may be more explicitly canalized under genotypic control. Nucleotide substitution might still play a role here by modifying the level of activity rather than the specificity of neighboring loci, and elective recognition of transient states spontaneously derived then remains as a formal, if farfetched, possibility for other morphogenetic inductions.

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Basic Research in Industry

A count of scientific publications suggests the extent of U.S. industry's effort in basic research.

J. C. Fisher

It is difficult to find out how much basic research is going on in industry in the United States. There are at least three stumbling blocks in the way: different companies do not agree in their definitions of basic research; some companies are not sure how much of it they are doing according to their own definitions; and others are not willing to say even if they know. In spite of these difficulties, the National Science Foundation has made a good statistical study by supplying its own definition, sending out questionnaires, and providing strictly confidential treatment of the replies (*1*). Except perhaps for companies engaged in research in the engineering sciences (such as advanced mechanics, fluid dynamics, and aerothermodynamics), where the National Science Foundation suspects its definition may have been liberally interpreted, the aggregate amounts of basic research in different industries seem to have been established fairly well.

There is more than one name for the body of scientific work that is directed toward increasing our knowledge and understanding of nature. Some call it "learning work." Others call it "scientific research," "basic research," or "fundamental research." The National Science Foundation calls it "basic or fundamental research" and defines it as "projects which are not identified with specific product or process applications, but rather have the primary objective of adding to the overall scientific knowledge of the firm." It found that industry in 1953 employed about 5500 scientists and spent about $150 million for this

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activity, a level of effort amounting to about 4 percent of the nearly \$3.7 billion total spent for industrial research and development. Well over half of the basic research was concentrated in the chemical, petroleum, electrical, and aircraft industries, and large companies appeared to be doing most of it. (The National Science Foundation survey did not include scientific and engineering consulting firms or commercial laboratories.)

It would be instructive to know in detail the effort that individual companies devote to basic research. The National Science Foundation study does not reveal this information, because its figures are confidential and are presented in such a way that the contributions of individual companies are hidden. However, there is an independent means for determining the extent of the effort devoted to basic research, based essentially upon the idea that publication of the results of basic research provides a clue to the work that preceded publication. Publications are a matter of record, and it is possible to select and count those that deal with basic research. Insofar as the number of publications originating in a given company is proportional to the quantity of work going on there, this method will work.

Most scientists engaged in basic research have strong motivation for publishing the results of their activities. Through publication they achieve recognition, build their reputations as scientists, and make their work available to others for appraisal. If a scientist's employer does not allow him to publish, he tends to go elsewhere, for without competent appraisal of his work he is at a serious disadvantage and his effectiveness is diminished. For this reason it would seem that a count of publications could give a relatively good picture of the quantity (not quality) and distribution of basic research effort. The analysis now to be described (*2*) is based upon this assumption, which will be more fully tested and verified as the analysis proceeds.

Method of Counting Publications

Publications were counted indirectly, by counting abstracts (of articles only, not of patents) in the 1955 volume of *Chemical Abstracts*. This journal publishes abstracts of all the world's technical literature that is concerned with "learning" in chemistry, metallurgy, solid-state and nuclear physics, and certain branches of biology and physiology. These fields of science encompass most of the learning carried on by U.S. corporations, save for subjects in the engineering sciences, such as fluid mechanics and aerothermodynamics, and in electron physics. It is only approximately true that *Chemical Abstracts* finds and abstracts all publications concerned with basic research and rejects all publications concerned with applied work. However, the proportion of abstracts dealing with applied work appears to be reasonably small and invariant, so a count of the abstracts should give a fair approximation of the true number of basic research publications.

The procedure followed in counting abstracts was simply to examine the approximately 100,000 abstracts included in the 1955 volume of *Chemical Abstracts* and to prepare a card for each of the approximately 3000 publications whose author was an employee of a company in the United States. (An additional 50 or so articles in electron physics, mostly originating in the Bell Telephone Laboratories, were discovered by examining the appropriate scientific journals.) The engineering sciences are believed to be the only industrially important fields not covered in this survey.

The work represented by the approximately 3000 publications under study probably was performed sometime around 1953, most of the technical articles having been published in 1954,

Table 1. Companies with ten or more basic research publications per year. The approximate numbers of 1954 publications representing basic research in the physical sciences were obtained from *Chemical Abstracts* (1955), the *Bell System Technical Journal,* and five Institute of Radio Engineers publications. These sources do not provide a record of publications that have been classified for security reasons, or that describe the aircraft industry's work in the engineering sciences. Publications from scientific and engineering consulting firms, commercial laboratories, and a few laboratories operated by private companies for the Federal Government (such as General Electric's KAPL and Hanford laboratories and Union Carbide and Carbon's Oak Ridge National Laboratory) have not been counted.

Company (including subsidiaries)	No. of publications	Company (including subsidiaries)	No. of publications	Company (including subsidiaries)	No. of publications
1. General Electric	170	22. Socony Mobil Oil	31	43. Searle (G. D.)	15
2. Bell Telephone Laboratories	134	23. Sterling Drug	31	44. Sun Oil	15
3. DuPont (E. I.) de Nemours	121	24. Ciba Pharmaceutical Products	28	45. Procter and Gamble	14
4. American Cyanamid*	107	25. U.S. Steel	28	46. Sperry Rand	14
5. Merck	90	26. Standard Oil of California	24	47. Blockson Chemical‡	13
6. Eastman Kodak	81	27. Armour	23	48. Esso Research and Engineering§	13
7. Shell Oil	73	28. Olin Mathieson Chemical†	23	49. General Motors	13
8. Monsanto Chemical	65	29. Hercules Powder	22	50. Smith, Kline and French Laboratories	13
9. Union Carbide and Carbon	63	30. Pfizer (Chas.)	22	51. Atlantic Refining	12
10. Dow Chemical	58	31. Schering	22	52. Goodyear Tire and Rubber	12
11. Westinghouse Electric	57	32. General Aniline and Film	21	53. Irwin, Neisler	12
12. Lilly (Eli)	54	33. Humble Oil and Refining	21	54. Allied Chemical and Dye	11
13. Standard Oil (Indiana)	48	34. North American Aviation	21	55. Bristol-Myers	11
14. Rohm and Haas	45	35. Ethyl	20	56. Ford Motor	11
15. Upjohn	44	36. General Mills	19	57. Minnesota Mining and Manufacturing	11
16. Burroughs, Wellcome	35	37. Hoffmann-LaRoche	19	58. Continental Oil	10
17. Radio Corporation of America	35	38. Goodrich (B. F.)	18	59. National Lead	10
18. Sylvania Electric Products	33	39. Gulf Oil	18		
19. Abbott Laboratories	32	40. Aluminum Company of America	17		
20. Parke, Davis	32	41. U.S. Rubber	16		
21. Phillips Petroleum	31	42. American Home Products	15		

* Includes 60 publications from Lederle Laboratories. † Includes 12 publications from Squibb. ‡ Now a division of Olin Mathieson Chemical. § Standard Oil (N.J is a holding company and does not itself appear in this list.

the abstracts in 1955. It should be possible, therefore, to make a meaningful comparison with the National Science Foundation study, which also was based upon work done in 1953.

Publications of Individual Companies and Industries

When the publications were grouped by companies, it was found that about 500 companies were represented, most of them by but a single publication. On the other hand, a few companies were very prolific. Table 1 lists all companies represented by ten or more publications, in order of the number provided by each. There are 59 companies in this list, and together they account for just over two-thirds of the total number of publications. Most of them are engaged in pharmaceutical, chemical, petroleum, or electrical enterprise, where the importance of basic research is well recognized.

When the publications are grouped according to industry, the results shown in the first two columns of Table 2 are obtained. The chemical and pharmaceutical industries clearly lead, with, altogether, about 1450 publications, or nearly half the total. The electrical equipment and petroleum industries follow, with about 500 and 400 publications, respectively. All the remaining publications add up to about 700. The third and fourth columns of the table give the cost of basic research in each industry according to the National Science Foundation report, and the cost per publication. Similarly, the last two columns give the number of scientists doing basic research in each industry and the ratio of the number of scientists to the number of publications. Separate figures are given for each of the industries that published significantly more than 100 papers, and all the others are lumped together. The cost-per-publication and scientist-per-publication figures should be fairly reliable, even though the National Science Foundation's classification of firms into industries may differ somewhat from that employed in our study.

The chemical, pharmaceutical, electrical, and petroleum industries produce large numbers of publications, altogether about 80 percent of the total. Their basic research costs run between $26,000 and $38,000 per publication, and each publication represents a year's work for about 1.34 scientists. It is encouraging to find that there is a fixed ratio of basic research scientists (as determined by the National Science Foundation) to basic research publications (as determined by counting abstracts). The existence of this fixed ratio confirms the idea that publications provide a reasonably good measure of the amount of basic research that is going on in these industries, at least statistically on an industry-wide basis. To obtain an estimate of the number of scientists engaged in basic research, all one has to do is to multiply the number of papers published in a year by 1.34.

For the other industries that together produce about 20 percent of the publications, the number of scientists per publication jumps to an average of 3.45 from the average of 1.34 characteristic of the pharmaceutical, chemical, petroleum, and electrical industries. Either

Table 2. Basic research publications, costs, and scientists (by industry).

Industry	No. of publications		Cost: Total* ($ million)	Cost: Per publication (in dollars)	Scientists: Total†	Scientists: Per publication	
Chemical	833	1457	37.8	26,000	1990	1.37	1.34
Pharmaceutical‡	624						
Electrical		501	19.1	38,000	660	1.32	
Petroleum		384	11.1	29,000	480	1.25	
Primary metals	117	686§	81.7	120,000	2370	3.45	
Food	108						
Transportation equip.	81						
Fabricated metals	61						
Instruments	61						
Paper	60						
Rubber	57						
Stone, clay, glass	41						
Others and unknown	100						
Total		3028	149.7		5500		

* According to the NSF study. † Derived from (i) basic research costs and (ii) average cost of research and development per scientist or engineer, both as given in the NSF study for the industry in question. ‡ Including Lederle Laboratories and Squibb. § Not including publications relating to basic work in the engineering sciences, of particular importance to the aircraft and instrument industries.

Table 3. Basic research versus company size in four industries. (Quartile No. 1 contains the largest companies in an industry; quartiles No. 2 and 3, the next largest; quartile No. 4, the smallest, down to 1000 employees.)

Quartile No.	No. of companies	No. of employees	No. of publications	No. of scientists per 1000 employees
		*Pharmaceutical industry**		
1	3	34,800	136	5.2
2	3	28,400	41	1.9
3	4	31,100	115	5.0
4	16	30,100	126	5.6
Total	26	124,400	418†	4.5
		*Chemical industry**		
1	3	213,000	260	1.64
2	6	178,000	211	1.59
3	18	197,000	145	0.99
4	82	168,000	102	0.81
Total	109	756,000	718†	1.27
		Petroleum industry		
1	3	173,000	98	0.76
2	6	208,000	159	1.02
3	23	211,000	80	0.51
4	83	188,000	23	0.16
Total	115	780,000	360†	0.62
		Electrical industry		
1	2‡	344,000	304	1.18
2	6	404,000	110	0.36
3	23	371,000	63	0.23
4	155	394,000	11	0.04
Total	186	1,513,000	438†	0.43

* Lederle Laboratories and Squibb are now included with parent companies in the chemical industry. † Slightly less than the total in Table 1 because of the inclusion in Table 1 of companies with less than 1000 employees or of unknown size. ‡ Bell Telephone Laboratories and Western Electric are counted as a single enterprise, comparable to other companies in the electrical industry.

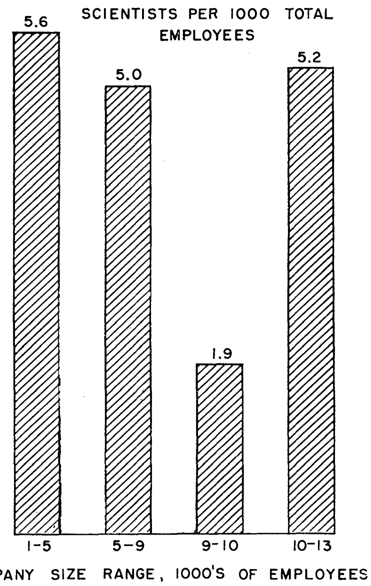

Fig. 1. Pharmaceutical industry quartiles. In most industries, small companies do relatively little learning in proportion to their size. The pharmaceutical industry is an exception. Small and large companies show about the same intensity of effort.

scientists in these other industries publish less, or some of their publications were overlooked (as many of them undoubtedly were, because publications related to basic work in the engineering sciences were not included in the survey), or there was some exaggeration by these industries when they reported their basic research effort to the National Science Foundation. Owing to this uncertainty, further analysis is restricted to the chemical, pharmaceutical, electrical, and petroleum industries. The data are plentiful and reasonably complete for these industries, which employ over 3000 of the 5500 basic research scientists the National Science Foundation finds in all industry. The only industry likely to be seriously slighted by this restriction is the aircraft industry, whose relatively weak showing may result from the poor coverage of engineering science publications.

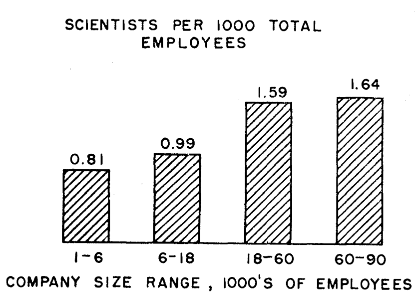

Fig. 2. Chemical industry quartiles. The intensity of effort in learning in small chemical companies is only 50 percent of that of large companies.

If the ratio of scientists to publications were 1.34 for each of the individual companies listed in Table 1, the numbers of basic research scientists employed by each company would range from about 230 for General Electric down to about 13 for National Lead. Confidential information concerning the number of basic research scientists actually at work in the laboratories of some of these companies suggests that the factor 1.34 gives surprisingly good results when applied to individual companies and may perhaps be relied upon to an average accuracy of 20 percent or so.

In the light of the relationship between publications and scientists just established, it is instructive to examine Table 1 again with the object of converting the numbers of publications to (i) numbers of basic research scientists and (ii) dollars per year spent for basic research. The conversion factors are, roughly, 1.34 scientists per annual publication; $26,000 per publication (chemical and pharmaceutical); $38,000 per publication (electrical); and $29,000 per publication (petroleum). In other words, in 1953 the basic research staffs of the companies listed in Table 1 ranged from about 230 to about 13 scientists and the basic research budgets of these companies ranged from about $6.5 million to about $0.3 million.

Role of Company Size

The present analysis bears out the National Science Foundation's observation that most basic research is done in large companies. In order properly to show how the intensity of basic research effort depends upon company size, it was necessary to obtain a reasonably complete list of all the companies in each industry—whether or not they did any basic research—together with the number of employees in each company. Lists of this type were prepared for each industry by examining *Poor's Register of Directors and Executives* (*3*). About 1800 companies of 1000 or more employees were listed and classified. Nonmanufacturing companies and companies with fewer than 1000 employees were not counted. The industry to which each company belonged was determined from the list of products given in *Poor's*. The large companies were checked again in the second *Fortune* directory of the 500 largest U.S. manufacturing companies

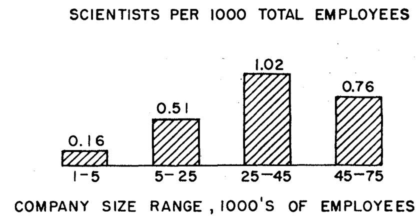

Fig. 3. Petroleum industry quartiles. The intensity of effort in learning in small petroleum companies is only 20 percent of that of large companies.

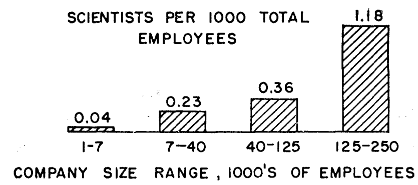

Fig. 4. Electrical manufacturing industry quartiles. The intensity of effort in learning in small electrical manufacturing companies is only 3 percent of that of large companies.

(*4*), and where *Fortune's* figures for the number of employees differed from *Poor's, Fortune's* figures were used.

The companies in each industry were divided into quartiles, containing as nearly as possible equal numbers of employees. The first quartile contained the largest companies, the second the next largest companies, the third the next largest, and the fourth the smallest companies, down to 1000 employees. For each quartile the following figures were assembled: number of companies, number of employees, number of publications, and number of basic research scientists per 1000 total employees. The last figure was derived on the assumption that one publication corresponds to 1.34 scientists. All these data are presented in Table 3, and the ratios of scientists to total employees are shown graphically in Figs. 1–4.

The information in Table 3 and in Figs. 1–4 shows that small companies engage in learning activity to a much greater degree in some industries than in others. In the pharmaceutical industry, for example, the average intensity of effort is as great in companies of 1000 employees as it is in the largest companies. This uniform distribution of learning activity was not found in any other industry. In the chemical industry, the small companies do only about half as much learning *per employee* as the large companies; in the petroleum industry they do only about 20 percent as much; and in the electrical manufacturing industry, only about 3 percent as much.

One possible explanation for the small amount of learning done in small companies in some industries is that these companies buy their learning from outside agencies instead of doing it themselves. The National Science Foundation study casts considerable doubt upon the validity of this explanation, however.

Whatever the reason for the small learning effort in small electrical manufacturing companies, it is an economic fact. There appears to be a critical company size, for research effort, of very roughly 20,000 employees; companies with more than 20,000 employees sometimes do learning work at the same rate as large companies, but smaller companies almost never do. Of the 170 companies in the 1000-to-20,000-employee class, only two (Hughes Tool and Sprague Electric) come up to the average of the largest companies in intensity of effort. For petroleum companies the critical size is very roughly 5000 employees; only 4 of 83 companies in the 1000 to 5000 employee come up to the level of the top two groups in intensity of effort. For chemical companies there is no true critical size, but it is roughly at the 4000-employee level that the intensity of effort drops to half that in the top two groups.

Factors Favoring Research Support

So much for the factual presentation of data. What is revealed about the conditions under which industry finds it profitable (or thinks it profitable) to do basic research? It appears that two important requirements must be met. (i) The industry must be one in which innovation and associated obsolescence proceed rapidly. (The pace of innovation and obsolescence is very rapid in the pharmaceutical industry and moderately rapid in the chemical, petroleum, electrical manufacturing, and aircraft industries. These are the industries in which basic research flourishes. The pace in other industries is slow by comparison.) (ii) The company must be sufficiently large and diversified. (For pharmaceutical companies, almost any size seems to be large enough, but for electrical manufacturers, anything less than about 20,000 employees is definitely too small. It seems probable that small electrical manufacturing firms are poorly diversified in their activities and cannot make efficient use of the relatively unpredictable results of basic research.)

These two requirements seem reasonable. A company in a slowly developing industry need do no basic research. Innovations are few and far between, and it is more profitable to copy those adopted in other plants than to try to be first. Even in a fairly rapidly developing industry, it may be wise for small companies to wait until innovations appear, and then to copy them. Only the large competitors of such companies have both the resources for supporting an integrated research program and the wide diversification that enables them to take advantage of the products and by-products of basic research.

Size does not seem to be a factor in the pharmaceutical business. Perhaps this is because the pace in this field is so rapid that there is no time to copy one's competitors; by the time a competitor has been copied the product is obsolete. If a company does no basic research, it falls by the wayside.

Basic research in industry is a relatively new activity, which was almost unknown in 1900. It has grown to the point where in 1953 somewhere near $150 million a year was invested in it, in spite of the fact that a decade or so must elapse between the beginning of a research program and the point at which the possibility of practical results, if any, can first be glimpsed. The work is done by scientists whose motivation lies in science, not in economics. Yet such work is generally believed to be a sound investment for diversified companies in rapidly expanding industries, and it may even be necessary for survival in the pharmaceutical business.

Time alone will show how rapidly industry's rate of investment in basic research will grow, and by how much it will exceed industry's present value of 4 percent of its total expenditures for research and development.

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News of Science

Five Euratom Nations Consider Reactor Construction

Euratom, a six-nation cooperative organization set up to bring atomic power to Europe, has received letters of intention indicating that five of the member nations have "enterprises" within their borders that plan to submit proposals for reactors to be built under the Euratom–U.S. Joint Nuclear Power Program. The five nations are Belgium, France, Germany, Italy, and the Netherlands. Luxembourg did not submit a letter of intention. The term *enterprise,* which was used in an official announcement of the receipt of the letters, was not further defined.

Letters of intention for the proposals were submitted 28 May to Euratom headquarters in Brussels. These letters, however, as AEC authorities here stress, do not constitute commitments to build. They are submitted only to give Euratom officials some indication of response to the program. This was less enthusiastic than U.S. officials had hoped, according to observers. Members of the Atomic Energy Commission had hoped for six to eight proposals, to ensure an active role for the European power agency. The U.S., through an Export-Import loan, is providing $135 million in financial aid for the program.

The question that hung on the letters of intention was this: did European utilities find the offered United States