Chapter 2

Measuring the Economic Return: Progress and Problems

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INTRODUCTION

This chapter discusses past and current use of economic measures of the return on research and development (R&D) as an investment in individual industries and at the national level. Different approaches distinguish between direct and indirect returns, private and Federal spending, basic and applied R&D. This chapter examines the difficulties and ambiguities encountered when trying to extend the analysis of private sector R&D spending to Federal R&D investments. It reviews attempts— of mixed success-to use econometric methods to measure the returns on Federal R&D dollars in three industries that have been well-studied: agriculture, aviation, and health.

Federal R&D dollars may also have indirect effects on productivity by triggering spinoffs or spillovers; the chapter looks at the National Aeronautics and Space Administration (NASA) as an example of the use of econometric methods to measure such indirect effects. The chapter concludes that while econometric methods have been useful to track private R&D investment within industries, the methods fail to produce consistent and useful results when applied to Federal R&D support. From these findings, OTA concludes that economic investment models are not likely to be of great utility in helping to guide Federal research decisionmaking .

ECONOMETRIC STUDIES AT THE NATIONAL LEVEL

Over the past three decades economists have attempted to investigate the effect of research expenditures, technological change, and other research-related inputs to production on the growth of GNP, productivity, and employment. Their basic production function approach has been to separate the inputs to the economy into three groups: capital and labor supply—the major factors determining the productivity of a firm, industry, or national economy—and an "other factors" category, assumed to account for all changes in productivity that could not be explained by changes in labor and capital. This residuals category includes scientific knowledge, technological advance, managerial and marketing expertise, economies of scale, the health and education of the work force, and other factors that affect the efficiency of resource use.

In the 1950s, economists recognized that residual factors were a major influence in economic growth. Using the "factor productivity method, " E.F. Denisen attributed 20 percent of the growth in the Nation's real income between 1929 and 1957 to "advance of knowledge" and 11 percent to economies of scale.[1] Such studies indicated that technological change, however defined, is important to national economic performance. [2]

Private R&D Investment

Building 0,1 these studies, in the late 19 SOS economists began to include R&D expenditures (assumed to be a rough indicator of technological advance) as an input to their productivity calculations, along with capital and labor. Numerous studies found a strong correlation between R&D spending and productivity growth. Looking at R&D as an investment, economists sought

[1] E.F. Denisen, ***The Sources of* Economic *Growth in the U.S*** (New York: National Bureau of Economic Research, 1962).

[2] Zvi Griliches, "Issues m Assessing the Contribution of Research and Development to Productivity Growth *The Bell Journal of Economics*, ***vol. 10,*** spring 1979.

to measure its rate of return. Fellner[3] calculated a 31 to 55 percent rate of return for the entire economy. Terleckyj[4] estimated a 29 percent return to firm-financed R&D. Mansfield[5] estimated a 40 to 60 percent return in the chemical industry and Link* estimated 21 percent in the petroleum industry. More recent in-depth studies confirm the correlation between private R&D spending and productivity increases (see box A).

These studies are representative of the strong and consistently positive correlation found between privately financed R&D and productivity growth in the manufacturing industries. They suggest that econometric analysis of private R&D spending produces estimates useful in evaluation and planning. However, the wide range of calculated rates of return to R&D spending and the inability to assign causality to the correlations reflect the tentative and hypothetical nature of the methodologies. Each study works with different assumptions and definitions. Results are most definitive and consistent for private spending within one firm or industry, where it is easiest to define and measure inputs and outputs.

Social return often exceeds the private rate of return, as a company doing the R&D cannot reap all the benefits from its work. One industry's R&D can spin off substantial benefits to other industries and other sectors of society, a difficult output to quantify. In studies by Mansfield and others, the social rate of return was two or more times the private rate of return.[7]

In examining the applications of these economic models it should be kept in mind that they are only hypothetical constructs that attempt to describe complex events. Zvi Griliches, one of the foremost users of these models, warns that the equations in the models reveal correlation, not causality.[8] Nor do the models reveal the path by which R&D investment allegedly leads to productivity improvements. Moreover, the need to treat R&D as the "residual," or "the thing that remains after everything else is accounted for, " further weakens the proof of relationship, since it is entirely possible that other components of the residual exist, but have not been included in the analysis. Finally, the production function approach of neoclassical economics is simply an hypothesis about the way the world works; it has not been proven that such production functions exist or take the form assumed by economists. For all these reasons the impressive returns on private sector R&D investment reported above should be viewed with caution.

The Returns, or Lack Thereof, to Federally Funded R&D in Specific Industries

Econometric approaches have been unsuccessful in establishing a return on federally funded R&D. Unlike the strong and consistently positive correlations found between privately financed R&D and productivity growth in the manufacturing industries, only weak and inconsistent correlations have been found for federally funded R&D. Terleckyj, in the 1975 study reported above, found that for the 20 manufacturing industries he studied, "the coefficients for government-financed R&D are not statistically significant, and the coefficient for government-financed R&D performed in industry is actually negative. "[9] A decade later Terleckyj reported subsequent studies that confirmed the weak indicators and smaller effects of government-funded R&D.[10] Even in two industrial sectors enjoying high, long-term government funding and interest—aircraft manufacturing, and communication and electronic components—Ter-

'W. Fellner 'Trends in the Activities Generating Technological Progress, " *American Economic Review, vol. 60,* March 1970, pp. 1-29.

'Nestor E. Terleckyj, *Effects of R&D on the Productivity Growth of Industries: An Exploratory Study* (Washington, DC: National Planning Association, 1974).

'Edwin Mansfield, "Rates of Return From Industrial Research and Development, " American *Economic Review, vol. 55,* May 196.S, pp. 310-322.

*A.N. Link, "Productivity Growth, Environmental Regulations and the Composition of R& D," *The Bell Journal of Economics, vol. 13,* autumn 1982, pp. *166-l@.*

"Edwin Mansfield, "The Economics of Innovation, " *Innovation and U.S. Research,* W. Novis Smith and Charles F. Larson (eds.), ACS Symposium Series *129,* Washington, DC, 1980, pp. *96-97.*

'Ibid., p. *24,* emphasis added.

'Nester E. Terleckyj (cd.), *State of Science and Research: Some New Indicators* (Boulder, CO: Westview Press, 1977), p. 131.

"'Nester E. Terleckyj, "Measuring Economic Effects of Federal R&D Expenditures: Recent History With Special Emphasis on Federal R&D Performed in Industry, " paper presented to the National Academy of Sciences Workshop on "The Federal Role in Research and Development, " Nov. *21-22, 1985,* p. *5.*

Box A.—Recent Research Productivity Studies

Nestor Terleckyj, studying the productivity of entire industries in 1974, found that an industry's rate of productivity increase is directly related to the amount of its own R&D and to the amount of R&D carried out by its supplier industries.[1] In a study of the relationship between total factor productivity and R&D in 33 manufacturing and nonmanufacturing industries between 1948 and 1966, Terleckyj estimated a 28 percent productivity return on private l&D investment in the manufacturing industries. He found an even higher implicit productivity return on company-sponsored R&D by taking into account the R&D inherent in purchases from supplier industries. For the nonmanufacturing industries the correlation was much weaker, and in some cases actually negative.[2]

Zvi Griliches, in a 1975 study of 883 companies representing more than 80 percent of all the industrial R&D conducted in the United States, found a .7 percent rate of return to total R&D, private plus government funded, for the period 1957-65. There was a wide range in the rate of return by industry, with the chemical industry at the top at 93 percent; electric equipment and aircraft and missiles at the bottom at 3 to 5 percent; and metals, machinery, and motor vehicles in the middle at 23 to 25 percent. For privately financed R&D alone, Griliches found a substantially higher average return of 32 to 40 percent.[3] Terleckyj found this return to be quite comparable to his own value for the manufacturing industries of 37 percent return on private R&D when only direct R&D inputs were considered.[4]

Griliches, in a follow-up to his 1975 study, found that firms that spend a larger fraction of their R&D on basic research are more productive.[5] He found that basic research had 2.5 to 4.5 times as great an effect on productivity per dollar invested as total R&D. However, he cautioned that R&D or basic research may not drive productivity and profitability successes, but the correlation could well be that "success allows firms to indulge in these types of luxury pursuits."

Edwin Mansfield, the third major analyst in this field, refined Terleckyj's work on the 20 manufacturing industries by dividing R&D into its basic and applied components. He found a "strong relationship between the amount of basic research carried out by an industry and the industry's rate of productivity increase during 1948-1966."[6] In a further study of 37 innovations Mansfield compared the return on R&D for those innovations to the firm making the investment (the "private return") with the return to society as a whole (the "social return"). He found a median private rate of return of about 25 percent, but a median social return of close to 70 percent.[7]

[1] Edwin Mansfield, "Research and Development, Productivity, and Inflation," Science, vol. 209, Sept. 5, 1960, p. 1,091.
[2] Nestor E. Terleckyj (cd.), "Estimates of the Direct and Indirect Effects of Industrial R&D on Economic Growth," *The State Of Science and Research: Some New Indicators* (Boulder, CO: Westview Press, 1977), pp. 125-132.
[3] Ibid., pp. 133134.
[4] Ibid., p. 134.
[5] Zvi Griliches, "Productivity, R&D, and Basic Research at the Firm Level in the 1970s," NBER Working Paper No. 1S47, typescript (National Bureau of Economic Affairs, 10s0 Massachusetts Avenue, Cambridge, MA 02138), January 1985, p. 16.
[6] Edwin Mansfield, "Basic Research and Productivity Increase in Manufacturing," *American Economic Review*, vol. 60, No 5, December 1980, p. 866
[7] Edwin Mansfield, "How Economists See R& D," *Research management*, July 1982, p. 27.

leckyj "found strong positive association between private R&D and productivity," but "no effect of *government* R&D."[11]

Measuring Federal R&D spending is more complex than in the private sector. Tracing outputs through the long and nebulous path from basic research to commercial product is especially difficult. A company does research aimed at a specific product or market, controls the entire product development process, manages its marketing, and has a clear record of inputs and outputs. Federal research managers do not target R&D so sharply, have virtually no say in private sector decisions to develop a product, and have no influence and often no knowledge of what is happening in the market.

[11] Ibid., p. 6.

Terleckyj attributes the failure to find a return on federally sponsored industrial R&D to the fact that "government funded industrial R&D is a public good and therefore is used by all users to the extent where its marginal product is zero." Therefore, according to Terleckyj, "its contribution to productivity cannot be observed statistically by traditional techniques and approaches. "[12] In addition:

> there is an inherent conceptual limitation in the national income accounting (and the GNP data) in that it attempts to measure the real cost and the real product of the public sector at the same time. While the resource cost utilized in the public sector can be identified, the real output of public goods cannot be measured because their marginal product and implicit price is always zero.[13]

The inability to find a meaningful correlation between government-funded R&D and productivity increases in the economy as a whole has led economists to examine more closely the indirect impact of Federal R&D on privately funded industrial R&D. According to Terleckyj, studies done in the past 6 years "indicate that in most cases government R&D expenditures have been positively related to private R&D expenditures. "[14] Peter Reiss, reviewing the same literature, reports a "general impression that Federal R&D is a complement to private R&D efforts, " but finds a lack of "very good conceptual models of how Federal R&D affects private R&D incentives. "[15]

Frank Lichtenberg has attempted to distinguish the direct and indirect links between Federal arid private R&D. He argues that Federal R&D expenditures "may, in principle, increase the average and marginal cost of private R&D performance by driving up the prices of R&D inputs''—or "crowding out" private R&D. Alternatively, federally sponsored R&D may leverage private R&D, reducing the costs of private research and innovation and raising the productivity of private R&D—the "spillover effect." He finds econometric evidence for the crowding out hypothesis in the short run, although less so in the long run. He finds limited evidence for cost-reducing spillovers but concludes that "it is probably the case that a small fraction of federally supported R&D generates very large spillovers (some of which may be negative.)''"

[12] Ibid., p. 7.
[13] Ibid., p. 8.
[14] Ibid., p. 9.

"Peter C. Reiss, "Economic Measures of the Returns to Federal R& D," paper presented at the National Academy of Sciences Workshop on 'The Federal Role in Research and Development, " Nov. 21-22, 1985, pp. 11-12.

'*Frank R. Lichtenberg, "Assessing the Impact of Federal Industrial R&D Expenditures on Private R&D Activity, " paper presented to the National Academy of Sciences Workshop on "The Federal Role in Research and Development, " Nov. *21-22, 1985,* pp. 31-32.

INDUSTRY CASE STUDIES: AGRICULTURE, AVIATION, AND HEALTH

Despite the problems in linking government R&D expenditures to productivity improvements in the economy as a whole, studies have shown sector-specific productivity improvements from targeted government R&D programs. This section looks at econometric analyses of Federal R&D support of three industries-agriculture, aviation, and health—whose long and heavy dependence on Federal R&D financing has made it feasible for economists to estimate inputs, outputs, and rates of return. The results of, and problems with, those evaluations are presented below.

Agriculture

For nearly a century, since the passage of the Hatch Agricultural Experiment Station Act in 1887, the Federal Government has had a program to support applied research related to improved farm productivity. The program today has three main elements: 1) the Agricultural Research Service, which funds research and technology transfer projects at the USDA's own research stations and at state universities; 2) the Cooperative Research Service, which consists primarily of matching (Hatch Act) grants to State Agricultural Experiment Stations located at the State Land Grant Universities set up by the Land Grant College Act of 1864; and 3) the Economic Research Service. The budgets for the three services for fiscal year 1985 were $470 million, $320 million, and $50 million, respectively.[17] In addition, the States provide more than $500 million a year in research funding to their agricultural experiment stations. The evolution of Federal and State support for research and extension directed at improvements in agricultural production technology is presented in table 3 below.[18]

Many econometric studies of the productivity return to agricultural research have been carried out in the past three decades, beginning with Zvi Griliches' classic 1958 study of hybrid corn technology. All but one of the studies have shown a very high internal rate of return on public sector agricultural research, as can be seen from table 4 below. The rate of return varies from a low of 21 percent to a high of 110 percent, with the vast majority in the 33 to 66 percent range. Public sector agricultural research has generally been considered to have been a significant success. Richard Nelson summarizes the characteristics of the agri-

"National Science Foundation, ***Federal R&D Funding by Budget Function, Fiscal Years 1984-1986,*** NSF 85-318 (Washington, DC: NSF, March 1985), pp. 74-75.

[18]R.E. Evenson, "Agriculture," ch. 5 of Richard R. Nelson ed.), *Government and Technical Progress: A Cross-Industry Analysis* (New York: Pergamon Press, 1982), p. 252.

Table 3.—Expenditures by the Public Sector on Research and Extension Oriented to Improved Agricultural Production Technology, 1890.1970

	Expenditures on research State agricultural experiment stations				USDA funded	Expenditures on Public
Year	Total[a]	% State funded	% Federally funded	% USDA funded	outside State[a]	Extension Service[a]
1890	97	22	78		2.6	0.3
1900	12.2	34	66		10.4	1 3
1910	370	39	61		474	2 4
1915	342	72	28		62.5	18,0
1920	287	77	23		49,0	464
1925	425	85	15		59.2	61 6
1930	75.6	73	27		96.5	772
1935	793	57	27	16	665	702
1940	113,2	54	28	18	1199	107. 7
? 945	1142	56	23	20	978	1020
? 950	1943	63	17	20	834	140.8
1955	251 4	63	17	20	89.2	152 1
1960	3448	55	15	30	876	169.5
1965	385.5	58	16	26	678	179.7
1970	414,5	66	16	18	109.5	2210
1975.	420.0	na	na	na	110,0	264.0
1980.	428.0	na	na	na	110.0	314.0

[a]In millions of constant 1980 dollars

SOURCE R E Evenson, "Agriculture," ch. 5 of Richard R Nelson (cd.), *Government and Technical Progress" A Cross-Industry Analysis* (New York Pergamon Press, 1982), p *252*

Table 4.—Econometric Studies of Productivity Return to Agricultural Research in the United States

Author (date)	Commodity	Time period	Rate of return
Griliches (1964)	Aggregate output	1949-59	35-40
Latimer (1964)	Aggregate output	1949-59	Not significant
Peterson (1967)	Poultry	1915-60	21
Evenson (1968)	Aggregate	1949-59	47
Cline (1975)	Aggregate	1939-48	41-50
Knutson and Tweeten (1979) , ,	Aggregate	1949-58	39-47
		1959-68	32-39
		1969-72	28-35
Bredahl and Peterson (1976)	Cash grain	1969	36
	Poultry	1969	37
	Dairy	1969	43
	Livestock	1969	47
Davis (1979)	Aggregate	1949-59	66-100
		1964-74	37
Evenson (1979)	Aggregate	1868-1926	65
		1927-50	95 (applied R&D)
		1927-50	110 (basic R&D)
		1948-71	45 (basic R&D)
Davis and Peterson (1981)	Aggregate	1949	100
		1954	79
		1959	66
		1964	37
		1969	37
		1974	37
Norton (1981)	Cash grain	1969	31[a]
	Poultry	1969	27
	Dairy	1969	56
	Livestock	1969	30
	Cash grain	1974	44
	Poultry	1974	33
	Dairy	1974	66

[a]Based on maximum lag length estimated (9 years)

SOURCE: Robert D Weaver, "Federal R&D and U S Agriculture An Assessment of the Role and Productivity Effects, ' paper presented at the National Academy of Sciences Workshop on "The Federal Role in Research and Development, " Nov 21-22 1985, p 27 cultural sector that have made it amenable to this success:

> In the first place, farming is an atomistic industry and farmers are not in competition with each other. Differential access to certain kinds of technological knowledge, or property rights in certain technologies, are not important to individual farmers. This fact at once means that farmers have little incentive to engage in R&D on their own behalf and opens the possibility that the farming community itself would provide the political constituency for public support of R&D.
>
> The Federal/State agricultural extension system . . . marshaled that support and put the farmers in a position of evaluating and influencing the publicly funded applied R&D. The system is highly decentralized. The regional nature of agricultural technology means that farmers in individual states see it to their advantage that their particular technologies be advanced as rapidly as possible.
>
> It was [the] combination of an evolving set of agricultural sciences based in the universities and supported publicly, and applied research and development also publicly funded but monitored politically by the farming community, that has made public support of agricultural technology as successful as it has been. Where private companies are funding significant amounts of innovative work and the industry is reasonably competitive, it is in the interest of the fanners as well as the companies that public R&D money be allocated to other things. [A] reasonably well defined division of labor has emerged between publicly and privately funded applied research.[19]

The nature of the agricultural sector explains why Federal R&D has a powerful effect and why econometric methods can arrive at relatively reliable estimates of this effect.

Aviation

Since World War II the Federal Government has provided a considerable amount of R&D support for aviation. Indeed, according to David Mowery, "the commercial aircraft industry is virtually unique among manufacturing industries in that a Federal research organization, the National Advisory Committee on Aeronautics (NACA, subsequently the National Aeronautics and Space Administration, NASA) has for many years conducted and funded research on airframe and propulsion technologies."[20] In addition, the Department of Defense has provided considerable support for research and development on military aviation that has generated considerable civilian spinoffs, and the aircraft industry itself conducts a great deal of in-house R&D. The total national R&D expenditure for aircraft from 1945 to 1982 was $104 billion (in 1972 dollars), of which $77 billion was provided by the military, $9 billion by NACA/NASA and $17.4 million by industry. Figure 1 breaks out those expenditures by year. About 45 percent of the total R&D budget went to aircrames, about 30 percent to avionics, and about 25 percent to engines.

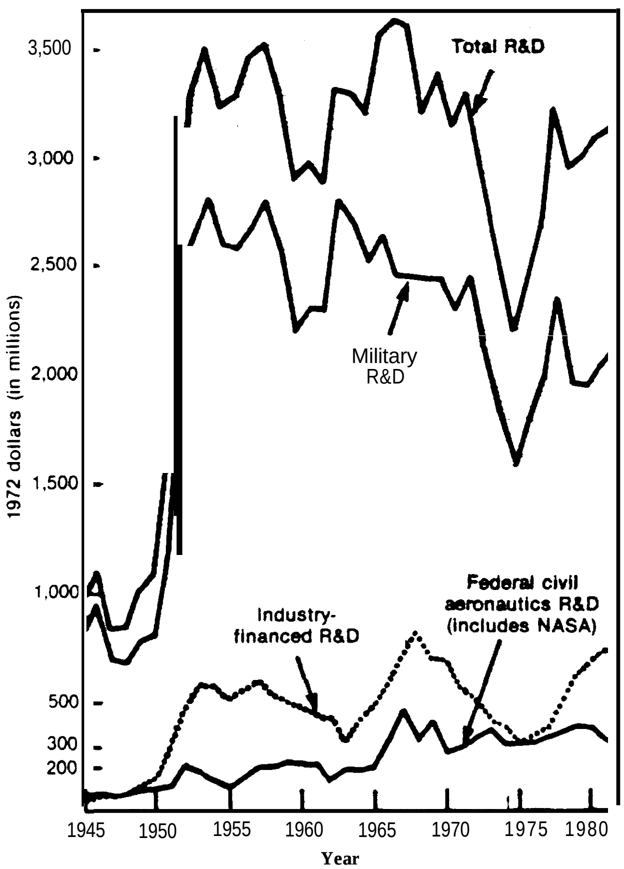
The benefits of this investment to the U.S. aviation industry and the consuming public were substantial. According to Mowery, the "total factor productivity in this [the commercial aviation] industry has grown more rapidly than in virtually any other U.S. industry during the postwar period."[21] Two commonly used indices of aircraft performance are the number of available seats multiplied by the cruising speed (AS X Vc) and the direct operating costs per available seat mile (DOC). Between the DC-3 of 1940 and the Boeing 707 of 1959 the AS X Vc increased by a factor of 20 and the DOC fell by a factor of 3. The introduction of the Boeing 747 in 1970 increased the AS X Vc by another factor of 3 and halved direct operating costs. According to Mowery's calculations, if the total volume of airline passenger traffic in 1983 were to have been flown using 1939 technology (primarily the DC-3), the cost to the Nation would have been $24 billion (in 1972 dollars) rather than the $5.8 billion actually incurred (also in 1972 dollars). Thus, improvements in commercial aircraft technology led to more than $18.2 billion (in 1972 dollars) in additional air transportation services rendered for the actual amount paid. This benefit is considerably overstated in that consumers would have undoubtedly

[19] Richard R. Nelson (cd.), ***Government and Technical Progress: A Cross-Industry Analysis*** (New York: Pergamon Press, 1982), pp. *466-467.*

[20] David C. Mowery, "Federal Funding of R&D in Transportation: The Case of Aviation," paper presented to the National Academy of Sciences Workshop on 'The Federal Role in Research and Development," Nov. 21-22, 1985, p. 13.

[21] Ibid., p. 6.

Figure 1.—Annual R&D Investment, 1945-82
(1972 dollars)



SOURCE: David C. Mowery, "Federal Funding of R&D in Transportation: The Case of Aviation," paper presented to the National Academy of Sciences Workshop on "The Federal Role in Research and Development," Nov. 21-22, 1985.

used other modes of transportation, or foregone a considerable amount of travel, had the aircraft operating costs not declined so substantially. On the other hand, the benefit does not take into account the value of the time saved by more rapid airline travel, the additional economic activity generated by an expanded airline industry, and the foreign trade benefits of the multibillion dollar sales of U.S. aircraft abroad.

If the $18 billion in additional air transportation services is taken as the benefit of improved aircraft technology, and the $104 billion total industry plus government R&D expenditure from 1945 to 1982 as the cost, then the social return from this investment appears to be on the order of 17 percent per year. If military development expenditures—about half of total military aviation R&D costs—am subtracted from the cost side, on the grounds that they do not directly support the commercial market, then the return on investment increases to close to 27 percent per year. Mowery has carried out a more sophisticated return on investment calculation in which he finds the internal rate of return from industry-financed and civilian Federal R&D to be about 24 percent.

Mowery also emphasizes that other factors play an important role. Civil Aeronautics Board regulations encouraged the adoption of new aircraft technologies between 1938 and 1978 by controlling air fares, which encouraged the airline industry to pursue a marketing strategy of technical innovation and service improvements. The regulatory incentive to innovate probably amplified the apparent social return.

Although it is not possible to isolate the civilian return on Federal aviation R&D, the dramatic expansion of the airline and aircraft industries in the United States after World War II is clear indication of the benefits of this unique Federal sectoral policy. Even in this industry, the economists are not unanimous on the productivity benefits. Terleckyj, for example, claims to have found "no effect of government R&D" on productivity improvements in the airline industry.[22] That his conclusions clash with common sense and other analyses illustrates the danger of depending solely on economic formulas to guide Federal R&D decisions.

Health

In 1985, the United States spent $381.2 billion on health care. Three percent of that, $11.5 billion, went to health R&D. The Federal Government funded two-thirds of the research, with half the money going to the National Institutes of Health (NIH).[23] With health care accounting for more than 10 percent of GNP and health research

[22] Terleckyj, "Measuring Economic Effects of Federal R&D Expenditures: Recent History With Special Emphasis on Federal R&D Performed in Industry," op. cit., p. 6

[23] U.S. Department of Health and Human Services, *NIH Data Book*, MH Publication No. ***85-1261*** (Washington, DC: DHHS, June 1985).

claiming 33 percent of all nondefense Federal R&D funds,[24] health policymakers have asked whether it is possible to measure the economic benefits of biomedical research and development in terms of the primary output, improvements in health.

Measuring the productivity of health R&D is complicated by the value-laden issue of setting comparable economic values on well-being, illnesses, diseases, and life span. The economic costs of illness and disease, embodied in a "cost of illness" model, inform the national health agenda and the allocation of Federal health research budgets. An agency of the Public Health Service, the National Center for Health Statistics, has been directed by Congress to calculate annually the economic costs of illness and disease.

In response to an NIH initiative in the early 1970s, Selma Mushkin and her colleagues attempted to use a human capital methodology to quantify the economic costs of disease between 1900 and 1975.[25] They first calculated straightforward direct costs: expenditures on hospital care, physician's services, nursing home care, drugs, and medical appliances. The human capital model also includes indirect costs, specifically morbidity costs, which are losses incurred when illness results in absence from employment or a disability removes someone from the work force; and *mortality costs,* losses due to premature death. Mortality costs, in particular, embody the human capital approach in that they value one's life according to one's earnings, or according to the market value of one's skills. They estimate present value of future losses due to premature death, taking into account life expectancies for different sex, race, and age groups, varying labor force participation rates, and the discount rate.[26]

Mushkin attempted to estimate the contribution to the observed reduction in the national mortality rate of a number of factors, such as better public health measures, improved working conditions and nutrition, better personal health care and higher income, and biomedical research. She treated the mortality rate as a function of five independent variables—economic factors, societal factors, environmental factors, provider characteristics, and a measure of technical advances attributable to biomedical research and development. She then used regression analyses and other statistical techniques to determine the coefficients of each of the five variables in the equation predicting mortality rates. Indicators of technical advances due to research and development proved especially difficult to find, so Mushkin and her colleagues were forced to treat the technology variable as a residual; any reduction in mortality not attributable to the other variables in the function was attributed to biomedical research.

Based on this model, Mushkin found that biomedical research accounted for 20 to 30 percent of the reduction in mortality between 1930 and 1975. She estimated that each l-percent increase in biomedical research funds lowered mortality rates 0.05 percent. She also estimated that 39 percent of the reduction in days lost due to illness could be attributed to the results of biomedical research. Using human capital theory she estimated the value of each premature death averted at $76,000 and each work-year gained when illness is averted at $12,250. With these dollar values inserted for the reduced mortality and morbidity attributed to biomedical research, Mushkin found a return of $145 to $167 billion on a $30 billion investment, equivalent to an internal rate of return of 46 percent.

Critics have attacked the cost of illness model on economic and ethical grounds. Stephen Strickland argues that applying such estimates to decisions on public spending "carries an unacceptable implication that people should be protected, or saved, in proportion to their economic productivity and personal earnings."[27] Such an approach devalues or dismisses the lives of many older citizens, children, women working in the home, or underemployed minority groups. In addition, a person's earnings may vary significantly over

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[24] American Association for the Advancement of Science, ***Research & Development, FY* 1986 (Washington,** DC: AAAS, **1985), p. 27.**

[25] Selma Mushkin, ***Biomedical Research: Costs and Benefits*** (Cambridge, MA: Ballinger Publishing Co., 1979).

[26] For extensive illustrations of the human-capital approach, see, B.A. Weisbrod, "Costs and Benefits of Medical Research: A Case Study of Poliomyelitis," *Journal* ***of Political Economy, vol. 7Q,*** May-June 1971, pp. **527-544.** Also R. Fein, ***Economics*** *of Mental* Illness (New York: Basic Books, 1958). Also, S.J. Mushkin, "Health as an Investment," *Journal of Political* ***Economy, vol. 70,*** October 1962, pp. 129-159.

[27] Stephen P Strickland, ***Research and the*** *Health of Americans* (Lexington, MA: Lexington Books, 1978), p. 45

time, making extrapolations unrealistic. Furthermore, depending on the data and methodology used, calculations of the cost of a disease to the economy can produce a wide range of conclusions. Table 5 illustrates the divergent estimates of three groups analyzing the costs of the same diseases.

Many important costs of illness are also less quantifiable, such as the psychological costs for the patient and family. Costs can extend beyond the immediate period of illness and go unaccounted for if the disease is chronic. Some illnesses entail intergenerational costs, creating immeasurable long-term effects.

Measuring productivity gains in health care raises additional questions for economists. First, how does one assign a value to the health of individuals? Because almost all medical bills are paid by a third party-the government or an insurance company—health care is not as subject to market forces as other industries, and it is impossible to know the value of the care to the consumer. One indirect measure of the economic benefits of public health is increased worker productivity, but this gives no value to the health of the retired or those outside the work force. Distinguishing the inputs to improved health is as difficult as measuring the outputs; changes may be due to improved biomedical technology, nutrition, environmental conditions, exercise habits, more widely available or affordable health care, or a host of other factors.[28]

Physician and economist Jeffrey R. Harris summarizes the knotty conceptual and methodological problems inherent in measuring economic returns on investment in biomedical research:

1. In the biomedical sciences, the separate contributions of basic and applied research in biomedicine can be difficult to distinguish. . . .
2. The separate contributions of public and private investments in biomedical R&D are similarly difficult to distinguish. . . .
3. Not all biomedical innovations have arisen from biomedical research and development. . . .
4. The relative contributions of domestic and foreign investments in biomedical R&D will become an increasingly important issue.
5. Assignments of improvement in health to specific biomedical innovations is not always possible. . , . Observed improvements in health may have resulted from public health measures or changes in life style and the environment. . . .
6. The economic valuation of improvements in health raises important conceptual questions. In particular, innovations that prolong life generally result in increased economic transfers from younger, productive generations to older, less productive generations.

[28] Charles L. Vehorn, et al., "Measuring the Contribution of Biomedical Research to the Production of Health," Research Policy vol. 11, 1982, p. 4.; and Mushkin, "Health as an Investment, op. cit., p. 133.

Table 5.—Economic Costs of Disease: Differential Estimates

Disease	NIH estimates provided to House Appropriations Committee[a]	Estimates of special Commissions[b]	Estimates developed by methodology of Social Security Administration[c]
Arthritis	$4 billion	$13 billion	$3.5 billion
Asthma	$187 million		$855 million
Blindness	$5.2 billion		$2.2 billion
Cancer	$15 to $25 billion (range)		$17.4 billion
Diabetes		$5.3 billion	$3.5 billion
Digestive disease	$16.5 billion		$17.5 billion
Heart, lung, and blood disease	$58 billion		$12 billion
Epilepsy	$4.3 billion		$522 million
Influenza	$700 million		$4,1 billion
Mental illness	$40 billion	$36.8 billion	$13.9 billion

[a] Estimates offered in the testimony of NIH Institute directors or staff or provided in supplementary materials in the course of hearings on NIH appropriations for fiscal year 1977

[b] Estimates developed, respectively, by the National Commission on Arthritis and Related Musculoskeletal Diseases and the National Commission on Diabetes

[c] Estimates developed with the help of Barbara S Cooper, Office of Research and Statistics, Social Security Administration

SOURCE Stephen P Strickland, Research *and the Health of Americans* (Lexington, MA" Lexington Books, 1978), p 46

7. Although considerable attention has been devoted to valuing loss of life, the state of the art in gauging improvements in quality of life is far less advanced.
8. . . . assessments [based on gains in productivity] may substantially understate the public's willingness to pay for certain innovations.[29]

The three sectors analyzed above have similarities that make them amenable to quantitative analysis. Federal agricultural R&D is particularly suited to econometric analysis because the farmers themselves do almost no research; the government plays a significant role in promoting the application of its research; the government is a major customer, both directly and through farm and trade policies; and productivity improvements are easy to measure. The aviation industry is also a long-established, well-defined sector, dominated by Federal support. Aviation R&D is heavily weighted toward the development end and often incremental, making it easier to trace the returns on research. Despite the ease of tracking the products of the aviation industry and the extensive historical records, the case illustrates the difficulty of defining the scope of outputs to be included in an economic analysis; should these include only improved air transportation services, overall improved transportation, or all the indirect social and economic benefits of the airline industry? The health sector is less tractable, but has received significant attention because of the large sums of Federal money involved. Many of the great advances in heath care come serendipitously from basic research, making it difficult to trace the return on investment.

These analyses do not reveal the extent to which return on private or Federal R&D investment of an industry depends on variables such as R&D intensity, size, degree of concentration in a few large companies, whether the industry is emerging or stagnant, extent of technological competition within the industry, capital intensity}', market position, and government influences other than R&D.

"Jeffrey R. Hams, "Biomedical Research and Development: Measuring the Returns on Investment, " currently unpublished typescript of the National Academy of Sciences, National Academy of Engineers, and Institute of Medicine, November 1985, and for a further discussion of the basic-applied distinctions and the pathways between the two, see Julius H. Comroe and Robert Dripps, "Scientific Basis for the Support of Biomedical Science, " *Science*, vol. 192, Apr. 9, 1976, pp. 105-111.

SPINOFFS AND SPILLOVERS: NASA

The bulk of Federal research supports the internal missions of agencies like the Department of Defense (DOD) and NASA. While not aimed at commercial products, this research contributes indirectly to the development of commercial products or processes. These "spinoffs" and "spillovers" differ from the direct economic impacts of research sponsored by the Department of Agriculture, NIH and the civil aeronautics program of NASA in that they are unintended byproducts of activities carried out primarily to support non-economic mission agency goals, such as the exploration of space and national security. The economic impacts of the NASA R&D programs have been studied with special thoroughness and will therefore be described in some detail.

Three different approaches have been used to estimate the economic benefits of NASA's programs, according to former NASA chief economist, Henry Hertzfeld.[30] First are macroeconomic studies similar to those described for R&D investments in the economy as a whole. Second are macroeconomic analyses of the direct and indirect benefits from inventions and innovations resulting from the NASA R&D programs. Third are studies of the patents and licenses resulting from space R&D programs, used as a measure of the transfer of technology to the private sector.

Macroeconomic Studies

The first macroeconomic study, carried out by the Midwest Research Institute in 1971, estimated productivity changes in the national economy and

[30] Henry R. Hertzfeld, "Measuring the Economic Impact of Federal Research and Development Investments in Civilian Space Activities, " paper presented to the National Academy of Sciences Workshop on "The Federal Role in Research and Development:, " Nov. 21-22, 1985.

then subtracted changes due to capital, labor, and such non-R&D residuals as demographics, education, length of workweek, and economies of scale. The discounted rate of return to NASA-sponsored R&D, calculated by doing a least-squares regression of the remaining residual, came to 33 percent, or a seven to one benefit/cost ratio. This study has several major liabilities. Assigning residual benefits to one factor, such as R&D, is inherently dangerous because we cannot be certain about the importance of other, unknown residual factors. The study did not look specifically at NASA R&D, but simply gave it credit for a proportionate share of the benefits of all R&D. The lifetime for benefits was arbitrarily set at 18 years .31

Chase Econometrics, in 1975, carried out a far more sophisticated analysis of the economic impact of NASA R&D, again using a residual calculation from a production function. Chase calculated a "cumulative 'productivity' return to NASA R&D of 14 to 1," which "translated into an annual discounted rate of return of 43 percent to NASA outlays. " However, when asked to replicate its methodology in 1980, using an "updated and longer time series, " Chase found that "productivity changes from NASA R&D spending proved not to be statistically different from zero. " Hertzfeld concludes that the revised Chase study "shows that *due to the theoretical and data problems with the macroeconomic model and data sets available, this approach to finding aggregate economic returns to R&D expenditure is difficult at best, and probably impossible.* "3[2]

Macroeconomic Studies

The two major macroeconomic studies of the economic benefits of NASA R&D programs used the "consumer surplus" approach to estimating the value to society of introducing a new product or reducing the cost of an existing product. The "consumer surplus" approach assumes that many people would be willing to pay more than the market price for a new or improved product, and uses supply and demand curves to estimate that "surplus. " Based on this approach, Mathematical, Inc., in 197.5, estimated the overall benefits to society from four NASA-stimulated technologies-gas turbine engines, integrated circuits, cryogenics, and "NASTRAN," an advanced computer program dealing with structural analysis. They found that "over a ten year period from 1975 to 1984 the four technologies could be expected to return a discounted total of $7 billion (in constant 1975 dollars) in benefits that were attributable to NASA's involvement in their developmerit. " This could be compared to a total NASA budget in fiscal year 1975 of $3.2 billion. (But about $30 billion over that 10-year period in 1975.)33

In 1977, another consulting firm, Mathtech, Inc., conducted a benefit/cost analysis of products adopted by the private sector as a result of NASA's formal technology transfer program. Mathtech only estimated the costs to the private sector "of further developing and transferring the innovations rather than the costs of the initial space R&D development of the technology. " The assumption here was that the initial developmental costs would have had to be incurred for the space program whether the technology was transferred or not. Unfortunately, this makes a calculation of the return on the NASA investment impossible. However, the benefit/cost ratios to the private sector were most impressive: 4:1 for the cardiac pacemaker, 41:1 for a laser cataract tool, 68:1 for a nickel-zinc battery, 340:1 for zinc-rich coatings, and 10:1 for a human tissue simulator.[34]

Both the Mathematical and the Mathtech studies are undermined by important weaknesses in the "consumer surplus" theory. The demand curves used to calculate the surpluses in that theory are inherently unreliable when applied to new technologies that have no well- formed demand function and to evolving technologies whose demand functions change over time. In addition, both studies fail to compare benefits to NASA development costs.

Patent Analysis

A third approach is to study what industry does with the licenses and patent waivers granted by NASA. Analyzing patent waivers, in which NASA allows a company to patent an invention devel -

"Ibid., p. 9.
"Ibid., pp. 11-12, emphasis added.

"Ibid., pp. ***18-19.***
"Ibid., pp. 19-20.

oped under contract, Hertzfeld has found that the commercialization rate (total commercialized inventions divided by total waivers) averaged 20.8 percent over the period 1961-75, with electrical machinery, communications equipment, and instruments accounting for over 69 percent of all commercialized specific waivers. Of the more than 197 NASA patents licensed to industry, Hertzfeld found that 54 were commercialized between 1959 and 1979. This was still a very small fraction (1. s percent) of the more than 3,500 patents owned by NASA at the time.[35]

"Ibid., pp. 24-26.

Finally, Hertzfeld points out that another economic benefit of the NASA space R&D program has been the creation of a multibillion dollar satellite communications industry and a tenfold reduction in the cost of satellite communications. However, Hertzfeld stresses that "economic returns are not the primary reason for space investmerits, " and therefore "no economic measure or calculation can, by definition, encompass the entirety of the return to space investment. "[36]

[36]Ibid., p. 4.

IMPLICATIONS FOR USING ECONOMIC INVESTMENT MODELS TO GUIDE FEDERAL R&D DECISIONMAKING

The studies described above present a discouraging picture for the use of economic returns as a valid measure of the value or desirability of Federal research Funding. Although strong positive returns to private sector research funding in general, and basic research funding in particular, have been indicated by macro-level econometric studies, no such positive returns have been shown for Federal research spending. Using econometric models to estimate the aggregate rate of return to all Federal research pushes the methodology beyond its limited capabilities.

The fundamental stumbling block to placing an economic value on Federal R&D is that *improving productivity or producing an economic return is not the primary justification for most Federal R&D programs.* The basic justification for Federal support of R&D is to encourage research that is socially desirable, high risk, or in the national interest but that is unlikely to be funded by the profit-driven private sector. The very concept of measuring the return to Federal investment in research in economic terms is therefore inherently flawed.

Economists who have studied this issue describe these flaws must vividly. At a fundamental level, Federal research is a public good which cannot be valued easily in economic terms. As Peter Reiss has expressed it:

> Typically the [activities of] the Federal government . . . produce things that have no market values that economists can even begin to mea;-ure. There is no market price, for example, for most health advances, and there is no conceivable evaluation for . . . public goods . . . like a strong national defense. These things are just not quantifiable .37

In many cases substantial economic benefits, such as NASA spinoffs and the computer and microelectronics technology spawned by DOD research, were secondary to the primary political and national security missions.

Frank Lichtenberg has found that Federal procurement has a far greater and more positive effect on private R&D expenditures than does Federal R&D. This finding is consistent with that of a number of other economists. [38] The direct influences of R&D support keep company with indirect but powerful Federal influences on private sector R&D through patent law, macroeconomic policies, tax incentives, trade policies, technology transfer, antitrust practices, and regulation.

[37]The National Academy of Sciences, Committee on Science, Engineering and Public Policy, ***The Federal Role in Research and Development,*** typescript transcript (Washington, DC: NAS, Nov 21, 1985), p. .s3.

[38]Nelson, op. cit., pp. 459-462, *471-472.*

In addition, there are fundamental flaws with the econometric methodology for measuring returns on investment when applied to Federal R&D. First, macroeconomic studies measure the aggregate return to the total expenditure on past R&D. They do not provide any information on the incremental return to the marginal expenditure on future R&D, which is the concern of the policymaker. Another major stumbling block in econometric analyses is that they measure inputs (R&D investments) and outputs (productivity changes) while ignoring the process that goes on in between. That process is the critical stage of turning laboratory research into a tangible return —innovation and commercialization. Research cannot result in product or process improvement unless each step in the move from idea to market is successful: advanced development, pilot studies, legal blessing of patents and licenses, production, and marketing. These intermediate commercialization steps are as important a factor in the move from R&D to productivity as is the R&D investment itself. However, the Federal Government has direct control only over its R&D investment, and very little influence over commercialization in the private sector.

According to Hertzfeld, the production function model used in most econometric analyses "assumes that a formal relationship between R&D expenditures and productivity exists" but "skips a number of steps in the process . . . creation of new knowledge, which will lead to ideas, inventions, innovations, and eventually, with proper marketing and distribution, commercial products . . . *Assuming that all of these missing steps take place from any given set of R&D expenditures is taking a giant leap without looking.* 39

Hertzfeld concludes his study of the economic impact of Federal R&D investments in civilian space activities with a statement that seems applicable to the more than 80 percent of the Federal research budget that is not aimed directly at improving economic competitiveness:

> . . *no economic study **should attempt to put a "bottom** line" ratio or return on space R&D in**vestments.*** There is no such number in existence—it only lives in the uncharted world of general equilibrium theory. . . . All such numbers are products of economic models with many limiting assumptions. Even when these assumptions and qualifications have been carefully laid out, the existence of the number is an attractive bait to those politicians and others who need to justify space R&D. Once a "total" returns number is used, it quickly finds its way into misuse .40

Clearly, R&D expenditures may be conceptualized as an investment flow, largely on the notion that R&D expenditures support the growth of an "R&D capital stock" or knowledge base, which contributes to economic growth and productivity improvement. However, a number of scholars recently have argued that the overenthusiastic application to investment decisionmaking of principles of portfolio management has led U.S. firms to underinvest in new technologies because of an "extreme of caution" (see ch. 4). Hence, even if satisfactory methodologies to calculate return could be developed, it might be unwise to adopt them.

R&D investment, and investment in basic research in particular, are characterized by high levels of *uncertainty* about their outcomes. A market that does not yet exist cannot be measured. While quantitative models of financial and other investment planning do provide methods for reducing *risk,* there exist virtually no models that can incorporate uncertainty. An explanation of this problem requires a brief description of the differences between risk and uncertainty.

Risk exists when decisionmakers can define the range of possible outcomes and assign probabilities to each. Models of risk analysis and reduction that have been developed for financial and investment decisionmaking rely heavily on the ability to quantify risk by assigning a probability to a specified set of likely, discrete outcomes.

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*Hertzfeld, op. cit., p, 7.

*Ibid., p. 42, emphasis added.

[41] Spence's analysis of "Investment, Strategy and Growth in a New Market" explicitly disavows any attempt to deal with uncertainty:

> And finally, and less happily, uncertainty about **demand, technology, the rates of entry, and competitors' behavior—all** of which are practical **problems for firms and inherent features of most new markets—is set** aside ***to*** focus on the issue of the optimal penetration of the market and the dynamic aspects of strategic Interact Ion Integrating uncertainty into an appropriate model remains a high priority **research topic**

A.M. Spence, "Investment Strategy and Growth in a New Market," *Bell Journal of Economics*, **vol.** 10, No. 1, 1979, pp. ***1-19*** (quotation from p. ***2).***

True uncertainty, as defined by Frank H. Knight and others,[42] is the inability to specify possible outcomes. Estimating consequences, and therefore risks, is impossible. If one cannot specify outcomes, possibly due to the uniqueness of the process (e.g., the creation of an entirely new technology) or the lack of historical data on relations between actions and outcomes, quantitative models for risk-minimizing investment strategies are not applicable.

R&D investment, especially basic research investment, is a classic example of investment undertaken under conditions of severe uncertainty. Not only are research outcomes dimly perceived, assigning credible probabilities to the possible outcomes is impossible. Quantitative models developed to assess risk in energy exploration or financial management cannot address the uncertainty inherent in basic research spending decisions. As one moves from basic research to applied research or development, quantifiable risk replaces uncertainty. For this reason, quantitative models are likely to be far more useful in the evaluation of applied R&D or development decisions than for exploratory research. In addition, quantitative models are more applicable to decisions about distributing R&D investments among research installations or performers within a single discipline than allocating basic research funds across competing fields.

For the wealth of reasons presented above, it is clear that using economic returns to measure the value of specific or general Federal research expenditures is an inherently flawed approach. The only exceptions to this rule are certain Federal R&D programs whose specific goals are to improve the productivity y of particular industries or industrial processes.

‘Nelson and Winter describe the search behavior of a firm in an uncertain environment as follows:

> The areas surveyed by a decisionmaker inside the firm may well include identifiable “alternatives” that could be explored, but these are only dimly perceived and it may not be at all clear which will turn out to be best. The process of exploring perceived alternatives, or ●xogenous ●vents, may bring to light other alternatives not even contemplated in the original assessments. . It is clearly inappropriate to apply uncritically, in the analytical treatments of that process, formalisms that posit a sharply defined set of alternatives..

Richard R. Nelson and Sidney G. Winter, An *Evolutionary Theory of Economic Change* (Cambridge, MA: Harvard University Press, 1982), pp. 171-172.