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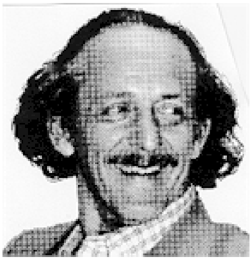

Current Comments

The Economic Impact of Research and Development

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Recently, President Reagan signed a bill to reduce federal spending over the next three years by $130 billion. Almost as soon as the ink dried, Administration officials announced that further reductions totaling about $75 billion were needed to erase the federal budget deficit by 1984. Subsequently, it became evident that even that was not enough. It is clear that these budget plans will adversely affect many research and development (R&D) programs that depend on federal support.

In the past, I've expressed concern about support for scientific research.[1-3] As early as 1973, I discussed the need for a lobby to advance the interests of research scientists.[1] More recently, I concentrated on how we might prove the value of basic research.[3] These issues are even more compelling today, in view of the planned reductions in R&D funding. In this essay, I'll try to report in detail on the estimated impact of R&D on the American economy—its contributions to the US gross national product (GNP) and industrial productivity. Unfortunately, it is a vital subject for which there are only limited, but still important, data available.

R&D is an umbrella term covering three separate activities—basic research, applied research, and development. The National Science Foundation (NSF) defines basic research as "knowledge or understanding of the fundamental aspects of phenomena and observable facts without specific applications...in mind."[4] Applied research determines "the means by which a recognized and specific need may be met,"[4] according to NSF. Finally, NSF says development is concerned with the "production of useful materials, devices, systems, or methods, including design and development of prototypes and processes."[4]

Table 1 shows the federal obligations to R&D at NSF and the National Institutes of Health (NIH) for fiscal years 1979-1982. The government's 1980 fiscal year (FY), for example, started on October 1, 1979, and ended on September 30, 1980. The data in Table 1 represent the total amounts committed for orders, contracts, and services by NSF and NIH. They take into account the cutbacks and amendments proposed by the Office of Management and Budget (OMB) for FY 1981. However, they do not reflect Congress' later decision to restore the funds earmarked for elimination from NIH's 1981 budget. Also, the figures reported for 1982 should be read as "lower limit" amounts, since the budget for that year is still subject to congressional approval or revision.

Table 1 shows that total R&D funds for NSF increased from about $808 million in 1979 to $882 million in 1980, a rise of 9.1 percent. This amount was expected to increase by 6.3 percent in 1981, to $937 million. In the March budget for 1982, the increase would have been 6.7 percent, to $1 billion. But in the revisions proposed by OMB last

Table 1: *Federal obligations to research and development at the National Science Foundation (NSF) and National Institutes of Health (NIH). Amounts shown are in thousands of dollars.*

NSF

FY	TOTAL R&D	BASIC RESEARCH	APPLIED RESEARCH	DEVELOPMENT
1979	807,925	733,255	66,770	7,900
1980	881,792	815,246	58,441	8,105
1981 (est.)	937,404	873,640	59,764	4,000
1982 (est.)*	999,900	945,444	54,456	——

NIH

FY	TOTAL R&D	BASIC RESEARCH	APPLIED RESEARCH	DEVELOPMENT
1979	2,953,133	1,463,703	1,066,408	423,022
1980	3,181,830	1,642,341	1,145,129	394,360
1981 (est.)	3,328,345	1,745,645	1,188,645	394,055
1982 (est.)*	3,570,821	1,883,650	1,270,400	416,771

*Figures for 1982 are "lower limit" amounts, based on the budget for FY 1982 submitted by the President to Congress in March of 1981. These figures are subject to congressional approval and/or revision.

SOURCE: National Science Foundation. *Federal funds for research and development, fiscal years 1980, 1981, and 1982: detailed statistical tables.* Washington, DC: NSF, 1981. Vol. 30.

September, the NSF total is *reduced* to $881 million, a *decrease* of six percent from 1981.

When we "disaggregate" these amounts, we find that basic research funds for NSF increased by 11.2 percent from 1979 to 1980, and showed a 7.2 percent rise from 1980 to 1981. For 1981-1982, the estimated rise is expected to be 8.2 percent. Applied research funds at NSF have dropped dramatically—a *decrease* of 12.5 percent from 1979 to 1980 was followed by an increase of only 2.3 percent from 1980 to 1981. But for 1981-1982, another *decrease* of about nine percent is expected. Funds for NSF sponsored development programs show a rise of 2.6 percent from 1979 to 1980, followed by a *decrease* of more than *50 percent* from 1980 to 1981. Development funds at NSF will be *discontinued* in 1982! NSF development funds were targeted entirely for science education—discontinuing funds for science education programs is a questionable goal in the Administration's effort to balance the budget. Unless the President withdraws the amendments proposed last September, or Congress adds to the requested levels, NSF will have to reduce R&D support in 1982.

NIH will also be forced to reduce its support of R&D across the board because the proposed budget doesn't even cover the shrinking value of the dollar due to inflation. Total R&D funds for NIH increased by 7.7 percent from 1979 to 1980, but the increase amounted to only 4.6 percent from 1980 to 1981. For 1981-1982, the increase is estimated to be 7.3 percent. NIH funds for basic research increased by 12.2 percent from 1979 to 1980, followed by a rise of 6.3 percent from 1980 to 1981. The estimated increase for 1981-1982 is 7.9 percent. Applied research funds at NIH increased by 7.4 percent in 1979-1980 and just 3.8 percent in 1980-1981. A 6.9 percent increase is estimated for 1981-1982. Funds for NIH sponsored development programs *decreased* by 6.8 percent in 1979-1980, and the amount for 1981 showed virtually no change in funding over 1980. An increase of 5.8 percent in 1982 was projected in March. Keep in mind that the rate of inflation has fluctuated between eight and ten percent from 1979 to 1981. If R&D funds aren't increased by *at least* eight to ten percent, scientific research budgets are decreasing because their research dollars are shrinking.

Published data on 1982 budgets for NSF and NIH cover the period through March 1981, when the new Administration announced its budget plans. OMB recently indicated that the budget for FY 1982 which the President submitted to Congress in March will be reduced by *another* 12 percent. NIH and NSF have to wait until Congress acts on the new OMB plan before they can estimate their budgets with reasonable accuracy. This may be the right time for the scientific community to suggest guidelines for R&D funding to the Administration and legislators.

Frank Press, president, National Academy of Sciences (NAS), says that scientists "must point out more effectively—with documentation, if necessary—that the nation's economic strength...is dependent upon scientific accomplishment."[5] At the end of October, NAS sponsored a two-day conference of about 100 leading US scientists to discuss the impact of current budget policy on scientific research. The participants issued a statement urging the Administration to review the government's role in supporting scientific research. They stated that OMB's plan to further reduce the 1982 budget by 12 percent would "do irreversible damage unless longer term research...is protected."[6] They also said that research, and the training and education of scientists and engineers, is central to the Administration's goal of stabilizing the economy.

The NIH has already made a significant step in documenting the contribution of scientific accomplishment to the nation's economy. In March, the NIH's Office for Medical Applications of Research issued a draft report entitled, "Biomedical Discoveries Adopted by Industry for Purposes Other Than Health Services."[7] It describes ten examples of basic biomedical research that led to very profitable commercial applications. This brief report presents a convincing argument that basic research has a significant impact on the US economy. It also shows that benefits unanticipated by basic science researchers often "spill over" into the private sector.

For example, physics researchers investigated the possibility of transmitting images through fiber optic bundles during the 1950s. In 1956, NIH funded projects to adapt this new technology to the development of a flexible endoscope. Endoscopes enable physicians to visually examine hollow internal organs, like the throat and bronchial passages, rectum, and urethra, without relying on surgical procedures. Endoscopes were the first demonstration that fiber optic technology had a practical application. Fiber optics have since been applied to telecommunications, military operations, and industrial process controls. The current annual contribution of fiber optics to the GNP is calculated at about $100 *million*, "but it is projected to be worth $1.5-4.0 billion by FY 1990."[7]

Basic researchers have studied the hormone secretions of endocrine glands for many years because of their central role in tissue metabolism. Steroid hormones, for example, influence anabolism, the construction or synthesis of tissue. In 1935, researchers isolated testosterone from bull testes. One of the functions of this steroid hormone is to enhance the growth of skeletal muscle. Soon after it was isolated, biochemists devised a way to synthesize testosterone from cholesterol, which made available large quantities of this hormone. Steroid hormones are now used to increase the growth rate and bulk weight of cattle, making more meat available at lower costs. Steroid hormones and their derivatives contribute an estimated $1.5 *billion* to our economy every year.[7]

Another animal feed supplement traces its origin back to the mass production of penicillin during World War II. Industrial and academic researchers began searching for new antibiotics after witnessing the humanitarian and commercial value of penicillin. In 1948, industrial investigators discovered chlorotetracycline, a broad-spectrum antibiotic described as "the most important antibiotic developed since penicillin."[7] That same year, chlorotetracycline was used as an animal feed supplement in the form of "animal protein factor" (APF). It was found that chlorotetracycline stimulated the growth rate of chickens, turkeys, and pigs. Today, antibiotics used in animal feed contribute about $3.4 *billion* to the GNP[7] although there is some controversy over the possible hazards of this procedure.[8,9]

Basic biomedical researchers began searching for a way to preserve expensive biological specimens, like antisera, rabies virus, and blood, in their laboratories as early as 1909. They knew that fishermen in northern climates preserved their catch by hanging it outside in cold, dry air. The fish froze solid and slowly dried to a stable form by a physical process called "lyophilization" or "sublimation." Biomedical researchers improved on this centuries-old practice by combining low temperatures with vacuum conditions. This procedure, now called freeze-drying, quickened the rate of sublimation. In the 1960s, General Foods and Nestle developed freeze-dried instant coffee, the first time the food industry adopted this method. Since then, companies have produced freeze-dried meat, vegetables, and poultry for instant soup mixes. Today, US producers of freeze-dried food products have annual retail sales of $3.8 *billion*.[7]

For decades, enzymes have been a focus of basic researchers interested in knowing more about the physical basis of life and the biological activity of proteins. Pancreatic and other enzymes in the digestive tract were the centers of early interest. These early studies enabled researchers to purify and crystallize many digestive enzymes. The availability of pure enzyme extracts had a great impact on industry. For example, beer could be chilled without becoming muddy and cloudy if enzymes were added. Brewers were able to sell beer stored in cans and bottles for long periods. Wine and fruit juice manufacturers also used enzymes for the same purpose. Pancreatic enzymes were used in the leather industry to prepare hides for tanning. Enzymes were also added to laundry detergents to remove food and biological stains from clothing. Meat tenderizers, bread dough conditioners, and milk coagulants for cheese production all rely on enzymes originally isolated and purified by basic biomedical researchers. Enzyme biochemistry in the food industry adds $23.3 *billion* to the US economy each year.[7]

The NIH report goes on to describe five more instances of basic research adopted by industry. The vaccine for Marek's disease in chickens resulted from basic research into the role immune factors play in controlling herpesvirus infections:[10,11] the annual savings in poultry loss is estimated as at least $48 *million*. Rat poisons based on anticoagulants derived from basic research into hemorrhagic sweet clover disease in cattle: annual retail value is between $50-100 *million*. Home permanent kits for cold waving hair are spin-offs of basic research into the structure of keratin, the protein in mammalian hair: sales contributed $122.7 *million* to the US economy in 1980. The manufacture of high fructose corn syrup and reduced lactose milk products are only two food processes that rely on basic research into immobilizing enzymes on solid supports: industrial products made with immobilized enzymes increase our annual GNP by $2.1 *billion*. Major computer technologies, like miniature tape drives, point plotting displays, and CRT-based consoles, spin-offs of the Laboratory Instrument Computer (LINC), were developed at MIT for biomedical research: over $2.5 *billion* in sales last year resulted from this innovation.[7]

The dollar figures quoted in the NIH report are *gross* amounts. That is, the cost of R&D for these discoveries was not subtracted from the estimated contributions they made to the GNP through industrial applications. However, Charles Lowe, acting director, Office for Medical Applications of Research, points out that R&D input is much smaller than the eventual industrial output. He says, "These ten selected examples are estimated to contribute approximately $37 billion annually to the Gross National Product, a figure that exceeds the total combined appropriations for the NIH since its inception in 1937. This amount is ten times greater than the NIH budget for FY 1980."[7] Clearly, basic research, and its application and development in industry, has a major impact on the US economy. These ten advances alone account for 1.5 percent of the 1980 GNP, estimated at $2,523 billion. Also, the National Science Board observed in 1979 that "investigation of long-term U.S. economic performance has indicated that about 34 percent of measurable U.S. economic growth between 1948 and 1969 derived from advances in knowledge."[12]

The pioneering work of Edwin Mansfield, University of Pennsylvania, and other economists documents the rate of return from R&D investments by the *private* sector—individual business firms and entire industries. Mansfield's calculations tell us the private rates of return to the innovating firm/industry and the social rates of return to the public/consumers. The econometric model on which these calculations are based is complex, so I'll describe only its general features without providing detailed formulas.

In a 1977 article,[13] Mansfield detailed the social and private rates of return from 17 industrial innovations. There are two broad types of innovations. Product innovations introduce a new product that is used by a firm or household. Process innovations reduce the cost of manufacturing already existing products.

The social rate of return from product innovations is determined by first estimating the "resource saving" resulting from the use of the innovation. This is added to the corresponding increase in output of the industry using the innovation. The resource saving must be adjusted if the innovation displaces another product—the revenues from sales of the displaced product are lost to the economy and must be subtracted from the profits of the innovator. The resource saving is also adjusted if other firms imitate the innovation—their profits from sales of the "bootlegged" innovation are added to the profits of the innovator. The sum of resource saving and increase in output represents the social benefit from the innovation, which is used to compute the social rate of return.[13]

The private rate of return from product innovations is determined by first estimating the total investment in the innovation—R&D, plant and equipment, manufacturing start-up, and marketing start-up. Also, the innovating firm is likely to have invested R&D funds in failed projects that never resulted in new products. A proportion of this "uncommercialized R&D" is also taken into account. The firm's total investment in the innovation is then related to the profits generated by the new product to calculate the private rate of return.[13]

The social and private rates of return on *process* innovations are calculated by a single formula, if they don't result in lower product prices. Process innovations reduce the cost of manufacturing—they increase the innovator's profit by making the operation more efficient. Other firms increase their profits by reducing costs when they imitate the process innovation. Society, too, benefits from process innovations—less energy is consumed by the more efficient operation, for example. Mansfield explains, "The total decrease in costs (which equals the increase in profits) of all the relevant firms is a measure of the social benefit of these innovations in a particular period. It equals the social saving in resources due to the innovation."[13] But if the process innovation results in reducing the price consumers pay for the firm's product, the social rate of return is determined as described above for product innovations. The same is true for the private rate of return.

After calculating these returns for the 17 industrial innovations, Mansfield stressed three conclusions. First, the median social rate of return was a "handsome" 56 percent, and this is a *conservative* estimate. Second, the median private rate of return was 25 percent before taxes. Third, the private rate of return from about one-third of the 17 innovations was "so low that no firm, with the advantage of hindsight, would have invested in the innovation, but the social rate of return...was so high that, from society's point of view, the investment was well worthwhile."[13]

In 1980, J.G. Tewksbury, vice president, Foster Associates, Washington, DC, used Mansfield's method to calculate the social and private rates of return from 20 commercial innovations: 12 industrial products, four consumer products, and four industrial processes.[14] These 20 R&D projects were evaluated "in terms of resources 'returned', or saved, compared to resources 'invested', or allocated, by the nation."[14] Resources invested include R&D costs, plant investment, advertising outlays, and so on. Resources returned include the innovator's profits, imitators' profits, and consumers' surplus resulting from reduced prices. Again, adjustments were made for profits lost from displaced products, uncommercialized R&D, and environmental hazards, where necessary. Tewksbury stresses that only economic returns are calculated: "Esthetic and other quality-of-life benefits were generally not included, these being difficult or impossible to measure in dollars."[14]

The results of Tewksbury's analysis confirmed Mansfield's findings. The median social rate of return was 99 percent, considerably more than the 56 percent Mansfield observed. Also, the median private rate of return was much lower—27 percent, almost the same as Mansfield's calculation of 25 percent. Again, many firms would not have elected to invest in their innovations in hindsight, and significant social benefits would have been lost.[14]

In a 1980 article,[15] Mansfield focused on the contributions that basic and applied research make to the productivity of firms and industries. This time, no dollar value calculations were made. Instead, Mansfield tested the hypothesis that an industry's or firm's change in productivity varies directly with the amount of research it conducts. If a significant portion of productivity can be accounted for by research, then we can say that research makes "a significant contribution to an industry's or firm's rate of technological innovation and productivity change."[15]

Mansfield analyzed data on 20 manufacturing industries in terms of a model used by many economists to measure the relation between R&D and productivity. However, Mansfield improved the model so that basic research and applied research could be separately tested. Briefly, the model's equation includes the following factors: the industry's profit or "value-added" in a given year, its stock and expenditure of basic research, its stock and expenditure of applied research, its stock of physical capital, and its labor input and the percentage of workers that are unionized.

The results of the computations are striking—more than "60 percent of the variation among industries in the rates of productivity increase are explained by the equation."[15] In particular, there is a strong correlation between an industry's basic research and its rate of productivity increase from 1948 to 1966 when applied research was held constant. But Mansfield noted that industries that engage in basic research also support long-term applied research. After testing these two factors, Mansfield found that long-term applied research was even more significant statistically than basic research.

In addition to testing the impact of research on productivity at the industry level, Mansfield analyzed data on 16 petroleum and chemical firms from 1960 to 1976. The results were the same. Basic research was directly and significantly related to a firm's rate of productivity increase when applied research expenditures were held constant.[15]

U.K.R. Chand, Ministry of State for Science and Technology, Ottawa, Canada, used a less complex method to analyze the overall performance of 19 Canadian industries according to the amount they invested in R&D.[16] The 19 industries were divided into different categories: five industries performed no R&D; seven industries were "low research-intensive"; and seven industries were either "medium research-intensive" or "research intensive." Research intensity was determined by the ratio of R&D to value-added, the employment of R&D personnel as a percentage of total employment, and the workers' overall skill level.

Chand found that research-intensive Canadian industries outperformed low research-intensive industries from 1961 to 1974: they had a 50 percent higher growth in employment, 23 percent higher growth in output, 29 percent higher growth in productivity, and 56 percent lower growth in prices. When compared with industries that performed *no* research, the performance of research-intensive industries was even more striking. They had 231 percent higher employment expansion, 66 percent higher growth in output, 43 percent higher productivity growth, and 57 percent lower growth in prices.[16]

Robert Evenson, Yale University, Paul Waggoner, Connecticut Agricultural Experiment Station, New Haven, and Vernon Ruttan, University of Minnesota, reviewed 32 studies on the economic benefits from agricultural research.[17] Agricultural research has a long history of public funding, through the US Department of Agriculture (USDA), state agricultural experiment stations, and agriculture extension programs. In fact, Congress mandated the establishment of agricultural experiment stations in every state by enacting the Hatch Act in the mid-1800s.[17]

The studies reviewed by Evenson and his colleagues were classified in two categories. Studies classified as "index numbers" computed annual benefits directly from the *total* cost of research on a given crop and the estimated increase in production that resulted. Rates of return reported in the 15 index number studies ranged from 20 to 90 percent on every dollar invested in research. They point out that this is "well above the 10 to 15 percent realized in typical investments."[17]

Seventeen studies were classified as "regression analyses," which estimated the annual production return resulting from *increased* research investment instead of total research costs. Regression analysis is a more sophisticated method than index numbers because it can assign parts of the return to various sources, like scientific research or extension advice. Thus, it can focus on the change in productivity that can be attributed specifically to research. Rates of return reported in these studies ranged from 21 to 110 percent![17]

Evenson also presented the results of his own study, in which "changes in the productivity of American agriculture from 1868 to 1971 were related to the research performed by the state agricultural experiment stations and the USDA, agricultural extension, and the schooling of farmers."[17] From 1868 to 1926, agricultural research yielded an annual rate of return of 65 percent. From 1927 to 1950, agricultural research was classified as either "technology-oriented" or "science-oriented." Technology-oriented research focused on plant breeding, farm management, agronomy, engineering, and animal production. Science-oriented research concentrated on soil science, botany, zoology, phytopathology, and plant and animal physiology. During this period, technology-oriented research yielded a rate of return of 95 percent. Science-oriented research returned benefits at an annual rate of 110 percent! Evenson observed, "The higher payoff to science-oriented research is achieved only when it is directed toward increasing the productivity of technology-oriented research."[17] From 1948 to 1971, technology-oriented research returned more than 90 percent on the investment. Science-oriented research returned 45 percent during this time.[17]

The studies by Evenson and colleagues, Chand, Tewksbury, and Mansfield indicate similar results and reinforce the same conclusion—research has a significant and direct impact on the economy. Basic research, applied research, and development in science, industry, and agriculture account for a large portion of US economic growth and productivity. These studies show that the dollar value rates of return on investments in research are two or three times higher than the ten to 15 percent return on typical investments.

It is ironic that the current Administration is limiting federal allocations for R&D in an overall effort to reduce the federal deficit and restrain inflation. By increasing productivity, investments in research help decrease the rate of inflation.[18] But inflation may increase and productivity may decrease as a result of dwindling federal support of research. Mansfield explains that this will also reduce *private* support of research: "To the extent that inflation reduces investment rates it tends to discourage R&D that requires new plant and equipment for its use. To the extent that inflation makes long-run prediction of prices and circumstances increasingly hazardous, it tends to discourage R&D that is long term and relatively ambitious."[18]

Until Congress and the President recognize the folly of undercutting R&D, the US government can stimulate research and innovation in other ways besides direct funding. Tax law reform is one way to encourage R&D in industry. For example, industry could have a major tax credit for R&D investments. If they were allowed to write off a significant portion of R&D as part of the cost of doing business, industries would be more inclined to perform R&D. In the Reagan tax program passed by Congress, businesses are given a 25 percent tax credit only for *increases* in R&D outlays—those that either can't afford to increase R&D commitments or are forced to decrease these investments would get no tax credit.[19] Also, the 25 percent tax credit *doesn't* apply to R&D funds covering salaries of support staff or nonsalary benefits for researchers.[19] If the cost of hiring new staff and researchers isn't covered in the tax credit, a business might not be able to expand its R&D program in a meaningful way.

Industry could be further encouraged to invest in more R&D if equipment used in research were depreciated sooner. Reagan's tax law permits companies to depreciate lab equipment in just three years instead of seven.[19] Companies should also be given increased tax breaks for donating equipment to universities. For example, they should be able to write off the market value of the equipment rather than the cost to build it, which is lower.[20] Universities desperately need to upgrade their equipment, especially now that the new budget has entirely cancelled more than $80 million targeted by the Carter Administration for this purpose.[20] Reagan could compensate for this regrettable budget cut by making it easier for industry to donate equipment to universities.

Deregulation would also stimulate research and innovation. Business must weigh the risk that a product or process may not be profitably marketed. George Eads, a former member of the President's Council of Economic Advisers who is now at the Rand Corporation, Washington, DC, explains, "Attention must now be given to whether the product can meet both current and anticipated tests for toxicity, carcinogenicity, mutagenicity, teratogenicity, etc.... The impact of such a 'regulatory risk premium' would be to slow—but not necessarily stop—new product development."[21] Of course, regulations ensuring environmental and worker safety must take priority over economic considerations. This is a very sensitive and emotionally charged issue. We need to carefully analyze the risks involved in new products and processes, and decide what level of risk is acceptable to society as a whole. I'll have more to say about risk analysis in a future essay.

Ironically, the agencies mandated to support innovative research—NIH and NSF—may actually discourage it! Gairdner Moment, Goucher College, Towson, Maryland, reported the results of an informal survey of granting officers about bias in the peer review system. He points out, "Granting officers agreed that the average panel member is very reluctant to recommend proposals that stray very far from the beaten path. There is indeed abundant historical evidence that...scientists are poor judges of proposals that might lead to major new departures."[22] Richard Muller, University of California, Berkeley, agrees that funding agencies take an overly cautious approach. He explains, "It is easy to fund the established scientist who continues to work in his established field. It is risky to fund the scientist working in an area that is not yet established, or a young scientist working in a field that has many experienced researchers."[23] Granting officers may be even more cautious about funding "risky" research as the government reduces their budgets.

The federal government must assume the burden of stimulating research and innovation. Simon Ramo, TRW Inc., Redondo Beach, California, says, "We could...sum it up by saying bluntly that the critical limitations on technological creativity in America are inflation, disincentives through wrong tax policies, and overregulation. The US government is rather heavily involved in all three of these factors."[24] Mansfield agrees that we have to focus on issues beyond specific questions of support for R&D: "Our nation's technology policies cannot be divorced from its economic policies. Measures which encourage economic growth, saving and investment, and price stability are likely to enhance our rate of innovation.... Indeed, improvements in our general economic climate may have more impact on the state of US technology than many of the specific measures that have been proposed to stimulate innovation."[25]

The Reagan Administration is acting to rewrite tax laws and regulations. This may improve the general economic climate and stimulate research and innovation. But this may not be enough to overcome the losses in productivity and economic growth that may result from research budget cuts. Remember that there is about a 20 to 30 year lag between basic research findings and their technical application in industry.[26] We may not feel the effects of the present budget cuts until the turn of the century. Federal administrators and legislators should keep one question in mind as they redline current allocations: are we purchasing short-term economic gains at the expense of future growth and productivity? This is a question that the American public cannot afford to ignore.

Scientists, I believe, have been remiss in conveying a message to Congress and to the public about the economic benefits of basic research. They prefer to point out the dramatic lifesaving effects of their work, but in a world dominated by economics this is not sufficient. Hugh Fudenberg, University of South Carolina, understood this point very well. In 1978 he wrote, "In this era of increasing demands on the federal budget...justification of biomedical research in terms of improvements in quality of life or indeed of lives saved no longer seems sufficient to convince the general public and their elected representatives in Congress that such expenditures deserve high priority."[27] Fudenberg went on to show that biomedical research on polio, measles, and other diseases resulted in saving *billions* of dollars in terms of avoiding medical costs and lost gross incomes over the lifetimes of the patients cured of these diseases.

The monumental work of Julius Comroe, University of California, San Francisco, and the late Robert Dripps, University of Pennsylvania, is also very significant. They showed that many of today's most important medical practices rely on basic research that went unrecognized for many years, even decades and centuries![28,29] The scientific community must come up with an efficient way to identify and encourage basic research that may lead to cost-saving innovations in medicine and industry.

This is one of the reasons why we stress *Citation Classics*.[30] In its own way, each of them demonstrates how basic research can have an enormous impact on theory and practice. This information needs to be brought to the attention of those who shape our economic policies. The few pioneers I've mentioned in this essay should receive major support that is unaffected by the inevitable vicissitudes in congressional and public thinking.

Since these are issues of international importance, it would be most appropriate if the United Nations Development Programme, Unesco, or the World Bank would sponsor an international conference on the subject. Let there be no doubt about it—the economic impact of basic research in the US is not limited to the US.

It is of course necessary to point out that more money for basic research does not necessarily produce better or more productive research. So we must couple our study of this issue with continued efforts to constantly evaluate those who are given support for research. That is why we have been so interested in identifying hundreds of research investigators who have made significant impact by their research activities but who have never been supported at a level that permits them to make their maximum contribution.

Clearly, there is some upper limit to the amount of money any nation can devote to basic research. But whatever it is, I am convinced we are a long way from it. Whatever weaknesses one may point to in the past two decades, the NIH report clearly demonstrates that we have had a handsome return on our investment. What it may not adequately show are the many other important positive impacts on education and other areas of our life. In the present political climate, that will not significantly affect congressional thinking.

May I suggest that you write your own Representatives, Senators, and the President expressing your dismay with prospective cuts in scientific R&D programs. Your letter will be particularly persuasive if you can detail how basic research in your field affects the economy. Of course, saving or extending human lives is highly important. But one should not overlook the appeal that a reduction in health care costs has for economy-minded legislators.

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