Estimating the Social Rate of Return

Mansfield calculated the social rate of return using conventional techniques. This rate, 28 percent, is the interest rate that makes the present value of the stream of benefits associated with the research equal to the costs. (In other words, it is the annual profit rate on society's investment in academic research.) The academic research that Mansfield examined led to both product innovations that created new sales and process innovations that reduced the costs of producing new and old products alike. The measure of benefits used to calculate the social rate of return was the total of new U.S. sales and reduced production costs resulting from academic research. The measure of cost of academic research was defined as the annual funding of academic research worldwide. This method is straightforward and uncomplicated. The accounting assumptions necessary to produce a value for benefits are less so.

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4. See Mansfield, "Academic Research and Industrial Innovation," pp. 1-12; Edwin Mansfield, "Academic Research and Industrial Innovation: A Further Note," *Research Policy* (June 1992), pp. 295-296 (referred to hereafter as "A Further Note"); and "Academic Research Underlying Industrial Innovations: Sources and Characteristics," paper presented before the American Economics Association, Anaheim, Calif., January 1993 (referred to hereafter as "Sources and Characteristics").

Benefits. Mansfield calculated the net social benefits attributable to academic research in three steps. First, he calculated gross benefits. Then, he derived net social benefits from gross benefits. Last, he separated the portion of the net benefits that was attributable to academic research from the portion that would be attributable to investment by the firms that actually developed the final product and brought it to market.

Mansfield's benefit calculation started with a sample of 76 firms in seven manufacturing industries, accounting for roughly one-third of the sales in their respective industries. (The industries were information processing, electrical equipment, chemicals, instruments, drugs, metals, and oil--industries that account for roughly 60 percent of industrially funded R&D.) Mansfield surveyed the firms to determine what percentage of the products or production processes that they introduced between 1975 and 1985 would have taken an additional year or more to bring to market without the benefit of academic research published within the previous 15 years.

The firms responded that, on average, 11 percent of their new products and 9 percent of their new processes fit these criteria. From his sample, Mansfield determined that such products would have accounted for roughly 3 percent of the sample industries' sales in 1985 (for products introduced between 1982 and 1985) and that the new production processes would have saved roughly 1 percent of the industries' costs that year. He also found that, for his sample, the commercialization of new products occurred, on average, seven years after the academic research findings.

To establish the net social benefits, Mansfield subtracted the lost sales of those firms whose products were replaced in the marketplace by the sales of the new products. In addition, Mansfield assumed that the net benefits of the academic research ceased eight years after introduction of the product. This assumption was based on his survey, in which the innovating firms estimated that, on average, the innovation would have been independently introduced after nine years even if there had been no academic research.

Mansfield also assumed that the net social benefits would equal the average benefits of the first four years after commercialization. Thus, he set his measure of social benefit much lower than the average social return that he and other economists found in earlier studies of 53 industrial innovations. In these earlier studies, social benefits continued to rise after the fourth year.

The difference between this lower social benefit and the average social benefit of the previous 53 products is the return that Mansfield attributes to the investment undertaken by the firms after the academic research has been published--that is, investment in product development, the plant and equipment necessary to bring the product to market, and start-up costs. Mansfield argues that this assumption is equivalent to attributing a 50 percent rate of return to the firms' investment--a value at the upper end of most studies.[5]

To recap, net social benefits were defined as the annual net increase in U.S. sales and decrease in production costs resulting from academic research, starting seven years after the academic research and lasting eight years. These benefits were set equal to the four-year average at the beginning of the benefit period.

Costs. Mansfield's estimate of the social cost of academic research is the amount spent by OECD and Soviet bloc countries on such research during the 1975-1978 period (seven years before the 1982-1985 sample period).[6] He used worldwide academic funding data to estimate costs even though

5. Mansfield, "A Further Note," pp. 295-296.

6. Mansfield adjusted published data from the Organization for Economic Cooperation and Development to account for different research and teaching practices in different countries.

he used only U.S. sales to calculate net social benefits, arguing that academic research is a worldwide effort.

Mansfield limited his estimate of academic costs to a single year for each year of the benefit period. Thus, he attributed the benefits beginning in 1982 to the research funded in 1975. Mansfield made this assumption on the grounds that he was trying to measure the rate of return on the last investment in academic research as a whole.[7] Whether the budget-year funding is the best measure of incremental investment in multiyear academic research projects, as opposed to measurement on a research-project basis, is left unexplored. Spending on academic research in any given year is a mixture of costs that only loosely approximates the marginal investment in academic research. His assumption may be justified, however, on the basis of this being a feasible method.

Determining the Characteristics of Academic Research Used by Industry

To discover the characteristics of the academic research that industry was using, Mansfield undertook a second survey. He polled 66 firms in the same seven industries, asking each to name five academic researchers

7. Note that this is the marginal (last) investment in all academic research, not, as discussed in the summary, the investment in the marginal academic research project.

whose work in the 1970s and 1980s contributed most to their products introduced during the 1980s.[8] He then surveyed the 321 academic researchers named by these firms to discover the sources of their funding and the nature of their work.

Not surprisingly, Mansfield found that the most prominent academic institutions were home to many of these researchers and that most of the researchers worked in applied fields, such as various branches of engineering, computer science, and chemistry. The survey also revealed some tendency by industry to fund basic research at the most renowned universities. For some applied or product-development research, however, firms would often use local schools, even if they were perceived as being of lower quality.

From the survey of researchers, Mansfield found that, even though these researchers have substantial ongoing relationships with industry, most of their funding comes from federal agencies, often two or more simultaneously. In general, the researchers stated that federal sources fund their more fundamental work, and industry funds their more applied work. They felt, however, that there was a great deal of interaction between the two types of work. In the electronics industry, academic researchers

8. See Mansfield, "Sources and Characteristics."

reported a shift in research funding from the 1970s, when roughly 80 percent of their support came from the federal government, to the 1980s, when roughly 80 percent came from industry.

RATE-OF-RETURN ESTIMATES AND FEDERAL BUDGETING

As was noted above, despite Mansfield's reservations about the limits of his methodology, the Bush Administration used his estimate as part of its justification for a $1 billion increase in funding for basic research. The high rate of return suggests that the current federal investment in academic research is economically justifiable. But does it really provide policymakers with much insight into the details of the funding allocation they must make?

The Marginal and the Average Return from Research

Mansfield's study analyzes the rate of return from the entire investment in academic R&D made by the economy as a whole, both federal and nonfederal sources. His result is of limited use in the detailed annual process of allocating federal funds. First, the estimate is for the average, not the marginal, rate of return from academic research and addresses only the proximate source of innovation. Even given a historical average rate of return of 28 percent, therefore, the return from an additional dollar spent on academic research is not actually known. Thus, if policymakers want to increase or reallocate federal funding of academic research, they should not expect that the return from the last dollars spent will be 28 percent; their rate of return could be higher or lower.

Overall funding for academic research has risen substantially since the period in Mansfield's study. During the 1975-1985 study period, funding for such research equaled less than 0.24 percent of gross domestic product (GDP). Currently, it equals 0.3 percent of GDP, roughly one-quarter higher.

Increasing federal funding of academic research need not lead to a proportional increase in the use of such research by industry. Mansfield's survey found that the academic researchers whose work was cited most often by industry received a disproportionately large share of federal and industry funding.[9] At the same time, an agency funding R&D will reduce or increase the number of grants depending on how the appropriation process allocates the last few dollars. The academic research most likely to be affected by such changes in appropriations is not that of the well-

9. See Mansfield, "Sources and Characteristics."

known scientist whose work is likely to be used by industry, but rather that of an unknown researcher just starting out.

Rate-of-Return Estimates and Science Policy Debates

Debates about science policy revolve around many issues beyond whether the endeavor of science as a whole has a high economic payback. U.S. science finds itself able to supply more peer-approved research projects than there is money to fund them. Consequently, setting priorities in research funding has been a major part of the debate of the last few years. These aspects of setting priorities include the trade-off between expensive big instruments (so-called "big science," such as the Superconducting Super Collider) and research conducted by a single principal investigator (so-called "little science," such as most projects funded by the National Science Foundation); between basic research and applied research; and between mission-oriented research and general research support.

Big Science Versus Little Science. Whether to fund academic research performed by a single principal investigator (little science) or work performed as part of a large collaboration on an expensive piece of equipment (big science) has been one focus of the science policy debate.

Mansfield's original estimate sheds little light in this area. For example, his first survey did not distinguish between academic researchers who will use the Superconducting Super Collider and National Science Foundation grant recipients who will engage in much smaller projects.

Mansfield's subsequent survey suggests that research in the more applied research fields, such as computer science and chemical engineering, are in fact the source of much of the academic research used by industry.[10] These applied fields are more properly characterized by little or midsized science than by mammoth projects. This finding would seem to suggest that the rate of return originally estimated by Mansfield might better be described as the rate of return from academic research in applied scientific fields.

Basic Versus Applied Research. One debate currently taking place in policy circles centers on how much federal funding should be allocated to basic research and how much to R&D that is nearer the marketplace. At first glance, Mansfield's results would seem to suggest that applied academic research may be the most useful avenue for federal funding of R&D to help the economy. However, as Mansfield notes, his method may

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10. See Mansfield, "Sources and Characteristics." Although the Department of Energy funds research in oil recovery, the academics surveyed by Mansfield obtained little of their support from the Department of Energy.

not be appropriate to determine the rate of return from basic research, since it is limited by assumption to 15 years from the publication of the academic results to the introduction of new products.[11] It may take longer for the results of basic research to reach the marketplace through new products.

For example, few advocates of the Superconducting Super Collider believe that the knowledge it will produce is likely to have commercial impact in the next 15 years. Rather, they argue that by changing the way knowledge is organized, basic research can eventually help to create capabilities not available at present. Furthermore, there are often very important synergies between basic and applied research--for example, advances in instrumentation technology (applied research) help basic research, which in turn provides the theoretical basis for applied research elsewhere.

It may be, however, that after a certain threshold is reached, basic research has little direct economic value and is more appropriately justified on purely scientific or training grounds. Given Mansfield's 15-year cutoff (as well as the inherent difficulty in using a longer time frame), there are

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11. Mansfield limited his period so as not to overstate the value of academic research, not wanting to include findings that had become common knowledge. See Mansfield, "Academic Research and Industrial Innovation," p. 1, footnote 2.

substantial limits to using his study to justify any specific division of R&D between basic and applied research.

Mission-Oriented R&D Versus General Science. Most federally supported R&D is mission-oriented--that is, it supports federal missions, such as defense, space exploration, or health. Mission-related R&D spending will rise and fall depending on the perceived need for the mission. For example, military R&D rose and fell with the perceived need for military capabilities.

Federal missions often include producing public goods whose true contribution to national welfare is not captured in conventional economic indices. For instance, the national income and product accounts do not include an economic measure of national security beyond its cost.

Depending on the value of the mission, the true social return from research in support of that mission may be higher or lower than the economic return from academic research that can be used by industry. Thus, even if most studies of the economic benefits of mission-related R&D--outside of a few fields, such as health and agriculture--show that such R&D has little if any positive effect on the U.S. economy, the appropriate criterion for judging that research is the value of the mission itself or the contribution of the research to the mission.

Direct economic return, however, is often used as a justification for federal missions that use advanced technology, such as space or defense. Insofar as a mission is justified in those terms, it would be appropriate to compare the economic returns from advanced, technology-oriented R&D projects with the economic return that Mansfield found for academic research. Mansfield's high return for academic research, and the low return found for most nonacademic federal R&D, suggests that policymakers should substantially discount the economic justifications for large technology projects.

As long as the federal government has missions that involve R&D, there will be some tension between funding research designed to promote the mission and funding research for industry. With the end of the Cold War, the tension between mission-related R&D and academic R&D may abate somewhat--defense R&D was not academic, and the civilian missions that replace it use academic R&D more freely. However, as the federal funding for global climate research increases, this tension between mission-related R&D and general R&D could rise again. Judging from Mansfield's sample, research about the greenhouse effect and other climate changes is not likely to be used by industry in the short run, even though, if the alarms are correct, understanding such natural phenomena is of crucial economic significance.

HOW PRECISE IS MANSFIELD'S ESTIMATE?

As Mansfield himself makes very clear, major uncertainties are associated with virtually every step of his surveys and calculation. These uncertainties accumulate through the calculation. Thus, statistically speaking, one can have little confidence that the actual rate of return from academic research is very close to Mansfield's estimate. The problem is not that Mansfield has deliberately inflated his numbers--his methodology and assumptions generally seem sensible, often conservative. Rather, the calculations require a series of explicit and implicit assumptions about things that are very difficult to measure. Taken together, these uncertainties substantially reduce one's confidence in the reliability of the final result. (The discussion of the previous section is independent of the frailty of Mansfield's results--even if a more precise estimate could be calculated, it still would have limited relevance to the science funding debate, for the reasons previously discussed.)

Mansfield claims to have generally erred on the conservative side. However, without reconstructing the results, it is difficult for CBO to tell whether the cumulative effect of the assumptions is indeed biased one way or another. Two examples--training benefits and related federal spending--show opposite, and perhaps offsetting, biases. These examples, discussed below, are not necessarily the most crucial assumptions. (Without replicating Mansfield's results, it is impossible to know, in an arithmetic sense, which assumptions are most critical to the result.) However, both are straightforward and easy to understand.

Training Benefits Are Excluded

A potentially significant bias in Mansfield's study is his omission of the return to society from the students who are trained while performing academic R&D. Many analysts suggest that the most important benefit academia has for industry is trained personnel. Mansfield purposely excluded this contribution of academia, most likely because of the added difficulties of calculating the value of new scientists and engineers. However, this exclusion probably biases his measurement of social return from academic research downward.

Modern R&D requires hands-on practice to acquire familiarity with research methods and equipment to complement the theoretical studies that come from classroom exercise. Stated another way, scientific knowledge is composed of a tacit component, which can be delivered only through hands-on experience, and a codified component, which is more amenable to formal teaching methods. A complete advanced scientific education requires both.

At the same time, a university faculty that concentrates entirely on research often neglects the classroom exercise of the bulk of its students while accelerating the tacit component in the education of its best graduate and postdoctoral students. The concentration of federal R&D funding in a relatively small number of schools probably exacerbates this problem at those schools.

Related Federal Spending Is Excluded

On the other side, Mansfield excludes spending on national laboratories and other federally funded research and development centers from his calculations.[12] Academic researchers often spend time at various national

12. Mansfield, "Academic Research and Industrial Innovation," p. 8, footnote 24.

laboratories or federally funded R&D centers doing portions of their work that will eventually be published as academic research. For example, researchers from various medical schools commonly serve as visiting researchers at the National Institutes of Health while on sabbatical from their regular positions. Similarly, at one Army laboratory, 9 of the 22 cooperative research agreements with nongovernmental organizations are with colleges and universities. These schools' Ph.D. students conduct their laboratory work at the federal site, and researchers from both sides regularly visit, lecture, and correspond with each other.

In addition, the national laboratories house national user facilities, scientific installations whose resources cannot be easily duplicated by any single university. For example, researchers in material sciences from many universities work at the National Synchrotron Light Source at Brookhaven National Laboratories in New York. They are not charged for the use of this facility as long as the work is published.[13] The Department of Energy's national laboratories have many such user facilities whose primary users are from academia and industry. A casual perusal of scientific journals reveals many authors and collaborators who work at national

13. Similarly, some academic fields, such as high-energy physics, could probably accomplish little empirical work without the national laboratories.

laboratories or draw on such work.[14] As an indication of the effect of such institutions on industrial R&D, Adam Jaffe, an economist from Harvard University, found that having federally funded research and development centers nearby was significantly correlated with the number of corporate patents in a state.[15]

Without some estimate of the national laboratories' contribution to academic research, the cost side of Mansfield's estimating equation is too small. Most of the R&D done at national laboratories is not related to academic work, but some obviously is. Furthermore, the total of such expenditures is large enough that Mansfield ought to account for it in some way other than saying that it does not fit the study's definition of "academic." The federally funded R&D centers run by universities and colleges spent roughly one-quarter as much as universities did in 1991 on R&D ($4.8 billion versus $17.2 billion).[16] Federally run national laboratories and agencies spent $6.9 billion (equivalent to 40 percent of academic R&D spending) on basic and applied research in 1991. Some of

14. Mansfield's own work is an example. Although he is an academic, the statistics he cites on U.S. R&D spending are produced by a government agency. These data provide more than just background information; without a government publication, he would have to independently compute U.S. academic R&D to use as the basis for his calculation. Other academic disciplines may be similarly affected.

15. Adam Jaffe, "Real Effects of Academic Research," *American Economic Review* (December 1989), pp. 957-970. Although subsequent researchers have criticized Jaffe's use of patents as a measure of industrial innovation efforts--indeed, Mansfield has independently and on a number of occasions noted the limitations of using patent data--none took issue with Jaffe's finding about the positive effect of federally funded research and development centers on industrial innovation.

16. National Science Foundation, *Science and Engineering Indicators, 1991* (1991), pp. 308-311.

this funding should be included in a measure of total U.S. academic research funding.

Similarly, Mansfield excludes some industry funding of academic R&D from his estimate of total academic R&D funding. Only those industry funds that were spent through formal university channels would show up in the statistics that Mansfield uses in his estimate. Funds that were spent directly on researchers--say, in a consulting relationship or as directed research--would very likely be missed in the statistics.

Mansfield has said that, if his estimate for total spending on academic R&D was 25 percent too low, his estimate for the social rate of return from academic R&D would be 25 percent, rather than 28 percent.[17] Thus, changing this one number (and there appears to be good reason to believe it is too low) could change his estimate by 3 percentage points. The cumulative result of similar changes could be substantial. Overall, however, there appears to be convincing evidence that the resulting estimate of the rate of return from academic research would still be high.

17. Mansfield, "Academic Research and Industrial Innovation," p. 8, footnote 24.

Sensitivity of Definitions

Mansfield's studies find that academic research has made a greater contribution to industrial products than some previous studies have shown.[18] He explains the difference by saying that his definition of contribution is broader than those in previous studies. Although previous research looked only at products or processes invented at universities, his study included products and processes for which academic research may have been necessary but not sufficient.

As was discussed above, Mansfield's measure involved asking R&D directors to name products that would have taken an extra year to develop without the contribution of recent academic R&D. Part of the problem with this measure is that research efforts, as opposed to product-development efforts, are notoriously difficult to time. Although the concept Mansfield is trying to establish--that, in these cases, replacement of academic research by industry research would be a costly but not impossible proposition--is certainly correct, it is very subjective. Consequently, with slight modifications to the wording of the definition, Mansfield might have obtained results much more similar to those in earlier surveys.[19]

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18. Ibid., p. 3.

19. Ibid., pp. 2-3.

This is not to say that Mansfield's definition is wrong and the others are correct. Indeed, Mansfield's approach seems to correspond more closely to the way the economy actually works than others do. Rather, this merely shows how sensitive the results may be.

CONCLUSIONS

Since World War II, U.S. science policy has been guided by Vannevar Bush's vision that, if funded and left to set their own agenda, scientists would amply reward the nation for its investment.[20] Mansfield has shown that, on average, academic scientists have indeed kept their part of the bargain. The return from academic research, despite measurement problems, is sufficiently high to justify overall federal investments in this area.

Nevertheless, the very nature of the estimating methodology, as Mansfield has noted in his articles, does not lend itself to use in the annual process of setting the level of federal investment in R&D, nor to allocating that investment among its many claimants. Furthermore, given the nature of the assumptions, definitions, and other methodological questions, as Mansfield notes, his result is more properly regarded as indicating a broad

20. Vannevar Bush, *Science--The Endless Frontier*, 40th Anniversary Edition (National Science Foundation, 1990).

range of likely orders of magnitude of the return from academic R&D than as a point estimate (28 percent) of the return from federal investment in this area.