

Academic research and industrial innovation *

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1. Introduction

The purpose of this study is to estimate the extent to which technological innovations in various industries have been based on recent academic research, and the time lags between the investment in recent academic research projects and the industrial utilization of their findings. Because no attempt (to my knowledge) has been made to estimate the social rate of return from academic research,¹ we also make some rough and tentative estimates of this sort. While the results are subject to many limitations discussed below, they should be of interest to public policy-makers concerned with science and technology, as well as to

economists and others that study the process of technological change.

At the outset, it should be noted that I am concerned primarily with recent academic research—that is, academic research occurring within fifteen years of the commercialization of whatever innovation is being considered.² A great many new products and processes are based on relatively old science that to some extent was due to academic research. In estimating the social rate of return from academic research, I ignore such long-term effects of academic research because they are very difficult to measure, because benefits occurring many years after the relevant investment in research are so heavily discounted,³ and because the effects of relatively old science may not be a reliable guide to the present situation. This, like many other features of my estimation procedure, tends to impart a downward bias to the estimated rate of return.

2. New products and processes based on recent academic research

A random sample of 76 major American firms in seven manufacturing industries—information processing, electrical equipment, chemicals, instru-

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¹ Relatively few detailed studies of the contribution of academic research to industrial innovation have been carried out. Most seem to have focused on the drug industry. For example, see Mansfield et al. [15, ch. 8] and Schwartzman [24]. Also, Mushkin [26] estimated social rates of return for biomedical research, much of which is carried out at universities and colleges. In addition, Project Hindsight and the Traces study dealt with about 20 weapons systems and five major innovations, and Gellman [7] provided relevant data bearing on this topic.

² By “recent”, we mean recent in relation to the time when the innovation occurs. Some observers, particularly in the drug industry, have argued that 15 years is too short, because it often takes longer than this for academic research to be applied. Our reason for using 15 years is to be very conservative. Results based on other time intervals would, of course, be interesting and valuable.

³ For example, a dollar of benefits occurring 20 years hence is worth now only about 3 cents if the interest rate equals 0.20.

Table 1
Percentage of new products and processes based on recent academic research, seven industries, United States, 1975–85

Industry	Percentage that could not have been developed (without substantial delay) in the absence of recent academic research		Percentage that were developed with very substantial aid from recent academic research	
	Products	Processes	Products	Processes
Information processing	11	11	17	16
Electrical	6	3	3	4
Chemical	4	2	4	4
Instruments	16	2	5	1
Drugs	27	29	17	8
Metals	13	12	9	9
Oil	1	1	1	1
Industry mean ^a	11	9	8	6

Source: See section 2.

^a Unweighted mean of industry figures.

ments, drugs, metals, and oil—was chosen.⁴ This sample accounts for about one-third of these industries' total sales in 1985. Data were obtained from each firm's top R&D executives concerning the proportion of the firm's new products and processes commercialized in 1975–85 that, according to these executives (and their staffs) could not have been developed (without substantial delay) in the absence of academic research carried out within 15 years of the first introduction of the innovation.⁵ As indicated in table 1, about 11 percent of these firms' new products and about 9 percent of their new processes could not have been developed (without substantial delay) in the absence of recent academic research.⁶

The percentage of new products and processes based in this way on recent academic research

seems to be highest in the drug industry (which has an obvious interest in the large amounts of medical, biological, and pharmaceutical research carried out at universities) and lowest in the oil industry. To a considerable extent, these inter-industry differences with respect to new products can be explained by differences among firms in R&D intensity. A firm's percentage of new products based in this way on recent academic research seems to be directly related to the percentage of its sales devoted to R&D. Holding R&D intensity constant, interindustry differences are not statisti-

⁵ While our initial requests for information and cooperation were made to the firms' chairmen, the respondents were often the top R&D executives who based their responses in part on detailed data obtained from people at lower levels of their organizations. (For further comments on the data, see footnote 11.)

By "substantial delay", we mean a delay of a year or more. Of course, it is always hard to rule out completely the possibility that, in the absence of the relevant academic research, industrial or government researchers might have provided the necessary information; but according to the firms, this would have been extremely unlikely for the innovations they included in this category. As pointed out in section 5 below, they believe that, without the completion of the academic research, it would have taken at least 9 years longer, on the average, for these new products and processes to have been introduced.

⁶ The figures in table 1 for each industry are weighted means of the firm percentages, the weights being the 1985 sales of the firms. The unweighted means of the firm percentages tend to be higher than the weighted means in table 1. The standard errors of the unweighted means are about 2 percentage points.

⁴ The frame for this survey was the list of major firms in these industries in *Business Week*, 23 June 1986. This list includes all firms spending over \$1 million (or 1 percent of sales, if sales were at least \$35 million) on R&D in 1985. A random sample of 76 of these firms was chosen, and data were obtained from all of them (sometimes after considerable discussion and negotiation) through questionnaires and interviews. The number of firms included in each industry is: information processing, 25; electrical equipment, 14; chemicals, 15; metals, 6; instruments, 7; drugs, 6; oil, 3. An attempt was made to allocate the sample optimally among industries (that is, with sample size being proportional to the total number in each industry times the relevant standard deviation). The sample size of 76 was chosen because it seemed large enough to result in the desired precision. See Cochran [4, ch. 5]. The firms in our sample accounted for about one-third of the sales in the population of firms in these industries in 1985.

cally significant.⁷ One of the most important reasons why relatively R&D-intensive firms are more likely than others to carry out innovations based on recent academic research is that they tend to be more closely abreast of such research.

In some cases, new products and processes could have been developed without the findings of recent academic research, but it would have been much more expensive and time-consuming to do so.⁸ In table 1, such cases are designated as ones where development occurred with "very substantial aid from recent academic research". About 8 percent of these firms' new products and about 6 percent of their new processes during 1975–85 fell into this category. Frequently, while it was technically possible for the firm to have developed them without the findings of recent academic research, it seemed economically undesirable to have attempted it. Thus, in a practical sense, many of these innovations could not have been developed (without substantial delay) in the absence of recent academic research.

The percentages in table 1 are somewhat higher than those based on Gellman's study [7] of 121 innovations occurring in these industries during 1953–73 in the United States, which indicated that about 7 percent were based on inventions conceived at universities. (Among innovations designated as "radical breakthroughs", the percentage was 14 percent.) This would be expected since many innovations that are not based on inventions conceived at universities could not be developed (without substantial delay) in the ab-

sence of academic research.⁹ For example, academic research often provides new theoretical and empirical findings and new types of instrumentation that are essential for the development of a new product, but does not provide the specific invention itself. Thus, academic studies by Professors Kipping and Staudinger provided basic information concerning organo-silicon chemistry which laid the groundwork for industrial silicones.¹⁰

3. Academic-research-based products and processes: Sales and savings

While the previous section indicates that about 11 percent of the new products introduced in these industries in 1975–85 could not have been developed (without substantial delay) in the absence of recent academic research, it tells us nothing about the economic importance of these new products. To help fill this gap, data were obtained from each firm concerning the 1985 sales of its new products first commercialized in 1982–85 that could not have been developed (without substantial delay) in the absence of recent academic research. From these data, estimates were made of the total 1985 sales for all such new products first commercialized in 1982–85 by all major firms in each of these industries, the results being shown in table 2.¹¹

The total sales of such new products in 1985 in these seven industries seems to have been about \$24 billion. Because there are large differences among firms in the sample with regard to the 1985 sales of such new products, the estimated total sales figures for individual industries contain large sampling errors. Thus, although the drug, infor-

⁷ Letting P_i be the percentage of the i th firm's new products that could not have been developed (without substantial delay) in the absence of academic research, and R_i be the i th firm's percentage of sales devoted to R&D in 1985, the regression equation is:

$$P_i = 7.11 + 2.18R_i \quad (R^2 = 0.10).$$

(2.73)

where the t -statistic is shown in parentheses below the regression coefficient. Holding R_i constant, both industry dummy variables and firm size (as measured by 1985 sales) are statistically non-significant.

⁸ Frequently, academic research results in new techniques that enable scientists and engineers in firms and elsewhere to carry out R&D in particular areas more cheaply, quickly, or accurately. For example, high resolution nuclear magnetic resonance spectroscopy, which was based on research at Stanford and Harvard Universities, has become indispensable in many chemical laboratories.

⁹ In the drug industry, table 1 shows that about 27 percent of the new products could not have been developed (without substantial delay) in the absence of recent academic research. This percentage is considerably higher than the percentage of drug discoveries made by the universities. According to Mansfield et al. [15] and Schwartzman [24], the latter figure may have been 10 or 15 percent. As noted in the text, the reason why the figure in table 1 is higher than the latter figure is that academic research often results in findings that are necessary but not sufficient for the discovery or improvement of a drug. Industrial R&D must be carried out to extend, supplement, and focus the findings of the academic R&D. (In addition, of course, some of the differences may be due to sampling errors, which are discussed in footnote 34.)

¹⁰ Jewkes, Sawers and Stillerman [8, pp. 296–299].

mation processing, and electrical equipment industries seem to have the largest sales of new products of this sort, these differences could be due in substantial measure to sampling errors. Given our objectives, the important figures are the seven-industry totals (\$24 billion and \$17.1 billion) which, although they have substantial sampling errors, are sufficiently precise to be useful. (Note too that these totals are quite consistent with McGraw-Hill [10] data.¹²)

¹¹ To make this estimate, we multiplied the number of major firms in each industry by the mean 1985 sales of such products of the firms in the sample. A major firm is defined here as one that is big enough to be included in the *Business Week* list cited in footnote 4. Many of the firms went to a considerable amount of trouble to provide reasonably accurate data. For other firms, the data are rough, but we tried in a variety of ways to make sure that the executives had what seemed to be a solid basis for their estimates. Nonetheless, data of this sort have obvious limitations, and should be treated with appropriate caution.

¹² The results in tables 1 and 2 seem to be quite consistent with McGraw-Hill's survey of business plans for research and development expenditures [10], which provides data for five of our seven industries. In its 1982 survey, McGraw-Hill asked the respondents what percentage of their 1985 sales would be in new products introduced for the first time in 1982–85. If this percentage for the k th industry is L_k , if the k th industry's 1985 sales equal M_k , if the percentage of new products in the k th industry that could not have been developed (without substantial delay) in the absence of recent academic research is N_k , and if the total sales during 1985 of new products commercialized in 1982–85 that could not have been developed (without substantial delay) in the absence of recent academic research is Y_k :

$$Y_k = L_k M_k N_k.$$

Inserting our estimates of N_k in table 1 into this equation, together with McGraw-Hill's estimates of L_k and the actual values of M_k , we find that the resulting estimates of Y_k for these five industries are close to our estimates of Y_k . The differences generally can be attributed to sampling errors.

The McGraw-Hill data cannot be used to check our results for the drug and information processing industries, because these data are not available for them. To obtain data concerning L_k for these two industries, we contacted leading firms in each industry, which provided us with rough estimates. For the information processing industry, the resulting estimate of Y_k is reasonably similar to our estimate of Y_k . But in the drug industry, it is much lower than our estimate of Y_k . According to some leading R&D executives in the drug industry, this is because our estimate of L_k for this industry is too low. But if this is not the case, and if our estimate of Y_k for this industry is too high, our final results will not be affected very much. For example, even if this estimate were double what it should be, the social rate of return in table 4 would be 26 percent, which is not very different from the figure of 28 percent given now.

Turning to new processes, data were obtained from each firm in our sample concerning the savings during 1985 from new processes first commercialized in 1982–85 that could not have been developed (without substantial delay) in the absence of recent academic research. From these data, estimates were made of the total savings during 1985 from such new processes for all major firms in each industry.¹³ The seven-industry total was about \$7.2 billion, as shown in Table 2. The information processing industry seemed to have greater savings than the other industries, but the sampling errors in the figures for individual industries are very large. The important figures are the seven-industry totals (\$7.2 billion and \$11.3 billion) which, while they contain substantial sampling errors, are accurate enough to be useful.

4. Time lags between academic research and industrial innovation

To understand the relationship between academic research and industrial innovation, we need data regarding the length of the time lags between academic research findings and the commercialization of the innovations based on these findings. Information concerning these time lags was obtained from the firms in our sample. For each firm's new products and processes introduced in 1975–85 that could not have been developed (without substantial delay) in the absence of recent academic research, data were obtained concerning the mean time interval between the relevant academic research finding and the first commercial introduction of the product or process. If more than one such research finding was required for the development of the innovation, this time interval was measured from the year when the last of these findings was obtained.¹⁴

¹³ To make this estimate, we multiplied the number of major firms in each industry by the mean 1985 savings from such processes of the firms in the sample. For some firms, these savings data, like the sales data discussed in footnote 11, are rough. Our comments at the end of footnote 11 apply to these data as well.

¹⁴ Because not all of the firms could provide data of this sort, and because others sometimes could only approximate these dates, the results contain errors, but the averages in table 3 should be reasonably accurate.

Table 2

Estimated sales of new products based on recent academic research and estimated savings from new processes based on recent academic research, seven industries, United States, 1985^a

Sales or savings	Innovations that could not have been developed (without substantial delay) in the absence of recent academic research	Innovations that were developed with very substantial aid from recent academic research
Total 1985 sales by major firms of new products first commercialized in 1982-85 and based on recent academic research:		
Billions of dollars	24.0	17.1
Percent of total sales of major firms	3.0%	2.1%
Total 1985 savings by major firms due to new processes first commercialized in 1982-85 and based on recent academic research:		
Billions of dollars	7.2	11.3
Percent of total costs of major firms	1.0%	1.6%

Source: See section 3.

^a The seven industries that are included are listed in table 1.

As shown in table 3, the mean time lag in these industries was about 7 years.¹⁵ In general, it appears that the time lag tends to be longer in larger firms, which is consistent with the view that development often takes longer in larger firms. Also, some small firms are formed to commercialize the results of academic research. When size of firm is held constant, the average lag tends to be greater in the metals industry than in the others, but the sample size in this industry is rather small, so this finding should be viewed with considerable caution. Letting D_i be the mean time lag (in years) for the i th firm,

$$D_i = 5.72 + 0.38S_i + 5.68Y_i \quad (R^2 = 0.30), \quad (1)$$

(2.25) (2.95)

where S_i is the 1985 sales (in billions of dollars) of the i th firm and Y_i is a dummy variable that equals 1 if the i th firm is a metals firm and zero otherwise.¹⁶

For each firm's new products and processes introduced in 1975-85 that were developed with very substantial aid from recent academic research, similar sorts of data were obtained. As shown in table 3, the average lag for these innovations was 6.4 years, which is close to our result for

innovations that could not have been developed (without substantial delay) in the absence of recent academic research.

It is interesting to note that Gellman [7] found almost precisely the same average lag for academic-research-based innovations in 1953-73 (his average was 7.2 years). Also, an analysis of Gellman's data indicates that academic-research-based innovations tend to be carried out by much smaller firms than other innovations. Whereas about 20 percent of other innovations were carried out by firms with under 100 employees, almost 60 percent of these innovations were carried out by such small firms, some of which were probably established to exploit the relevant academic research.¹⁷

¹⁷ Of course, one should bear in mind that Gellman's data are in many regards not comparable with ours. Besides the differences pointed out in the last paragraph of section 2, it is worth noting that, whereas the lag can be longer than 15 years for innovations in Gellman's sample, this cannot be the case in ours, because we are concerned entirely with innovations based on recent academic research. Also, in this comparison (but not in that in the last paragraph of section 2), his data pertain to all industries, not just to those included here. Nonetheless, it is reassuring to find that his results are so close to ours.

Note too that there is no contradiction between our finding here that academic-research-based innovations tend to be carried out by small firms and our findings in footnote 7. The latter are based entirely on data for major firms.

¹⁵ The standard error of each of the overall means in table 3 is about 0.6 years.

¹⁶ In equation (1), the t -statistics are shown in parentheses below the regression coefficients.

5. The social rate of return from academic research: The basic model

To calculate the social rate of return from the investment in academic research, we must compare the stream of social benefits if this investment takes place with what it would have been without this investment, holding constant the amount invested in non-academic research. In other words, we are interested in what would happen if the resources devoted to academic research were withdrawn—and not allowed to do the same or similar work elsewhere.¹⁸ Specifically, suppose that all academic research were to be terminated permanently at the end of year $t - 1$.

Without the investment in academic research in year t , the findings of this research (on which new products and processes are based) would not be available, thus preventing or delaying the development and introduction of the new products and processes based on these findings. According to the firms in our sample, it would have taken at least 9 years longer, on the average, for the new products and processes in tables 1–3 (that were based on academic research) to have been introduced. But since estimates of this sort obviously are subject to large errors, we make the more conservative assumption that it would have taken 8 years for this to occur. As we shall see, our findings change relatively little, even if we assume that this average delay is much less (for example, 3 years).

The social rate of return from the investment in academic research in year t is the interest rate that makes the present value in year t of the extra social benefits due to the earlier introduction of these new products and processes equal to the

Table 3

Average time lag between a recent academic research finding and the first commercial introduction of a new product or process based on this finding, seven industries, 1975–85

Industry	Innovations that could not have been developed (without substantial delay) in the absence of recent academic research (mean number of years)	Innovations that were developed with very substantial aid from recent academic research (mean number of years)
Information processing	7.0	6.2
Electrical	5.3	4.9
Chemical	6.8	7.3
Instruments	4.2	4.2
Drugs	8.8	10.3
Metals	9.8	5.7
Oil ^a	N.A.	N.A.
Industry mean ^b	7.0	6.4

Source: See section 4.

^a Reliable data could not be obtained for a sufficiently large number of innovations to allow us to present figures for this industry.

^b Unweighted mean of industry figures.

investment in academic research in year t . This is an incremental rate of return, since it is the rate of return from only the final installment of the total investment required to bring forth the relevant academic research findings. Absent the investment in year t , the findings of this research would not have been produced (without considerable delays), but this investment is not the total investment required to elicit these findings. Because of the cumulative nature of science, this total investment may have extended over decades or centuries. Nonetheless, for policy-makers who must decide how much to invest next year in academic research, this incremental rate of return is of primary significance. Past investments in academic research are sunk costs, and the social rate of return from next year's investment is what counts.

To calculate this rate of return, we assume, based on the average time interval in table 3, that the new products and processes made possible by the investment in academic research in year t are introduced 7 years later (that is, in year t' , where $t' = t + 7$). The social benefits from the innovations commercialized in year t' that are based on academic research in year t are assumed to con-

¹⁸ Note that we focus on the rate of return from the entire investment in academic research, not the rate of return from an extra dollar spent on academic research. While the latter rate of return is of great significance, we cannot estimate it with the existing data. Our objective is not to allocate the growth in output among various contributing factors, as in Edward Denison's pioneering work (for example, Denison [5]). Instead, it is to estimate the extent of the social benefits which would have been forgone in the absence of recent academic research, which obviously is a polar extreme. In interpreting the results, it is important that this be borne in mind (see section 7). For interesting discussions of other relevant considerations, see Kendrick [9] and Nelson [21].

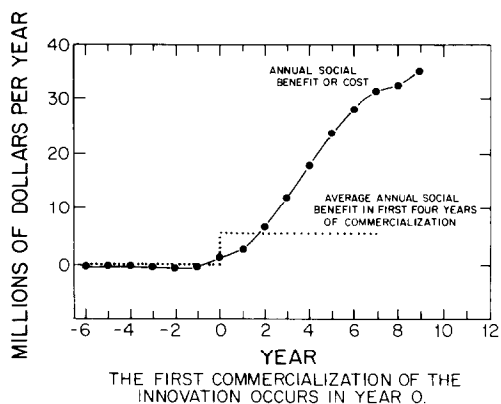


Fig. 1. Annual social benefit or cost, by year, from first commercialization of innovation, mean for 53 industrial innovations. Source: Foster Associates [6], Mansfield et al. [13], and Nathan Associates [17].

tinue up to year $t' + 7$ (and no longer) at their average annual level in the first four years after commercialization, and to be zero before year t' . This, as explained in the following paragraphs, is a very conservative assumption.

Figure 1 shows the average annual stream of social benefits and costs for the 53 industrial innovations studied in Mansfield et al. [14], Foster Associates [6], and Nathan Associates [17], the three principal sources of data on this topic.¹⁹ For the innovations based on academic research in year t , we are replacing the time form of social benefits and costs in fig. 1 with the dotted line shown there. This dotted line underestimates the average social benefits in the years after the commercialization of the innovation, as well as the social costs (due to investment in applied R&D, plant and equipment, and startup activities) prior to year t' . On balance, this a very conservative assumption, if the time form of social benefits (savings from new processes, profits from new products, and benefits to those other than the innovator) and costs is at all similar to that of the 53 innovations included in fig. 1. If the interest rate is 0.25, the discounted net social benefits based on this assumption are about half of their

actual value. If the interest rate is lower, this assumption is even more conservative.

The reason why the social benefits stop in year $t' + 7$ is that we make the conservative assumption that, in the absence of academic research, the relevant research findings would have been obtained (through industrial, government, or other research) in time to permit the introduction of the new products and processes based on these findings in year $t' + 8$ —that is, 8 years after they would have been introduced if the investment in academic research in year t had been made. Hence, after year $t' + 7$, there are no social benefits in excess of those that would have accrued without academic research in year t .²⁰ Note once again that the firms in our sample regard this assumption of a 8-year delay as being conservative (that is, on the low side).²¹

Thus, based on the very conservative assumptions described in this section, if we want to estimate the social rate of return from the annual investment in academic research during 1975–78, we must find the value of i which satisfies the following equation:

$$X \left[\frac{1}{(1+i)^7} + \frac{1}{(1+i)^8} + \dots + \frac{1}{(1+i)^{14}} \right] = C, \quad (2)$$

where C is the annual investment in academic research during 1975–78, and X is the annual social benefit from this investment.

²⁰ This assumes that the average social benefit during the first four years after commercialization is about the same if the innovation is delayed 8 years as if it is not delayed. Whether or not this is true will vary from case to case, but since benefits 8 years or more after commercialization are so heavily discounted, the results are not influenced much by this assumption. Moreover, it is a conservative assumption so long as the delay does not increase the annual social benefit from the innovation, which seems unlikely in most cases.

²¹ In considerable part, this long delay occurred because industrial researchers often had little or no incentive to do the kinds of work that academic researchers carried out. Whereas the academic research underlying the innovations in tables 1–3 was of interest to academic researchers (and to the federal agencies that financed much of it), it often seemed to be of little or no direct use to firms; and even when it did seem to be of use, there often was no effective means for the firms to appropriate the benefits.

¹⁹ Three of Nathan's innovations had to be omitted because of incomplete data. A fourth was excluded because the timing of the social benefits from this innovation was affected dramatically—and very atypically—by the outbreak of an epidemic. The costs and benefits in fig. 1 are in constant dollars.

6. Academic research during 1975–78: Estimated rate of return

To solve equation (2) for i , we need the values of C and X . With regard to C , we use the worldwide investment in academic research, since academic science is in many respects an international enterprise, and firms in all countries draw on the findings of foreign as well as domestic academic research. OECD data and Campbell [2,3] are used to estimate the annual investment during 1975–78 in academic research (other than the social sciences and psychology) in the OECD countries and the Soviet Union (which, according to the National Science Foundation,²² carry out almost all of the world's scientific and technological activities). Because of the difficulties in distinguishing R&D from teaching (and for other reasons), the resulting estimate of C (which is expressed in 1985 dollars²³) is rough.²⁴ Fortunately, our results are not very sensitive to reasonable variations in this estimate.

To estimate X , the first thing to note is that, since there is a 7-year lag, the investment in academic research during 1975–78 results in new products and processes commercialized in 1982–85. Let b_{ij} be the social benefit during year $t' + j$ (where $j = 0, \dots, 3$) from the i th new product or process (based on academic research) commercialized in year t' . If we define $B(t')$ as $\sum_i \sum_{j=0}^3 b_{ij}/4$, where the first summation is over all of the new products and processes commercialized in year t' that were based on academic research, it follows that $B(t')$ is the sum of the social benefits accruing annually from the new products and processes commercialized in year t' that were based on

recent academic research, if one accepts the very conservative assumption in section 5—that is, if we assume that the annual social benefits equal their average annual level in the first four years after commercialization.

Under this very conservative assumption, X equals the mean value of $B(t')$ during 1982–85.

²⁴ For a description of the OECD data, see OECD [22]. Data for 1975–78 were provided by Allison Young of OECD. For the United States, the OECD figures exceed the NSF figures, because they include capital spending and federally funded research and development centers administered by universities. Since work by the centers is not included in our definition of academic research, the R&D performance of these centers is deducted from the OECD figures.

To estimate academic research expenditures in the Soviet Union, we use Campbell's figures [3] for 1975–78 and his dollar-ruble conversion ratio for 1976 and 1977. See Campbell [2].

There are several important problems in these data. For one thing, unsponsored research by U.S. faculty members is omitted. According to the National Science Foundation [19], about 16 percent of engineering research in universities was unsponsored in 1978, as well as about 22 percent of research in the physical sciences, 13 percent in the life sciences, and 16 percent in the environmental sciences. Thus, to take account of unsponsored research, the American figure should be increased. Also, some spending by states on research at state universities, if it is not designated as research, is omitted. On the other hand, Japan counts all of its university teaching budget as academic research, which means that its figure for university R&D is too high. See *Science*, 2 October 1987. According to experts in the field, there is no reason to believe that the OECD figures for all member countries as a whole are biased downward.

Martin and Irvine [16] have made a careful study of academic research financed by government in France, Germany, Japan, the Netherlands, the United Kingdom, and the United States. Including estimates of unsponsored research by faculty members, they estimate the amount that was spent on academic research financed by general university funds and academic, separately budgeted, research in these six countries in 1975. Since these countries account for about 86 percent of all OECD academic research, according to the OECD data, a reasonable estimate of the OECD total academic research supported by government in 1975 is their figure divided by 0.86. Including the Soviet Union, the total (excluding psychology, social sciences, vocational studies, and humanities) provides no indication that our estimate of C is on the low side.

Nonetheless, even if our estimate of C were 25 percent too low, our results would not be changed, except in detail. The social rate of return is 25 percent (rather than 28 percent, as shown in table 4). Neglecting the benefits to users from new products, the social rate of return is 8 percent (rather than 10 percent, as shown in table 4).

²² National Science Foundation [18, p. 4]. According to the National Science Foundation [18, p. 278] about 11 percent of academic R&D in the United States in 1975–78 went for the social sciences, psychology, and other research not concerned with engineering or the physical, environmental, mathematical, or life sciences. In other countries like Japan, this percentage may be higher [18, p. 206], but to be conservative, we assume that the U.S. percentage is true in all countries. This may tend to bias the estimated rate of return downward.

²³ Like the National Science Foundation, we use the GNP deflator to convert to 1985 dollars. As pointed out in Mansfield [11], this deflator has important weaknesses, but for present purposes it should be good enough. While it may result in some downward bias in C , this bias will be too small to affect the results materially.

That is,

$$X = \sum_{t'=1982}^{1985} B(t')/4 = \sum_{t'=1982}^{1985} \sum_{j=0}^3 B(t', j)/16, \quad (3)$$

where $B(t', j) = \sum_i b_{ij}$. (That is, $B(t', j)$ is the sum of the social benefits in year $t' + j$ accruing from the new products and processes commercialized in year t' that were based on recent academic research.) Under this conservative assumption, the sum of the social benefits during 1985 of all of the new products and processes first commercialized in 1982–85 that were based on recent academic research is:

$$B_{85} = \sum_{t'=1982}^{1985} B(t', 1985 - t'). \quad (4)$$

Assuming for simplicity that the effects of j on $B(t', j)$ are independent of those of t' on $B(t', j)$,²⁵ we can approximate X by $B_{85}/4$. (Note that X , like C , is in 1985 dollars.)

²⁵ Put differently, we assume that the changes over time (during the first 4 years) in the sum of the social benefits accruing from the new products and processes commercialized in year t' (that were based on recent academic research) are the same, regardless of whether $t' = 1982, 1983, 1984$, or 1985 . In other words, if we constructed an annual social benefits curve (like that in fig. 1) for the sum of all innovations commercialized in 1982, its slope (for number of years = 0, ..., 3) is assumed to be the same as for innovations commercialized in 1983, 1984, or 1985. This assumption seems to be a reasonable first approximation. Without much more detailed data (which do not presently exist), some assumption of this sort must be made.

For a simple case where the effects of j are independent of those of t' , take the situation where $B(t', j) = f(t') + g(j)$. Under these circumstances, it follows from equations (3) and (4) that

$$X = \bar{f} + \bar{g}, \quad (5)$$

and

$$B_{85} = 4(\bar{f} + \bar{g}), \quad (6)$$

where

$$\bar{f} = \sum_{t'=1982}^{1985} f(t')/4$$

and

$$\bar{g} = \sum_{j=0}^3 g(j)/4.$$

Obviously, $X = B_{85}/4$, which is the point made in the text.

As is well known, the social benefits from a new process consist of the savings to the innovator plus whatever net benefits accrue to others, and the social benefits from a new product consist of the increased gross profits (cash flow adjusted for effects on displaced products) of the innovator plus the net benefits to users.²⁶ To make a conservative estimate of B_{85} , we begin by adding the savings from the new processes in the left-hand column of table 2 to the gross profits (cash flow adjusted for effects on the profits of displaced products) from the new products in the left-hand column of table 2.²⁷ However, this figure must be adjusted for three reasons. First, we have assumed that the investment in academic research resulted in no social benefits from the new products and processes developed “with substantial aid” from recent academic research. In fact, it seems reasonable to assume that at least half of these new products and processes would not have been developed (without substantial delay) in the absence of academic research. Thus, half of the savings from the processes and gross profits from the products in the right-hand column of table 2 are added to the above figure.²⁸

Second, we have assumed that only American firms enjoy savings and profits from innovations based on academic research. Even in the 1960s, when America was far more dominant technologically than in 1982–85, the National Science

²⁶ For a much more detailed and complete discussion of the measurement of the social benefits from a new process or product, see Mansfield et al. [13].

²⁷ As explained in Mansfield et al. [13], gross profit—that is, profit without depreciation being deducted—is the relevant concept here. To estimate gross profit, we multiplied the estimated 1985 sales of the products that could not have been developed without recent academic research by the average ratio of gross profit (net profit plus depreciation) to sales in 1985 in the relevant firms, the latter ratio being obtained from the firms’ accounting records. Next, a rough adjustment was made to allow for the fact that the new products’ profits were partly at the expense of older products (sold by other firms as well as by the innovators) they partially or entirely displaced [13]. Based on interviews with company executives, the resulting gross profit figures are reasonable, but rough.

²⁸ Here too we assume that there would be an 8-year delay in the absence of academic research. To see what the effects would be if we made the even more extreme assumption that academic research resulted in no social benefits from the new products and processes developed “with substantial aid” from recent academic research, see table 4.

Foundation [20] estimated that American firms carried out only slightly more than half of the major innovations in the leading OECD countries. Based on this and more recent evidence,²⁹ it appears that a conservative estimate of the worldwide savings and gross profits in 1985 from new products and processes first commercialized in 1982–85 that were based on recent academic research would be double the American figure obtained in the previous paragraph. (Note that, even if we were to assume that they were only 1.5 times the American figure, our results would change relatively little.)

Third, we have assumed that new products and processes based on recent academic research result in no social benefits other than to the innovator, which is ridiculously conservative.³⁰ For the product innovations in Mansfield et al. [13], the benefit to users during the first four years after their introduction was about eight times as great as the gross profit from these products, even though in some cases we must ignore the effects on the profits of displaced products, thus reducing the ratio of benefits to users to gross profit.³¹ (For the product innovations in Foster Associates [6] and Nathan Associates [17], the ratio was even higher.) Based on a small random sample of academic-research-based innovations, this 8-to-1

ratio seems to be too low.³² Nonetheless, we make the seemingly conservative assumption that this ratio prevails for new products.³³ For new processes, we ignore social benefits other than to the innovator.

The resulting estimate of X , together with our estimate of C , implies that the estimated social rate of return—that is, the value of i in equation (2)—is 28 percent. Of course, the roughness of this figure should be emphasized, but it is noteworthy that the estimated rate of return is so high, given the many ways in which it has been biased downward. Among other things, we have ignored: (1) the social benefits from innovations based on academic research in all industries other than the seven in table 1; (2) the increases in annual social benefits from innovations based on academic research after their first four years of commercialization; and (3) the social benefits from innovations based on academic research findings that are commercialized more than 15 years after the findings or that are introduced by non-major firms.

Moreover, as shown in table 4, the estimated rate of return is 23 percent, even if we exclude all social benefits from innovations developed with substantial aid from academic research. Going to an even more conservative extreme, the figure is

²⁹ According to the National Science Foundation [18, p. 203] the United States carried out 39 percent of the industrial R&D in these industries in seven countries (Japan, Germany, the United Kingdom, France, Canada, Italy, and the United States). Since many countries, including the Soviet Union, are omitted, the percent of world R&D must be well below 39 percent. According to Gellman's data [7], the proportion of innovations based on academic research in other countries (Canada, France, Germany, Japan, and the United Kingdom) was as high as in the United States, and the average time lag was not significantly different.

³⁰ For a description of methods to estimate the benefits to users, see Mansfield et al. [13]. Even without the work of the past decade or so, it is obvious that the exclusion of the benefits to industrial and individual users results in a gross under-estimate of the social benefits, since the benefits of new products are passed on (in substantial measure) to users (including consumers).

³¹ This pertains to the first 4 years after commercialization, which is the period used here to estimate benefits. One reason why the ratio is relatively high is that profits often are lower than in later years.

³² Because the direct estimation of the benefits of an innovation to users is a very laborious and expensive process, we have had to limit this part of our study to ten new products in these industries that were based on recent academic research. These products were randomly chosen. In every case, the ratio of the benefits to users to the innovator's gross profit (in the first four years after the product's introduction) exceeded 8. These results, taken in combination with the findings of Mansfield et al. [13], Foster Associates [6], and Nathan Associates [17], which provide detailed estimates for about 40 new products, seem to provide substantial evidence that the 8-to-1 ratio is conservative.

³³ It would be preferable, of course, to make direct estimates of the benefits to users, rather than to make crude estimates based on this ratio, but existing resources do not permit such an ambitious undertaking. In table 4, it is shown that the estimated social rate of return is 10 percent even if the benefits to users are assumed to be zero. Thus, even if this ratio were too high, the rate of return would still be substantial.

Note too that we ignore the benefits to imitators of new products based on recent academic research, as well as the benefits to customers of firms that carried out process innovations based on recent academic research. These benefits can, of course, be considerable.

Table 4

Estimated rate of return from worldwide investment in academic research in 1975–78, based on alternative assumptions

Assumption	Rate of return (%)
Including half of innovations developed with substantial aid from academic research	
Including estimated benefits to users from new products	28
Excluding benefits to users from new products	10
Excluding all innovations developed with substantial aid from academic research	
Including estimated benefits to users from new products	23
Excluding benefits to users from new products	5

Source: See section 6.

10 percent (not excluding all social benefits from innovations developed with substantial aid from academic research) or 5 percent (excluding all social benefits from innovations developed with substantial aid from academic research), even if we ignore all social benefits to users from new products based on recent academic research.³⁴

7. Conclusions

Because the results of academic research are so widely disseminated and their effects are so fundamental, subtle, and widespread, it is difficult to identify and measure the links between academic research and industrial innovation. This paper

presents, apparently for the first time, data concerning the percentage of new products and processes that, according to the innovating firms, could not have been developed (without substantial delay) in the absence of recent academic research. Since these data were obtained from key technical and managerial personnel of the innovating firms, they merit attention, although they, like other such survey data, are rough and contain sampling errors.

Our findings suggest that about one-tenth of the new products and processes commercialized during 1975–85 in the information processing, electrical equipment, chemicals, instruments, drugs, metals, and oil industries could not have been developed (without substantial delay) without recent academic research. The average time lag between the conclusion of the relevant academic research and the first commercial introduction of the innovations based on this research was about 7 years (and tended to be longer for large firms than for small ones). A very tentative estimate of the social rate of return from academic research during 1975–78 is 28 percent, a figure that is based on crude (but seemingly conservative) calculations and that is presented only for exploratory and discussion purposes. It is important that this figure be treated with proper caution and that the many assumptions and simplifications on which it is based (as well as the definition of a social rate of return used here) be borne in mind. While interesting, it is by no means a full or satisfactory solution to the long-standing—and extraordinarily difficult—problem of evaluating the payoff to society from academic research. It is at best a very crude beginning.

Nonetheless, our results provide convincing evidence that, particularly in industries like drugs, instruments, and information processing, the contribution of academic research to industrial innovation has been considerable. Needless to say, this does not mean that other inputs like industrial research, plant and equipment, labor and management have not been important as well. But whereas the contribution of these other inputs generally is taken for granted, the role of academic research sometimes has been regarded as far more questionable. Our results, while they do not address the very difficult question of how to allocate the social returns between academic and industrial research, indicate that, without recent academic

³⁴ There are sampling errors in the estimated rates of return in table 4. Since our sample was randomly chosen, rough estimates can be made of these sampling errors. Because there is considerable variation among firms and because the sample size in some industries is quite small, the figures for individual industries in table 2 contain very large sampling errors. However, what is important here is the sum of the industry figures for savings from new processes plus gross profits from new products. If we include half of the innovations developed with substantial aid from academic research, as well as the benefits to users from new products, the probability is 0.975 that the rate of return exceeds 15 percent, based on the assumptions in the previous section. Note too that the estimates by Mushkin [26] of the social rate of return from biomedical research are about 50 percent, which exceed those in table 4.

research, there would have been a substantial reduction in social benefits. This really is what the estimated social rate of return, as defined above, is saying.

To prevent misunderstanding, it may be worthwhile to conclude by recognizing that the rationale for academic research extends far beyond the sorts of narrowly defined economic benefits considered here. Obviously, knowledge concerning the universe is important for its own sake, and the education of students, which occurs in many academic research projects, is socially important as well. Nonetheless, it is interesting to find that, even if academic research is judged in these relatively restricted terms, its role seems to be substantial.³⁵

³⁵ It should also be emphasized that our results do not rest on the so-called linear model of innovation, which assumes that universities first perform basic research, the results of which are transferred to industry, which in turn does the development leading to the innovation. As is well known, this linear model is often violated. For example, academic research frequently occurs in response to R&D carried out, and problems encountered, in industry. Our analysis in no way assumes that the linear model is true. It is just as valid if the relevant academic research is in response to industrial research.

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