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POLIO RESEARCH AND ITS APPLICATION:

COSTS AND RETURNS

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ABSTRACT

The resources that have been devoted to polio research in the United States have produced vaccines that are both safe and effective in preventing polio. The analysis in this paper shows that -- except under the most extreme assumptions -- this research is raising output and reducing treatment expenditures in amounts producing a rate of return on the research costs of at least five percent, and probably twice that high.

Because of the narrowness of the operational measure of benefits used in this paper -- including its abstraction from the pain and anguish accompanying disease -- there is little doubt that the real value of the medically-successful polio research is greater than what is estimated in this paper. In addition, even the more-narrowly financial benefits are probably understated, in part because of the disregard for the benefits occurring outside the United States.

The knowledge about means for preventing polio has the technical characteristics of a pure "public" good: its use by one person does not reduce its availability to others. But the resources required to apply the knowledge are another matter. Indeed, one of the major points of this paper is that the value of knowledge cannot be assessed independently of the costs of applying it.

Polio Research and Its Application: Costs and Returns

Burton A. Weisbrod

Introduction

Medical research has come to attract large and growing expenditures; medical research expenditures by the federal government alone have surpassed $1.4 billion in 1966-67, up from $400 million in 1959-60, and from only $69 million a decade earlier.[1]

Do expenditures on medical research represent an efficient use of resources? In what terms can "efficiency" be measured? The key difficulty in evaluating all research -- whether medical or other -- rests with the difficulty of forecasting the effects (output) resulting from a particular quantity and quality of research resources. There is hope, however, that the retrospective analysis of research efforts that have been "successful" -- in the technical sense of having produced a useful output -- will shed some light on the relationships between costs and returns in research generally. It is true that analyses of past research

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[1] Ida C. Merriam, "Social Welfare Expenditures, 1929-67," Social Security Bulletin, 30 (December 1967), p. 5. See also U. S. Bureau of the Census, Statistical Abstract of the United States: 1967 (88th edition), Washington, D. C., 1967, Table 773, p. 538.

will not provide sufficient evidence on which to base decisions regarding current or future research. Yet insofar as circumstances are similar, it would seem desirable to know more about the relationship between costs and returns associated with previous research efforts as a guide to current action.[2]

This paper reports on a recent major success of medical research -- the development of effective vaccines (Salk, Sabine) against poliomyelitis. The approach involves estimating the following: the time stream of research expenditures directed toward poliomyelitis; the time stream of a number of forms of benefits predicted to result from the application of the polio vaccines; the costs of utilizing the vaccines; and, finally, the internal rate of return on the research expenditures.

Evaluating medical research does pose a problem not often encountered in other research. How should one evaluate a life saved or a lifetime of paralysis avoided? The complexity of the philosophical and empirical issues involved require no elaboration. In this study only a subset of the benefits from research on polio are considered; these include (1) the increased production, and (2) the reduced costs of treatment, for persons who would have become ill or died from polio were it not for the successful research. Since this approach understates the total benefits, our estimates of rates of return on costs will also be understated.

By examining the case of a successful research effort this study may portray a biased picture of the average results from medical research.

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[2]For an example of such a study see Zvi Griliches, "Research Cost and Social Returns: Hybrid Corn and Related Innovations," Journal of Political Economy, October 1958, pp. 419-431.

At the same time it should be noted that not all expenditures on polio research contributed to the ultimate success of the Salk and Sabine vaccines; that is, the rates of return that will be estimated below are, implicitly, weighted averages of the much larger rates of return on the "useful" lines of research, and much smaller -- perhaps even negative -- rates of return on the less useful lines of research.[3] Thus, with respect to the generalizability of the findings of this study to other medical research, a key issue is whether the probability of "false starts," weighted by the amounts of resources going into each, is likely, *a priori*, to be higher or lower in other areas of medical research than it was in polio research. The answer is not obvious.

There are other issues involved in generalizing from the findings for polio. For one, the measurable benefits per-case-prevented differ among diseases; for another, the costs of applying the fruits of research also differ. This latter point -- the cost of applying new knowledge -- deserves emphasis. Medical research is often regarded as "successful" when it has produced knowledge of means for preventing or treating some disease. Yet such knowledge is of little value unless it is applied, and so the costs of application are an important component of the economic-evaluation process. It does make a difference whether application of the new knowledge requires, for example, taking an impregnated sugar cube which can be provided at a marginal cost measured in cents and administered in a few seconds by non-physician personnel -- as is the case with the Sabine polio vaccine -- or whether application requires costly equipment,

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[3]Griliches notes the same circumstances with respect to the research on hybrid corn. (*Op. cit.*, pp. 426-427.)

skilled operatives, and considerable time in a hospital -- as is the case with some kidney dialysis devices.

In the following pages, estimates are made of polio research costs dating back to 1930 and of measured benefits and vaccination costs beginning with 1957, the year at which we date the research success. Several alternative sets of assumptions regarding costs and benefits are employed, producing an equal number of estimates of rates of return.

The Model

The internal rate of return on polio research is the rate which equates the time stream of research costs with the stream of benefits. Specifically, the rate of return is r in the denominator of the following expression:

$$(1) \quad \sum_{t=1930}^{T} \frac{R_t - [B_t(N_t - W_t) - V_t]}{(1+r)^t} = 0,$$

where R is research costs,

B is the benefit per case prevented (or loss per case occurring),

N is the number of cases occurring in the absence of a successful program of research and application,

W is the number of cases occurring after a successful program of research and application,

V is the cost of applying the research findings,

t is a particular year, and

T is the terminal horizon year, the year beyond which the values of variables are asserted to be irrelevant (*T* could take on any value, including infinity).

The bracketed terms in equation 1 express the research benefits in year t, net of the cost, V, of applying the research knowledge. I turn, now, to the operational form of the variables, discussing each in the order in which it appears in equation 1.

Research Costs (R)

The nature of medical research is such that identifying an expenditure with a particular disease is frequently not easy or clear-cut. Expenditures on "basic" research may contribute to development of an operational method for preventing a specific disease. And research aimed at a particular disease may produce results that are useful in connection with some other disease. As a result, it is not clear, even conceptually, precisely what should be included in an estimate of the cost of research leading to the successful polio vaccines.

The conceptual problem is matched by the empirical problem of obtaining data. In Table 1, column 1 shows the time series of amounts awarded for polio research, on the basis of information obtained by the Science Information Exchange (SIE). The data represent awards, not actual expenditures, and then only those research awards (grants and contracts) registered with the SIE by national granting agencies. The SIE series begins with 1946, and I have arbitrarily extended it back to 1930 in the interest of tolerable completeness. Because of the incompleteness of the SIE expenditure data, and because of the necessarily arbitrary nature

TABLE 1

Estimated Awards for Poliomyelitis Research, 1930-1956
(Thousands of Dollars)

Year	Current Dollars (1)	Price-Adjusted (1957=100) (2)
1930		$ 100
1931		200
1932		300
1933		300
1934		300
1935		300
1936		300
1937		300
1938		300
1939		300
1940		300
1941		100
1942		100
1943		100
1944		100
1945		100
1946	$ 242	356
1947	492	631
1948	746	891
1949	1,513	1,823
1950	1,729	2,064
1951	2,609	2,883
1952	2,744	2,967
1953	2,022	2,170
1954	1,920	2,051
1955	2,176	2,332
1956	1,962	2,072

Source: Column 1: Science Information Exchange.

Column 2: For years 1946-1956 -- adjustments of data in column 1 by the Consumer Price Index, 1957 = 100.
For years 1930-1945 -- the author's estimates.

of the extrapolation, two alternative research-expenditure series are utilized in the calculations described below.

The research data in column 1 are in current dollars. In order to take into account price level changes, and, in the absence of a truly satisfactory basis for doing so, I used the CPI to adjust the expenditure estimates to the 1957 level of prices. The results appear in column 2.

Benefits Per Case Prevented (B)

Measured benefits from prevention of polio are the sum of: (1) the market value of production lost because of the premature mortality due to polio; (2) the market value of production lost as a result of morbidity -- illness and disability -- caused by polio; and (3) the costs of resources devoted to treatment and rehabilitation of polio victims. The basic methodology by which each of these three components was estimated is described in detail in my Economics of Public Health[4] (hereinafter cited as EPH), and will only be summarized briefly here. The present paper extends this earlier work, which dealt only with the benefit side, to a full benefit-cost analysis in which the costs incurred to discover the effective vaccines, and the costs of vaccinating people -- applying the new knowledge -- also are considered.

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[4] Burton A. Weisbrod, Economics of Public Health (Philadelphia: University of Pennsylvania Press, 1961), especially Chapters VII and VIII.

Mortality losses for people of specified ages had been estimated previously (in EPH) as the present value of "expected" future earnings,[5] utilizing 1951 earnings data and U. S. life tables for 1949-51.[6] For women, the market earnings data were supplemented by estimates of the value of household services.[7] From these gross-loss figures were subtracted my estimates of the marginal consumption expenditures attributable to an incremental person in a household -- the point being that mortality involves the loss of a consumer as well as of a producer.[8] The resulting values of net future earnings were weighted by the actual reported number of deaths attributable to polio among males and females, by age, to obtain the estimated "premature mortality" loss per death from polio.[9]

Morbidity losses -- those resulting from the temporary loss of a producer -- were derived from the same age-specific and sex-specific earnings-productivity data used for the mortality-loss estimates, it being assumed that an average of one-fourth of a year of work time was

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[5]Alternative discount rates of ten percent and five percent were used, but the ten percent calculations are utilized in the present paper.

[6]EPH, op. cit., Tables 2, 3. The assumption was made that age-specific and sex-specific incidence rates for other diseases are independent of those for polio. Thus, a reduction in the incidence of polio -- as would result from a successful prevention program -- was assumed to leave unchanged the incidence rates, morbidity and mortality rates from other diseases.

[7]Ibid., Appendix II.

[8]For details of the estimation procedure see EPH, ibid., especially pp. 33-36; Tables 2, 6 and 12; and Appendix I.

[9]Ibid., Table 6.

lost per case because of temporary or permanent disability.[10] For the permanently and totally disabled, the entire remaining working lifetime was lost, but the overwhelming majority of cases produced little or no loss of work time -- in part because the effects were very short-term and occurred among children.

Treatment losses are the third form of social cost of polio that had previously been estimated. Prevention of a disease makes treatment costs unnecessary, thereby liberating resources for alternative uses.[11] The range of treatment costs for polio victims has been great, running into many thousands of dollars when respiratory equipment was utilized, but for the large proportion of cases, which have been non-paralytic, these costs have been far smaller. Earlier I have estimated the mean at around $550 per case as of 1950.[12]

These three forms of losses were summed to give an estimated mean loss per case of $1,150 -- the estimate of the expected benefit per case prevented.[13] It is possible that a successful prevention program could bring about a significant change in the labor supply (and, hence, in the marginal productivity of labor) or in the demand for treatment; and in

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[10] Ibid., Table 9 and the accompanying discussion.

[11] It might be noted that a freeing of resources from treatment activities would produce no direct effect on GNP, since treating the sick is regarded as a final output. Notwithstanding the absence of a change in GNP, it would seem clear that such a reallocation of resources -- made possible by a successful disease-prevention program -- would increase economic welfare.

[12] EPH, op. cit., p. 80.

[13] Ibid., p. 90.

this case the $1,150 figure would be invalid. In the case of polio, however, the disease was not so widespread that substantial effects on factor supply or demand were likely to result from a successful prevention program.

Thus, it was assumed that for each case of polio prevented, a benefit of at least $1,150 resulted -- "at least" because, as noted above, benefits in such important forms as reduced pain and suffering have not been considered. This estimated benefit per-case-prevented is derived from data for various years between 1949 and 1954, but since the data were largely from around 1950, the $1,150 figure was assumed to apply to that year. This figure has been adjusted to prices in 1957 -- the year of research "success," when the Sabine oral vaccine first became widely available -- by the arbitrary use of the CPI, thereby producing a figure of $1,350 in 1957 prices. In some of the calculating described below a productivity-growth adjustment was also made; more about this later.

Number of Cases Prevented (N-W)

We turn next to determination of the number of polio cases prevented. This requires estimation of the number of cases expected for each year following 1957, with and without the research success.

Expected cases -- no research success (N). During the period 1920-1956 the trend in reported cases of polio was upward, although there was substantial year-to-year variation.[14] Some of the "increase"

[14] Health, Education, and Welfare Trends, 1962 edition (Washington, D. C.: U. S. Government Printing Office), p. 17.

was the result, simply, of improved reporting, and so the incidence rates for the later years should be given heavier weight in a forecast. The procedure actually used, therefore, was to calculate the mean rate for the ten years ending with 1956. This gave an average of some 21 new cases annually per 100,000 persons in the population. For the U. S. population in 1957 -- 168 million -- this produced an estimate of 36,000 new cases for each year after 1957, holding constant the size and age distribution of the population in that year.[15] Since the U. S. population is actually growing, and for reasons quite independent of the incidence of polio, the absolute number of polio cases would be expected to rise in the absence of a successful research program. The assumption of population constancy is relaxed, later, to assess the sensitivity of the rate of return to this assumption.

Expected cases -- successful research program. Granted that in the absence of the research, 36,000 new cases of polio could be expected each year, it is necessary next to estimate the degree of success of the research. Here an important -- if simple -- point must be reiterated: knowledge without application is valueless. And since application of new knowledge is rarely costless we can expect application of new knowledge to be less than complete and immediate. Polio vaccine illustrates this generalization. There are costs of producing and delivering vaccine, and there are implicit costs -- in the form of time -- for the individual taking it. Thus, we can expect the vaccine to be utilized by less than

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[15] The age distribution is relevant because the incidence of polio is markedly age-specific. The incidence among persons over 50 has been virtually zero.

the entire population (or even less than the more-vulnerable population under 40), and, consequently, the number of new cases of polio may well not fall to zero.[16] In any event we must take these application costs into account when we turn to the net benefits of the polio research effort, and this will be done, below.

The number of new cases expected in a given year after the successful research is a function of the amount of resources devoted to vaccinating people over the previous 40-50 years or so. The larger the expenditures on application of knowledge -- that is, the more people are vaccinated -- the smaller the number of expected new cases.

In the procedure utilized in this paper, the number of cases expected after 1957 was assumed to equal zero, but alternative assumptions were employed regarding the number of persons who had to be vaccinated -- and, hence, the total cost of vaccinations -- in order to produce this result. Alternative assumptions also were made regarding the cost per person vaccinated. (More details in a moment.) Thus, in equation 1, $N_t - W_t$, the number of cases prevented, was assumed to equal 36,000, the number of cases expected in the absence of a successful research-vaccination program.

Application (Vaccination) Costs (V)

Turning to the vaccination costs, V, it was assumed that to eliminate polio would have required (1) vaccinating the entire 1957

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[16]Since the number of cases prevented, as well as the costs of prevention, vary directly with the expenditures on applying knowledge, there is an economic optimum level of application; this may well involve less than complete vaccination of the population.

population under 50,[17] (2) vaccinating either all, or, alternatively, none of the subsequent newly-born children -- assumed constant at the 1957 level of 4.25 million, and (3) incurring a vaccination cost per person of either $0.66 or $3.00 of direct cost plus an opportunity cost of time.[18] The $0.66 figure assumes three "shots" (actually impregnated sugar cubes) at a cost of $0.22 each. This is an estimate of how low the cost might be if mass vaccination techniques were used.[19] It includes the purchase price of the drug, advertising costs, and my estimate of the implicit cost of the time donated by physicians, dentists, pharmacists and others (utilizing 1959 income data for these occupations, from the 1960 Census). The total cost, so computed, was, simply, divided by the number of persons vaccinated to obtain the average cost estimate of $0.22 per shot, or $0.66 per person receiving the series of three.

The $1.00 per shot alternative cost is a rough estimate of the charge made by private physicians (in 1957 prices).

Obtaining a vaccination also requires time of the persons being vaccinated. In my calculations the average opportunity cost of time per shot received was judged to be around $1.00 for adults and $0.50

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[17]The Sabine vaccine provides lifetime protection.

[18]In fact the disease was not entirely eliminated in 1957, but, then, neither was the entire population under age 50 vaccinated.

[19]The figure is derived from information provided by the Dane County (Madison), Wisconsin "Sabine Oral Sunday" program. I have simply assumed that the costs of this program are representative of such programs generally.

for children. These figures are guesstimates. I assumed that about one-half hour, including travel time, was required for each of the three shots, at an opportunity cost of $2.00 per hour per adult. The lower figure for children (under 18) was based on the assumptions that, typically, a mother would take more-than-one child at a time, so that even if the mother were not also obtaining a vaccination herself, the opportunity cost to her of the time required would be well under the $1.00 per hour figure; in addition, in many instances the vaccination would coincide with a physician-visit for some other purpose, thus making the marginal time required rather modest.

Internal Rates of Return -- The Results[20]

We can now relate the data on benefits and costs in order to obtain estimates of internal rates of return on polio research. Table 2 presents the rates of return under various assumptions about the variables, and with alternative time horizons. Column 1 indicates the saving per case prevented (equivalent to the loss per case-occurring, B in equation 1). In example I the assumption is made that the saving per case will remain constant over time, at the 1957 level of $1,350. By contrast, examples II and III assume that the saving per case will increase through time. The reasoning is this: more than half (actually $825) of the

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[20] The rate-of-return estimates are not, strictly, internal rates of return. The reason is that the benefits-per-case-prevented include an estimate of mortality loss which is, in turn, a present value of expected future earnings, discounted at 10 percent. (See EPH, op. cit., Tables 2 and 3.)

TABLE 2

Internal Rate of Return on Polio Research
Under a Variety of Alternative Assumptions

Example	Savings Per Case Prevented (1)	Vaccination Costs In 1957 (2)	Vaccination Costs After 1957 (3)	Research Costs--Ratio of Actual to Reported (4)	Rate of Return 1930-1980 (5)	Rate of Return 1930-2200 (6)	
I	Constant (at $1350)	$350m.	$9m./yr.	1	8.4%	9.7%	(1)
				5	5.1	7.0	(2)
		625m.	19m./yr.	1	0.4	4.5	(3)
				5	-0.7	3.7	(4)
II	Growing	350m.	0	1	13.4	14.2	(5)
				5	9.0	10.4	(6)
		625m.	0	1	7.9	10.0	(7)
				5	5.8	8.4	(8)
III	Growing	350m.	9m./yr.	1	11.7	12.9	(9)
				5	7.8	9.6	(10)
		625m.	19m./yr.	1	4.5	8.1	(11)
				5	3.0	7.1	(12)

Sources: Columns 1-3 -- See discussion in text.
Column 4 -- For "reported" data see Table 1, above.
Columns 5-6 -- The author's calculations.

$1,350 figure consists of productivity (earnings) lost because of illness and premature mortality of polio victims. Since labor productivity may be expected to increase through time, a productivity-growth factor -- of three percent per year -- was applied in examples II and III to the labor-productivity portion of the $1,350 loss per case.[21]

As discussed in a previous section, I have estimated that an average of some 36,000 new cases of polio could be expected annually in the absence of a successful vaccine, assuming a constant population with constant age distribution. In making the estimates of the rate of return on polio research I assumed, further, that the number of cases subsequent to 1957 would be negligible (strictly, zero) if everyone under age 50 were innoculated in 1957, and if, alternatively, (a) pessimistically, all newborn babies after 1957 would have to be innoculated in order to sustain the complete polio control (example III); or (b) optimistically, no further innoculations of newborns would be required after 1957, the disease having been completely and permanently eliminated by the vaccination program in 1957 (example II). The truth, no doubt, is between these extremes; the object, however, is to assess the sensitivity of the rate-of-return estimate to a wide range of values of the variables.

Columns 2 and 3 of Table 2 reflect these and other alternative assumptions as to the cost of a completely successful vaccination program

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[21]By adjusting the <u>treatment-cost</u> portion only for price-level changes I have assumed implicitly that real costs of treatment would remain constant in the absence of a successful prevention program.

(V, in equation 1). The total vaccination costs in 1957 and, if necessary, thereafter, are a function, of course, of the number of persons vaccinated and the cost per person. Regarding the former, in each of the three examples in Table 2 the assumption was made that the number of newborn children remained constant at the 1957 level of some 4.25 million.

Vaccination costs, as noted above, include the direct cost of producing and distributing the vaccine, and also the opportunity cost of the time required to obtain the vaccination. In column 2, the cost of vaccinating the 1957 population under age 50 is shown for each of the three examples -- first, under the low-cost assumption, $0.22 per shot plus opportunity cost, and second, under the high-cost assumption, $1.00 per shot plus opportunity cost. The respective total costs are $350 million and $625 million.

Column 3 is similar to column 2. It shows the estimated costs of vaccinating all newborns in the years after 1957 under the low- and high-cost assumptions, which produce total costs of, respectively, $9 million and $19 million per year for the case of a constant number of newborns. (In example II, it is assumed that no post-1957 vaccinations are required.)

Column 4 reflects two alternative assumptions as to the accuracy of the data on polio research expenditures (awards) which appear in Table 1. The rate of return estimates thus may be examined to see their sensitivity to substantial underestimates of the research expenditure series. It is quite likely that the research series in Table 1 understates the volume of resources entering polio research -- in particular because it excludes expenditures by the pharmaceutical industry as well as expenditures on basic research that contributed to the eventual success of polio research efforts -- but the degree of understatement is a question mark.

There is some possibility, however, that the polio research series in Table 1 overstates research expenditures devoted directly to polio. For example, James D. Watson comments that he had a Polio Foundation fellowship while doing research on the tobacco mosaic virus and on the DNA molecular structure -- research that ultimately led to the Nobel Prize for physiology and medicine in 1962 (shared with Francis H. C. Crick and Maurice H. F. Wilkens).[22] It seems that either such expenditures should not be included fully in polio research costs, or that the total benefits of polio research should be recognized as including external benefits -- those extending beyond that specific disease. Either way, the result would be to raise the rates of return estimated in this paper.

Similarly, John F. Enders, Frederick C. Robbins, and Thomas H. Weller, who shared the Nobel Prize for physiology and medicine eight years earlier, in 1954, won it for discovering a simple method of growing polio virus in test tubes;[23] yet their polio-related research had far more general value, for it "showed that viruses could be grown outside the body in tissues that they do not usually attack within the body."[24]

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[22] J. D. Watson, The Double Helix, New York, Atheneum, 1968, p. 132.

[23] World Book Encyclopedia, 1965 edition, volume 14, p. 347.

[24] Op. cit., volume 6, p. 223.

Here again, we see that research produced a finding the applicability of which was considerably wider than to the single disease, polio.

Finally, a decision was required as to the time horizon relevant for the analysis. How long into the future should the savings from polio research be assumed to occur? Again, the procedure employed was intended to assess the implications of various choices of horizons. Five horizons were considered (1980, 1990, 2000, 2100, 2200), but the results for only two of them, 1980 and 2200, have been presented in Table 2 (columns 5-6). There may be little justification for selecting a horizon as near as 1980; yet it may well be true that current vaccines will eventually (as soon as 1980?) yield to new strains of polio, and when that occurs the economic life of present vaccines will have ended.

The more distant the horizon the larger is the rate of return on polio research, although it is clear from Table 2 that the rate-of-return estimates are not highly sensitive to the horizon choice. Among the dozens of cases considered -- only some of which are reported in Table 2 -- the extension of the horizon from the year 2100 for an additional 100 years never made a difference of more than one-tenth of one percentage point, and the extension from the year 2000 to 2100 seldom increased the rate of return by more than one point. Considering the variety of assumptions considered, the range of rates of return seems modest. Even extending the time horizon by one hundred years or more beyond 1980 does not make a substantial difference in a number of the cases examined. Generally speaking, the internal rate of return appears to be within the range of 4 to 14 percent.

The "most likely" rate of return would seem to be about 11-12 percent. This conclusion was reached in the following way: (1) Since labor productivity (earnings) can be expected to continue to grow, I consider examples II and III (Table 2) to be more relevant than example I; (2) the most likely assumption regarding the need for post-1957 vaccinations is somewhere between the opposite extremes assumed in examples II and III, column 3, and so my choice of a rate of return will be bounded by these two examples; (3) research expenditures reasonably ascribable to polio were probably not more than three times as great as those reported in Table 1 (although I certainly cannot be confident about this); (4) with respect to the social cost of applying the polio research knowledge, the low-cost vaccination assumption seems to be preferable, (for the high-cost assumption rests on an estimate of physician charges for individual vaccinations -- charges which are likely to exceed the level of the marginal social cost that is possible when more efficient, mass innoculation techniques, are used); and (5) a time horizon extending to the year 2100 or 2200 -- it makes virtually no difference which is selected -- is reasonable.

These five judgments lead me to conclude that the most likely rate of return on polio research is between an upper bound of around 12 percent -- the mean of the figures in column 6, rows 5 and 6 (example II) -- and a lower bound of 11 percent -- the mean of the figures in column 6, rows 9 and 10 (example III).

All of the rate-of-return estimates in Table 2, however, may well be biased low -- even with respect to the so-called "economic" consideration they are intended to reflect. For one thing, the benefits accruing outside the U. S. have been disregarded. (It is true, on the other hand, that research costs incurred outside the U. S. have also been ignored, but the sums involved are probably quite tiny.) For another, the risk-aversion which doubtless characterizes most people's preferences has not been considered, benefits from reduced incidence of polio being estimated at their actuarial level.

Moreover, in order to be conservative, the productivity loss attributable to mortality from polio was taken to be net of the victim's expected individual consumption. Since death takes a consumer as well as a producer, this approach has some merit. Such a net-productivity view examines the losses from polio as they are seen by non-victims, for whom the excess of a victim's productivity over his own consumption may be most relevant.

Alternatively, however, the point of view could be the entire society, including the victims who, of course, cannot be identified *ex ante*.[25] This would imply estimating mortality losses by gross productivity. Were this done, the mortality losses per case of polio would be increased by perhaps 15 percent, but the total loss per case (including also treatment and morbidity losses) would rise by only some five percent. Such an increased loss-per-case would raise the Table 2 estimates of internal rates of return by only about one-half of a percentage point.

Another conservative assumption was that the number of newborn children would be constant at the level in 1957. If this number were

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[25] Alternative points of view regarding definitions of "society" are discussed in EPH, *op. cit.*, pp. 35-36 (footnote 7).

assumed to increase at the rate of two percent per year -- a figure somewhat larger than that which actually occurred in the 1950-1960 decade[26] -- the rate of return would rise by about two percentage points above the levels shown in Table 2. Although the assumption of growth of the number of newborns raises vaccination costs, it also raises the number of cases of polio subsequently prevented.

Finally, some analysis of the importance of application costs is in order. The economic efficiency of research cannot properly be isolated from the costs of applying any new knowledge it generates. Expansion of knowledge and application of that knowledge are joint inputs, both of which are essential if benefits are to be obtained from any research. One implication of this point is that an efficient choice among alternative research strategies should take into account the costs of applying the research, once it has become successful. A higher cost research approach may be more efficient than a less costly one if the latter would entail greater application costs.

To underscore the significance of application costs in the case of polio research, the rates of return summarized in Table 2 have been re-estimated under the assumption that the successful research could be applied costlessly, thus eliminating all vaccination costs. The results appear in Table 3. The rates of return shown therein differ from those in Table 2 for only one reason -- the different treatment of vaccination costs. (In the interest of expository simplicity, Table 3 compares only

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[26]See Statistical Abstract of the U. S., 1964, p. 48. Since 1961 the absolute number of births has actually been decreasing.

TABLE 3

Internal Rates of Return on Polio Research, With and Without Vaccination Costs

		Rate of Return				
		1930-1980		1930-2200		
Example	Research Costs--Ratio of Actual to Reported (1)	With Vaccination Costs (2)	Without Vaccination Costs (3)	With Vaccination Costs (4)	Without Vaccination Costs (5)	
I	1	0.4%	20.0%	4.5%	20.1	(1)
	5	-0.7	11.9	3.7	12.3	(2)
II	1	7.9	21.0	10.0	21.1	(3)
	5	5.8	13.2	8.4	13.6	(4)
III	1	4.5	21.0	8.1	21.1	(5)
	5	3.0	13.2	7.1	13.6	(6)

Source: Columns 2 and 4 -- Table 2, above.
Columns 3 and 5 -- The author's calculations.

Note: The results in columns 3 and 5 for examples II and III are identical. The reason is that these two examples differed in Table 2 only with respect to their assumptions about post-1957 vaccination costs.

some of the examples from Table 2 -- specifically those involving the higher-cost -- $1 per shot -- vaccination cost assumption. These appear in Table 2, lines 3, 4, 7, 8, 11 and 12.)

Comparisons in Table 3 between the rates of return in columns 2 and 3, and in columns 4 and 5 are striking. Whereas the assumptions of example I produced a rate of return of only 0.4 percent for the period 1930-1980, this soars to 20 percent when vaccination costs are disregarded. If there were no vaccination costs it appears that, *ceteris paribus*, the internal rate of return on polio research would have been satisfactory even by ordinary market standards -- all of the rates of return shown in Table 3 being 11.9 percent or greater. Of course, vaccination costs are not zero, and so the costs of vaccination serve to cut substantially the rates of return on polio research efforts.