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ABSTRACT

Cooperative research relationships between universities and industry are discussed. Attention is directed to the following topics: historical developments in university-industry relationships; the motivations and expectations for research relationships among the two sectors; the range and variety of research relationships currently engaged in by universities and corporations; the variety of roles, perceptions, and organizational structures within companies and universities relating to university-industry connections; the role of individual contacts and initiative in the development of relationships; the appropriate roles of universities, nonprofit entities, industries, and government in the initiation and development of such enterprises; and issues and problems in university-industry research relationships. In addition to describing federal government actions over the past decade, the findings of several studies commissioned by the National Science Foundation are considered. Finally, a hypothesis concerning the general line of future development is set forth, and some likely specific activities are discussed. It is concluded that in both academic and industrial circles there are positive expectations about the future of mutual exchange and about the contributions that these interactions can make. (SW)

University–Industry Research Relationships

FOURTEENTH ANNUAL REPORT OF THE NATIONAL SCIENCE BOARD

MYTHS, REALITIES AND POTENTIALS

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NATIONAL SCIENCE BOARD
WASHINGTON, D.C. 20550

Letter of Transmittal

October 1, 1982

My dear Mr. President:

In accordance with Section 4(j) of the National Science Foundation Act, as amended, it is my honor to transmit to you, and through you to the Congress, the Fourteenth Annual Report of the National Science Board entitled, *University-Industry Research Relationships: Myths, Realities and Potentials.*

This report, together with the special studies upon which it is based, illuminates a relationship between research universities and private companies that bodes well for the economic strength of the Nation. Private industry looks to our research universities for trained people and the results of fundamental research in science and engineering, both of which are essential to the companies' ability to innovate and increase their productivity.

Since private investment in a competitive marketplace is the best means for allocating the scientific and engineering resources of our industry, it is appropriate that government leave to industry the task of exploiting the knowledge base created by our universities. The more effectively industry carries out this task the greater the economic leverage of our public investment in university research. Strong and dependable Federal support for a broad spectrum of academic scientific and engineering research is a major factor in making our universities exciting and fruitful places for industrial collaboration. Further, exposure of professors and students to industry's knowledge needs not only helps prepare young scientists and engineers for careers and future technical leadership in industry, but also improves coverage by academic researchers of industrially relevant areas of investigation.

This study explores the kinds of cooperative relationships that exist. Cooperation seems to be growing rapidly, suggesting that the effectiveness with which university research is guided and utilized by the private sector may be substantially improving.

We believe this report will be valuable to both the Administration and Committees of Congress seeking to understand the complex but important processes whereby university scientists participate in the solution of important industrial problems and the industrial community avails itself of the vital public investment in academic science.

Respectfully yours,

Lewis M. Branscomb

Lewis M. Branscomb
Chairman

The Honorable
The President of the United States
The White House
Washington, D.C. 20500

The Committee on 14th NSB Report thanks those present and past members of the National Science Board who assisted in reviewing various aspects of the preparation of the Report. The Committee also expresses its appreciation to Dr. Carlos Kruytbosch who, as Executive Secretary, effectively coordinated its work. The authors of the commissioned background studies deserve special thanks, as does Mr. Jack Kratchman for his editorial assistance.

In addition, a large number of individuals provided information, suggestions, reviews of manuscripts, and other assistance during the course of preparation of the Report. We thank these individuals for their contributions, and list them below with our apologies for any possible omissions.

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CHAPTER I

PERSPECTIVES

1. INTRODUCTION

Research relationships between American universities and industry have been numerous, constructive and important since the turn of the century. The persistence of this long and fruitful relationship has rested, and continues to rest in good measure upon industry's overriding need for highly qualified new scientists and engineers. Recent developments suggest that university research programs are becoming of increasing interest to industry in their own right. The principal functions of the university, of course, include not only undergraduate and graduate education, but also scholarship and the conduct of research.

Direct research linkages between universities and corporations currently constitute only a miniscule portion (less than one-half of one percent) of the national R&D effort. But rapidly changing conditions in science and technology, in the national and world economy, and in academic and industrial organizations, have increased interest in university-industry relationships and prompted this report. National and international attention, and not inconsiderable controversy, have been stimulated by the publicity over the past two years attending new multi-year, multi-million dollar research agreements between corporations and research universities. Research agreements of such magnitude are of intense interest to both the scientific and business communities. But there are other more fundamental reasons why this report is timely.

The first of these are the much publicized effects on the United States of the scientific and technological successes of other countries. While some of this success is inevitable, the effects can be mitigated by improving the effectiveness of our own efforts in science and technology.

Another reason has to do with the rapid rise of Federal research support in the 1950's and early 1960's and the stagnation of real growth of Federal support in the late 1960's and early 1970's. The rapid growth period gave the country a great capacity both to educate scientists and engineers and to broaden the base and the depth of its research ability. But the flattening of growth of Federal support has stimulated efforts to find new sources of funding, and, even more important, to a renewed search for ways to make the Nation's research more effective.

Interest in university-industry research relationships is also more intense because of the growing perception that industrial products and services are increasingly dependent on fundamental scientific understanding. With this dependency the distinction between basic and applied work often disappears. Fundamental ideas and approaches become a necessity and they are used in both universities and industry. The interdependencies between good science and good development have been long recognized, but because of the changing character of the problems, more direct research interactions between science and industry are now occurring.

This report starts from a conviction that the health, welfare, and defense of our society are directly, and not at all mysteriously, related to the strength and vigor of our science and research capability. Further, this capability while requiring proper support, is no better than the competence, talent, and motivation of our scientists and engineers.

Institutional relationships are examined in this report mainly to secure and present whatever data are available, so that discussion of the topic will be informed and awareness of past experience and future opportunities and problems will increase. This approach is followed because ours is a pluralistic system with the huge advantages and certain disadvantages this implies. It is important to search continually for ways in which the effectiveness of science and research and development in the United States can be enhanced. Understanding the conditions for and experimenting with modes of industrial-academic cooperation is one fruitful area for achieving such improvements.

The activities described in this report concern the decisions of people in corporations and universities, as well as in the other institutions upon which they depend for support. One of those is the Federal Government. While this report does deal with the nature of the Federal Government's participation in university-industry relationships, and may be useful in evolving Federal policy in this area, it is not narrowly directed to that goal. Instead it is our hope that the report will be particularly useful to present and potential participants in university-industry relationships who seek to profit from the experience, data and perspectives we have gathered here.

The topics covered in this report and its background studies include:

- Historical developments in university-industry relationships;
- The motivations and expectations for research relationships among universities and corporations;
- The range and variety of research relationships currently engaged in by universities and corporations;
- The variety of roles, perceptions, and organizational structures within companies and universities relating to university-industry connections;
- The role of individual contacts and initiative in the development of relationships;
- The appropriate roles of universities, non-profit entities, industries, and government in the initiation and development of such enterprises;
- Issues and problems in university-industry research relationships;

In dealing with these topics, Chapter I examines the evolution of university-industry research relationships, data on the recent past, and descriptions of current developments, including Federal Government actions over the past decade. Finally a hypothesis concerning the general line of future development is set forth, and some likely specific activities are discussed. Chapter II summarizes the observations and findings of several commissioned studies which will be published separately by the National Science Board. Finally, Chapter III summarizes the observations and conclusions reached in the course of this review.

It is clear from the brief studies we have made that in both academic and industrial circles there are positive expectations about the future of mutual exchange and about the contributions that these interactions can make, for example, to the content and direction of undergraduate and graduate education in the sciences and engineering, the quality of the graduates, and, in industry, the rate of technological innovation. Our studies touched upon these matters but it was beyond our scope to provide systematic information or rich detail for each issue. Future study efforts could be usefully devoted to a number of consequences of university-industry interactions. We list some of these below.

What are the effects of university-industry interactions:

a) in universities
   - on the shape of undergraduate curricula?
   - on emphases in graduate programs?
   - on faculty research project selection?
   - on the openness of scientific communication?
   - on the balance of disciplines within the university?
   - on the costs of university research?

b) in companies
   - on the rate of technological innovation?
   - on the quality of new and continuing science and engineering manpower?
   - on patterns of industry-wide technological cooperation and competition?

2. PAST AND PRESENT

a. Sketches from Before World War II

The research university as we know it became established in the last quarter of the 19th century, at about the same time as the emergence of the modern industrial corporation. Industrial research laboratories began to flourish after 1910 with the formation of new laboratories reaching a peak in the early 1930's. A contemporary source estimated total national R&D expenditures in 1927 at $212 million, which was a tenfold increase over the previous decade. Further, over 90% of these funds were estimated to represent work by industrial concerns in their own research organizations. The proliferation of industrial research laboratories during the 1920's and 1930's was important because it created a locale for advanced research and development and required staffing by scientists and engineers with advanced training and degrees.

Progress in research in the American universities during the 1920's and 1930's can be attributed in good measure to philanthropic support from individuals and corporations, and especially from the large foundations, such as the Rockefeller Foundation and the Carnegie Institution of Washington. Agriculturally related research was sustained by State and Federal Government support. In addition, the remarkable continuing growth of student enrollments (U.S. university enrollments doubled every 20 years from 1900 to 1960) provided a consistent flow of student fees and state funds which helped to build facilities for science and engineering teaching and research.

The extent of direct support of university research by industrial corporations in the pre-World War II period has not been systematically documented. Several episodes are, however, worth noting as illustrations of the motivations and problems encountered.

Between 1916 and 1930 there was a movement to start a National Research Fund with corporate contributions to be administered by the National Research

Council to support basic research in universities. The effort foundered upon corporate reluctance to contribute to openly published research that might assist their competitors. The 1929 crash sealed the fate of this effort, as none of the few interested companies had any resources to spare. It may be a sign of the changed environment for university-industry relationships to note that, while the "free rider" issue continues to exist today, several collective corporate efforts to support fundamental, publishable academic research are under way.

The following excerpt from an address to the American Association for the Advancement of Science by Frank B. Jewett of Bell Laboratories nearly sixty years ago reminds us that many of the issues of concern today have a long history.

> Not only must [universities] advance the frontiers of knowledge at a rate commensurate with our demands for industrial advancement, but they must, at the same time, develop the scientifically trained personnel required to carry on the work of the industries as well as to carry their own work. It is a well-recognized fact that within recent years industry has made extremely heavy demands upon the faculties of the universities by reason of their ability to offer greater monetary rewards, and frequently better facilities for research.
>
> We now find ourselves confronted with the need of increasing the bargaining powers of universities and the attractiveness of academic positions. In this matter the industries have a clear-cut obligation to the universities, an obligation which they cannot avoid without themselves being the chief sufferers. It is an obligation which rests upon all industries alike, for in the final analysis...what benefits one industry, benefits the others. That thoughtful men in all walks of life are coming to see the vital need of a proper coordination of the nation's scientific interests is a happy augury for the future.

A look at the postures during the 1920's and 1930's toward industry adopted by the chemical and chemical engineering departments in three major universities conveys a sense of the variety, vitality, and problems of the modes of cooperation during that period.

Between 1915 and 1930, under the leadership of William M. Walker, Warren K. Lewis, and Arthur D. Little, the Massachusetts Institute of Technology (MIT) pioneered in developing a chemical engineering curriculum closely suited to the needs of the chemical industry. Through his Research Laboratory for Applied Chemistry (RLAC), William Walker was able to attract considerable financial support from companies searching for solutions to practical problems. The success of chemical engineers seeking answers to applied questions diminished attention to fundamental chemistry, and conflicts developed between Walker and A. A. Noyes whose more fundamental Research Laboratory of Physical Chemistry was much less able to attract financial support. Noyes eventually left MIT for the California Institute of Technology (CalTech). Only when the Depression years brought a dramatic decrease in the funding of RLAC did MIT modify its course toward emphasizing fundamental research by setting the conditions under which industrial research support would be accepted.

While MIT invested heavily in direct industrial links in the 1920's, CalTech took the opposite road, emphasizing "cooperative research" on problems of fundamental scientific importance that crossed disciplinary lines.

The CalTech leadership (including Noyes) solicited support from three kinds of patrons, in decreasing order of importance—philanthropy from local Los Angeles and Pasadena industrial wealth, the large private foundations, and a small portion from private industry. CalTech's stress on its independence was further expressed by the adoption of restrictive policies regarding faculty industrial consulting.

CalTech was also the locus of a noteworthy case of an academic researcher contributing heavily to the growth of a whole new industry—namely Theodore von Kármán and the aeronautical industry. Here too, the CalTech pattern of research support was maintained—a large long-term grant from the David Guggenheim Fund for the Promotion of Aeronautics provided the core support for the establishment of a school of aeronautics and a research laboratory. Von Kármán helped set up and later was appointed director of this school.

That these relative extremes by no means represented the only modes of relationships is illustrated by the development in the 1920's and 1930's of chemistry and chemical engineering at the University of Illinois under the leadership of Roger Adams. His approach could be characterized as a broad spectrum of efforts including:

- Building the University of Illinois chemistry (including chemical engineering) department into the world's largest producer of Ph.D.'s in any discipline.
- The forging of a rich network of connections in industry. Some 65% of his Ph.D.'s took positions in industry (as compared to only 8% of the Johns Hopkins University chemistry Ph.D.s), and about half of these later attained high positions in corporate research management.
- A successful, if modest, venture, involving graduate students into the commercial **manufacture** of rare organic chemicals.
- The founding of two chemical journals owned by private corporations which sold stock to patrons.
- Use of his network of industrial contacts to generate consultantships and generous support for graduate and postdoctoral fellowships at Illinois.

The case of Roger Adams at the University of Illinois shows an inventive use of industrial opportunity while remaining within academic tradition. Yet his pattern of working with industry did not include a major component of direct industrial support for academic research—it centered primarily on the flow and exchange of people.

On the whole, the history of pre-World War II research connections between corporations and campuses suggests that academic research efforts were supported primarily by institutional funds and by philanthropy—most of which, to be sure, derived from industrial fortunes. Direct corporate support of university research did, however, play a small but significant role, and there were then, as there continue to be now, many highly productive relationships between individual faculty members and corporations.

b. World War II to the 1960's

Seeds for change were sown during World War II. Numerous wartime research, development, and production efforts (atom bombs, radar, penicillin, synthetic rubber, etc.) had brought together unprecedented numbers of industrial, academic, and Government scientists and engineers in close working relations. These collaborations on wartime projects showed the power of academic scientists tackling practical, applied problems. The scientists themselves found the process exhilarating and intellectually exciting. This excitement was also communicated to their graduate students who learned that product oriented work can give high intellectual stimulation. In addition, the contacts made in the process broadened student perspectives on their work and career options.

Many of these relationships persisted after the war and were reflected in consultantships and the employment of many academics in new corporate research laboratories.

The spectacular performance of science during the war affected many companies. The discovery of the transistor in 1947 at the Bell Laboratories further kindled great expectations of the commercial potential of fundamental investigations. There was an increase in hiring of scientists, and building and equipping of laboratories to house them. But many of the companies set up laboratories to do fundamental science far removed from their business needs. A contemporary witness recollects that Henry Ford II introduced the director of his new research laboratory as, "The man who is going to win Ford our first Nobel prize." However, during the 1950's and 1960's, several of these laboratories were closed down, or in some cases were reorganized and tied to the needs of operating divisions, thus reducing the emphasis on long-term research. Many of the scientists affected by these developments migrated into the rapidly growing university system.

While no definitive history of these happenings has yet been written, accounts in the literature on R&D offer several explanations for the weakening of this wave of industrial interest in basic research. One theme is that management held overly optimistic expectations of the role of and possible returns from very broadly conceived basic research. In addition, the management of the laboratories and their integration into the rest of company activities left much to be desired. It is also argued that there was a shift in balance at top corporate levels from managers with operational experience to those with a more cost-accounting approach to management who tended to put lower priority on long-range activity—characteristic of fundamental research. Finally, the recessions of the late 1950's and early 1970's no doubt caused some companies to reduce their research budgets.

The declining interest of some corporations in long-range, in-house research was paralleled by a perception of slackening of industrial support for university research. In fact, during the early 1960's industrial support stayed flat at about the same constant dollar level. The concurrent rapid growth in Federal funds for academic science appeared to eclipse the industrial research presence on campus. Thus, there arose a widespread belief that university-industry relationships had undergone significant deterioration during this period. A variety of related themes can be seen in articles discussing this decline. The Vietnam war was seen as aggravating anti-business ideology on campus, thus creating barriers to faculty involvements with industry, not to mention physically obstructing company recruiting. The rise of Federal support was seen as encouraging a "who needs it?" faculty attitude toward industry.

These themes of decline led to some confusion in discussions concerning rebuilding of deteriorated university-industry relationships, for there are many indications that such relationships remained both vigorous and varied. Many of the leading research universities in America were founded on industrial fortunes, and leading industrialists sit on the governing boards of the major universities—private and public alike. In Europe and Japan the U.S. is enviously described as the prime example of ready access and individual mobility between industry and academia.

A number of observations flow from this review of the university-industry connection over the past century:

- Support of research and education by philanthropy of individuals, corporations, and the foundations created by personal accumulations of industrial capital helped develop a strong institutional structure for basic research.

- Industrial corporations have not provided much direct support for basic research in universities because the connection to their needs is uncertain and long-range, and because of the inability of the contributing company to capture many of the benefits. In the early period, corporations providing such direct research support tended to overcontrol the effort in the direction of short-range results.

- Rapid expansion of industrial research laboratories during the 1920's and 1930's created a demand for well trained graduate scientists and engineers, as well as consulting opportunities for faculty members.

- Corporations have long had fruitful relationships with individual university professors on a consulting basis. This flexible connection has been and continues to be one of the strengths of the system.

- The companies that developed major in-house research laboratories have been the strongest supporters of academic research. While company long-term research budgets are vulnerable to the business cycle, these budgets have fluctuated least in the research oriented companies.

- Some of the post-World War II corporate ventures into in-house fundamental research suffered from a lack of plans and objectives for integrating the laboratories into the total corporate enterprise, and as a consequence did not achieve their promise.

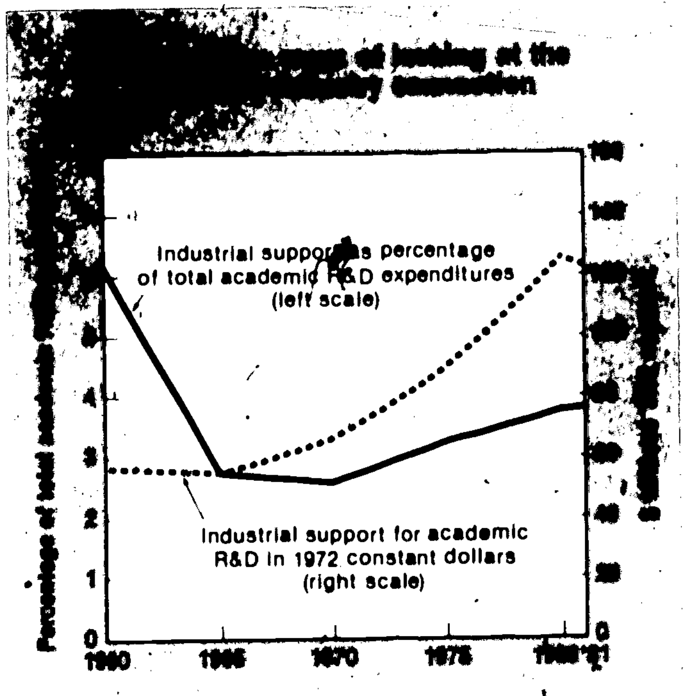
- While important quantities of high quality academic-industrial research relationships have occurred over the years, this has not been achieved without conflict, friction, and sustained effort.

c. Data: 1960-1980

Quantitative assessment of the university-industry research connection is made difficult by the fragmentation of the data base. The problem lies in the diversity of the mechanisms of exchange. Contracts, grants, purchase orders, solicited and unsolicited gifts, loans of equipment or facilities, discounts on equipment, purchases, personnel exchanges, scholarships and consulting arrangements only describe the principal forms of relationships. Universities and corporations have kept track of only some of these exchanges—and then not necessarily consistently.

In this section we first present and analyze data primarily from NSF surveys on dollar support of research in universities more or less limited to tracking grants and contracts for research. We turn then to a different source for estimates of support for academic research through corporate philanthropy. Unfortunately, the data from these two sources partially overlap in their coverage and thus cannot be cleanly added to provide a sum total of corporate support for academic research. Looking at the two sources side by side, however, makes it clear that the level of total corporate support for academic research is significantly higher than generally understood. Finally, national surveys of university faculty consulting activities provide estimates of the pattern and extent of this important form of linkage.

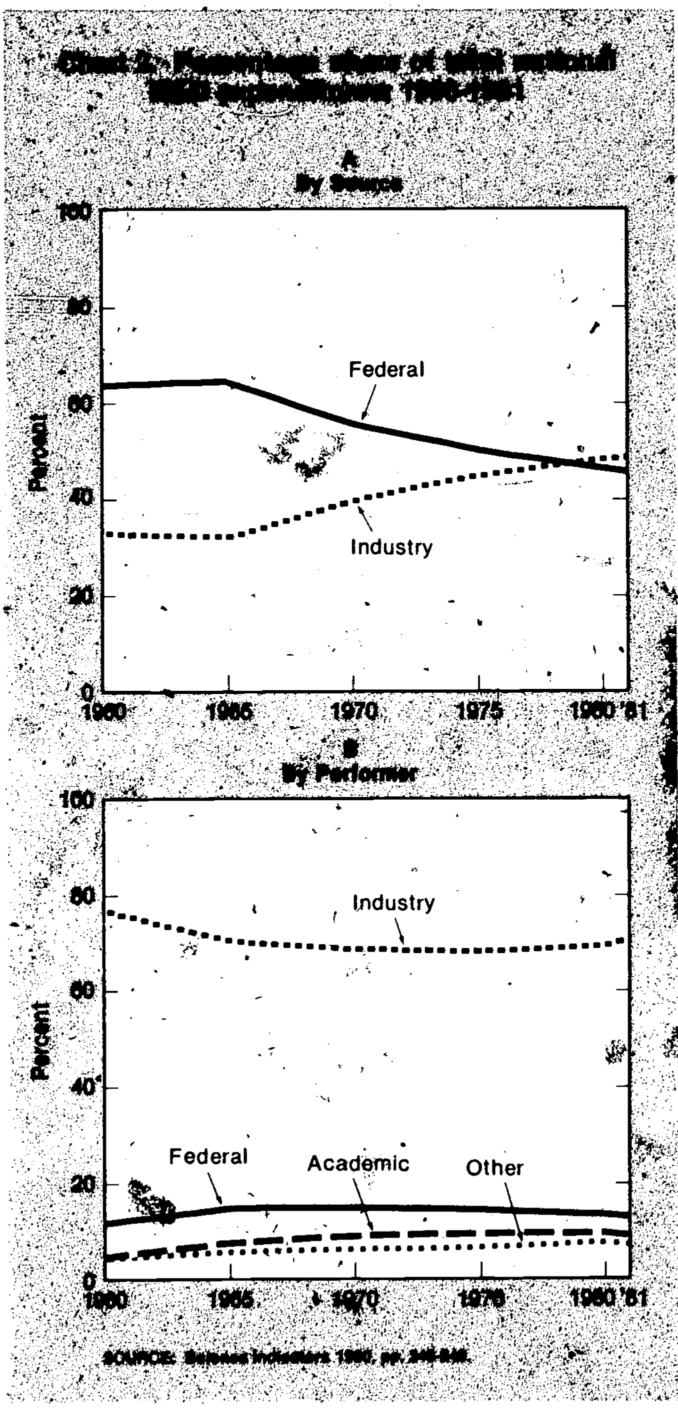
The data on industrial R&D support at universities and colleges suggest that from 1960 (and probably from 1953) to 1965 industrial support of academic research remained virtually flat in constant dollars. However, industry's percentage share of support for academic research fell sharply, due primarily to rapidly growing Federal support (Chart 1). Since 1965, constant dollar support for university R&D from industries has doubled, but industry's percentage share has remained at a low level of 3%-4%. The data for the most recent years suggest that the percentage of industrial support is increasing. Industrial support of academic research for FY 1980 is estimated at $235 million in current dollars. Further details on research performance and support are summarized below.

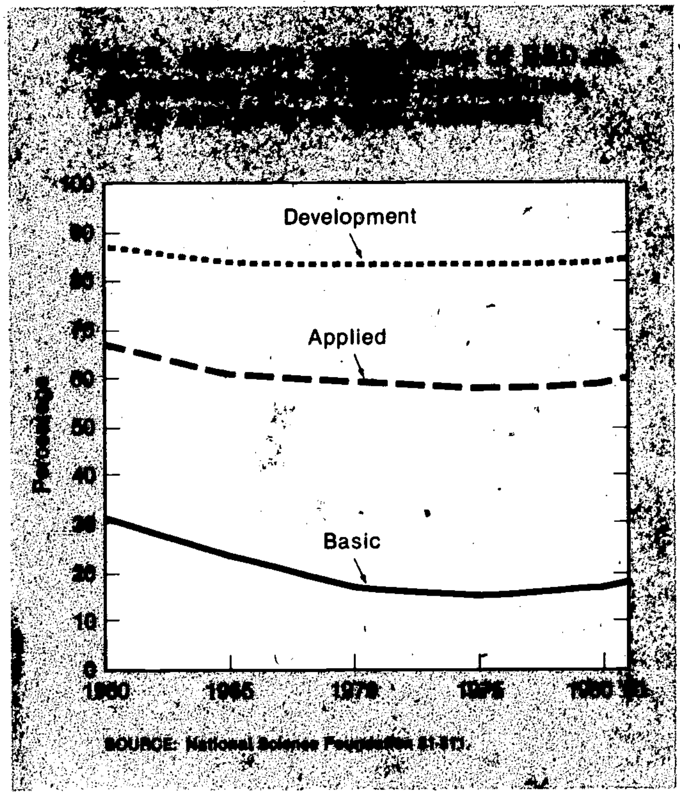


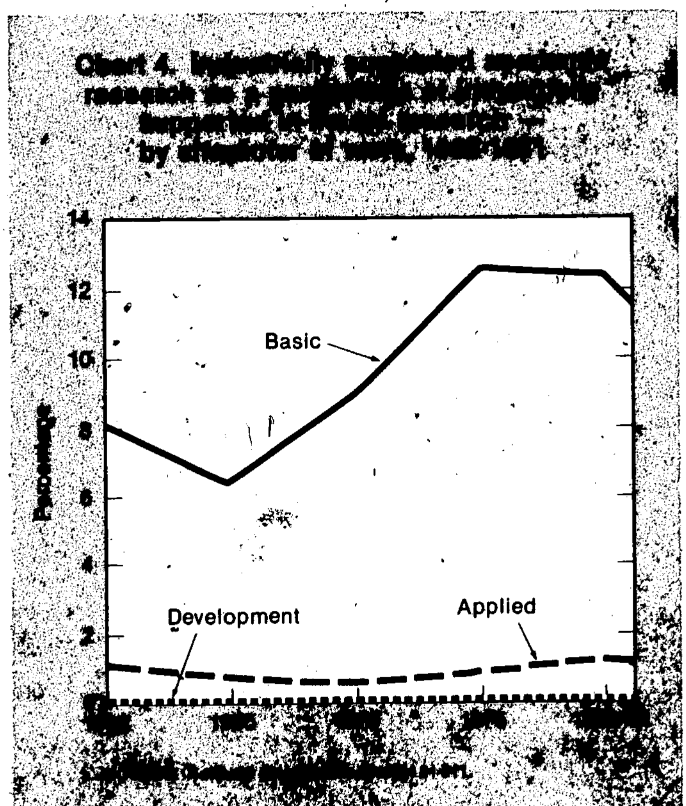
- U.S. national R&D spending in 1981 amounted to about $69 billion. Two thirds ($45 billion) of this was for "Development." The "Research" portion was made up of $15 billion in applied research (22%) and nearly $9 billion in basic research (13%). As universities perform very little development, it is in the research area that the closest academic and industrial joint interests lie.

- Industrial laboratories and contractors have carried out a fairly constant 70% of all U.S. R&D since 1965 (Chart 2A). Up to 1970 industry supplied between 30-40% of the support, but this rose to 49% in 1981 (Chart 2B).

- Between 1960 and 1970 basic research done in industrial laboratories shrank significantly from nearly one-third to about one-sixth of total basic research activity (Chart 3). Industrial support for basic research shrank by about the same propor-



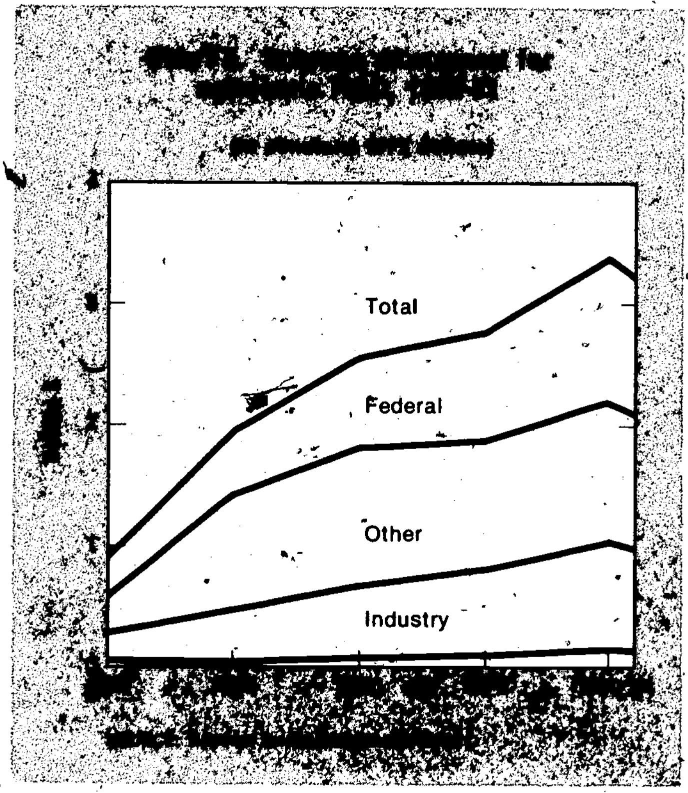




tion. Industry's percentage share of both support and performance of basic research remained more or less constant (15-17%) between 1970 and 1981.

- While total industrial budgets for basic research shrank between 1960 and 1970, the portion of these budgets allocated for university basic research decreased only slightly from just over 8% in 1960 to about 6% in 1965. By 1975, however, it rose to about 12% where it has remained since then (Chart 4).

- There was rapid real growth (see Chart 5) in Federal Government support for academic research during the 1950's and 1960's, leveling off and remaining fairly stable after 1969 until about 1975, fol-



lowed by an upswing in the late 1970's. Total academic R&D expenditures from all sources in 1981 were estimated at $6.6 billion in current dollars of which two-thirds ($4.4 billion) was classified as "basic research," $1.8 billion (just over one quarter) as "applied research" and only $0.4 billion (6%) as "development."

- The industrial share of university R&D support dropped rapidly from just over 6% in 1960 to below 3% in 1965. It wasn't until after 1970 that the percentage rose above 3% reaching its 1981 level of 3.8% (Chart 1,). However, in constant 1972 dollars industrial support for academic research doubled between 1966 and 1978.

- The 1980 amount of industrial R&D support at each of the nation's top 200 research performing universities and colleges is shown in Table 1. The data are derived from university responses to an annual NSF survey and generally tend to understate industrial support because, among other things, a number of institutions do not report their industrial R&D income, institutions are inconsistent about reporting philanthropic gifts for research, and gifts or loans of scientific equipment are rarely reported at all. Despite these shortcomings, the data present a fascinating portrait of the diversity of the national academic-industrial R&D connection. Only 25 of the 200 campuses report more than 10% of their R&D expenditures as coming from industry. The majority of these are at the low end of the ranking for total campus R&D expenditures—many are the smaller technological institutes. Several of the "ivy league" research universities are average or below average in their industrially derived R&D expenditures, some having less than 1%. The rankings by industrial support are no doubt significantly correlated with the presence of engineering schools on campus, yet there are a number of obvious exceptions. These data deserve further analysis and hopefully the quality of the data can be improved.

- Though no regularly collected comprehensive data on the field distribution of industrial support for academic research are available, several discrete pieces of information suggest strong variation by field. Data on academic engineering show that over the past decade between 6% and 10% of engineering research was supported by industry (Chart 6). Further, the data suggest that in 1979 nearly half of all industrially sponsored research in universities was in engineering ($86.7 million out of a total of $190.3 million.) Even within engineering there is great variation. A 1981 survey of all departments listed in the American Chemical Society's *Directory of Graduate Research* showed that 23% of extramural research funds for chemical engineering departments came from industry. The same survey showed that 7% of extramural research support for chemistry departments was industrially derived (Table 2).

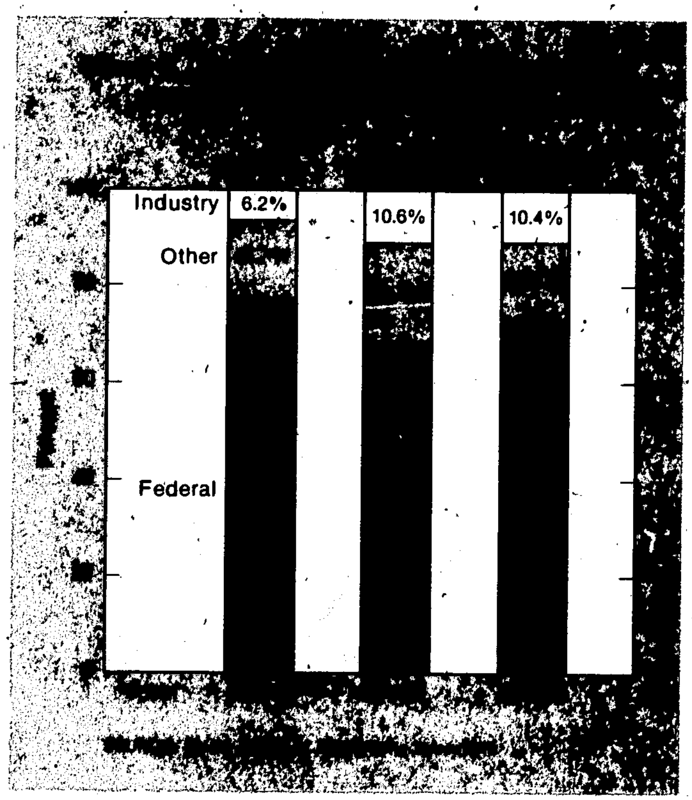


Table 1

Academic R&D Expenditures Derived From Industry Among the Top 200 R&D Performing Campuses, FY 1980

Rank in Total R&D Expenditures / Range of Expends.	Rank 1-25 $68.4-$253.2 Million			Rank 26-50 $38.9-$65.8 Million			Rank 51-75 $25.6-$38.9 Million			Rank 76-100 $16.5-$25.0 Million		
Avg. Ind. Share	Average 4.39%*			Average 4.38%*			Average 3.84%*			Average 4.62%*		
Percentage of Total R&D Derived from Industry	Campus	Industrial R&D Support $1,000's	% of Total	Campus	Industrial R&D Support $1,000's	% of Total	Campus	Industrial R&D Support $1,000's	% of Total	Campus	Industrial R&D Support $1,000's	% of Total
<3.6%	Columbia	364	0.4	U. Hawaii	184	0.5	U. Kentucky	312	1.0	Va Cmwlth U.	143	0.8
	Yale	582	0.8	Northwestern	290	0.7	U. Missouri	509	1.5	Temple U.	185	1.0
	U. Tx. Austin	1,237	1.6	U. Chicago	402	0.7	Princeton U.	423	1.5	Boston U.	241	1.0
	U. Wisconsin	2,615	1.9	Washington U.	1,029	1.7	Mississippi St.	458	1.6	Florida St. U.	247	1.2
	U. Penn.	2,010	2.1	U. Alaska	830	2.0	Rockefeller U.	678	1.8	Syracuse U.	213	1.3
	Stanford	3,215	2.8	Duke U.	779	2.0	CUNY Sch. Med.	554	2.1	George Wash. U.	359	1.9
	U. Washington	3,830	3.4	U. Connecticut	959	2.2	SUNY Stony-brook	565	2.2	Utah St. U.	533	2.2
	Mich. St. U.	2,543	3.5	Louisiana St.	1,267	2.4	U. Utah	851	2.3	U. Massa-chusetts	413	2.5
				Oregon St.	1,572	3.5	U. Pittsburgh	774	2.4	Auburn U.	530	2.6
				UNC-Ch. Hill	1,370	3.5	Wash. St. U.	795	2.5	West VA. U.	519	3.0
							Indiana U.	831	2.7			
							Rutgers	1,008	2.8			
							U. Iowa	1,095	2.8			
							U. Nebraska	996	3.1			
3.6-5.9%	U. Minnesota	4,352	3.6	New York U.	2,080	3.7	U. Virginia	984	3.6	Brown U.	650	3.6
	Harvard	3,995 E	4.0	U. Georgia	2,076	3.7	Kansas St. U.	1,101	4.0	U. Delaware	702	4.2
	U. Illinois	3,404	4.1	Iowa St.	1,854	3.8	U. Cincinnati	1,237	4.3	U. Arkansas	1,186	5.6
	Cornell	5,153	4.8	NC St-Raleigh	1,800	4.2	U. Tx. Hlth. Ctr. Dallas	1,319	5.0			
	Ohio St. U.	3,699	5.2	U. Colorado	2,674	4.3	U. Alabama	1,585	5.1			
(Avg.—200 Insts. 4.6%)	U. Michigan	6,145	5.5	Case Western	1,790	4.4						
				U. Miami	1,895	4.6						
				Cal Tech	1,993	4.6						
				U. Florida	3,045 E	5.4						
				U. Md-Col. Pk.	2,263	5.7						
6.0-9.9%	Texas A&M	4,[illegible]81	6.0	Colorado St.	2,505	6.2	Baylor Col. Med.	2,801	7.4	Clemson U.	1,126	6.1
	MIT	11,402	7.0	Purdue U.	4,756	7.7				U. Dayton	1,257	6.4
	U. Arizona	5,923	8.6							Wayne St. U.	1,604	7.7
										Georgetown U.	1,535	8.8
										Vanderbilt U.	1,890	9.1
										Oklahoma St. U.	2,224	9.5
≥10%	USC	7,462	10.0	Georgia Tech	6,243	11.0	Va. Poly. St. U.	3,692	11.0	U. New Mexico	2,822	11.6
	Penn. St. U.	7,842	10.9	U. Rochester	7,869	11.9	Carnegie Mln. U.	5,010	17.1			
No Data on Industrial Support	Johns Hopkins			Yeshiva U.			U. Tx. Cancer Ctr			U. C. Riverside		
	U. C. San Diego						New Mex. St. U.			SUNY Buffalo		
	U. C. Berkeley									U. C. Irvine		
	U. C. Los Angeles									U. Kansas		
	U. C. San Francisco									U. Rhode Island		
	U. C. Davis											

We turn now to a discussion of the support of university research through industrial philanthropy. Corporations have administrative mechanisms for making deductible contributions to educational institutions for both research and educational purposes. Sometimes this is organized as a contributions office in the corporation, sometimes as a foundation. Most of the foundations are rather tightly tied to the operating policies of the company.

The relative magnitude of academic research supported by corporate contracts, on the one hand, and research supported by corporate philanthropy, on the other hand, is not clearly understood. However, existing data on corporate philanthropy to higher education permit an educated guess that academic research supported by corporate gifts and grants roughly equals that supported by corporate contracts. This is not inconsistent with the data for chemistry and chemical engineering in Table 2.

A survey in early 1982 of over 200 corporate chief executive officers reported that 60% of the corporations planned to increase their charitable contributions—most of which go to higher education—beyond the inflation rate over the next few years. Some observations from the survey (as reported in the *Chronicle of Higher Education*, 5/26/82) illustrate the motives and character of corporate giving.

Table 1 (Continued)

Rank in Total R&D Expenditures / Range of Expends.: **Rank 101-125, $11.4-$16.0 Million** — Avg. Ind. Share: Average 5.54%*

Percentage of Total R&D Derived from Industry	Campus	Industrial R&D Support $1,000's	% of Total
<3.6%	U. Md. Balti.	114	0.8
	Tufts U.	224	1.9
	U. Idaho	301	2.2
	U. Oregon Hlth. Ctr.	325	2.5
	U. Maine	392	2.7
	U. Tx. Med. Br. Galv.	467	2.9
	U. Tenn. Inst. Agr.	455 I	2.9
	Howard U.	357	3.1
	U. IL. Med. Ctr. Chicago	449	3.1
	U. Oklahoma	508	3.2
3.6-5.9%	U. Houston	602	4.8
	U. Vermont	801 E	5.1
	U. Tx. Hlth. Ctr. S. An.	722	5.2
	Emory U.	867	5.5
6.0-9.9%	Tulane U	781	6.3
	Montana St. U.	1,070	7.8
	Albany Med. Col.	896	7.9
	N. Dakota St. U.	1,221	9.4
	Rensselaer P.I.	1,394	9.4
≥10%	U. Tenn. Knox.	1,354 E	10.6
	U. Denver	1,697	11.5
	Tex. Tech. U.	1,969	15.1
No Data on Industrial Support	U. Ca. Santa Barbara		
	Col. Med. Dent. N.J.		
	U. Puerto Rico		

Rank 126-150, $7.2-$11.3 Million — Average 5.89%*

Percentage of Total R&D Derived from Industry	Campus	Industrial R&D Support $1,000's	% of Total
<3.6%	St. Johns U.	6	0.1
	U. Oregon	34	0.4
	U. New Hamp.	184	1.8
	U. Ok. Hlth. Ctr.	139	1.9
	SUNY Dwnst. Med. Ctr.	275	2.6
	U. Mississippi	214	2.7
3.6-5.9%	U. Tx Hlth. Ctr. Houston	421	3.7
	Thom. Jef. U.	355 E	3.7
	So. Dak. St. U	313	3.9
	U. Tn. Hlth. Ctr.	400	4.2
	U. Ill. Chig. Cir.	393	4.4
	Med. U. So. Car.	401	4.6
	U. Nevada	391	5.0
	Med. Col. Wisc.	593	5.6
	Rice U.	467	5.8
6.0-9.9%	U. Neb. Med. Ctr. Omaha	546	7.4
	U. Notre Dame	683	7.7
	Rush U.	792	9.0
≥10%	U. Wyoming	1,104	10.0
	N. Mx. Inst. Mn. Tch.	786	10.8
	Lehigh U.	1,076	11.4
	Mich. Tech. U.	2,064	24.3
No Data on Industrial Support	Dartmouth Col.		
	Brandeis U.		
	U. C. Santa Cruz		

Rank 151-175, $5.0-$7.0 Million — Average 5.58%*

Percentage of Total R&D Derived from Industry	Campus	Industrial R&D Support $1,000's	% of Total
<3.6%	Boston Col.	54	1.0
	U. Tx. Dallas	87	1.4
	Wake Forest U.	97 E	1.6
	Arizona St. U.	124	1.8
	Northeastern U.	107 I	1.9
	U. Central Fl.	108	1.9
	U. Wisc.-Milwaukee	139	2.0
	U. Missouri-Rolla	168	2.6
	Med. Col. Ga.	144	2.6
	N.Y. Med. Col.	152 E	2.9
3.6-5.9%	U. Ark. Med. Sci. Cam.	209	3.8
	Polytech Inst. NY	287 E	4.2
	U. No. Dakota	216 I	4.3
6.0-9.9%	Drexel U.	348	6.4
	U. Louisville	421	6.4
	SUNY Col. Env. Sci. For.	504	8.8
≥10%	Sth. Ill. U-Carbndl.	967	14.7
	Desert Res. Inst.	1,814	33.3
No Data on Industrial Support	SUNY at Albany		
	St. Louis U.		
	U. So. Carolina		
	SUNY Upstate Med. Ctr.		
	U.S. Naval PG Sch.		
	U. C. Sys. Wd. Progs.		
	Med. Col. Ohio-Toledo		

Rank 176-200, $3.2-$5.0 Million — Average 11.40%*

Percentage of Total R&D Derived from Industry	Campus	Industrial R&D Support $1,000's	% of Total
<3.6%	U. Mass. Md. Sc. Worc.	14	0.4
	Loma Linda U.	18 E	0.4
	N. Illinois U.	31	0.8
	Ohio U.	35	1.1
	San Diego St. U.	61	1.4
	Wright St. U.	87	1.8
	U. Sth. Florida	92	1.9
	U. West Florida	89	2.1
	Loyola U. Chicago	88 I	2.5
3.6-5.9%	SUNY Binghampton	160	3.6
	Hahneman Med. Col.	160 E	3.9
	U. Ark.-Pine Bluff	183	5.1
6.0-9.9%			
≥10%	Colo. Sch. Mines	497	11.0
	Inst. Paper Chem.	442	12.1
	Clarkson Col. Tech.	594	16.3
	U. New Orleans	582	16.9
	Oregon Grad. Ctr.	878	27.4
	Stevens Ins. Tch.	1,198	29.0
	Worcester Ply. In.	1,630	44.1
	Brigham Young U	2,198 E	54.9
No Data on Industrial Support	NC Ag. Tech. St. U.		
	CUNY City Col.		
	U. Missouri Central Office		
	N. Texas St. U.		
	U. Puerto Rico-Med. Camp.		

*Excluding "No Data" Institutions. "E" = Estimated; "I" = Imputed.

SOURCE: National Science Foundation, Academic Science: R&D Funds, FY 1980 (NSF 82-300)

A corporation can only benefit from good relationships with the academic community.

Universities train the talent that many corporations hope to recruit, and house a segment of the public whose general approval is important for the functioning of business.

Supplementing these self-interested objectives is the fact that corporations have substantial competence to evaluate educational institutions and projects—and certainly more competence than they generally have to evaluate, say, a social-welfare project.

Finally, contributions to education are typically noncontroversial and—most often mentioned—prominent corporate citizens were once students of recipient schools.

The report adds that higher education's large share of corporate gifts is related to the sophisticated mechanisms that universities have developed to solicit support.

In 1980-81 colleges and universities reported $778 million in voluntary donations from corporations. This was 18.4% of total voluntary support from all sources, including alumni, non-alumni individuals, and foundations. The corporate share was up from 14% a decade earlier. Corporate philanthropy to universities is more than twice as likely to be earmarked for research (27%, or $210 million in 1980-81) as donations from all other sources (12%, or $416 million in 1980-81). Chart 7 depicts the trend in corporate philanthropy to higher education over the past seven years.

The proportion earmarked for research has fluctuated between 25-35% with no clear trend evident. However, because corporate giving has been rising faster than other sources of voluntary support, and because a higher proportion of corporate gifts are for research, the corporate share of all gifts for research has risen steadily from 27.9% in 1974-75 to 33.6% in 1980-81. It should be added that these estimates of corporate gifts supporting university research are on the low side because university administrators may spend significant amounts of "unrestricted" gifts on research facilities or instrumentation.

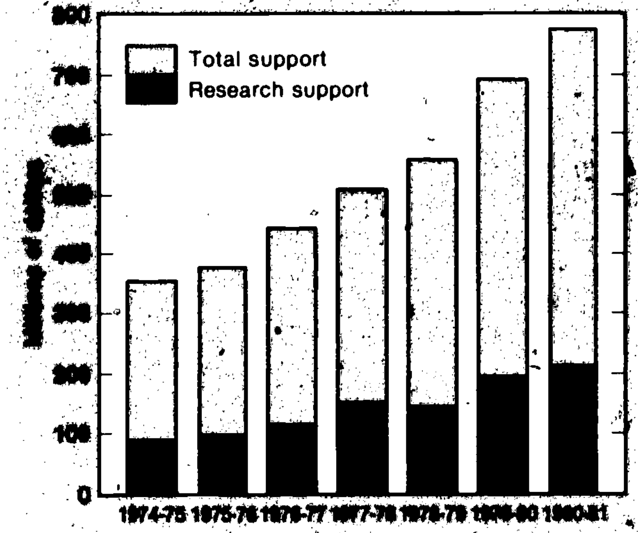
Table 2

Industrial Support for Research in University Chemistry and Chemical Engineering Departments by Type of Support (Calendar 1980)

Types of Industrial Support	*Chemistry*		*Chemical Engineering*	
	$1,000's	*%*	*$1,000's*	*%*
Uncommitted (uncommitted gifts or grants to departments)	1,910	19	3,139	31
Committed (gifts or grants to specific faculty members, or for specific areas of research)	2,469	24	1,845	18
Proposals (grants or contracts for specific research projects in response to explicit proposals)	5,516	54	4,477	44
Associate (membership fees from industrial associates programs)	260	3	564	6
Other	59	0	157	1
Total Industrial Support	$10,214		$10,182	
Total extramural support	$145,672		$44,338	
Industrial Funds as Percentage of Total Extramural Funds	7%		23%	
(Number and Percentage of all Departments Reporting)	186 (72%)		79 (81%)	

Source C. Judson King presentation to Council for Chemical Research, November 3, 1981.

Chart 7. National estimates of corporate voluntary support of colleges & universities, 1974-75 to 1980-81



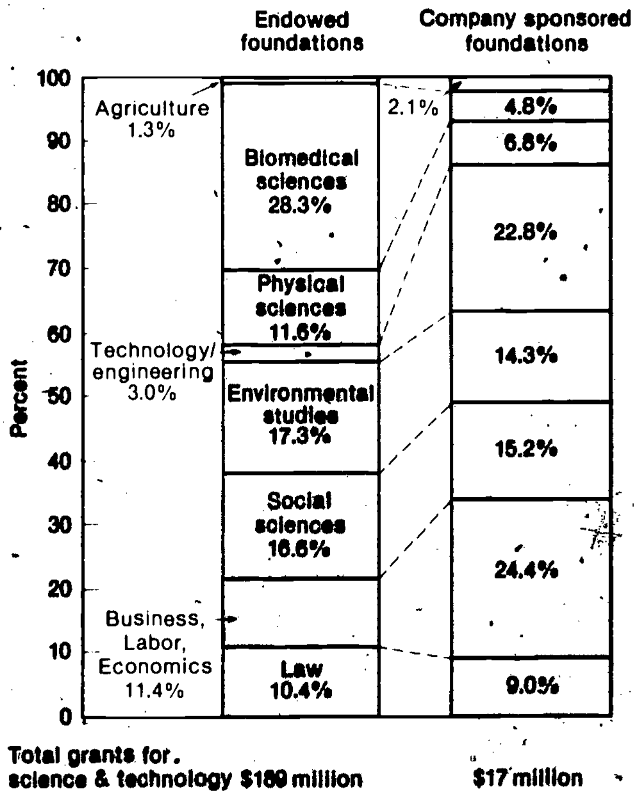
SOURCE: Council for Financial Aid to Education, Special Tabulation, March 1982.

Corporate philanthropy is not evenly distributed among academic fields. There is no comprehensive tabulation of corporate gifts for academic research by field. However, a 1979 comparison by field of the gifts for science and technology (see Chart 8) by company sponsored foundations and the endowed foundations showed that while the latter placed their principal emphasis upon basic research in the biomedical and physical sciences, the company sponsored foundations emphasized engineering, technology, business, labor, and economics. These data, of course, exclude some of the largest donors of corporate philanthropy such as IBM and DuPont which do not have company sponsored foundations but make their gifts directly.

Table 3 arrays the top 100 colleges and universities in terms of their total receipts of corporate philanthropy in 1980-1981, as well as by the proportion of the total that was earmarked for research purposes. It thus provides some indication of the level of general corporate interest in a particular institution of higher education, as well as identifying those universities in which the corporate philanthropic interest appears to be primarily or largely in their research capabilities, including, of course, their output of trained scientists and engineers.

These data are reported annually by the recipient institutions to the Council for Financial Aid to Education. The judgments concerning the purposes of the gifts and grants are made by the university officials submitting the reports. Some of the unexpected results in the table may be due to inconsistencies among institutions in

Chart 8. 1979 Grants of endowed and company sponsored foundations for science and technology, by field



SOURCE: Special tabulation by the Foundation Center, May 1980.

their standards and procedures for classifying the gifts.

The data for industrial gifts and grants reflect the same trends found for other outside support, i.e., a small percentage of institutions receive the bulk of the gifts. On the whole, the greater the total philanthropy received from corporations, the higher the percentage restricted to research purposes. However, in general the public institutions tend to have higher proportions of their corporate contributions restricted to research than private institutions which, of course, have always relied more heavily upon philanthropy from all sources for the operation and growth of their organizations.

The data on direct or indirect industrial support for academic research give little indication of the most pervasive academic-industrial connection, namely the private consulting relationship between a professor and a unit of a company. National surveys of academics in 1969 and 1975 showed that nearly 40% reported doing paid consulting of some kind (Chart 9). However, only 6% indicated that they consult more than one day per week. About 10% said that they consulted with national corporations, and nearly 20% reported consulting for local business, government, and schools. Faculty at the high quality rated research universities were much more likely to be selected as consultants by national corporations than were their colleagues at lower rated institutions. However, faculty at all types of schools (junior colleges excepted), whether high or low in prestige, were equally likely to report paid consulting with local business, government, and schools.

Overall opportunities for consulting differed considerably by academic field (see Chart 10). Nearly two-thirds of the academic engineers reported paid consulting activities, as compared to less than one-third of their physical and biological science colleagues. About half of the faculty in the professional schools reported paid consulting, but only one-fifth of the humanities professors were so engaged. In the above discussion, only the 1969 data has been reported because the 1975 material was not available. However, no significant changes in patterns of consulting occurred in the period and there was no increase in the proportion of faculty engaged in consulting. Comparable recent data have not been collected. It can be added that according to these surveys, faculty engaged in paid consulting teach as much and publish more than their colleagues.

The following section sketches in a kaleidoscope of recent initiatives in university-industry research relationships which outlines the current front of activity.

d. Current Activities

Discussions about university-industry research coupling began to intensify around 1978, thus the provisional figures for 1980 and 1981 on levels of support do not fully reveal the degree to which talk is being followed by action. There is, however, strong anecdotal evidence of increased activity. Several large and visible agreements for long term research collaboration between companies and universities have been signed within the past few years, for example, Harvard-Monsanto; Washington University-Mallinckrodt Inc.; Harvard Medical School-Seagrams; MIT-Exxon; Carnegie Mellon-Westinghouse; Massachusetts General Hospital (Harvard)-Hoechst A.G.; and most recently, Washington University-Monsanto.

In the biotechnology field events have been moving so fast that some major arrangements have been announced and then canceled during the period of writing this report—a case in point is the arrangement between DNA Sciences, Inc. (E.F. Hutton) and the Weizmann Institute of Science in Israel. The dizzying commercial growth of this field was expressed in late 1981 by Dr. Leslie Glick, president of Genex Corporation:

> In 1978, there were only 4 companies worldwide that specialized in applying recombinant DNA technology to industry. Their total capitalization was roughly $20 million. As 1981 draws to a close, there are perhaps 110 young firms specializing in recombinant DNA technology with total capitalization of

Table 3

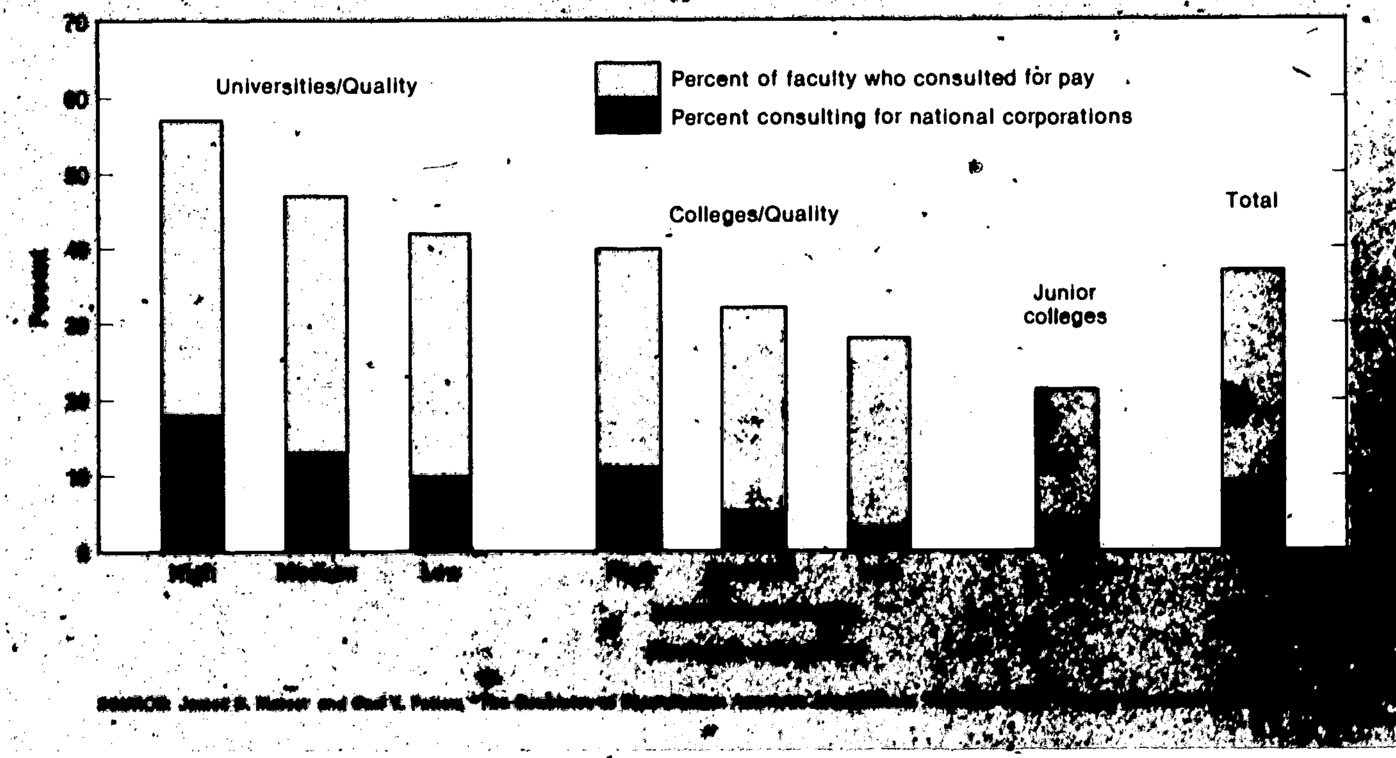
Corporate Philanthropy to Institutions of Higher Education, 1980-81: Contributions Restricted to Research as a Percentage of Total Corporate Contributions (Gifts for operating purposes only: capital gifts excluded)

Rank in total Corp. Contr. Range	Rank 1-25 ($4,284-$14,180)			Rank 26-50 ($2,634-$4,166)			Rank 51-75 ($1,343-$2,613)			Rank 76-100 ($835-$1,338)		
Percentage of total Contributions for Research	Campus	Contributions for Research: $1,000's	% of Total	Campus	Contributions for Research: $1,000's	% of Total	Campus	Contributions for Research: $1,000's	% of Total	Campus	Contributions for Research: $1,000's	% of Total
0%				Washington U.*	----	--	Rensselaer Poly.	----	--	American U.	----	--
										Tex. Christian U.	----	--
										Beloit College	----	--
										U. of Mississippi	----	--
										Loyola U.-Chic.	----	--
1-8%	Ball State U.	173	2	Dartmouth Coll.	142	5	Brandeis U.	9	0.4	Wake Forest U.	2	0.2
	Georgetown U.	140	4				Rice University	20	1	Oklahoma St. U.	18	2
							Ga. Inst. Tech.	55	3	Clarkson Col. Tech	19	2
							W. Virginia U.	43	3	Colorado St. U.	23	2
							Illinois Inst. Tech.	60	3	Pace U.	31	3
							Sthn. Methodist U.	78	5	U. of San Francisco	37	4
										Mich. Tech. U.	42	4
										Marquette U.	64	8
										Rutgers U.	76	7
										Reed College	66	8
										Domin. Col. Blavlt	84	8
9-32%	U. of So. Cal.	1522	26	Carnegie-Mellon U.	372	11	U. of Kansas	221	12	Wichita State U.	139	12
	Stanford U.	3034	28	U. of Chicago	579	14	U. of Rochester	192	12	U. of Denver	118	12
	Harvard U.	3192	28	U. of Missouri	637	20	Colo. Sch. of Mines	200	15	Harvey Mudd Coll.	115	12
	U. of Georgia	2384	29	Duke U.	856	21	St. Louis U.	232	16	Boston U.	192	19
				Northwestern U.	789	22	U. of Tennessee	386	19	U. of Cincinnati	253	20
				Creighton U.	623	23	Howard U.*	519	23	U. of Pittsburgh	325	25
				U. of Houston	802	23						
				Princeton U.	669	25						
				U. of Sth. Fla.	944	28						
				Purdue U.	933	29						
				Yale U.	1160	29						
				New York U.	1235	31						
33-100%	Columbia U.	2884	40	Vanderbilt U.	1235	35	Brown U.	543	33	Auburn U.	448	48
	Ohio State U.	1804	42	U.C.-San Diego	1308	35	U. of Virginia	794	35	U.C.-Irvine	730	77
	U. of Illinois	5924	42	Tulane U.	1464	53	Emory U.	1445	55	Baylor Col. Med.	1215	91
	U. Texas-Austin	2416	42	Johns Hopkins U.	1779	58	U. Nebraska	1298	55			
	Case Western R. U.	1822	42	Cal. Inst. Tech.	2144	57	U. of Kentucky	997	57			
	U. of Pennsylvania	3586	42	Virginia Poly. Inst.	2807	83	U. of Delaware	978	81			
	U. of Minnesota	2472	48	Wayne State U.	1881	85	Oregon State U.	1888	68			
	M.I.T.	6102	49	Pennsylvania St.	2658	74	U. of N. Carolina	1028	88			
	U.C.L.A.	3119	51	U. of Colorado	2828	81	Rockefeller U.	1171	77			
	U. of Miami	2898	55	Wash. St. U.	2377	83	U. of Conn.	1281	80			
	U.C.-Berkeley	4190	58	U.C.-San Fran.	2424	89	U.C.-Davis	1872	81			
	U. of Michigan	5854	82				U. Tex Hlth Ctr-San Antonio	1475	87			
	Louisiana St. U.	4324	83									
	Texas A&M U.	8806	72									
	Cornell U.	4370	73									
	U. of Maryland	3938	74									
	U. of Wisconsin	3858	78									
	Michigan St. U.	5578	81									
	U. of Arizona	8755	84									

Source: Council for Financial Aid to Education data tape

* The bookkeeping systems of some institutions, including Washington University, do not permit separate identification of corporate research contributions.

Chart 9. Faculty participating in consulting for pay, by types of institution, [illegible]



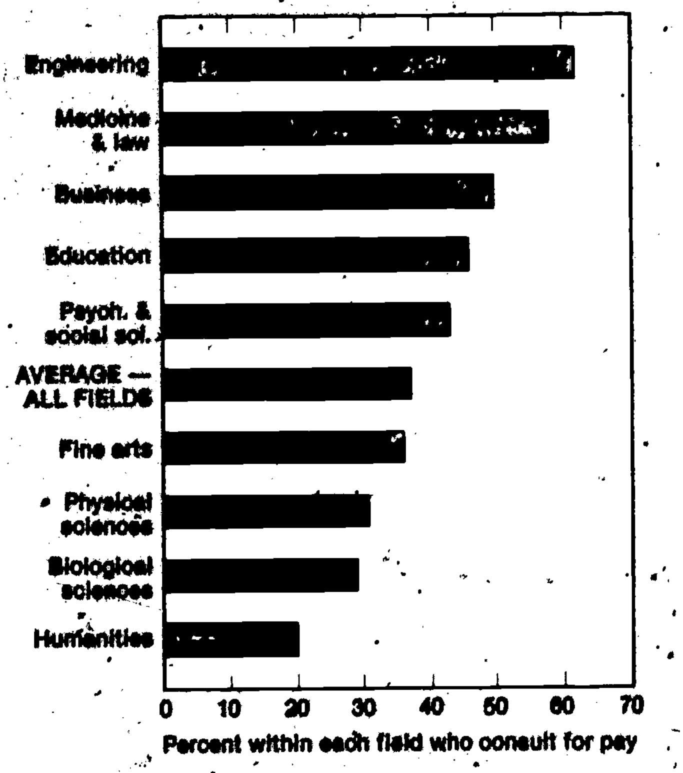
about $700 million. In addition to these new small firms, roughly 120 large companies worldwide (are) currently involved in recombinant DNA technology.

Further, over 70 firms have been identified as working in monoclonal antibody research—an area in which the basic techniques were only discovered five years ago. It is certain that most of these companies have academic advisers and consultants and that some of them are "spin-off" companies founded, owned, and managed by academic scientists.

The biotechnology boom is also giving rise to innovative organizational experiments in connecting university research to commercial development. Experiments with complexes of overlapping non-profit and for-profit organizations such as the arrangements between the University of California at Berkeley, Stanford University, and six corporations (Engenics, Inc.) aim to develop commercial processes and also to channel significant portions of the profits back into academic research. A related area of active experimentation is use of limited partnerships to permit partners to invest in university research and obtain tax credits under the recent tax legislation, in addition to possible capital gains on products of the research. The potential problems generated by the very rapid growth of university-industry research relationships in biotechnology prompted an unprecedented two day meeting in March 1982 between the presidents of five leading research universities and their counterparts in ten high technology firms involved in biotechnology to develop suggested guidelines for the complex relationships that have sprung up between industry and academe.

Research managers from most major chemical companies have held three annual conferences with chairmen of university chemistry and chemical engineering departments which have resulted in the establishment of a Council for Chemical Research. This Council aims to fund academic research and work toward forging new relationships between academic and industrial chemists and chemical engineers. The Semiconductor Industry Association has set up a non-profit subsidiary, the Semiconductor Research Cooperative, the intent of which is to encourage increased efforts by manufacturers and universities in long-term semiconductor research, and to add to the supply and quality of holders of professional degrees in the field. Expenditures of $20 million over two years are planned. The American Electronics Association (AEA) has recently analyzed the national engineering shortage problem and proposes that their members donate 2% of their research budgets against very specific targets to alleviate the problem. If this is accepted there is a potential of more than $50 million being made available to electrical engineering departments. In April 1982 the AEA published a useful

Chart 10. Faculty participation in consulting for pay, by academic subject field, 1969



SOURCE: James D. Marver and Carl V. Patton, "The Correlates of Consultation: American Academics in 'The Real World,'" *Higher Education*, 5(1976), 319-335.

guidebook of model university-industry engineering programs to encourage companies to increase investments in engineering education.

In addition to these collective efforts, a number of individual companies are responding to needs for scientists and engineers in certain areas of shortages with a variety of philanthropic support programs.

Two of the major U.S. higher education associations are conducting liaison activities with industry. The American Council on Education with a membership of about 1,600 colleges and universities, is hosting a "Business-Higher Education Forum" which periodically brings together chief executive officers of universities and corporations to explore means of interaction for mutual benefit. The Association of American Universities, whose membership is composed of 48 leading research universities, has been holding periodic meetings with corporation directors of industrial research.

Several federally funded national research facilities including the Stanford Synchrotron Radiation Laboratory and the new Brookhaven National Synchrotron Light Source are becoming increasingly instrumented and utilized by industry—a clear case of the relevance of fundamental research facilities to industrial goals.

A variety of consortia-like programs in which several companies jointly provide support for focused academic research activities have generated a surprising amount of support. CalTech's Silicon Systems Project and Stanford's Center for Integrated Systems are examples. Similar arrangements with some initial Federal support are MIT's Polymer Processing Center and the Center for University of Massachusetts—Industry Research in Polymers.

A significant development is documented by a recent survey conducted by the National Governors Association. The survey of all fifty states looked for programs to spur technological innovation and productivity growth. At least 88 separate initiatives were found to be underway with state leadership, and many involved public-private partnerships. To give some examples, several states, including North Carolina, New York, California, and others, have made long-term commitments of large sums for implementation of ambitious plans to develop academically connected R&D centers in microelectronics with extensive corporate participation. In Michigan, a flexible factory automation research center is planned. Arizona has announced a major expansion of university engineering research and education with heavy corporate support.

Universities are actively examining their patent and licensing policies and there is increasing faculty awareness of the potential patentability of their discoveries. While the potential benefits of interaction with industry are receiving strong university attention, there is also concern with potential dangers. For example, the Association of American Medical Colleges has asked one of its committees to examine the effects of outside money on the open exchange of data and other aspects of academic freedom.

Both universities and companies are beginning to take inventory of their arrays of gifts, grants, contracts and other relationships with each other. One of the largest U.S. companies recently completed for the first time such a comprehensive audit to aid in planning its future relations with academia. Most major universities have begun significant efforts to kindle industry connections. At MIT, perhaps the university with the best industrial connections, industrially supported research contracts have enjoyed a 300% growth in the six years prior to 1980.

Clearly, the signs of increased traffic between companies and campuses are many.

e. Government Involvements

The several levels of government have played important roles in university-industry relationships. The story of agricultural research is well known and both World Wars saw government initiating and supporting extensive joint efforts in science and technology. The post World War II period saw assumption by the Federal Government of responsibility to support basic research with the establishment of the National Science Foundation in 1950.

It is interesting and important to note that the view of technology as a positive development in government economic policy only emerged after World War II. President Roosevelt's programs for economic recovery in the 1930's included no specific provisions for the stimulation or support of R&D, although some programs had the effect of providing support for some academic researchers. In fact, a dominant belief of the time was that technology *caused* unemployment—precisely the problem they were trying to cure. It was not until after the war that the fear of technological unemployment receded, and a current view of technology as an economic growth agent could come to the fore.

Recent Federal Developments.

As mentioned above, current concerns with the national economy have brought renewed policy attention to the role of R&D in economic growth, and to the role of research as the base of new technology. Governmental focus upon the university-industry connection has been a small but significant part of this.

In the recent period, university-industry cooperation was spurred initially by President Nixon's message to the Congress on March 16, 1972. His message urged the National Science Foundation and the National Bureau of Standards to "determine effective ways of stimulating non-Federal investment in research and development and of improving the application of research and development results." NSF responded with experimental programs involving university-industry interaction, of which the major ones were the University-Industry Cooperative Research Centers Experiments (1973) and the Innovation Centers Experiments (1973). The University-Industry Cooperative Research Projects Program was added five years later (1978). These programs provide mechanisms intended to encourage collaborative research by academic and industrial scientists and engineers according to their own research priorities.

At the National Bureau of Standards the Experimental Technology Incentives Program (ETIP) was launched in 1973 to conduct policy studies and experiments in cooperation with Government agencies having direct policy responsibility. The objective was to help the participating agency formulate a new policy and to test it through a formal, evaluated experiment. The policy experiment was an innovation in industrial policy research, and several examples involved the direct participation of universities (examples include the patenting of university research and the joint adoption by a university and an adjoining urban community of an advanced energy supply system).

In 1978 the President initiated a domestic policy review of industrial innovation. University-industry cooperation in research was one of the topics reviewed. In late 1979, based on these reviews, the administration made several recommendations to expand existing Federal university-industry programs, and to extend these programs to other agencies. Several of these proposals were incorporated in the Stevenson-Wydler Technology Innovation Act of 1980 (P.L. 96-480).

The 96th Congress passed additional legislation intended to encourage the commercialization of innovative ideas and technologies developed as a result of Federal sponsorship of university and industry-based R&D projects. The principal thrust of the provisions of the Uniform Federal Patent Policy Act of 1980 (P.L. 96-517) is to permit universities, non-profit firms and small businesses to elect to take title to inventions arising from Federally funded R&D activities.

Another significant development in 1980 was publication by the Antitrust Division of the U.S. Department of Justice of its *Antitrust Guide Concerning Research Joint Ventures*. The document was intended to clarify for private firms the conditions under which cooperative research and other R&D ventures would be admissible under the antitrust laws.

The change in administration in January 1981 signaled a new conception of the Federal Government's role in the area of university-industry relationships. While previous administrations had attempted to develop Government-directed programs for the stimulation of research and development in general, or university-industry research interactions in particular, President Reagan's Administration demanded a more limited view of Government intervention in the private sector. Research and development was given high priority by the new administration, and the significance of university-industry interactions received early recognition. However, the principal thrust of the new policy involved provision of incentives for R&D investments through tax legislation. The Economic Recovery Tax Act of 1981 (P.L. 97-34) includes several provisions aimed at stimulating increased support for research and development by industry:

- A 25% tax credit for incremental increases in industry R&D expenses when compared with historic R&D expense levels. This provision includes direct in-house industry R&D expenses (wages, supplies, and payments for leased equipment), contributions to a qualified fund, and research contracted-out (allows up to 65% of contracted-out cost). It excludes depreciable plant and equipment and expenses for research: (a) outside the U.S., (b) in the social sciences and humanities, and (c) funded by other persons or Government agencies.
- An increase in charitable deductions to cost plus one-half the difference between the cost and the fair market value, for donation of new equipment (less than two years old) by an equipment manufacturer to an institution of higher education (for re-

search and training in the physical and biological sciences).

- Suspension (for two years) of tax regulations requiring firms to allocate research expenses between U.S. and foreign source income and requires further study of this area by Treasury.
- A change in regulations to allow taxpayers to depreciate research equipment over three years instead of five years.

It seems clear that in recent times at least, all administrations, regardless of their political and economic complexion, have viewed the university-industry research connection as a positive and desirable element in national economic policy. Administrations have diverged, however, in their conceptions of appropriate Government roles and degrees of emphasis upon different means to encourage the relationships. This Administration's approach reflects the fact that effective long-term university-industry research interaction will be based on the perceived worth of the university work by the industry—not on initiatives originating in Washington by third parties.

3. TRENDS AND OPPORTUNITIES

There is general consensus on the likelihood of increased university-industry research interaction during the 1980's. Questions are raised about whether industry has sufficient resources available to increase allotments to university research; whether academic research can really benefit industry; and whether academic freedom and the openness of scientific communications can be preserved in the face of the constraints and temptations of commercial concerns. But the new arrangements highlighted here reflect an optimistic mood that is grounded in an awareness that the problems and opportunities in technologically based industrial production are substantially different from those of the past. Three general factors characterize this change.

First, product and process improvement and innovation in some industries have evolved to levels of complexity that demand understanding of fundamental physical and biological phenomena, and thus require much higher levels of training in and use of basic science and engineering than the "cut and try" inventor of yore. One factor contributing to increased complexity is that manufacturing is becoming a process-oriented activity, rather than an assembly oriented activity. Process manufacturing, being easier to automate than assembly, is more productive but also requires much greater involvement with the fundamental properties of the materials being worked. For example, in microelectronics, as the manufacturing of microcircuits is pushed down to ever smaller dimensions, puzzling phenomena occur which require new scientific and engineering explanations before further progress can take place.

Further, incremental advances in narrowly focused technical areas, characteristic of much industrial development in the past, are giving way to the use of a broad range of science and engineering disciplines on complex, often ill-defined problems, or exploitation of new analytical capabilities. Hence, it is becoming increasingly difficult for any one industrial laboratory to fully encompass the requisite expertise. A partial remedy for this situation is to seek out the pertinent skills wherever they may be found in the Nation's universities.

And finally, the rapid expansion of the Nation's R&D system over the past three decades has diffused research capabilities over a much broader range of institutions—academic and industrial—than before. Thus it is quite unlikely that any one company could hold and maintain a leading edge on technical advance in a given area, as, for example, DuPont was able to do in polymer fibers during the 1930's and later.

These changes are interactive, and we may be seeing these factors converging to create new configurations of academic and industrial research.

Beyond these trends, several additional features of the world environment in the 1980's may well affect university-industry research relationships in new ways. Rising prices for material resources will require higher levels of company R&D both to perfect more efficient modes of using existing resources, as well as to develop alternate materials and processes. There will also be continued fierce economic competition from the other advanced industrial nations.

Momentous changes are underway in several areas of science and engineering which have great potential implications for industrial applications. In some of these areas, e.g., recombinant DNA research in microbial, animal, and plant cells, and solid state physics as it applies to microelectronics, there are wide areas of overlap in the work of academic and industrial laboratories. While less visible to the public, this would also apply to other areas such as catalysis and materials research.

The rapid development of potentially lucrative new science-based technologies will create strong industrial demands upon universities for scientists and engineers trained in these technologies. These pressures have become so severe in some areas that they will require cooperative solutions. Companies can be expected to step up their activities in scanning universities for promising potential employees as well as to increase support for students and postdoctorals.

The perspectives and understanding of many industrial managers concerning academic research have changed so that corporations may be better able to utilize academic research, as well as create more effective management for in-house fundamental research. Industrial interest in and concern with this issue is expressed in current research management publications exploring such topics as the management of "directed basic research." At a recent conference on this subject, an industrial research manager advised his colleagues to "leverage your research dollar whenever possible with working university relationships and competitively won Federal study contracts in areas of basic research relevant to your company's technologies." Also, the Industrial Research Institute has recently initiated a series of dialogues between corporate directors of research and other senior corporate managers to explore improved ways of integrating longer term "downstream" research into corporate business strategy. The research directors believe that the balance between long and short-term research in industrial laboratories has been excessively weighted toward short-term work.

That industry is planning to intensify its research efforts over the next half decade is demonstrated in a 1982 survey by Haines Lundberg Waehler, an architectural, engineering and planning firm specializing in the design of research and high technology facilities. Their study of 81 corporations reported that four out of five industrial companies plan to increase their R&D expenditures over the next five years, and that one third plan increases of over 25 percent. The report concluded, "Competitive pressures, changing technologies and aging facilities are among the major factors spurring larger investments in research".

Increased industrial needs for R&D will create pressures to find improved ways for making the products of Federal investment in academic science and engineering more available to industry. In most defense and space related Government R&D the Government is, so to speak, its own customer because it buys the products of its investments. But much of the Government's research investment by such agencies as the National Science Foundation, the National Institutes of Health, and the Departments of Agriculture and Energy is through universities and colleges. It is expected that the 1980's will see an intensified search for means to make this considerable public investment in research more available for the development of useful products and processes and eventual commercialization. A significant step was taken in this direction with the patent legislation of 1980. The law assures that the creators of inventions may obtain title to their work, even if part or all of it resulted from federally supported work. At this point, however, the legislation applies only to universities, non-profit organizations, and small businesses. This Administration is supporting extension of this legislation to all Federally funded contractors.

These general economic and technical factors are further reinforced by several conditions within the academic sector operating to increase attention to industrial needs. The leveling off over the past decade of the rate of increase in federal research support, and declining student populations have combined to put research universities into a "steady state" posture. Academic administrations are exercising great ingenuity in the development of new sources of income to support their faculties and facilities. Research support from industry will look very attractive during the 1980's.

In the interest of income generation, universities will put much greater emphasis upon staking claims to patent rights to the discoveries made by their science and engineering faculty and staff. This will engage universities more frequently in patent and licensing negotiations with interested companies.

It can be expected that during the 1980's the competition for students will lead universities to put greater emphasis upon the development of curricula that promise relevance to industry. These will frequently involve cooperative arrangements with companies. A number of such cooperative curricular innovations in engineering were discussed at an October 1980 National Academy of Engineering Symposium on "Academe/Industry/Government: Interaction in Engineering Education."

In the next chapter we turn to a narrative account of selected findings from the several studies commissioned as background material for this report.

CHAPTER II

FINDINGS FROM RECENT STUDIES

1. INTRODUCTION

At the outset of its review of university-industry interactions, the National Science Board became aware that a stronger data base was needed to deal with such a complex subject. Only recently has there been a surge in the literature of the subject, but these contributions, while welcome, generally lack historical depth, adequate field data or systematic coverage. To help remedy these deficiencies, and in support of its analysis, the NSB commissioned several studies which are published separately from this Report.* These studies are intended to fill in some of the gaps in our knowledge, guide follow-on investigations and serve as a foundation for NSB findings and recommendations.

In all, one major field study was commissioned as well as three smaller studies and a day-long workshop. The field study examined over 400 cases of university-industry research relationships to describe and assess the status of university-industry research interactions, and to identify the factors that nurture or limit university-industry research interactions. The other studies addressed: industry relationships of science and engineering faculty at a sample of non-doctoral colleges and universities; the historical relationships between the chemical industry and academic chemistry and chemical engineering; and university-industry-state government consortia in microelectronics research. The workshop explored issues of intellectual property rights in industry-university cooperative research. All of the studies were subjected to critiques by NSB and outside reviewers, and modified in the light of their comments.

Given the voluntary and pluralistic nature of university-industry interactions, the changing aims of the participants and the difficulties inherent in spanning the gulf that always exists between organizations, it is not surprising that extreme diversity is found. What gives this diversity coherence is the fact that basic motivations and some major types of research relationships persist, and the factors and processes of university-industry relations can be identified. These ordering elements and issues as revealed in the studies, will be highlighted in this chapter.

2. STUDY HIGHLIGHTS

a. Why Do Universities and Companies Cooperate With Each Other?

Company representatives cited many reasons for their interest in establishing research interactions with universities. The following reasons were mentioned most frequently:

- Access to manpower (students and professors)
- Access to technology
- Problem solving or obtaining information
- Prestige or enhancement of the company's image
- Use of an economical resource
- General support of technical excellence
- Proximity
- Access to university facilities

Those industries which derive their major source of personnel from universities are most likely to provide cooperative funding. Sometimes, industry looks to the university as a window on new technology, but in rapidly growing high technology industries, both the university and the industry must participate in all aspects of the cycle. Industry also looks to the university to solve very specific scientific problems in which the university has special expertise. The function of these problem solv-

*The activities are listed in the Appendix.

ing services is to disseminate information, not to generate fundamental new knowledge.

Contrary to some expectations, *innovation is not a major industrial motivation for university-industry interactions.* Industry rarely looks to the university for technological innovations that result directly in new products or processes. Universities often perceive themselves as idea generators, but if a company must go outside its own organization for such innovations it is unlikely to go to a university.

Industrial motivations are grounded in the characteristics and values of individual companies and their competitors. Industry exists to make a profit by producing a product, a process, or rendering a useful service. To achieve those goals and safeguard the associated investment, patent protection and proprietary positions must be established. Consequently, communications and publications may be restricted. Industry's approach to research is governed by the view that research is a support mechanism for profitability. Translating that view into specific types of university-industry exchanges depends on corporate perceptions of the importance of fundamental or applied research; the relevant time frame; available capital; traditions of dependence on federal or state support; and the complexity of technology required by the industry.

Corporate size and complexity also play a significant role. Only a few industries, and comparatively few companies among them, pursue much research related contact with universities. The companies most active in research interactions with universities tend to be in the chemical, electronic, food, manufacturing, petroleum and pharmaceutical industrial groupings. Those industries which find university research to be ill-suited to their needs are apt to go to contract research organizations if they have a research problem that cannot be solved in-house.

With regard to size, only the larger companies tend to participate in university-industry research programs. Smaller companies, if they interact with university researchers, tend to do so in knowledge transfer programs of various types. Directors of such programs advise that it is difficult to attract small company participation except in advanced technology fields. This situation appears to stem from smaller company needs to solve specific problems that university professors do not consider to be sufficiently challenging, or the absence of company funds for such university-industry purposes, or the absence of research personnel in small companies to foster technical contacts with universities.

Universities interact with industry mainly to acquire funding for basic research and graduate training, or to support the facilities that make research possible. In general, industrial funding is seen as involving less red tape, and reporting requirements are seen as less time-consuming than equivalent support from the Federal Government. Other motivating forces for a university to seek industrial support for its research are:

- Access to scientific and technological areas where industry has special expertise.
- Industrially sponsored research provides an opportunity to expose students to new insights and to practical research problems that may be of immediate importance to society.
- Some government funds are available for applied research where a university couples with industry.
- Employment expectations for graduates.

These motivations are always tempered by the universities' perception of their mission to educate students and extend and apply knowledge. Communications and publication are essential if this dual mission is to be accomplished. In recent years, universities have increasingly begun to regard research as an additional source of financial support for the university. Despite the differences in university and industry missions, there are common interests such as the production of qualified graduates and development of new ideas and concepts. As a result, it is possible to point to highly productive convergences between universities and industry. The highest degree of convergence between the universities and industry is in high technology research where technology transfer is rapid and requires close proximity between fundamental and product-oriented research. Current examples of such research are microelectronics and molecular biotechnology.

b. How Do Universities And Companies Cooperate With One Another?

Assuming that the parties are sufficiently motivated, their cooperation involves a transfer of resources, people (through cooperative research) and information. Obviously, these are merely categories of convenience and no sharp line can or ought to be drawn between them. For purposes of discussion, however, each mode of transfer—resources, people and information—will be dealt with separately.

Resources. General gifts in support of university research are a highly valued source of income because of their flexibility and because they provide benefits that greatly exceed the dollar percentage of support. Such funds can be used as seed money to start new projects, help young scientists get started, provide for travel to conferences or tide-over funds between contracts and a host of worthy purposes. Despite the benefits, there is a growing awareness on the part of industry that unrestricted gifts or grants-in-aid do not promote interactions between the two partners—university and industry. Increasingly, there is recognition that more interactive modes of support may accomplish similar purposes, and by integrating such funds into a more formal structure, provide a more reliable source of funds and a stable link to industry.

Although equipment gifts, particularly computers and related systems, are sometimes easier for universities to obtain from industry than from government, equipment donation does not currently appear to be an extensive source of support of university research. Recipients often find equipment gifts to be a problem because the equipment donated is unsuited for teaching or research; and maintenance is difficult. Corporate giving occasionally takes other forms than general gifts or equipment donations. Sometimes contributions toward the building of research facilities are made, or in other cases endowment funds are established that may be used as ongoing sources of funds to aid in constructing or operating a research facility or in creating endowed research chairs or professorships.

Cooperative Research. Unlike donations of funds, equipment, research facilities or endowed contributions, cooperative research essentially involves interactions of people and is the area where there is now the most creative movement. Cooperative research is an informal activity where two or more parties plan their research in very general forms and what to do with the outcomes when the program is finished. Money may or may not change hands. This type of interaction should be distinguished from comparatively rare collaborative research which involves close and intensive interaction between university and industry scientists on well defined project activities. Most industrial scientists believe university scientists should not become unduly involved in development. On the other hand, by becoming too involved in basic research the industrial scientist runs the risk of losing sight of practical solutions.

Three principal approaches are found in institutional agreements for cooperative research. The greatest dollar support to universities from industry is through individual investigators using contract research. Another approach that is more sweeping in scope though not necessarily in total funding, is to adopt industrial affiliates or consortial arrangements fostering cooperative university-industry research. In other instances, institutional facilities in the form of research centers attract industry support by providing equipment in a central facility, coordinating research done in a general area or serving as a research focus.

Individual Research Contracts. In the first approach, involving university researchers in individual contractual arrangements, support is usually mission-oriented and specific to a research program or project. Industrial support in this mode is generally for the purpose of fairly immediate benefit.

Although these agreements generate extremely valuable person-to-person interactions, funding is usually for individual projects on a year-by-year basis. They are readily terminated if funding is limited, or return on investment is insufficient or if the industrial project manager is transferred. Also, in applied research and development, universities face strong competition from industry, government laboratories and non-profit research laboratories, and have few comparative advantages in relation to these performers. More fundamentally, problems arise because university and industry research have different objectives, different time frames for obtaining and reporting results, and different policies for publications and patents.

Despite these difficulties, the advantages of close interaction and access to special expertise are so great that a few long-term, high level commitments for support of basic research have been negotiated in return for proprietary advantage. An example of such a commitment is the 1974 agreement between the Monsanto Chemical Company and Harvard University for a ten year, $23 million research program in the biology and biochemistry of organ development. To deal with some of the anticipated obstacles the company and the university created a special advisory board of individuals not connected with either institution to review plans for publication, dissemination of information and use of discoveries made under the program. In particular, the board has the authority to require some licensing of the program's inventions. This program is of particular interest because it illustrates so well the classic development of university-industry linkages through a long standing consulting relationship involving a professor at a university with excellence in the scientific field that a company wanted to enter.

At a significantly lower level of support, interactions at the individual level may take the form of gifts or grants to a professor to pursue research in a general area at the frontiers of a discipline, rather than on a specific topic. Although this type of program is well received, it is clear that resources for such programs are extremely limited and industry cannot, in any way, fulfill the role of government agencies in funding basic science.

Individual investigators may sometimes be a conduit for graduate fellowship support as part of cooperative research. This type of graduate support is not formal, and it is understood that the graduate student will be working on a specific area of research. Engineering and other applied sciences such as forestry and fisheries are fields in which this type of support is most prevalent. Students prefer to draw their term projects from the "real world" rather than working with simulated laboratory exercises. Formal programs for graduate student support not tied to principal investigators are discussed below.

The descriptions of individual cooperative research described so far involve only industry and universities. In recent years however, the Federal Government has been trying to find ways to encourage university-industry cooperative research programs. For example, one of the results of the National Science Foundation (NSF) cooperative research project activity has been to increase participation of academic science faculty in university-industry linkages. The bulk of industrial support of university research goes to engineering research and less than one-third goes to academic science programs in physics, mathematics, and biology. In 1980, about one-half of NSF support for university-industry cooperative research was in academic science.

Not all individually oriented cooperative research is carried out by financial support of one type or another. Sometimes donations and loans of equipment are made in order to get feedback on development and modification of the firm's equipment. Even if the equipment is given for general research, its use may be limited to applied research.

Industrial Affiliate Programs. The second principal approach followed in institutional agreements for cooperative research seeks to broaden participation and, at the same time, create stable industrial support of university research. This approach engages firms through an industrial affiliates program. Emphasis is on individual contacts between the representatives of member companies and the faculty, staff, and students in the program. Access to students is the prime reason why companies join such programs. Most programs of this type host meetings on campus, provide reports and resume listings, and encourage company campus participation. Affiliate members are encouraged to bring technical problems of a non-proprietary nature to the attention of the faculty members and to outline what they believe to be the key problems in advancing the state of the art of their fields. Thus, members may have an influence on future research directions. As this advisory capacity becomes more formalized, to the extent where the member companies form an advisory board, this activity is better characterized as a research consortium.

Research consortia are distinguished from industrial affiliates programs because they are created to address specific missions, and organized to ensure that the mission oriented research will be carried out. The key to the development of successful consortia programs appears to be the development of a leader through the industrial affiliates program. When this occurs, the consortia evolve through the give-and take of personal contacts between the industrial associates members and the university scientists. When faculty initiative is absent, or a mere matching of interest is attempted, consortia attempts are conspicuously less successful. Industrial leaders may provide initiative as well. In the field of chemistry, the Vice President for Corporate Research of the Dow Chemical Company took the lead in convening a conference of heads of engineering and chemistry departments as well as directors of industrial research. Out of this conference and follow-on meetings, a decision was made to form the Council for Chemical Research (CCR). CCR is intended to secure additional industrial funding for university research in chemistry, and the founders of the organization expect technology transfer and new ideas to occur more readily. Coordinated university-industry action is expected to produce more vigorous research programs.

Use of University Facilities. A third approach to university-industry cooperative research involves the use of several types of university facilities. Research centers and institutes are one type and they help attract industry by providing coordinated research and/or equipment in a central facility.

The key is to provide a focus to research either through equipment availability or by research coordination. By far the greatest number of centers or institutes interact with industry through contracted research. Most centers or institutes have a combination of State and Federal Government or industrial and some university support. Those centers closely associated with a department seemed to suit industrial needs of access to students more closely and cause less friction.

Another type of use of universities' facilities is cooperative research centers having associated industrial affiliates programs. This is a relatively new mechanism that seems to be gaining momentum, particularly at private universities. Here again, the most critical factor appeared to be an energetic leader with vision. Sometimes companies assume all funding requirements, but many cooperative research centers have had Government seed money at the outset of the program.

Finally, a rare type of cooperative research involves jointly owned or operated facilities that are unique or especially expensive. New synchrotron light source research facilities at federally supported laboratories have recently attracted considerable numbers of corporate users. Innovative patterns of joint academic-industrial-government use and support are being worked out.

Personnel and Information Exchanges. Forging stronger ties between universities and industries is best accomplished by personal interactions between scientists. Informational contacts, consisting of such activities as consulting, personnel and publication exchanges, seminars, and speaker programs, are the most frequent means by which university-industry research coupling is initiated.

Personnel exchanges are particularly critical in helping to initiate large cooperative university-research programs. The practice is extensively implemented through formal and informal programs that include: visiting professorships, post-doctorals, travel overseas, assignments at universities engaged in high priority research, company seminars by visiting scientists, workshop participation, and lectures by company scientists.

The emerging interest in facilitating personnel exchange is indicated by its incorporation into several new university-industry research programs. Frequently, personnel exchange is accompanied by equipment gifts or loans, and, in a few instances, the exchange depends on availability of unique equipment facilities. Such interaction is particularly feasible when the participants are in close proximity to one another.

Initiation of university-industry research interactions often result from consulting by university faculty. Most academic scientists and administrators are in favor of consulting if it is kept under control. Policies for exerting such controls, however, vary widely from permitting a professor to supplement his income, to acting as a conduit for bringing industrial research projects to a university, or to maintaining communications between the university and industry. To facilitate the accomplishment of these goals several universities have set up liaison programs to assist in generating consulting opportunities for their faculty. In other cases, reference systems have been established with a centralized listing of all research interests and activities of the faculty. This enables industrial firms with a particular problem to determine quickly if the university has people with the required capabilities.

Consulting is more likely to be encouraged at private than at public universities. Business and engineering schools have a much higher level of consulting than science departments. Indeed, engineering schools may view extensive consulting activities as evidence of engineering excellence.

Even in those universities that encourage consulting, problems exist of reconciling faculty status with industrial relationships. Faculty must maintain a balance between their outside consulting activity and their university obligation to teaching and research. Also, use of university facilities, while it attracts industry and fosters collaboration, can bring the university into direct competition with small consulting and laboratory businesses.

Other practices of fostering personal interactions such as participation in advisory boards, seminars, speakers' programs, publication exchange, and adjunct professorships can lead to greater cooperation, but were not identified as being critical. Some formal information programs have been established to supplement the informal and unstructured transfer of knowledge through personnel exchanges. These formal programs may take the form of general industrial associates programs, extension services, and innovation centers designed primarily to assist small businesses.

Increasingly, general industrial associates programs are viewed as not beneficial to university or industry partners because they are too broad and general. As a result, they don't attract attention and commitment, and companies usually receive little that is specific and concrete for their membership fees. Those few schools that have been able to create successful general industrial associate programs have active and energetic liaison representatives to arrange programs and facilitate linking the professor and company.

Extension services are used primarily as a means of bringing technical assistance to small companies or helping industry develop in a rural area. They are a service rather than a mechanism to facilitate cooperative research. However, they do establish a network of industrial contacts and make the universities that participate more sensitive to industrial needs.

Innovation centers cover a broad variety of activities intended to supply support and technical assistance for entrepreneurs to develop their skills to the point where they can start their own company. The great majority of local programs to assist the development of new business and to improve productivity are supported from non-Federal sources. Federal involvement in these centers has been on a limited, experimental basis. The data from the field study* suggest that some centers have demonstrated in the shorter term an ability to generate entrepreneurial ventures, jobs, and tax revenues in excess of program costs. Their longer term contributions to the innovation process remain yet to be assessed.

c. Making University-Industry Interactions Happen

The availability and desire for resources, personnel, and information does not ensure that a flow in either direction will ensue from those who have to those who want. Inertia, uncertainty, institutional sloth, rejection, disincentives of various kinds all take their toll of initiative in university-industry interactions.

Field investigations emphasize that the process of establishing university-industry interactions is not linear; it is circular, iterative, and sometimes discontinuous. It is not a mere mechanical matching of needs and capabilities followed by a definition of objectives and a working plan and schedule. It is, more importantly, an exercise in mutuality where understanding is more important than contracting; where personal contacts outweigh administrative mechanisms; and where ostensible purposes shelter undefined, and even more valuable priorities. In short, the process of exchange in university-industry research cooperation is much like the scientific enterprise itself—and where it is most successful it is most like the community from which it springs.

Clearly, it requires very positive action to make a beneficial university-industry interaction take place. Above all, the first requirement for success is enthusiastic and competent individuals who understand the motivations of the people and institutions involved. These factors determine the viability of university-industry interactions and will now be discussed in detail.

Influence of Individuals. Successful attempts to obtain funding almost always are based on prior personal contacts. An investigator may often consult with a company leading to development of a cooperative research program. But usually the consulting arrangements are started by the company. Major investigators often have a past history of working in the industry. For example, the massive layoffs in the California

*See Appendix

aerospace industry in the late 1960's released a considerable number of engineers and scientists to positions in higher education. Because of the critical importance of personal interactions at the working level, programs rarely succeed if conceived at top levels of university administration. Of course, senior administrators have an important role in formulating, shaping, and ratifying underlying cooperative agreements, but the process of cooperation almost always begins through personal contacts at the working level. Starting in this familiar way is no guarantee of success, however, because the key individual must also have management capabilities as well as excellence in science.

Microelectronics provides two examples that illustrate the point dramatically. Stanford's departments of electrical engineering and computer science cooperate with industry for training and to generate new scientific and technical ideas for Very Large Scale Integration (VLSI) microelectronic circuits. Four Stanford faculty members recognized that a university cannot be isolated from the industry it serves, and universities need the latest tools and equipment to train people for industry. In addition, the faculty members felt that students should learn to handle whole computation, control, and communications systems. Working with industrial friends who were close to the university geographically, intellectually, and socially, a plan was worked out and presented to the Stanford Board of Trustees that led to the Stanford Center for Integrated Systems. In the words of the Director of the Center, "You always run into problems when you want to do something significantly different." Some people viewed any change as a threat to their position, while others feared that closer ties with industry would compromise the university's independence. Similar problems were encountered by members at the California Institute of Technology before the Silicon Systems Project was established to deal with the overwhelming complexity of VLSI circuits and to educate students in all the disciplines needed to design and work with such circuits.

Bridging the Gap. Although the real value of university-industry interactions is realized by individuals, they in turn are based in and work through the structures of their own organizations. Such structures are the abutments on which rest efforts to bridge institutional gaps.

Perhaps the clearer focus of university motivation has prompted creation of more formal structures for industrial research cooperation. Since universities are far fewer and more homogeneous than industrial firms their structures are not as diversified as the private sector. In both public and private universities there is usually a Development Office devoted to generating and administering philanthrophic gifts, and an Office of Sponsored Research (or Grants and Contracts) which receives funds for externally supported research. Usually, in both public and private universities, these are two separate offices under separate administrators who tend to maintain minimal contact.

The Development Office generally receives gifts that are put in trust or endowment accounts of the university, or are applied to the general operating budget of the university. Equipment gifts and loans are administered through the Development Office as well as earmarked funds for designated departmental research, research facilities, endowed chairs, and other purposes. The Office of Sponsored Research or Grants and Contracts is generally responsible for negotiating agreements for all externally sponsored research.

These offices assist faculty in proposal preparation and grant administration. But they are also frequently seen by faculty as representing the central university administration which is taking a large bite out of their awards for overhead or indirect costs. This issue has generated considerable tension between faculty and administration for over two decades.

The diversity of industry organizational structures that interface with universities in cooperative research reflects the variety of industrial objectives. It is possible, however, to distinguish four basic corporate components that may interact with universities, but not necessarily in all cases. In the most general way a corporate foundation or corporate headquarters can provide general financial support for charitable, educational, and cultural purposes. In the area of corporate needs, university relations may be conducted by a central laboratory that normally provides technical support throughout the company for specialized or longer range efforts, or pursues investigations that can be a source of new products and processes. Corporations may also have divisional laboratories to provide direct support for a particular division and its established business interests. At a still lower corporate level there are corporate units which manufacture and distribute the products that make up the business of the corporation. Industrial laboratories, corporate or divisional, are free normally to use their operating funds for any forms of university research cooperation. It is less likely to use such funds for fellowships since other corporate entities such as a foundation can be called on. Since divisional and corporate laboratories are financed in accordance with their separate functions and needs, they establish linkages with universities in light of these separate requirements and opportunities, not usually as a part of a coordinated, corporate-wide master plan for supporting university research.

At the corporate operating unit level, university research may be supported on the basis of either subject matter or "geography", i.e., being a good citizen of the city or region. Subject matter can be a basis for support when a local university is known as a center of excellence in a particular technical area.

Although some of the larger research oriented corporations may have an office for university-industry relationships, it does not take responsibility for the totality of company actions. In fact, the guiding principle is normally to encourage direct interactions between the research personnel within the company and those of the appropriate university, and thus decentralize such arrangements. Consequently, there are usually many linkages proceeding independently throughout the technical structure of a large corporation, the results of which tend to appear within the operating budgets of the individual laboratories or business units.

Interface institutions are not limited to the well established university or industry structures just described. Circumstances may dictate new structures or activities that influence or create new ways for making university-industry cooperation work.

With increased needs for research funds, there has been a push within the university system to generate its own research money. Consequently, there is heightened interest on campuses in technology brokerage and licensing for university developed products and processes.

In general, inventions, innovations, discoveries, and improvements made with the use of university facilities or services, or during the course of regularly assigned duties, are the property of the university. Typically, university patent policies provide the inventor with between 25 and 50 percent of the royalties. If an invention occurs under a sponsored grant or contract, the sponsor's policy terms are controlling, although some universities try to have the sponsor follow the university's patent policy.

Many universities have agreements with patent management organizations (PMOs), but research universities are increasingly developing their own patent management internal capabilities. Although having this capability is expensive, the return on investment is believed to be greater and can have a significant impact on research programs. Companies usually feel comfortable with the university owning a patent arising from a sponsored grant or contract, particularly if the university is willing to provide an exclusive license for a certain time period.

As a means of facilitating patent ownership and commercialization through licensing, some universities have established separately incorporated units to serve as legal entities for administering sponsored research. These entities, referred to as foundations, institutes, or a variety of other names, are able to provide specialized attention to research projects or the organization of multi-disciplinary research teams in ways that are beyond the university's regular academic and administrative capabilities. While a university connected research institute may function like a private contract research institute, it has the advantage of being backed by programs of research and education. This makes such institutes particularly attractive to outside sponsors.

Some other approaches have been tried but have not been generally successful. The industrial park model has been attempted at several major campuses to improve relationships between research intensive companies and sponsoring universities which rent out space for corporate activities. The successful Stanford University Industrial Park (SUIP) has encouraged faculty consulting and entrepreneurship, industrial staff enrollments in university courses, and the use of industrial scientists as university lecturers. Unfortunately, only a few universities have been able to achieve the same success as SUIP, and most industrial parks are generally not significant stimuli to technology transfer. Close proximity and strong university-cooperative research programs characterize some of the more effective industrial park efforts.

Another variant of university-industry cooperation is to be found in the companies that "spin off" from university research programs, or nearby companies. Such companies sometimes have an initial informal association with the university which includes sharing of facilities and hiring of students. With time, however, the companies tend to become more isolated from the university. It is uncertain how many spin off companies have been formed, and there may be an untapped potential for cooperation between these new companies and university research programs.

Unlike some countries such as Germany, the role of U.S. trade associations in fostering university-industry research interactions has been minimal. Technical units, if they exist within a trade association, may deal with testing and standardization of the industry's products and processes. Some testing facilities are located on university campuses and students may get some training in techniques. For those trade associations serving industries with heavy technical requirements, a common practice is to set up a separate foundation or corporation which acts as its research arm. Minor amounts of university research may be supported by such trade association research units.

Despite this past history, recent initiatives in the electronics, semiconductor and chemical industries indicate a new industrial interest in utilizing trade associations to support research and the training of scientists and engineers at universities.

Rather than work through trade associations, a few industries are served by independent R&D institutes which provide a pool of advanced science and technology for companies to draw upon. Institutes such as the Institute of Paper Chemistry and the Textile Research Institute provide the industry with a cooperative research facility dedicated to solutions of industrial problems through basic and applied research of long-term interest, plus developmental projects. Sometimes these industrial institutes provide advanced training for students and serve as a bridge between industry and the university.

In sum, these descriptions of the more common organizational arrangements for carrying out university-industry research cooperation are by no means exhaustive. Within each type of arrangement there is a wide range of emphases and specific provisions dealing with central issues such as the selection of research projects, rights to discoveries, and publication practices. The variety of forms reflects the diversity of functions, purposes and needs of the partners in the relationships.

While the studies of various aspects of university-industry research relationships were intended primarily to provide facts, they also identified issues and problems arising in the course of the relationships. A number of the more important of these were listed in the Introduction, and some are touched on in the Conclusions which follow.

CHAPTER III

FINDINGS AND CONCLUSIONS

1. INTRODUCTION

This Report was conceived as an effort to gather and present data and to assess the growing literature and commentary about university-industry interactions. We did not seek to develop recommendations for specific courses of action, but our investigations did result in some conclusions about general lines of policy development.

Our findings and conclusions are grouped under four themes:

- the evidence delineating the trends and levels of corporate support for academic research.
- the findings concerning major actors—campuses and corporations—their current and historical characteristics, and the dynamics of their research relationships.
- findings and broad comments concerning the role of state and federal governments.
- concluding remarks about the future.

2. CORPORATE SUPPORT OF ACADEMIC RESEARCH

Our review of the evidence led to two major findings about levels and trends of joint activities. First, when both corporate philanthropic and contractual support of academic research are taken into account, the level of corporate support of academic research is significantly higher than has generally been believed. Second, over the past decade there has been a steady upward trend in corporate support of academic research—through both contractual and philanthropic mechanisms. This is perhaps the more remarkable considering the several major downturns in the business climate during this period.

a. Levels of Corporate Support

In most recent public discussions of industry-university relationships a base figure of between 3% and 4% of academic R&D is attributed to industrial sources of support. The evidence obtained in this study is that this significantly underestimates industrial support for academic research and graduate student support. For a more complete picture the following omissions should be added into the data base:

- major research universities not reporting R&D expenditures from industrial sources;
- corporate philanthropy restricted to research through corporate foundations—frequently reported by universities as "foundation and non-profit" sources, or not reported at all;
- gifts and loans of scientific equipment;
- an estimate of the portion of unrestricted corporate gifts of operating and capital funds that is eventually spent on research facilities, equipment, and faculty and student fellowships.

Faculty consulting also represents an important component of industrial support for academic research, but data on the dollar value of consulting are difficult to compile.

The analyses in the Report make a start toward estimating some of these amounts, but the current gaps in the data base limit conclusions to an educated guess. Taking the above-mentioned uncatalogued resources into account, it is not unreasonable to estimate that the current corporate contribution is in the neighborhood of 6%-7% of the total academic R&D. This represented a sum of between $400-$450 million in 1980-81.

b. Trends in Corporate Support of Academic Research

With its excursions into history, this Report has affirmed the importance of university-industry research connections in the United States since the beginnings of the research universities and the corporate research laboratories. There was intense interaction during World War II between academic, corporate, and government scientists and engineers. This was followed in the late 1940's and 1950's by an upswing in corporate interest in basic research which fueled efforts to maintain connections with academic science and access to trained personnel. Available data show that the early 1960's was a period of stagnation in corporate-academic research relations. The 1970's, on the other hand, show small but consistent real increases in industrial support for academic research, with a spurt in plans for and actual research working agreements in the 1980's.

It remains a question whether this spurt represents a permanent jump to a new level of interaction, or whether it is part of a cyclical upswing driven by temporary shortages of research personnel in certain fields, coupled with slower growth rates of Federal research funding and the attempts of universities to obtain new sources of research support. The argument advanced in this Report is that there are sound reasons to believe that we may be at the threshold of a permanent new state of corporate-academic research relationships. This belief will be reinforced if current levels of corporate contracting and philanthropy for academic research are maintained through the 1982 business recession.

Having said this, it remains a fact of life that should corporate contributions to academic research double or even treble they would still support only a small portion of the total academic research effort, and such support would be concentrated in selected fields. All available evidence indicates that private industry has neither the resources nor the intention to compensate for any substantial cuts in publicly funded academic research. The implication is clear: if the present level of academic research is to be maintained, the principal burden will continue to fall upon the public purse, both Federal and State Governments.

3. COMPANIES AND CAMPUSES

a. Current and Historical Characteristics

It is obvious that the main actors in continuing and improving the conditions for academic industry exchange must be the scientists and engineers, administrators, and managers themselves.

The trend data and cases surfaced in this Report show that these exchanges are proceeding apace, and yet academics often assume a lack of sophistication in industrial research, and company people have been known to express a low opinion of the capacity of academics to produce useful and timely research. That the increase in interaction is occurring despite the persistence of negative stereotypes on both sides is testimony to the presence of some healthy realism in both camps. Nevertheless, universities and companies often continue to hold distorted images of each other's concerns and capabilities. These attitudes deserve active reexamination. In addition, efforts to search out each other's needs and capabilities can increase the likelihood of making fruitful connections.

An historical perspective is useful in understanding some of the conditions for university-industry exchanges. A hallmark of the American research system for nearly a century is the relative ease of individual passage between industry and university. Cooperation in research has taken a wide variety of forms which have been pursued as long as they provided benefits to each party.

Periods of intense interaction in certain fields have alternated with periods of mutual neglect. Various university disciplines find themselves industrially relevant at different periods of history as new technologically based industries are born. Chemical engineering was one of the earliest university-based technical professions to establish patterns of relationships between universities and companies that have provided both with benefits, without undermining the integrity of either. Both the aerospace and the electronics booms in the 1950's and 1960's included intense university-industry interactions in research, consulting, exchange of personnel, and "spin-off" companies. Mineral exploration, agronomy and agricultural chemicals, econometric forecasting, and many other fields have evolved in a context of university-industry exchange.

An historical perspective also teaches that in different time periods universities dominate some fundamental research areas, and industry is dominant in others. Molecular biology and biotechnology were long creatures of academic research laboratories, but they are currently being rapidly assimilated into industrial laboratories as their commercial potential unfolds. Research on polymers and catalysis was carried forward for years in industrial laboratories, and universities began to make contributions at a later stage.

Another historical feature of the U.S. research system, which applies both to campuses and to corporations, is the 80-20 rule of thumb, i.e., 80% of the research is performed by 20% of the organizations. Only a few corporations conduct much research of the kinds done in universities. The reasons for research concentration in the corporate sector are complex. For example, whole industries such as textiles and utilities (before the Electric Power Research Institute) have relied heavily upon their suppliers for R&D. Other industries such as non-fuel minerals and mining have relied upon familiar technologies. Whatever the reasons, the fact remains that the vast majority of U.S. businesses have little understanding of how research might relate to their enterprise. However, a number of factors such as higher energy and transportation costs, more stringent standards for pollution and safety and competitive pressures may motivate more companies to evaluate the potential of R&D activities for contribution to their objectives.

While only small proportions of corporations and universities engage in frontier research, most colleges and universities participate in some form of technical cooperation with a wide range of companies—small and large, local and national. About one quarter of all academically employed doctoral scientists and engineers are located in colleges and universities that do not offer doctoral degrees. Their most frequent form of interaction with companies is through the often unnoticed mechanism of consulting. Taken as a whole such cooperative efforts may be a more important part of our technical infrastructure than we have yet discovered.

Research intensive corporations clearly understand the importance of the universities to their well-being. But individual corporations are reluctant to provide significant support for activities that are not in their fairly immediate interests, or of which they cannot be reasonably assured of capturing the benefits. The recent efforts by corporations in several industries collectively to address science and engineering manpower pool problems and the development of long-range research relevant to general industry problems, are promising and worthwhile, but their final outcome remains uncertain.

While diligently pursuing new sources of support for research and teaching, universities are concerned about protecting the freedom of inquiry that is at the heart of their real contribution to society.

A critical issue for the university is how to ensure that the professor's research agenda is enriched and informed by, yet not subordinated to, his contract research or his technical consulting. Among academic biotechnology researchers, who generally have little prior experience with industry, there is currently strong concern and sometimes acrimonious debate about subordinating research and teaching programs to potentially patentable and commercially valuable activities. The issue has had high priority since early 1981 on the agenda of the Advisory Committee to the Director of the National Institutes of Health.

These are proper and legitimate concerns, which deserve continuing attention. It would be instructive to make a closer examination of how faculty scientists and engineers in industrially relevant disciplines have come to terms historically with the delicate issues of academic responsibility and ethics in the context of commercial opportunity. The rapidity of the emergence of commercially relevant genetic-engineering research may pose some special problems, but the fundamental issues are no different.

b. The Dynamics of Research Relationships

A striking finding of the field study of university-industry research relationships published separately from this report is that the initial impulse in the majority of the sampling of university-industry research relationships came from the university. At first glance this would seem a rather one-sided relationship. Yet closer scrutiny reveals that a significant proportion of the academic researchers pursuing these relationships had prior consulting or other employment relationships with companies. If consulting relationships are generally initiated by companies, we have a multi-stage series of relationships: company wants technical/scientific advice (general or specific) and seeks out professor; professor/consultant sees opportunities for research and initiates research relationship; company tracks and (maybe) utilizes the research and makes employment offers to the bright graduate students and postdoctorates working on the project; the cycle is repeated in future years. Another loop in the relationship is traced by corporate philanthropy to departments and individual faculty, which may be initiated by either party.

One of the most frequently stated problems in developing university-industry relationships is the question of "matching" needs to capabilities. Professors want to know where they can go in a company to talk about their research interests; industrial researchers seek professors who can help define or solve their problems. Current matching mechanisms are based primarily on networks of interpersonal relationships. A few research intensive companies support fairly extensive "technology scan" activities in universities which turn up research areas of interest to the company. Professional society meetings and conferences are very important for making contacts, as are numerous one-time topical conferences sponsored by a wide range of organizations. Nevertheless, additional forums focussed upon mutually relevant research and related issues are desirable.

A type of forum which could become highly significant to developing research connections is the emergence of industrial-academic research associations such as the Council for Chemical Research initiated in 1979, and the Semiconductor Research Cooperative now under development. Should organizations such as these turn out to be viable, they would represent historic departures from the reluctance of U.S. corporations to associate with one another in the support of research. The fear of anti-trust violations has been a significant element in this reluctance and efforts currently being made in the Congress and the Commerce and Justice Departments may clarify these issues. These developments may well encourage other industrial sectors to consider such associations. While direct support of academic research is intended to be a key part of these associations, a benefit potentially as great or greater is the opportunity for discussion of mutual problems and the generation of "matching opportunities" in the framework of the associations' activities.

Our focus on research interactions should not obscure the primary interest of industrial research managers in making research connections with universities for manpower acquisition. Recruitment at the leading edge of science and engineering is a highly competitive process, not only between companies, but also between universities themselves. It is broadly recognized that there are currently shortages in both universities and industry of Ph.D. researchers in fields such as computer science, electrical or chemical engineering or plant biochemistry. It is reasonable to suppose that some significant portion of the current upswing in industrial support of academic research is directly related to company manpower concerns. The danger, of course, is that the gap between corporate and academic benefits will become so large that in some fields current faculty members will be tempted to leave the university and new Ph.D.'s will find themselves unable to afford an assistant professorship. This "seed corn" problem, or the threat that an adequate share of the best researchers will not be available to teach the next generation of students, is a significant factor both in a number of individual corporation initiatives, as well as the emergence of new industrial-academic research associations.

Another kind of connection is important too. There is an important potential role for university-industry relationships to improve the participation of minorities in research. A unique pioneering cooperative venture between Government, industry and universities is the effort to build research programs in solid state electronics at Howard University in Washington, D.C., and North Carolina A&T State University in Greensboro, N.C. Joint funding is being supplied by the Rockwell International Corporation Science Center, the National Aeronautics and Space Administration, and the Department of Energy. Cornell University is also participating in this venture by assisting in the development of an associated curriculum for an enriched M.S. program leading to the Ph.D. degree. Another rare example of corporate interest in building science and engineering capabilities in minority institutions is Gulf Oil's recent endowment grant of $500,000 over 5 years to the Hampton Institute to support the development of a department of chemical engineering.

Companies, of course, are active in sponsoring minority fellowships and encouraging minority enrollments in science and engineering. Organizations such as the National Action Council on Minorities in Engineering (NACME) and the National Consortium for Graduate Degrees for Minorities in Engineering (GEM) play leadership roles in helping to focus corporate support for minority students. But there is clearly abundant opportunity for corporations and minority institutions to collaborate in building research programs of mutual benefit.

There are diverse impediments to university-industry research cooperation. As mentioned above, negative stereotypical attitudes exist on both sides. While these do not necessarily prevent the parties from "doing business" when mutual interests coincide, they may, however, slow the seizing of opportunities and unnecessarily protract negotiations over agreements. There are also real limits to joint activity—including limits on available faculty time and limits on available industrial resources. Limitations are also imposed by the university's need to fit most research into pieces which meet the requirements for Ph.D. theses in terms of scheduling, depth, originality and sophistication of the work. Further, patent and license rights, the right to delay publication of manuscripts for review of possible release of proprietary information, and other critical questions frequently cause difficulties in negotiation of agreements and sometimes reach an impasse. Frequently such problems have been resolved when mutually perceived needs have been pursued in an atmosphere of trust and willingness.

The key to the university-industry connection is the effort of enterprising individuals—academic and industrial—pursuing their research interests, or need for technical information, or access to research facilities and potential recruits. Perhaps scientists and engineers are fortunate in the respect that they share a common technical culture. Not infrequently, after the first flush of an exciting technical interaction, they find themselves frustrated in developing a continuing relationship not by the other party but by rigidities within their own organization.

4. GOVERNMENT ROLES

Federal and State governments play a crucial support role in academic research. Without rigorous, high quality academic research, there would be little in the universities to enable them to be one partner of a university-industry research relationship. State and federal research priorities are, of course, reflected in academic research programs—especially those funded by mission agencies. But the most important function of public funding is to provide a base of support which permits the creative researchers themselves to determine the directions of the investigations.

a. State Governments

State governments are a key element in the Nation's research system. Their most essential contribution is to provide a support base for fundamental research through the expectation that professors on state salaries devote a significant portion of their work time to research. This means that teaching assignments in fact reflect this role. States also provide some direct support for university research programs generally related to the states' economies, human services, and natural resources.

This Report has noted an increase in the tempo of state supported research and development activities involving academic and industrial cooperation. North Carolina has provided dynamic leadership in this movement over the past decade, and significant developments are underway in Arizona, California, Colorado, Georgia, Michigan, New York, and other states. It must not be forgotten, however, that these initiatives are driven by concerns for industrial development, expanding employment and spurring technological innovation and productivity. They also involve heightened competition between the states, the future consequences of which are unknown. Scientists and engineers should avoid unrealistic expectations, and recognize that these ventures involve considerable risks, and that not all of them will succeed. There is nevertheless great merit to having those who are "on-site" and closest to the problems carry out the design and implementation (and assume the risk) of these activities.

b. The Federal Government

The Federal government supports the majority of fundamental research in the country, most of it in universities. In this manner it sustains a broad spectrum of science and engineering research based on criteria of excellence. Beyond this contribution to national strength, the role of the Federal government is, and should be, very limited in particular university-industry relationships. A robust and vigorous academic research capability makes the universities attractive to industry. It provides the base on which industry can draw, given mutually agreeable conditions, for relevant research findings, as well as new, young science and engineering talent. The other side of this relationship is the opportunity to infuse academic research with many of the needs and aspirations of society at large, and to improve the flow of knowledge from our research laboratories to implementation. Both our international competitiveness and our national security are thus enhanced. However, as noted in Chapter I, the level of financial contributions to university research from industry will remain relatively modest. The principal benefits of industrial involvement lie not so much in the quantity of the support as in a qualitative leavening and a new dimension added to academic research.

A relatively untapped potential for productive university-industry linkages exists in the Federal mission agencies' R&D programs. For example, throughout its history the National Bureau of Standards has encouraged cooperation and direct collaboration with industry and universities, both as an efficient means of carrying out its mission and as an effective means of getting results put into practice.

The Defense Department conducts some large R&D programs involving significant elements of university-industry cooperation, such as the program on Very High Speed Integrated Circuits (VHSIC) administered by the Defense Advanced Projects Research Agency. Another mechanism was described in Congressional testimony in March 1982 by Richard D. DeLauer, Under Secretary of Defense for Research and Engineering:

> [The Defense Department's] independent research and development (IR&D) program in industry can be the vehicle for accomplishing [strengthened university-industry interactions] by encouraging IR&D work to be contracted out to universities. We are now looking into this matter as a management tool to strengthen research within IR&D, to foster closer cooperation between academia and industry, and to speed transitioning technology out of basic research.

Outside of its mission agencies where it is its own customer, the Federal Government lacks any special wisdom to know what technologies should be selected for the market test. It is therefore, on the whole, not an appropriate Federal role to try on any large scale to "make science do something" related to the marketplace. The science process is open-ended: the technology development process is more focussed. Businesses, on the other hand, survive or fail by making the correct choices.

While some of the small-scale Federal programmatic experiments have shown pathways for fruitful exchange, the recently enacted tax measures have much greater potential for stimulating industry and university connections. As yet, however, their impact remains to be seen. Tax policy remains a fruitful field for further innovation to encourage in-house corporate research investments and contractual and philanthropic research relationships with universities.

Successive administrations have taken steps to revise patent legislation to encourage the translation of research results into useful products and processes by providing a fair return to the inventors and investors involved. It is nevertheless the case that negotiations between corporations and campuses over patent agreements are often difficult to work out. And further, a number of complex questions remain to be resolved, such as the problems involved in the commingling of research support funds and protecting the public interest against non-use of patented inventions. But the ability of potential research partners—academic, industrial, Federal and State Government, and nonprofit institutions—to arrive at negotiated solutions to these issues is impressive.

The proclivity and ability to enter freely into negotiations for mutual advantage is a basic requirement for a pluralistic system. The Government improves this environment by removing impediments to free exchange, as it has, for example, in loosening regulations on patent rights and in the on-going effort to clarify the regulations implementing antitrust laws as they refer to long-term research collaboration between companies. This environment can be further enhanced by continuing to explore ways to foster voluntary exchange including data gathering and analysis, information dissemination, experimental linkage programs, and support for joint research activities and tax incentives. Government can assist in these and other efforts, for example, by convening groups of interested parties to discuss areas in which their joint efforts might be useful.

Recent statements by leaders in the Federal science and technology community express these thoughts. Dr. George A. Keyworth II, the President's Science Adviser, addressed the issue in testimony to the Congress in March 1982, "While the relationships between universities and corporations are voluntary, the Federal Government can play an indirect role in influencing the conditions under which such linkages develop." Also, NSF Director, Dr. John B. Slaughter, said in a recent speech, "We in Government welcome the circumstances that encourage the increased participation of our industrial counterparts. We strongly believe that this closer coupling between the academic research community and industry is bound to be beneficial to both."

In this context, it appears that in the long run the greatest benefits from university-industry research connections may occur through a kind of iterative feedback process. The universities' perceptions of value are influenced, to some degree, by their industrial linkages, and these perceptions may affect their research goals at the project level. These, in turn, may result in shifts in emphasis in their research proposals to federal agencies. While the individual shifts are likely to be subtle and not easy to detect, the cumulative long-term effect may well be to move some academic research closer to areas of strong commercial potential. Conversely, the feedback to companies may well open up new avenues of commercially relevant research. It should be clear, however, only a relatively small proportion of academic researchers will be involved in these processes.

5. ADAPTING TO THE FUTURE

A leading hypothesis of this Report is that the opportunities and problems faced by industry today are different in degree if not in kind from the past. These opportunities and problems increasingly require fundamental research approaches in contrast to empirical work, cut and try, or incremental improvements. Such approaches point to the need for cooperation among researchers, wherever they may be, whose work impinges on a problem or an opportunity. Neither industry nor the university researcher can afford isolation.

Emerging trends in university-industry research interactions indicate a vigorous research enterprise determined by the mutual and evolving interests of the major participants, the universities and industry of the United States. There is an increased magnitude and duration of industry commitment to university programs, and greater efforts at collective industry support of university research. University associated research institutes and centers are being founded or redirected to conduct research programs in cooperation with industry, and there is an expansion of university activity to commercialize results from university research.

Governmental efforts, while necessarily peripheral, are nonetheless important because they provide support for the base of university research capability required for fruitful interactions.

A trend of great potential significance is the increasing collective industrial activity in support of research. While collective action is intended to supplement existing forms of support, it will also inevitably strengthen particular disciplinary areas and universities. In fact, the total level of industry support for the foreseeable future will be such that it will certainly bring about technical change in certain areas.

As the universities seek to expand and strengthen their research capabilities by experimenting with commercialization of university research, serious questions arise about maintaining the integrity and basic values of the university, especially as they relate to the traditional restraint of universities in engaging in competitive commercial activity. Whatever the outcome of this experimentation, the future university approach to research commercialization will set an important boundary condition to cooperation with industry.

It can be seen that the future paths for university-industry cooperation will depend on the way that each university and corporation perceives the essential role of the university. There is considerable opportunity for universities to work more closely with industry in research. If the university moves nearer to a partnership with industry, more resources can become available, but the university may relinquish some of its unique capabilities for unrestricted exploratory research and freedom of action. There are no absolutes, and the issues become matters of degree and common sense. The primary requirement, therefore, is not so much increased partnership, but increased understanding of each other's role. That is the ultimate basis for a healthy strengthening of university and industry cooperation.

NATIONAL SCIENCE BOARD COMMISSIONED STUDIES AND REPORTS ON SELECTED UNIVERSITY-INDUSTRY TOPICS

The reports listed here are available in a separately published National Science Board/National Science Foundation document.

- *Current U.S. University-Industry Research Connections.* Lois Peters and Herbert Fusfeld, with the assistance of Laurence Berlowitz, Harold Kaufman and Eli Pearce. New York University, Center for Science and Technology Policy.
- *State College Science and Engineering Faculty: Collaborative Links with Private Business and Industry.* Frank and Edith Darknell. California State University at Sacramento.
- *University-Industry Connections and Chemical Research: An Historical Perspective.* Arnold Thackray. University of Pennsylvania.
- *University-Industry-State Government Consortia in Microelectronics Research.* William Cromie, Council for the Advancement of Science Writing. With an Introductory Perspective by Eric Bloch, IBM and James Meindl, Stanford University.
- *National Science Foundation Workshop on Intellectual Property Rights in Industry-University Cooperative Research.* National Science Foundation, April 27, 1981.
- *Annotated Bibliography on University-Industry Research Relationships.* National Science Foundation.