Table II-2

Share of Federally Funded Industrial[1] R&D Directed to Basic Research

Fiscal Years 1970 - 78

Fiscal Year	Percent for Basic Research
1970	2.4%
1971	2.2
1972	2.0
1973	2.5
1974	1.6
1975	1.5
1976	1.5
1977(est)	1.6
1978(est)	1.8

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[1] Includes federally funded research & development centers (FFRDC's) administered by this sector.

Source: Federal Funds surveys. NSF
1/25/78

Table II-4: Basic Research in Industry by Source of Funds

(Dollars in millions)

1970 - 1978

	Total Basic R.	Federal	Company	Company as a % of total
1970	$602	$158	$444	74%
1971	581	125	456	79
1972	582	127	455	78
1973	620	129	491	79
1974	688	160	528	77
1975	717	157	560	78
1976	786	172	614	78
1977(est)	835	185	650	78
1978(est)	905	205	700	77
Avge annual rate of change 1970-1978	5.2%	3.3%	5.9%	

Source: National Science Foundation
1/25/78

Table II-6: Basic Research by Performing Sector, 1970 - 78

(Dollars in millions)

	Federal Govt.	Industry	Universities & Colleges	Nonprofit Inst.
1970	$541	$602	$2,065	$305
1971	491	581	2,174	322
1972	538	582	2,272	345
1973	537	620	2,352	357
1974	611	688	2,447	396
1975	682	717	2,713	407
1976	719	786	2,890	439
1977(est)	790	835	3,156	479
1978(est)	850	905	3,580	520

Percent Distribution

	Federal Govt.	Industry	Universities & Colleges	Nonprofit Inst.
1970	15.4%	17.1%	58.8%	8.7%
1971	13.8	16.3	60.9	9.0
1972	14.4	15.6	60.8	9.2
1973	13.9	16.0	60.8	9.2
1974	14.8	16.6	59.1	9.6
1975	15.1	15.9	60.0	9.0
1976	14.9	16.3	59.8	9.1
1977(est)	15.0	15.9	60.0	9.1
1978(est)	14.5	15.5	61.1	8.9

Source: National Science Foundation
1/25/78

Table II-8: Funds for Industrial Basic Research by Field of Science
(Includes Company and Federal Funds)
1971 and 1976

(Dollars in millions)

	1971	% of Total	1976 (Preliminary)	% of Total	Percent Change
Total	$581	100%	$786	100%	35.%
Physical Sciences	281	48	350	45	25
Chemistry	180	31	249	32	38
Other	101	17	101	13	0
Mathematics	14	2	13	2	-7
Environmental Sciences	8	1	15	2	88
Atmospheric Sciences	3	.5%	6	.8%	100.0
Geological Sciences	3	.5%	6	.8%	100.0
Oceanography	2	.3%	3	.4%	50.0
Engineering	159	27	175	22	10
Life Sciences	94	16	134	17	43
Biological Sciences	57	10	101	13	77
Clinical Medical Sciences	37	6	33	4	-11
Other Sciences	24	4	99	13	313

Source: National Science Foundation
1/15/78

Table II-10: Funds for Basic Research by Selected Industry and Source of Funds: 1971 and 1976

(Dollars in Millions)

	1971				1976 (Preliminary)			
	Federal	% Total	Company	% Total	Federal	% Total	Company	% Total
Total	$125	100%	$456	100%	$172	100%	$614	100%
Chemicals & Allied Products	30	24%	186	41	63	37	259	42
Electrical Equipment & Communication	35	28%	108	24	21	12	127	21
Aircraft & Missiles	17	14	36	8	20	12	32	5
Nonmanufacturing	24	19	7	2	15	9	14	2
All other industries	19	15	119	26	53	31	182	30

Source: National Science Foundation
1/25/78

Scientists and Engineers Population and Funding

Comparison of certain of the data on the population of scientists and engineers working in basic research and employed by industry with the data on funding patterns for basic research support in industry shows the following:

Rank Ordered by Percent of Total, By Field

Doctoral S&E's in Basic Research in Industry by Field of Science	
Total	100%
Physical scientists	58.4%
Life scientists	15.5%
Engineers	14.4%
Environmental scientists	4.4%
Psychologists	2.2%
Math & Stat.-scientists	2.0%
Computer scientists	1.7%
Social scientists	1.4%

Funds for Industrial Basic Research by Field of Science, 1976	
Total	100%
Physical sciences	45%
Engineering	22%
Life sciences	17%
Other sciences	13%
Environmental sciences	2%
Mathematics	2%

In both lists physical science, life science, and engineering are the top three in proportions of people and funding and in each list they include well over 80% of the totals. These not surprising parallels suggest a high likelihood of both interests and capabilities from the industrial basic research sector in these three fields if opportunities for funding relatively unstructured basic research were available. The dominance of these three fields should not suggest a lack of capabilities or interest in industry in other fields of science that have smaller resources. In the nature of basic research, it would be fallacious to assume that size or quantity are necessarily dependable indicators of ingenuity or creativity. The good record in technological innovation of small firms compared to larger firms illustrates this point.

Experience in other agencies, summarized in Part IV of this report, does not suggest the likelihood of extremely heavy proposal pressure or interest from private firms as measured by sheer volume of proposals when support is equally accessible to all proposers. Yet NSF has encountered very keen interest by a small business r and d sector that appears relatively limited in number but whose actual dimensions currently are not known in any systematic way.

NSF Proposal Pressure from Industry and Awards to Industry

The flow of proposals for research support from private firms to NSF programs is affected significantly by the views of the science community on the likelihood of proposal approval. This is true both for NSF directorates, and for individual fields of science or program areas within directorates. The observation is based on several dozen conversations with representatives of private firms coming to the Office of Small Business R&D for information and guidance, and the observation is confirmed to some degree by NSF data.

NSF's basic research supporting directorates adhere to the policy that awards to private industrial firms are made only under special criteria that are additional to the criteria of scientific merit applicable to all proposals. This is discussed in more detail in a later section.

The Directorate for Scientific, Technological and International Affairs and the Directorate for Science Education issue a number of program announcements each year. These announcements indicate who is eligible to apply for support. In a number of areas such as program evaluation, policy research and analysis, data processing and analysis, and program design and recommendations, commercial firms are eligible to submit proposals.

The Directorate for Research Applications (now succeeded by the Directorate for Applied Science and Research Applications), has from its establishment funded proposals from industrial concerns, including small business. Beginning in fiscal year 1976, the Congress directed a special emphasis toward the support of proposals from small firms capable of quality research and development.

NSF DIRECTORATES, EXCLUDING RESEARCH APPLICATIONS

In total, NSF directorates and offices (excluding RA) received 137 proposals from private firms for grant and contract support in fiscal year 1977. Seventy-nine such awards were made to private firms, 35 of them to small businesses.

The highest number, as well as proportion of FY 1977 total directorate obligations to commercial firms, is in the Directorate for Scientific, Technological and International Affairs. This is true also for awards to small business firms. Awards to private firms by STIA divisions support such work as policy studies and analyses and provision of assistance for international travel arrangements. The STIA small business awards range from processing of survey data for the Division of Science Resources Studies to research primarily by software firms on use of scientific information for the Division of Science Information.

Science Education awards to business firms supported such work as program evaluation, experimental science programs for television, and data processing.

RESOLUTION ON BASIC RESEARCH IN INDUSTRY
APPROVED BY THE NATIONAL SCIENCE BOARD
AT ITS 195th MEETING ON JANUARY 19-20, 1978

The National Science Board unanimously DECIDED that the Foundation's policy on the support of basic research by private profit organizations should be modified as indicated by the following language, which should be substantially reflected in National Science Foundation policy documents:

> The National Science Foundation welcomes unsolicited proposals from commercial firms. But it also wants to avoid substituting Federal support for normal commercial investment in research or compromising the vitality of research in educational institutions, where research makes a special added contribution to science education. Thus, unsolicited proposals for scientific research project support from commercial firms may be funded where: (a) the project is of special concern from a national point of view; (b) special resources are available in industry for the work; or (c) the project proposed is especially meritorious.
>
> The National Science Foundation is also particularly interested in supporting research projects that couple the research resources and perspectives of industry with the research resources and perspectives of universities. It therefore especially welcomes proposals for cooperative research projects involving both universities and industry.

General RA Program Area	No. Proposals from Industry	
Productivity	171	(134)
Environment	134	(94)
Resources	92	(87)
Technology Assessment	25	(14)

In fiscal year 1976, 247 proposals were received by RA from private firms, compared to the total of 431 in FY 1977. The FY 77 solicitation appeared to stimulate a substantial increase in proposals. Strong interest in the solicitation led to 8000 requests for the announcement in addition to 4000 in the initial mailing.

In the FY 1977 proposals from industry, some relatively small number of the proposals submitted in response to the solicitation would have been submitted without it, according to comments received at the Office of Small Business R&D. There were several advantages to submitting a proposal in response to the solicitation: the prospect of qualifying for Phase II support; no cost-sharing requirement and a fee allowed since the proposals were solicited; winning such an NSF competition could be commercially prestigious and advantageous to a firm; the tie-in to venture capital; and patent rights.

Table III-2

FY 77--Proposals Received by NSF from Industry--By Directorate--& Amount Requested

Directorate	No.	Amount
Mathematical, Physical & Engineering Sciences	22	$ 2,481,701
Scientific, Technological & International Affairs	45	4,975,938
Astronomical, Atmospheric, Earth & Ocean Sciences	29	9,865,225
Research Applications	431	23,829,799
Biological & Behavioral & Social Sciences	11	1,524,600
Science Education	17	2,256,902
Administration	5	634,445
Office of Planning & Resources Management	7	311,563
Office of Government & Public Programs	1	5,000
TOTAL:	568	$45,885,173

Directorate/Field	No.	Amount
Research Applications		
Resources	91	$ 3,235,800
Environment	134	11,871,300
Productivity	170	7,197,827
Communications	2	265,400
Industrial	8	142,819
Technology Assessment	25	1,115,675
Other	1	978
TOTAL:	431	$23,829,799
Science Education		
Science & Society	5	997,430
Science Education Development	11	1,248,984
Science Education Research	1	10,488
TOTAL:	17	2,256,902
Planning & Resources Management		
Other Studies	7	311,563
Administration		
Training	2	43,350
Data Processing & Equipment Rentals	3	591,095
TOTAL:	5	634,445
Government & Public Programs		
Audio-Visual	1	5,000

Table III-5

FY 1977 AWARDS TO INDUSTRY BY DIRECTORATE AND FIELD OF SCIENCE OR PROGRAM AREA WITHIN DIRECTORATE[1/]

Directorate/Field/Program Area	No.	Amount
Mathematical & Physical Sciences & Engineering		
Mathematical Sciences	1	3,000
Engineering	4	231,300
Materials Research	5	399,500
Chemistry	1	60,000
Other	1	24,535
TOTAL:	12	$718,335
Scientific, Technological & International Affairs		
Policy Research & Analysis	5	217,847
International Science	2	524,915
Science Information	8	694,979
Science Resources Studies	6	534,269
TOTAL:	21	$1,972,010
Astronomical, Atmospheric, Earth & Ocean Sciences		
Atmospheric Sciences	9	694,000
Polar Programs	10	7,443,372[2/]
TOTAL	19	$8,137,372
Biological, Behavioral & Neural Sciences		
Biological Sciences	4	245,356
Social Sciences	2	95,200
TOTAL:	6	$340,556
Research Applications		
Technology Assessment	10	781,935
Environment	25	3,664,079
Productivity	43	2,713,752
Industrial	6	385,578
Resources	13	1,179,637
Exploratory Research	2	138,115
Communications	8	468,887
Research Evaluation	2	120,607
RA Other	1	261,480
TOTAL:	110	$9,714,070

Table III-6

FY 1977 GRANT AND CONTRACT AWARDS[1]

TO SMALL BUSINESS[2]

Directorate	No. Awards	Amount	% of FY 77 Obligations	FY 77 Obligations
Mathematical & Physical Sciences & Engineering	5	258,635	.11	224.4
Scientific, Technological & International Affairs	16	1,754,163	9.0	19.4[3]
Astronomical, Atmospheric, Earth & Ocean Sciences	3	209,800	.09	233.5[4]
Research Applications	95	7,594,435	11.9	63.7[3]
Science Education	5	555,594	.94	59.0[5]
Biological, Behavioral & Social Sciences	1	82,700	.07	126.6
Planning & Resources Management	3	125,664		
Office of Government & Public Programs	2	28,055		
TOTAL:	130	$10,609,046	1.46	$ 726.6[6]

[1] Appendix C is an itemized list of NSF Awards to Small Business

[2] Excludes purchase orders

[3] These figures shown without $1.3 million transfer from RA to STIA for technology assessment as shown for FY 77 for consistency in the FY 1979 Budget request.

[4] Includes U.S. Antarctic Program.

[5] Science Education total obligations less Fellowships and Traineeships ($15.3m).

[6] FY 1977 Total NSF obligations ($791.8) less Special Foreign Currency ($4.4m), PD&M ($45.5m), and Fellowships and Traineeships ($15.3m).

Support of Basic Research in Industry by Five Other Federal Agencies

We inquired of five other science-supporting agencies about their experiences with proposal pressure and the likely subject areas of research contributions from industrial performers of basic research. Discussions were held with staff of the Office of Naval Research, Department of Energy, National Institutes of Health, National Aeronautics and Space Administration, and the Air Force Office of Scientific Research. Findings are summarized below:

DEPARTMENT OF ENERGY

The department's policies do not favor one sector of basic research performers over others. In practice, the preponderance of basic research award funds go to universities or to federally funded research and development centers (FFRDC's) administered by universities.

Proposal interest or pressure from industry is at a fairly low level, is about 5% or less of total, and is fairly constant. Awards to industry amount to about 2 to 4% of the total number of awards. These figures exclude FFRDC's.

About $90 million in basic research awards to universities is estimated for FY 1978; slightly over $1 million is estimated for basic research awards to industry.

At DoE the fields of basic science in which research is supported are heavily dominated by physical sciences, involving probably 80% or so of total dollars. Research support is primarily in the fields of nuclear physics, chemical sciences, high energy physics, metallurgy and materials sciences.

The agency has been so recently organized in its present form that some aspects of its experience must be drawn from its predecessor agencies, the Atomic Energy Commission and the Energy Research and Development Agency. The new Department of Energy has been taking initiatives to increase the participation of small business in its programs.

OFFICE OF NAVAL RESEARCH

Research support to outside performers is almost entirely through contracts. The basic research contracts tend to go to universities as a consequence of both industry interest and ONR's assessment of the capabilities of the proposers seeking basic research support for individual projects. About 15% of the dollars for "Defense Research Sciences" (that include some funds for applied research, though most are for basic) go to industry, 71% to universities, 3% to nonprofits (FY 1977 data). These proportions have been relatively stable in recent years. In FY 77, 19.4% went for energy conversion, 16.4% for materials, 10.9% for mechanics, 10.8% for math sciences, 8.9% for general physics, 7.1% for terrestrial, 7% for behavioral/social science, and 6.1% for oceanography.

Most basic research is carried out inhouse or by NASA's own personnel (about 45 - 50% of total). Industry represents the second major performing sector accounting for about 30 percent of the total in FY 1978. Universities and FFRDC's administered by universities accounted for almost all of the remaining NASA performance. In 1978, about two-thirds of NASA's basic research is in the physical sciences (astronomy and physics), one-fifth in the environmental sciences and one-tenth in engineering.

In space science the research interests of the NASA centers vary and they have much autonomy in choice of research performers. In the life sciences, it is a pattern that research tending toward general theory or research in biomedical areas is performed mostly at universities; research that is more technology oriented is more likely to be carried out by industrial performers.

NASA accepts unsolicited proposals for basic research but staff report that relatively few are received from industry. Most unsolicited proposals received come from universities. Those from industry are more likely to result from a program announcement. Requests for proposals stimulate proposals from both universities and industry; in the basic research areas, industry submits relatively few proposals. The more technological the area the more likely industry is to propose and the more likely such proposals are to be funded on competitive merit.

In engineering basic research, approximately 15% is reported as performed by industry; in biomedical involving mainly biology and medicine around 5%, but for the bioengineering and technology aspects 70 to 75% of the basic research is performed by industry; in space and terrestrial sciences, there is great variation by field. In magnetospheric research and astronomy, most extramurally performed basic research is done by universities. In remote sensing, industry interest and participation increases though the activity is described as mostly government. In the materials science area there is currently a growing interest in such areas as alloys of different purities, vacuum molding and casting, and composite materials. In such areas it is probable that there is good research capability in industry. The space and terrestrial sciences areas, as in the others, seem to involve industry more at the high technology end; for example, when expensive instrumentation is needed, large industries such as Bell Labs, and TRW may be the only ones with such capabilities.

Small businesses were said to be involved mainly in the support services area, except in the advanced technology aspects of the life sciences area. There the research capabilities of high technology small firms were mentioned specifically.

Most of NASA's support of basic research in industry appears to be supported through contracts rather than grants. As with NSF, NASA is required by appropriations legislation to require cost-sharing by grantees or contractors when such awards result from unsolicited proposals. This can be a problem for some small business firms.

Publication of basic research findings in the open literature is encouraged and in many cases is regarded by AFOSR as the appropriate way to report on the research to AFOSR; the policy appears very similar to that of NSF.

Cost-sharing is encouraged by AFOSR but is not required.

CONCLUSIONS

Industry participation in basic research programs of the five agencies varied substantially. Industry participation seemed to occur more often in those programs most clearly defined by mission areas and at the technology end of the spectrum; at the theoretical or abstract research end there seemed less industry interest and participation.

The missions of the agencies, the titles of their program areas and agencies' use of requests for proposals all serve to focus more identifiable research targets. This seems to facilitate industrial participation through submission of proposals or expressions of interest that link their skills and interests to problems for research.

The effects that flow from the known characteristics of agency missions and program areas tends to structure the basic research environment toward greater specificity than is the case with the National Science Foundation in most of its basic research areas.

FY 77--Proposals Recvd. by NSF from Industry--by NSF Program Element

MPE	No.	Amount
Other Math Sciences	1	$ 3,000
Atomic & Molecular Physics	1	95,800
Nuclear Physics	1	116,700
Engineering-Fluid Mechanics	2	708,200
" Devices & Waves	1	59,000
Solid State Physics	1	2,000
Metallurgy	3	237,500
Ceramics	3	511,900
DMR	1	175,200
Chemical Analysis	3	508,800
Software Engineering	1	50,000
International Travel	3	3,066
MPE	1	10,535
TOTAL:	22	$2,481,701

STI		
Policy Research & Analysis	8	701,039
Cooperative Science Program	2	1,500,000
Cooperative Science Program (Japan)	1	21,500
Cooperative Science Program (U.S.S.R.)	1	27,100
Scientific Organization & Resources Prog.	2	75,000
Economics of Information	3	197,900
Access Improvement	8	805,938
User Requirement	13	1,158,848
Studies of Science Resources	7	488,613
TOTAL:	45	$4,975,938

AEO		
Galactic & Extragalactic Astronomy	2	324,700
Astronomical Instrumen. & Development	3	74,000
Aeronomy	2	255,300
Meteorology (Atmospheric)	1	150,000
Solar-Terrestrial	3	397,000
Solar-Terrestrial Physics	2	64,701
Research Ship Support	5	1,862,447
Contract Support (DPP)	4	5,467,177
Oceanography	2	103,400
Meteorology (DPP)	1	181,500
Environmental Forecasting	1	40,700
Climate Dynamics	3	944,300
TOTAL:	29	$9,865,225

DSE	No.	Amount
Public Understanding of Science	1	$ 500,500
Alternatives in Higher Education	5	778,320
Continuing Education	1	15,132
Special Studies & Experimental Projects	1	117,245
Research in Education	5	486,037
Systems Approach	1	10,488
Ethical & Human Value Implications	4	496,930
TOTAL:	18	$2,404,652

ADA		
Equipment Rentals	2	581,095
Training Contracts	2	43,350
Data Processing Contracts	1	10,000
TOTAL:	5	$ 634,445

O/D		
OPRM--Other Studies	7	311,563
OGPP--Feature Film	1	5,000
TOTAL:	8	$ 316,563

FY 77 AWARDS TO INDUSTRY--BY NSF PROGRAM ELEMENT

RA	No.	Amount
Technology Assessment	10	$ 781,935
Environment	25	3,664,079
Productivity	43	2,713,752
Industrial Program	6	385,578
Resources	13	1,179,637
Communications	8	468,887
Exploratory Research	2	138,115
Research Evaluation	2	120,607
RA-Other	1	261,480
TOTAL:	110*	9,714,070*
SE		
Public Understanding of Science	1	203,100
Continuing Education	1	15,132
Special Studies & Experimental Proj.	1	124,854
Systems Approach	2	19,890
Technological Innovations in Educ.	2	344,662
TOTAL:	7*	707,638*
AD/A		
Training	1	17,100
Data Processing/Equipment	5	1,098,644
	6	1,115,744
OPRM		
Evaluations/Studies	6*	295,999*
OGPP		
Films/Other	2	28,055

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* Totals do not include Purchase Orders

MATHEMATICAL AND PHYSICAL SCIENCES, AND ENGINEERING DIRECTORATE

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
8/77	Institute for Scientific Information Philadelphia, Pa.	Data Extraction from the Science Citation Index	7722736	MPE	$ 24,535
2/77	Aerochem Research Labs Princeton, N.J.	Studies of the Thermodynamics of Coal Impurity Combustion Products	7615609	Engineering	$ 27,700
6/77	Manlabs Inc. Cambridge, Ma.	Calculation of Ternary Phase Diagrams by Computer Methods	7713861	Materials Research	$ 75,300
9/77	Manlabs Inc. Cambridge, Ma.	Evaluation of Advanced Cutting Tool Systems	7715577	Materials Research	$ 64,600
4/77	Bend Research Bend, Ore.	Fundamentals of Membrane Permeation	7617291	Engineering	$ 66,500

SCIENTIFIC, TECHNOLOGICAL, AND INTERNATIONAL AFFAIRS DIRECTORATE

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
9/77	Capital Systems Group Inc. Rockville, Md.	Research on the Use of Scientific and Technical Information and Its Impact on the Effectiveness of Scientists and Engineers	7718073	Science	$ 86,369
4/77	Moshman Associates Inc. Washington, D.C.	Data Processing and Other Related Services in Support of the Survey of Federal Funds for Research, Development, and Other Scientific Activities, Vol. XXVI	7715164	Science Resources	$ 33,274
12/76	Moshman Associates Inc. Washington, D.C.	Data Processing of Three University Survey Systems, FY 1977	7684638	Science Resources	$ 92,426
9/77	Computer Horizons Inc. Cherry Hill, N.J.	Codification, Explanation and Documentation of International Indicators Work	7722770	Science Resources	$ 30,559
9/77	Moshman Associates Inc. Washington, D.C.	Analysis of Distribution of Federal Funds for Research and Development	7720867	Science Resources	$ 28,900
9/77	Moshman Associates Inc. Washington, D.C.	Survey of Graduate Science Student Support and Postdoctorals, Fall 1977	7724140	Science Resources	$151,910
9/77	Westat Inc. Rockville, Md.	New Entrants Surveys of Recent College Graduates (1972 and 1974 Classes) In Science and Engineering	7727560	Science Resources	$197,200
9/77	King Research, Inc. Rockville, Md.	An In-Depth Study of the Interactions Between Scientists & the Publishing of Scientific Journals	7717943	Science In-	$ 49,800

RESEARCH APPLICATIONS DIRECTORATE

FY 1977 SMALL BUSINESS AWARDS

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
7/77	Cambridge Systematics, Inc. Cambridge, MA	Personal Transportation Modes: An Assessment of Use, Choice, and Future Preferences	77-16108	Tech. Assess.	$243,072
8/77	Gellman Research Associates Jenkintown, PA	Large Air Transport Technology Assessment	76-80328	Tech. Assess.	48,860
6/77	International Research and Technology Corporation Washington, D.C.	Materials Process - Product Model	71-01663 A06	Tech. Assess.	4,275
7/77	Kalba Bowen Associates, Inc. Cambridge, MA	A Framework for Analysis of Technologically-Induced Social Effects	76-24067	Tech. Assess.	136,400
12/76	Scientific Analysis Corp. San Francisco, CA	Evaluation Systems for Technology Assessments: A Planning Study	76-82745	Tech. Assess.	29,700
7/77	Scientific Analysis Corp. San Francisco, CA	Institutional Variables that Impact the Performance and Use of Technology Assessment Studies	77-15503	Tech. Assess.	153,100
6/77	The Futures Group Glastonbury, CT	Technology Assessment of Life Extending Technologies	75-10708 A02	Tech. Assess.	16,728
6/77	J. H. Wiggins Co. Redondo Beach, CA	Risk to Structures from Natural Hazards: A Technology Assessment	75-09998 A01	Tech. Assess.	30,000
9/77	Aerochem Research Laboratories, Inc. Princeton, NJ	Aerosol Characterization in Real Time	77-11252	Environment	113,800

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
9/77	Meteorology Research, Inc. Altadena, CA	Application of Computer Graphics to Air Quality Data Analysis	77-12487	Environment	133,100
9/77	North American Weather Consultants Goleta, CA	Workshop on Extended Area Effects of Weather Modification	77-15028	Environment	30,800
3/77	Panametrics, Inc. Waltham, MA	The Role of Solar Ultraviolet Radiation in the Formation of Hydroxyl Radicals in the Troposphere	76-23902	Environment	37,200
9/77	Perceptronics, Inc. Eugene, OR	Identifying, Evaluating, and Managing Environmental Risks - Part II	77-15332	Environment	208,300
9/77	William Spangle & Associates Portola Valley, CA	Post-Earthquake Land Use Planning	76-82756	Environment	213,200
9/77	Sterling Hobe Corporation Washington, D.C.	Development and Testing of Risk-Benefit-Cost Analysis for Policy Formulation	77-15501	Environment	154,000
9/77	Teknekron, Inc. Berkeley, CA	An Analysis of Urban Drought: A Case Study of the San Francisco Bay Area	77-16283	Environment	341,200
2/77	Weidlinger Associates New York, NY	Underground Lifelines in a Seismic Environment	76-09838 A01	Environment	42,170
5/77	Westgate Research Corp. Los Angeles, CA	An Investigation into the Chemistry of the UV-Ozone Water Purification Process	76-24652	Environment	93,600
9/77	J. H. Wiggins, Co. Redondo Beach, CA	Cost-Benefit Risk Analysis of Research Budgeted for Hazard Mitigation	77-08435	Environment	40,900
5/77	William & Works, Inc. Grand Rapids, MI	Use of Wetlands for Management of Pond-Stabilized Domestic Wastewater	76-20812 A01	Environment	6,400

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
9/77	Harmony Blue Granite Co. Elberton, GA	Studies of Improved Granite Cutting Techniques	77-03288	Productivity	60,800
8/77	Holosonics, Inc. Richland, WA	Scanned Acoustical Holography for Geologic Prediction	77-20075	Productivity	131,600
9/77	Holosonics, Inc. Richland, WA	Scanned Acoustical Holography for Geologic Prediction	77-20075 A01	Productivity	107,353
12/76	Holosonics, Inc. Richland, WA	Scanned Acoustical Holography for Geologic Prediction	73-03200 A03	Productivity	49,900
9/77	Holosonics, Inc. Richland, WA	Scanned Acoustical Holography for Geologic Prediction	73-03200 A04	Productivity	51,617
9/77	IRT Corporation San Diego, CA	In Vitro Detection of Allergy Using Human Head Hair	*77-19721	Productivity	24,646
3/77	Innocept, Inc. Dallas, TX	Federal Assistance Delivery System Productivity - Small Business	76-20856 A01	Productivity	55,900
9/77	Integrated Sciences Corp. Santa Monica, CA	Visual Feedback Speech Training System for the Deaf	*77-19883	Productivity	24,474
9/77	International Diagnostic Technology Santa Clara, CA	Improved Methods for the Rapid Detection of Microbial Contaminants	*77-19701	Productivity	25,000
9/77	Kellogg Corporation Littleton, CO	Resource Allocation System for Construction Industry Managers	*77-19782	Productivity	24,953
8/77	Koba Associates, Inc. Washington, D.C.	Condition Forecast: Economic Welfare Among Retirement Aged Blacks in the Year 2000	76-83410	Productivity	173,200

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
9/77	Stearns, Conrad, & Schmidt Consulting Engineers Long Beach, CA	Decision-Related Research on Technology Utilized by Local Government: Refuse Collection, Phase II	77-17354	Productivity	221,119
8/77	Technical Assistance Research Programs, Inc. Washington, D.C.	Identification of the Nature and Frequency of the Product/Service Problems of the Consumer	76-84200	Productivity	50,300
9/77	Terraspace, Inc. Rockville, MD	Hydraulic Bursting of Concrete and Rock	*77-19804	Productivity	22,012
9/77	Terra Tek, Inc. Salt Lake City, UT	Hydro-Mechanical Sensing of Deep Hole Drilling Deviations	*77-19526	Productivity	24,970
9/77	Terra Tek, Inc. Salt Lake City, UT	Research on the Simplification of Methods for Measuring Fracture Toughness	*77-19461	Productivity	24,993
12/76	The Futures Group Glastonbury, CT	A Study of the Consequences and Policy Implications of Increased Unionization of Court Personnel	76-84021	Productivity	160,900
12/76	Workers' Disability Income Systems, Inc. Washington, D.C.	An Evaluation of State Level Human Resource Delivery Programs: Disability Compensation Programs	75-01067 A03	Productivity	23,200
5/77	Manalytics, Inc. San Francisco, CA	Study of Government-Industry Cost-Sharing as an Incentive to Technological Innovation	74-18714 A04	Indus. Prog.	4,720
8/77	Mar-Jac Corporation Gainesville, GA	Studying the Feasibility of Automated Handling and Transfer Techniques for the Poultry Processing Industry	77-09749	Indus. Prog.	49,900

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
9/77	Experienced Resource Group, Inc. Baton Rouge, LA	Alternative Food Delivery Systems - An Exploratory Assessment	77-07184 A01	Resources	7,700
6/77	Capital Systems Group Rockville, MD	Support Operations for the RANN Technical Information Program	75-22472 A05	Communications	260,377
11/76	Courtesy Travel Washington, D.C.	Travel Support for RANN Symposium Speakers	77-01320	Communications	40,000
5/77	Courtesy Travel Washington, D.C.	BiLateral Research Coordination Meetings	77-01320 A01	Communications	1,500
	ck Young Productions York, NY	Preparation of Treatment/Concepts for Four RANN Films	77-04862	Communications	5,000
	pa Systems lington, VA	RFP 76-120 - Provide Expert and Technical Advice and Services for the Production and Staging of a RANN Symposium	76-23498	Communications	38,600
1/77	Media Four Productions Hollywood, CA	Preparation of Treatment/Concepts for Four RANN Films	77-04861	Communications	5,000
8/77	Media Four Productions Hollywood, CA	RFP 7F-102: Production of Four RANN Films	77-17353	Communications	113,410
1/77	Vision Associates New York, NY	Preparation of Treatment/Concepts for Four RANN Films	77-04863	Communications	5,000
7/77	Design Alternatives, Inc. Washington, D.C.	Workshop to Identify Appropriate Technological Responses to Resource, Environmental, and Social Challenges to the Economy	77-21824	Exploratory Research	84,515

ATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
5/77	Impact Assessment Institute Bethesda, MD	Revised Bibliography of NSF Technology Assessment Projects	RN-2556 7SP0806	Tech. Assess.	8,700
5/77	Information Transfer Rockville, MD	Proceedings of Conference on Sludge Management	RN-77026 7SP6756	Environment	6,250
5/77	International Planning Management Bethesda, MD	Problems of New Business Ventures Utilizing High Technology	RN-71217 7SP0795	Indus. Prog.	9,707
4/77	Kappa Systems, Inc. Arlington, VA	RANN II Exhibit	RN-2401 7SP0740	Communications	5,882
1/77	Underwater Systems, Inc. Silver Spring, MD	Statistical Analysis of Data Collected on the Evaluation of RANN Proposals	RN-0745 7SP0453	Research Evaluation	7,500
3/77	Woodward-Clyde Consultants San Francisco, CA	Implementation Measures to Reduce Earthquake Hazards of Dams	RN-6182 7SP1044	Environment	1,000
3/77	Harold Wise, Planning Consultant Washington, D.C.	Information on Federal Programs with Maximum Impact on State Policy Formulation	RN-6961 7SP0970	Intergovernmental Science	9,959
				Subtotal:	$ 7,669,242
Awards made with funds carried forward from Transition Quarter:					
11/77	Forecasting International Arlington, VA	Development of a Methodology to Forecast Events Affecting Productivity	75-16374 A02	Productivity	12,900
3/77	Bernard Wolnak & Assoc. Chicago, IL	Workshop on Enzyme Economics	76-10166	Resources	12,000
					7,694,142

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* Awarded under Program Solicitation 77-12 - Small Business Innovation Applied to National Needs

BIOLOGICAL, BEHAVIORAL, AND SOCIAL SCIENCES DIRECTORATE

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
8/77	Institute for Scientific Information Philadelphia, Pa.	A Citation Index for Physics: 1920 to 1930	7714957	Social Science	$82,700

OFFICE OF GOVERNMENT AND PUBLIC PROGRAMS

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
2/77	Dick Young Productions New York, N.Y.	Treatment/Concept of NSF Film	7708839		$ 5,000
11/76	Executive VideoForum Inc. New York, N.Y.	Content Analysis of Videotape from Project: Knowledge 2000	7684534	Community Affairs	$23,055

Table 5-9. Distribution of doctoral scientists and engineers by field, 1973 and 1975

Field	Number		Percent	
	1973	1975	1973	1975
Total	244,921	277,517	100	100
Physical scientists	53,425	59,267	22	21
Chemists	33,881	38,784	14	14
Physicists and astronomers	19,544	20,483	8	7
Mathematical scientists and computer specialists	16,458	18,204	7	7
Mathematicians	11,984	12,729	5	5
Statisticians	1,531	1,813	1	1
Computer specialists	2,943	3,662	1	1
Life scientists	64,540	72,316	26	26
Biological scientists	41,035	43,754	17	16
Medical scientists	11,612	14,285	5	5
Agricultural scientists	11,893	14,277	5	5
Environmental scientists	11,074	12,783	5	5
Earth scientists	9,142	10,076	4	4
Oceanographers	1,227	1,353	1	(1)
Atmospheric scientists	705	1,353	(1)	(1)
Engineers	37,569	44,425	15	16
Psychologists	28,288	31,613	12	11
Social scientists	32,773	38,251	13	14
Economists	9,678	11,049	4	4
Sociologists and anthropologists	7,455	8,775	3	3
Other social scientists	15,640	18,427	6	7
Field not reported	796	658	(1)	(1)

[1] Less than 0.5 percent.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States, 1975* (NSF 77-309), p. viii.

See Table 5-16 in text.

Table 5-15. Doctoral R&D scientists and engineers[1]
by field and type of employer, 1975

Field	Total	Business and industry	Four-year colleges and universities	Government	Other employers
			Number		
All fields[2]	113,796	45,352	41,776	15,470	11,198
Scientists	88,830	28,489	37,819	12,891	9,631
Physical scientists	31,753	18,010	8,322	3,321	2,100
Mathematical scientists	3,154	711	1,776	495	172
Computer specialists	1,892	1,137	418	185	152
Environmental scientists[3]	6,236	1,553	2,147	1,874	662
Life scientists	33,847	5,711	19,070	5,386	3,680
Psychologists and social scientists	11,941	1,367	6,079	1,630	2,865
Engineers	24,966	16,863	3,957	2,579	1,567
			Percent distribution across fields		
All fields[2]	100	100	100	100	100
Scientists	78	63	91	83	86
Physical scientists	28	40	20	21	19
Mathematical scientists	3	2	4	3	2
Computer specialists	2	3	1	1	1
Environmental scientists[3]	5	3	5	12	6
Life scientists	30	13	46	35	33
Psychologists and social scientists	10	3	15	11	26
Engineers	22	37	9	17	14
			Percent distribution across types of employer		
All fields[2]	100	40	37	14	10
Scientists	100	32	43	15	11
Physical scientists	100	57	26	10	7
Mathematical scientists	100	23	56	16	5
Computer specialists	100	60	22	10	8
Environmental scientists[3]	100	25	34	30	11
Life scientists	100	17	56	16	11
Psychologists and social scientists	100	11	51	14	24
Engineers	100	68	16	10	6

[1] Those whose primary work activity is R&D or R&D management.

[2] Includes 7 who did not report their field.

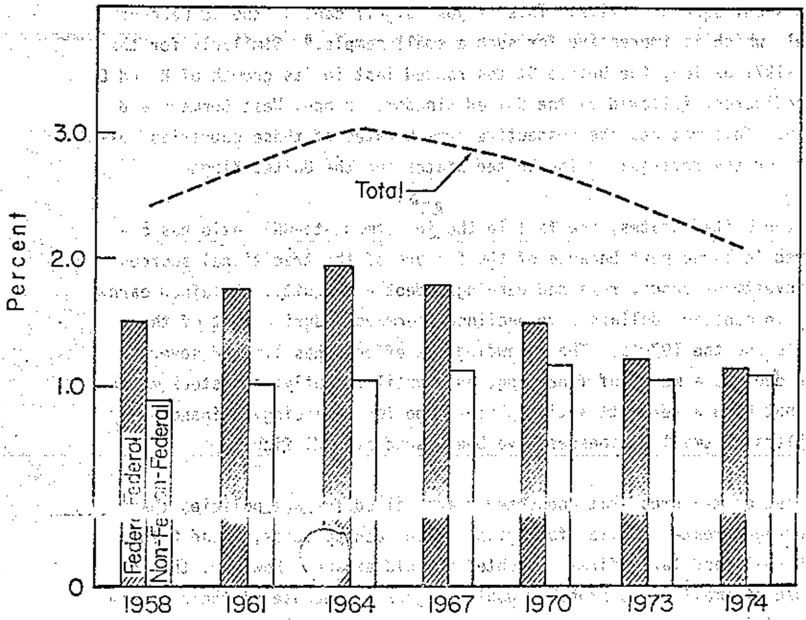
[3] Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States, 1975* (NSF 77-309), pp. 50-53.

See Figures 5-23 and 5-24 in text.

Figure I


Percent
3.0
2.0
1.0
0
Total
Federal
Non-Federal
1958
1961
1964
1967
1970
1973
1974

R and D output, i.e., in terms of technical change, the contribution of small firms may well be much greater than this percentage. Unfortunate very little has been written about R and D of small firms or about R an D that occurs outside the context of a formal program due to the lack o basic data concerning them. There is a considerable amount of literatu concerning R and D and firm size, but the smallest firms considered are generally larger than our small firm definition. The minimum size of the typical firm considered has more than 1,000 employees and, when sma er firms are included, firms with less than 1,000 employees are lumped together as the smallest size class. Consequently, some of the results reported here are for this size class and are noted specifically.

Doesn't fit normal definitions

We wish to distinguish among the <u>three different product phases of R an D,</u> i.e., *invention, development* and *innovation*. By *invention*, we mean the production of a model or an idea sufficiently developed to be paten able. There are important inventions, especially in the form of ideas, that would not be covered by this definition; however, for our purposes the definition has substantial advantages of specificity. *Development* refers to the process of bringing the innovation to the stage of commercial application. By *innovation*, we mean the actual adoption of the developed invention.

None of these definitions is entirely satisfactory, but they do convey useful sense of distinguishable product phases. The actual definition not very important since there is so little empirical work distinguishi among these different phases under any reasonable definition because there are little basic data available. This is also unfortunate for ou purposes, since an appreciation of these product phases is germane to questions about the role of small firms in R and D.

Although there is a considerable volume of work concerning larger firms and formal R and D programs, this almost uniformly suffers from importa limitations whose effects are to leave many of the important empirical and policy questions unsettled. These limitations arise from basic pro lems such as the absence of any well-regarded measure of R and D output or input. Some regard measures of R and D input as the best measure of R and D output, but the limitations of such measures, especially in considering the efficiency of R and D expenditures, is obvious. Beyond th measures of R and D input suffer from limitations of their own. Techni-

Peterson. For a sample of Nebraska firms, they found that 38 percent of firms with less than 500 employees engaged in R and D.[17] This is consistent with the results of a questionnaire study covering eight states by McConnell and Ross.[18]

Confidence in the McConnell and Peterson and McConnell and Ross results is increased by their consistency with the results of an earlier Harvard study containing a similar definition of R and D. For the early 1950's, 32 percent of firms with less than 500 employees had R and D programs. The definition of R and D in the studies used to obtain these results included the improvement of existing products and the development of new products or new production methods. The definition excluded market research, quality control and product testing, and R and D performed by part-time personnel and by specialists external to the firm. When the definition included part-time personnel and outside specialists, an additional 7 percent of the firms qualified for categorization as having R and D programs.

Where results were reported by industry, a wide variance was found in the percentage of small firms with an R and D program. For example, in the McConnell and Peterson study this percentage varied from a high of 68 in the chemical industry to a low of 13 percent in the transportation equipment industry. Size differences among small firms is the major explanation for this variance. The simple relationship reported by McConnell and Peterson between firm size and the percentage of firms engaging in R and D was striking. Only 11 percent of firms with one to five employees engaged in R and D, but this increased to 93 percent for firms in the largest category of 151 to 500 employees. The same trend is found when firms with more than 500 employees are considered. Even if the high 38 percent figure suggested by McConnell and Peterson as the portion of small firms engaging in R and D is accepted as reasonable (and I think it is), larger firms have still higher percentages. The relationship appears virtually monotonic with size.

The probable reasons for this factor are straightforward and important. The most important reason is the differential financial constraints faced by smaller firms. The availability of capital is often the crucial question determining the survival of the small firm. Research and development imposes a capital drain and increases the vulnerability of the accounted for about 65 percent of R and D spending as reported by the National Science Foundation, and by 1975 this figure had declined to about 58 percent.[22] Since federal R and D funding goes mainly to larger firms, this alone should contribute materially to a relationship between firm size and R and D size. Even on a percentage basis, the discrepancy is large. In 1965, federal funds apparently financed 57 percent of large company R and D, but funded only about 35 percent of R and D for firms with less than 1,000 employees.[23] Probably for firms with less than 500 employees, the percentage was much less than half of this. When federal funds were excluded, Smith and Creamer found that R and D expenditures as a percentage of sales fell from 5 percent to 2.1 percent for the largest size class and from only 1.8 to 1.4 for their smallest size class of less than 1,000 employees.[24]

However, the surprising result is that among small firms the relationship is generally quite weak between firm size and R and D spending. For McConnell and Peterson's sample, a simple regression of R and D employment against the number of employees indicates that only 34 percent of R and D variance is explained by firm size.[25] Separate regressions indicate a range from 72 percent for the chemical industry to 6.9 percent for stone, clay and glass. Again, there is some tendency for the relationship to be stronger for the more capital-intensive industries. Smith and Creamer's figures show that 83 percent of the R and D program of firms with fewer than 1,000 employees was less than $50,000 in 1965. This generally meant a staff of two people.

Intensity of R and D generally is measured by R and D employment or expenditures as a percentage of total employment or sales. McConnell and Peterson show a marked negative relationship between R and D intensity and firm size, where both are measured in employment terms. The rank negative relationship between firm size and R and D is perfect for their sample.[26] Research and development intensity falls steadily from 42 percent for firms of the smallest size class of less than five employees to 2 percent for firms of the largest class of between 151 and 500 employees. Probably there is a minimum size necessary for a successful R and D program. This means that while fewer small firms undertake R and D, the firms that do undertake the effort have programs larger relative to the size of the firm.

are among the five industries found by Gruber, Mehta and Vernon to be of dominant and crucial importance in U.S. export trade due to their R and D characteristics. Chemicals was one of the other five industries and, according to Scherer, exhibits diminishing returns to R and D input excluding the largest firms.[30] Scherer measured inventive output intensity in the form of patents rather than input intensity. The chemical industry showed decreasing returns of patent output to R and D until it reached sales of about $1.5 billion, at which point increasing returns appeared. This effect was due to essentially a very few giant chemical companies. When logarithms of the sales variables are taken to compress the effect of the largest firms and the regression is rerun, diminishing returns occur throughout. The electrical industry also was found by Scherer to exhibit diminishing returns. The chemical and electrical industries were the only two industries for which separate, unaggregated runs were made.

Scherer's general results are fairly consistent with those of McConnell and Peterson. Scherer found that "inventive output increases with firm sales, but generally at a rate less than proportional." The less than proportional contribution of larger firms to innovation is also consistent (except for their results for the largest four firms) with the work of Johannisson and Lindstrom[31] for Swedish firms in twelve industrial sectors.

Quite different results, generally for a different set of industries, are reported elsewhere. Mansfield[32] found that maximum innovational intensity occurred at about the size of the sixth largest firm in the petroleum and coal industries and at about the size of the twelfth largest firm for the pharmaceutical industry when patents are weighted for importance, and at a slightly larger size when they are not. Freeman[33] found that firms with less than 200 employees accounted for a much smaller proportion of the innovations than their share of employment or net worth. Their share of innovations was slightly less than one-half of their share of employment and net worth. However, the bias toward larger firm R and D produced by government funding may be considerably greater in Britain than in the United States, where it is nevertheless important. Possibly the disproportionate share of larger firms in R and D in Britain is a consequence of a greater proportion of R and D funding coming from the government there, with a similar bias toward large firms.

industrial laboratories. In a way, Mueller's results[41] are even more striking. From a sample of the twenty-five most important innovations actually developed by DuPont Co., in the 1920-1950 period, he found that only about 40 percent were discovered initially in DuPont's laboratories. This is especially impressive since the findings relate to an industry in which economies of scale in R and D have been noted, especially among the very largest firms, of which DuPont is one.

Even more persuasive evidence for the thesis advanced here that smaller firms have a comparative advantage in inventiveness is found in the literature survey of Hamberg[42] who surveyed studies with six different samples of major inventions. He concluded that large industrial laboratories mainly tended to produce minor inventions. Other inventive sources produced more important inventions. In sum, there is fairly strong evidence that the most important inventions come from small firms, or sometimes one-person operations, or from academic settings. As Hamberg notes, "----the probability that inventions will be significant thus appear to decline as a firm gets bigger---."[43] Schumacher's[44] "small is beautiful" thesis may be especially true for inventiveness. It appears likely that independence, freedom from bureaucracy and, perhaps, personalities antipathetic to that of the "organization man" are characteristics associated with inventiveness. Greater inventiveness perhaps would be achieved if a greater portion of R and D resources were invested by smaller firms.

However, not only are smaller firms more likely to produce more inventions, but also they are likely to do so at less cost. R and D expenditures per patent pending by size of firm for six different industry groups (machinery, chemicals, electric equipment, petroleum, instruments and all other industries) for 1953 showed just such a pattern.[45] In every industry except chemicals, firms employing more than 5,000 people spent more per patent than did firms employing less than 1,000 people. In fact, the cost per patent for the larger firms was about twice that for the smaller firms.

The notion of inventions of decreased importance at increased cost is nicely consistent with Comanor's study of the pharmaceutical industry in which he found that "marginal productivity of professional research appeared inversely related to firm size."[46]

Unfortunately, Connor does not separate invention from development or innovation. His questionnaire includes the three stages, which is somewhat at variance with the hypothesis here that the primary comparative advantage of small companies lies in invention, not in development or innovation. However, many of Connor's interviewees were from the electronics industry. From the material presented in the second section of this article, this appears to be an area in which R and D intensity is greatest for small firms and, thus, probably the sum of inventive and development costs in this industry tend to be less for smaller firms.

But, Connor presents a study of the parallel development of a product by large and small chemical companies. Costs for the small company (two research personnel) were about one-eighth those of the large company. Perhaps one should emphasize, though Connor does not, that this product was one for which the small company knew that a market existed because of customer requests and one for which development costs were not large (probably about $15,000). The point is that the risks associated with a developmental expenditure were not large and that this was a feasible project for a small company. Certain types of projects are clearly not suitable for development by a small company because of the specialization and investment required.

Further indication of the relative inefficiency of large firms in the production of knowledge is indicated by Sanders' results[49] that reveal that the biggest companies use about 50 percent of their patents, while the smallest companies use about 76 percent. Similar results are shown by the Patent Foundation of George Washington University.[50]

Evidently, as the size of the firm increases, there is a decline in the importance of its inventions, an increase in the cost per invention, a decline in the proportion of patented inventions used commercially and, for some products, an increase in the development cost per invention.

The argument being made here is not that smaller firms are more efficient in R and D, but that they are more efficient in certain, especially initial, stages of the product cycle, i.e., in inventiveness and even in development in certain instances. We also argue that they are relatively more efficient in certain industries such as electronics and scientific instruments. This view sees a certain complementarity between large and large for developing an invention into usable form is, of course, important in its own right. But what gives it a special urgency is that it runs counter to current myths created by Schumpeter[55] and emphasized by Galbraith[56] regarding firm size and structure and innovation. Schumpeter's hypothesis is usually interpreted as requiring monopoly power and large firm size for the most efficient innovation. Hence, Schumpeter's thesis usually is tested by measuring the relationship, if any, between industry concentration as a measure of monopoly and innovation and by measuring the correlation between firm size and innovation.

The correlation of monopoly power and innovation may be inappropriate as a measure of Schumpeter's thesis. Schumpeter stressed large firm size, the possibility of acquiring or holding monopoly power by innovation and the effect of potential or actual competition in stimulating innovation. It is quite unclear that the Schumpeterian thesis would lead one to expect any correlation between existing monopoly and innovation. Certainly, if innovation can lead to successful monopoly, which it clearly can, one would expect to find at least some correlation between monopoly and lagged R and D. However, this would not mean that monopoly is the market form best suited for producing innovation. The failure of existing studies to generally find correlation between industry concentration and innovation suggests that actual competition may be more important than monopoly as a spur to innovation. This is not necessarily inconsistent with Schumpeter's thesis; he notes:

> "in a capitalist reality, as distinguished from the textbook picture, it is not that kind of competition (price) which counts, but the new technology, the new source of supply--. It is hardly necessary to point out that competition of the kind we now have in mind acts not only when in being but also when it is an ever present threat. The business man feels himself to be in a competitive situation even if he is alone in his field."[57]

As Kamien and Schwartz interpret Schumpeter, "immediate imitation of a firm's new product or process by others as in perfect competition, would eliminate realizable rewards and thereby its incentive to innovate."[58] Essentially this is simply an argument for an effective patent system and an antitrust policy that exempts monopoly power acquired by technological superiority. This view is consistent with Comanor's findings that moderate barriers to entry were best in stimulating invention.[59]

would be optimal. Unfortunately, the assumptions necessary for this ideal system are far from met. Uncertainty in invention is especially great, and uncertainty is the enemy of efficient long-term contract.[61] Contracting costs become greater with uncertainty. One of the compelling reasons for the expansion of firms is the difficulty of making contracts in the presence of uncertainty; the expanded firm is an alternative to long large term interfirm contracts as Coase[62] noted long ago. The firm simply incorporates within itself those functions that previously were contracted out.

Thus it is not surprising that research intensity, measured say by R and D expenditures per unit of sales, increases with firm size up to a point and then decreases. Approximately the same pattern holds for research output except that research output per unit of size may peak at a somewhat smaller firm size than for R and D input. In part, this general pattern relating firm size to R and D may arise from the phenomena noted earlier with regard to inventiveness and development across firm size. Inventiveness tends to decrease as firm size increases, but developmental efficiency increases. Up to some firm size, the greater advantages of greater firm size on development outweigh the loss of inventiveness. Beyond this size, the marginal contribution of greater size to developmental efficiency and risk reduction is outweighed by the marginal loss of inventiveness. Actually, as firm size increases beyond some point, there is probably also a loss of efficiency in purely developmental work aside from inventiveness. Thus, there are definite and considerable forces preventing proportional increases in R and D efficiency beyond some point. Unfortunately, this point occurs at a firm's size that is absolutely quite large; certainly for most industries we are talking about firms with sales in the hundreds of millions of dollars.

PROPOSALS FOR REFORM

The preceeding analysis indicates that proposals for increasing the efficiency with which R and D resources are allocated should work to decrease uncertainty in patent ownership rights, increase the efficiency of contract between inventive and developmental firms and, in general, seek to lower these types of transactions costs. A step in this direction would be a more careful and definite awarding of patent rights than is presently the case. More rigorous standards on patenting could be imposed so that, in general, under ceteris paribus conditions, the can better guarantee the inventor really substantial rewards in the case of success than most alternative arrangements.

However, perhaps the most appealing proposal lies outside the patent system. This is a system of direct grants mentioned by Machlup and proposed originally by James Madison at the Constitutional Convention in 1787.[64] The government would give awards and bonuses to individuals and firms for invention in amounts related to the importance of the invention. Scherer, while noting the attraction of such a scheme, noted the drawback posed by the difficulties of estimating the value of inventive contributions.[65] However, this difficulty did not need to be a substantial one; awards could be made in two parts. The first, and perhaps smaller, part could be made at the time of invention. A second award could be made perhaps 10 years later on the basis of the value of the invention as shown by the intervening period. This second award also would serve as an disincentive to hold inventions idle, a practice for which the present patent system is criticized. This sort of system need not replace the patent system, but could as well serve as a supplement. The policy mentioned earlier of discrimination between large and small firms probably would be more acceptable and easier accomplished under a system of direct awards than through the patent system.

Any proposals for reform clearly need a more thorough working through than given here. In terms of both increasing allocative efficiency for R and D and of promoting smaller firms, the necessary effort seems worthwhile. Perhaps the suggestions here will encourage thinking in productive areas.

FOOTNOTES

*The author gratefully acknowledges the support of a grant from General Electric to the program in the Social Management of Technology at the University of Washington.

[1] R. Solow, "Technological Change and the Aggregate Production Function," *Review of Economics and Statistics* (August 1957), pp. 312-320.

[2] E. F. Dennison, *The Sources of Economic Growth in the United States and the Alternatives Before* (New York: Committee for Economic Development, 1962), pp. 271-272.

[3] There is good evidence of a postive relationship between R and D expenditures and profitability. However, my guess is that much of this, as for advertising, is due to the tax treatment of R and D as current expenditures rather than as depreciating assets. Presumably there is an argument that R and D is a depreciating asset.

[19] Smith and Creamer, "R and D and Small Company."

[20] McConnell and Peterson have data for eight industries. For each of these, I obtained the capital invested per worker in 1964. The top four industries by percentage engaged in R and D had a mean dollar invested per worker of 26.15, while the bottom four had a mean of 7.24. The t value calculated for small samples as

$$t=\frac{\bar{x}_1-\bar{x}_2}{\dfrac{\Sigma d_1^{2}+\Sigma d_2^{2}}{N_1+N_2-2}}\sqrt{\frac{N_1N_2}{N_1+N_2}},$$

give a t value of 5.94. Anything above 2.31 is significant at the one percent level.

[21] Smith and Creamer, "R and D and Small Company," p. 36.

[22] U.S. National Science Foundation, *National Patterns*.

[23] However, it is worth noting that Smith and Creamer find almost no drop of this percentage [from 39 percent to 35 percent] in moving from firms in their intermediate size class, 4,000 to 4,999 employees, to the size class of under 1,900 employees (p. 28).

[24] Smith and Creamer, "R and D and Small Company," p. 7.

[25] McConnell and Peterson, "Research and Development."

[26] Ibid., p. 359.

[27] Smith and Creamer, "R and D and Small Company," p. 36-37.

[28] J. Schmookler, "Bigness, Fewness and Research," *Journal of Political Economy* (December 1959), pp. 628-632.

[29] Professional and scientific instruments is a larger industry group than scientific instruments.

[30] F. M. Scherer, "Firm Size, Market Structure, Opportunity and the Output of Patented Inventions," *American Economic Review* 55(5) (December 1965), pp. 1099-1135.

[31] B. Johannisson and C. Lindstrom, "Firm Size and Inventive Activity," *Swedish Journal of Economy* 73(4) (December 1971), pp. 427-442.

[32] E. Mansfield, *Industrial Research and Technological Innovation--An Econometric Analysis* (New York: Norton for the Cowles Foundation for Research in Economics at Yale University, 1968).

[33] C. Freeman, "The Role of Small Firms in Innovation in the United Kingdom since 1945," Research Report No. 6 (London: Committee of Inquiry on Small Firms, 1971).

[34] A. Phillips, "Concentration, Scale and Technological Change in Selected Manufacturing Industries, 1899-1939," *Journal of Industrial Economics*, 4 (June 1956), pp. 179-193.

[35] A. Phillips, "Patents, Potential Competition and Technical Progress," *American Economic Review*, 56(2), Part II Supplement (May 1966), pp. 301-310; ________, *Technology and Market Structure: A Study of the Aircraft Industry* (Lexington, Mass.: Health, Lexington Books, 1971).

[36] Scherer, "Firm Size."

[37] L. Philips, *Effects on Industrial Concentration: A Cross Section Analysis for the Common Market* (Amsterdam: North Holland Publishing Co., 1971, pp. 119-142.

APPENDIX XVI

ARTICLE, "IMPROVING THE CLIMATE FOR INNOVATION—WHAT GOVERNMENT AND INDUSTRY CAN DO," BY ELMER B. STAATS, RESEARCH MANAGEMENT, SEPTEMBER 1976, PAGES 9–13

(Elmer B. Staats is Comptroller General of the United States. This article is a condensation of a paper he presented at the Annual Meeting of the Industrial Research Institute last May.)

Both attitudinal and tangible conflicts are hampering Government-industry cooperation in civilian-sector R&D. The U.S. Comptroller General suggests approaches to a more constructive partnership.

In times of crises, such as World War II and the threat of Soviet preeminence in space technology, our Government mobilized industrial resources—and industry responded well—in a partnership effort with industry to meet specific national goals. Such partnerships continue in defense and aerospace. However, we have yet to find the solution to the more complex interrelationships necessary to deal effectively with civilian sector problems, such as the energy crisis or the problems associated with environmental protection and safety.

Today the Federal Government is playing an increasingly important role in international economic relations by helping to establish better sharing of critical resources and by assuring American competitiveness in the international marketplace. More and more American companies are entering into world markets, not only through exports but also through investment in foreign subsidiaries. Many companies have developed into powerful multinational corporations. Consequently, a whole new dimension of industrial accountability has emerged. This partnership responsibility is highly important in fostering world peace, assisting the developing nations, and sharing critical resources for the benefit of all mankind.

The question, therefore, is how can we improve the communication, understanding, mutual goals, and working relationships between Government and industry, especially technology-intensive industry, in meeting both national domestic needs and international obligations.

Many people have attempted to diagnose the barriers to innovation and to offer solutions for improving the climate for Government-industry cooperation. The problems that have been identified generally fall into two broad categories. The first is to a large extent subjective and attitudinal. The second comprises a number of more tangible factors.

BARRIERS TO INNOVATION

Perhaps the major subjective problem inhibiting Government-industry cooperation is the lack of mutual trust. Many Government officials are suspicious of industrial motives and the potential economic and political power of large corporations, especially those with multinational affiliations. On the other hand, industry is concerned that Government officials do not understand and appreciate the profit motive. Industry also believes there is a lack of understanding by Government officials of the technology innovation process.

Also, the meaning of public accountability is commonly misunderstood. Some Government officials believe that public accountability means that every Federal dollar spent should be tagged with a program directive, management control, and Government ownership of whatever results.

There are situations in which a broader view of public accountability is appropriate which would not provide for specific direction and management by the Government nor Federal ownership of the resulting product. In such cases, the question to ask is whether Federal funds are being spent wisely in the public interest, such as to stimulate useful innovation. An example that comes to mind is Federal policy regarding patent licensing. Some Government officials believe that patents derived from federally funded R&D must be owned and controlled entirely by the Government. However, in most cases, the public interest may best

ESSENTIAL COMMERCIAL VENTURES

There are controversial views concerning the Federal Government's role in mobilizing combined nationwide scientific and technological resources required to develop major commercial products needed to meet national goals. For example, although the Energy Research and Development Administration, in combination with industrial firms, is investing heavily in nuclear power development, some experts question what the specific role of the Government should be in the energy area.

The basic argument is whether the Government should finance and manage such programs directly or attempt to provide the right climate and incentives for innovation by the private sector as well as insurance against the risks, with oversight sufficient to assure adequate public protection from potential hazards and monopolistic advantage or excessive prices.

The energy problem involves extensive industrial participation and its products ultimately will be commercially delivered to public utilities and other users. The technological and market uncertainties, combined with the long time frames and magnitude of capital investment, require that the Federal Government be involved. The question is: To what extent and how?

Two case studies, which shed some light on this question, are presented in the General Accounting Office reports dealing with the Liquid Metal Fast Breeder Reactor Program and the Federal Coal Research Program. In the case of the Breeder Reactor Program, the delicate question of judgment is at what point will the technology—largely Government financed—be sufficiently reliable, economic, and safe as to make it a viable commercial enterprise and how will the transition from major Federal involvement to commercial implementation by the private sector be accomplished.

Similar questions are involved in developing the means to convert coal to synthetic gas or liquid fuel, a problem made more complicated because of the environmental concerns associated with mining and developing coal as an energy resource and the fact that much of our coal reserves are located in areas which will require large-scale construction of public facilities, such as hospitals, schools, and roads.

These are only two of a number of examples which could be cited to illustrate the point that we have not yet established a consistent policy concerning the respective roles of Government and industry in developing major long-term commercial ventures to meet national needs. It is unlikely that a formula for general application can be devised, but I believe that studying of policy alternatives should be continued in an effort to establish a general policy and criteria for guidance in determining the Government's role in each situation of this type.

MANUFACTURING PRODUCTIVITY

Improving productivity in both public and private sectors has been generally recognized as one of the most effective means to stimulate economic growth. Since 1970 the General Accounting Office, in cooperation with executive branch agencies, has been fostering efforts to measure and enhance the productivity of Federal activities. In addition, we have recently completed a comparison of programs in the United States and other countries concerned with advancing the state-of-the-art of manufacturing technology, particularly in the manufacturing of parts and components produced in medium and small lots—with special attention to the potential for further application of computers to the design and manufacturing process.

We concluded that the United States generally uses more advanced manufacturing technology than other countries in the world. The U.S. total output and output per employed person is higher than any other nation's. However, our advanced technology is concentrated in a few high-technology and/or capital-intensive firms. It is not well diffused throughout medium- and small-sized companies. Our study also suggests that, without some added impetus, the advanced technology will not expand or diffuse widely to small- or medium-sized firms.

Our international competitors are capturing increasing shares of foreign markets and are increasingly penetrating U.S. markets. It is significant that they are competing in those markets with U.S. high-technology manufacturers. The principal U.S. exports for the future appear to be essentially the same as at present; i.e., primarily agricultural products, aircraft and components, electronics (principally computers), and nonelectrical machinery. Unlike the United

Discussion and debate in forums and panel meetings, such as those sponsored by the National Science Foundation, the National Bureau of Standards, professional societies, and trade associations can help; especially when all interested parties or sectors, including labor and consumer groups, are represented. I am told that workshops, such as those jointly sponsored by IRI and the National Bureau of Standards, have been productive.

Congressional hearings also are useful for improving understanding and perspective. For example, the Subcommitte on Domestic and International Scientific Planning and Analysis of the House Committee on Science and Technology has just completed hearings on "R&D and the Economy".

With regard to the more tangible issues, I believe several initiatives can be or are being taken. One of these is in the area of basic research. In proceeding from exploratory research to product development, risks tend to decline but costs increase. For example, the cost involved in basic research and exploratory development to demonstrate technological feasibility of an innovation is generally much less than the cost to complete prototype development, tooling for manufacturing and market development. These characteristics of the R&D process are suggestive of the respective roles of the Federal Government and industry.

For specific missions, such as defense and space, the Federal Government supports all phases from basic research to product development. For technology primarily related to commercial products, the role of the Federal Government, with few exceptions (notably agriculture and nuclear energy), generally has been limited to support of basic science and exploratory development of emerging technologies.

The private sector generally does not support basic research and education unless it can identify a direct, prompt, and adequate return on its investment. A few exceptions are large corporations and philanthropic foundations. As part of the Federal Government's responsibility, therefore, it must continue to provide major support for basic research and graduate education in both physical and social sciences and the engineering disciplines.

We have not been able to develop any "best" formula for the level of Federal support of basic research—a percentage of the total Federal budget, a percentage of the total R&D budget, a percentage of the gross national product, or the consensus of experts in various disciplines. However, I believe that a rationale can and should be developed and criteria established to assure continuity and stability of federally sponsored efforts.

In funding basic research and graduate education, the Government not only supports industry's R&D efforts by augmenting the science and technology base underlying the innovation process; it also supplies a stable base of scientists and engineers. Basic research should continue to be conducted at Government laboratories, universities, and private institutions, depending on the capabilities of each.

Some reorienting or rethinking of Federal policies and priorities toward funding the science and technology base may be appropriate. This reorientation could be based in part on increased distinctions between R&D policy supporting defense and space on one hand and consumer-oriented technology on the other. Several noneconomic criteria are important in decisions concerning defense and space R&D. While there are "spin-offs" from defense and space R&D to commercial markets, they are not crucial elements in the decision to fund defense and space R&D projects.

Federal financing of applied R&D in support of commercial technology should be considered in the context of potential economic and social benefits to the Nation and in relation to the private sector's ability and motivation to invest its own resources, as well as in relation to other Government initiatives that can influence the climate for private-sector innovation.

Some recent initiatives by the Federal Government both within the executive branch and by the Congress are aimed toward establishing more definitive and enlightened policies and priorities for resource allocation and for dealing with issues that transcend the purview of individual agencies and the private sector. Among these are:

The pending legislation, now passed by both the Senate and the House, to establish a Science and Technology Policy Advisory Office in the White House.

The Office of Technology Assessment comprehensive study of National R&D Policies and Priorities;

The National Science Foundation R&D Assessment Program.

The National Bureau of Standards Experimental Technology Incentives Program.

APPENDIX XVII

STATEMENT OF DR. BRUNO O. WEINSCHEL, VICE PRESIDENT, PROFESSIONAL ACTIVITIES, INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC., WASHINGTON, D.C.

STATEMENT

by

Dr. Bruno O. Weinschel*

on behalf of

The Task Force on U. S. Innovation in Electro-Technology
of the U. S. Activities Board,
Institute of Electrical and Electronics Engineers, Inc.

To

The Senate Subcommittees on:

Science, Technology and Space; and

International Finance

Concerning

U. S. High Technology - Impacts on U. S. Policy

Affecting World Markets

May 16, 1978

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Engineers, Inc.
2029 K Street, NW
Washington, DC 20006

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Executive Summary

In this document we have attempted to provide a brief review and evaluation of current U. S. policy concerning the development and commercialization of high technology, and suggested possible measures for improving our position. The essential points of our findings as they relate to the questions posed by the Joint Committee, may be summarized as follows:

1. There is a significant correlation between levels of R&D investment and the maintenance of U. S. technological leadership. There is no such strong direct relationship between U. S. exports of goods and services derived from such investments, but there could be if the time-lag prior to implementation and commercialization could be decreased.
2. Private investments in R&D in the U. S. are generally declining, and this has serious implications for high technology exports. The factors contributing to these trends, however, are many and complex, and are discussed in the body of this document along with recommendations for policies which may provide incentives to increased these investments.
3. If we over-simplify our comments, we could say that the role of the small firm is larger in the innovative process, but it is less equipped to capitalize on this lead in terms of exporting goods and services where management/marketing skills and especially the availability of venture capital play a dominant role. The need for incentives to further capital formulation is therefore essential. The larger firm is in a better position to play this "follow up" game, but is less likely to innovate because of its heavy investment in existing equipment, processes and product patterns.
4. Some U. S. R&D activity is indeed moving abroad, and the trend is likely to increase. Government actions could slow the process but would not stop it. The transfer is desirable from many points of view, and inevitable, but steps must be taken to minimize its negative effects on the U. S. economy.

1. The Role of the Institute of Electrical and Electronics Engineers

On behalf of this Institute, usually referred to as IEEE, I wish to express my appreciation for the opportunity to present our viewpoint on the matters being considered by this Joint Committee. The IEEE is well-qualified to address these issues. This organization has as its origin the incorporation in New York State in 1884 of the American Institute of Electrical Engineers, which merged with the Institute of Radio Engineers in 1961 to form the Institute of Electrical and Electronics Engineers. The aim of the original organization was "to advance the art and science of Electrical Engineering" by all appropriate acts and activities. In its 96 years of existence the membership has grown from 46 to over 185,000, and its scope has continuously expended as a unique leader in its field and a major institution in the field of engineering on both the domestic and the international scene. Its members cover the entire spectrum of associated interests, including teaching, research, government and industry, private individuals, small business, and mammoth multinational enterprises. We are deeply involved in the high technology areas of electro-science, from aircraft electronics through computers, lasers and microwave repeaters to satellite communications.

Our role in the current investigation is to try to point out the complexity, diversity and interrelationships of the factors which must be considered. We cannot propose a solution to all the related problems; we do believe that we have a contribution to make in terms of clarifying the issues, presenting the legitimate concerns of the affected parties, and making recommendations (in Section 10) for a phased program of investigation and supportive actions which will enhance understanding of the

2. Background

The typical pattern of Research and Development in the United States has changed radically since the time of the inventor working independently in a laboratory in his own home. At the start of World War I, the American Chemical Society offered to help President Wilson in any areas of chemistry or chemical engineering, to which his response was "Thank you very much for the offer, but we already have a chemical engineer working at Edgewood Arsenal." In contrast, we now have a formalized team structure to attack almost all aspects of R&D.

The U. S. has not in the past always been a leader in Science and Technology, but rather an "early adaptor" of R&D performed typically in Europe. We have made progress in the "four Is": generation of breakthrough ideas, and application and development phases - invention, innovation and imitation (or diffusion) - and as recently as 5 years ago it appeared that the U. S. had achieved and was likely to retain the position of world leader.* However, we are now in the process of letting this advantage slip away.

Measures of international stature are difficult to quantify, but we can get a general idea in the realm of science by looking at indicators, such as the citizenship of Nobel prize winners for Science. Table 1 shows the improvement in relative standing of the U. S. since the beginning of the century, moving up from fifth place prior to 1930, and subsequently maintaining a significant lead over other nations, until in the most recent

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*Cetron, M. J., "Technology Transfer: Where We Stand Today"; Technology Transfer (Eds.; Davidson, Cetron & Goldhar), NATO Advanced Study Institute Science; Noordhoff; (Leyden) 1974; pp. 1-28.

list the U. S. has more than all others combined. This rather sudden acceleration may be attributed in part to the substantial influx of scientists who were educated abroad and migrated to the U. S. because of the political or religious turmoil of the 1930s. It is also a result of the great material resources which are available in the U. S. The scientific areas where we lead are those which require expensive experimental equipment, which some nations cannot provide. (However these are not necessarily areas which can be readily commercialized.) Even here, however, if we examine the number of Nobel prizes as a function of population (Figure 1), the United States -- although still a leader -- no longer dominates as it did prior to 1950.

In the realm of technology, the U. S. has been pre-eminent over a much longer period. Two crude measures of comparative standing are shown in Table 2. Column A indicates by nationality the number of authors of major inventions from Colonial times to the present day. Such a tabulation can be regarded as distorted both by chauvinism in the selection of responsible individuals, and lack of discrimination in the choice of inventions. The remaining columns show the average patenting rate in the 1930s and in 1975, for the countries listed. By either criterion, the U. S. was ahead of other nations; however, this position of leadership has been eroded over the last decade, as shown in Figure 2. In a recent report,* OECD states that except for the computer, aerospace, and heavy electronics industries, technology is primarily transferred into the United States from other

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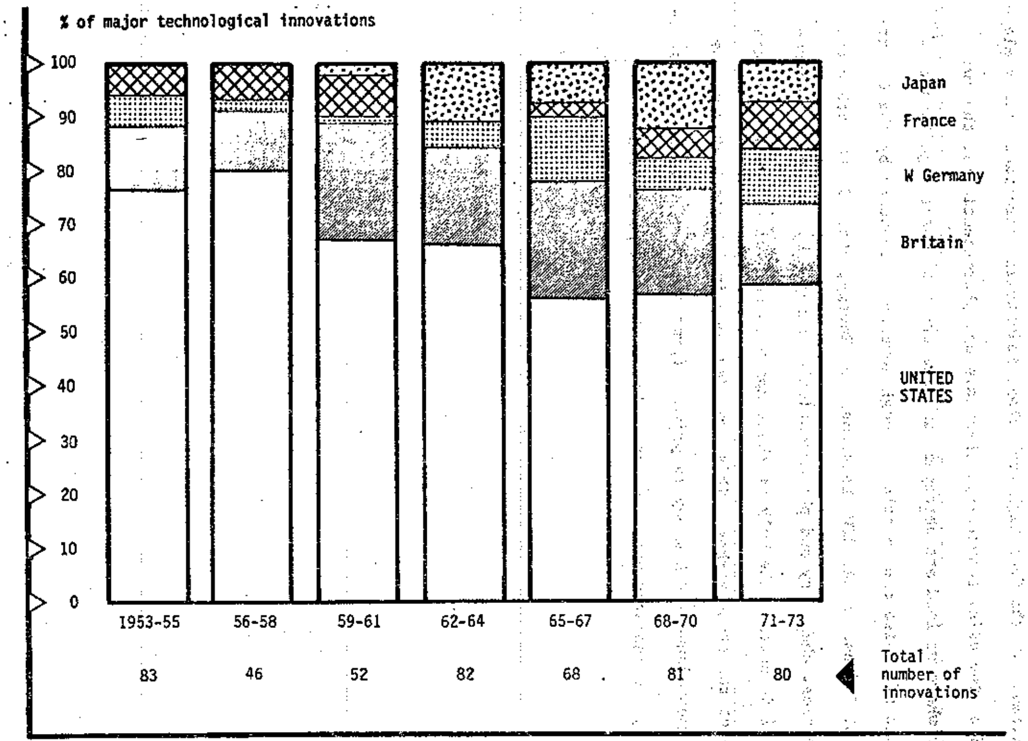
*Gaps in Technology, (Paris, France: Organization for Economic Cooperation and Development, 1970).

Figure 2

PERCENTAGE OF MAJOR TECHNICAL INNOVATIONS



Source: National Science Foundation Indicators, as depicted in "The Science Olympics", Business Brief, The Economist, May 20, 1978, pp. 86, 87.

3. The Importance of Technology

Both technology and technology-based products are of major significance to the U. S. in terms of international trade as well as in generating jobs and products for domestic consumption. The export of technology, as distinct from the export of products, brings revenues to U. S. companies, and thus to the U. S. economy, in the form of license fees and royalties. In 1977 the gross income from such sources was \$2.95 billion, compared to \$.66 billion in 1965. The net income (technology export minus technology import, neglecting products) for 1977 was \$2.67 billion, comparable in magnitude to the \$3.25 billion U. S. trade surplus for all manufactured goods.*

The total contribution of technology to our economic welfare however cannot be measured solely in terms of trade balance. The tremendous increase in productivity of U. S. industry over the past thirty years can be attributed primarily to the application and utilization of technological advances. Between 1947 and 1965, the average annual increase in output per man in private industry ranged from 2% to 6%, the greatest change being in the communications and utility sector,** where the growth in real output reached 7.5% p.a. by 1970. Advances in productivity are responsible for a large part of economic progress, in terms of GNP per capita, and these trends are expected to continue through 1990.*** One of the most important weapons in our arsenal against inflation is such increased productivity, which can be achieved through improved technologies and innovations.

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*Langan, Patricia, "Those Worrisome Technology Exports", Fortune, May 22, 1978. These data are confirmed by the latest figures provided by the U. S. Department of Commerce (Private Communication), excluding the category of management and services.

**Private communication from the National Bureau of Economic Research.

***The Conference Board, "The U. S. Economy in 1990", in A Look at Business in 1990, White House Conference on the Industrial World Ahead, Washington, D. C., 1972.

4. The Characteristics of Technology

The most obvious characteristic of technology in general is that it changes; old products and procedures are replaced by new. This is a continuing process, so that at any given time and place the technology being practiced covers a spectrum from the old and stable to the new and rapidly changing. The impetus towards newer technology is a consequence of its potential to increase the productivity of a society's stock of resources. Solow[*] estimates that over the past century, 80% of the growth in the U. S. economy has resulted from advances in technology. The remaining 20% has been due to increases in the amount of resources.

In general, the increase in productivity is more rapid when the technology is new, and it thus yields greater returns to society than does a mature technology. There may be argument as to the distribution of these returns -- the major profit almost never accrues to the original innovator -- but there is general agreement that all members of the society benefit.

The growth of a new technology follows the familiar S-shaped curve as shown in Figure 3. An incipient period of rapid technological change -- "leading edge" technology -- is followed by a period of high growth but less change, manifested by increasing standardization. This is succeeded by a "mature" period of relatively slow change and slowing growth, and maximum return on the investment. Because of this growth pattern, the bulk

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[*] Solow, R., "Technical Change and the Aggregate Production Function", in <u>Review of Economics and Statistics</u>, August 1957.

of a technology being practiced is relatively mature and approaching stability.* If a new technology were to disappear in its incipient stage -- as many do -- it would hardly be noticed in aggregate statistics. However, the industry and the nation alike suffer when this happens, since it is the subsequent stages which provide substantial economic rewards.

Once a technology has been firmly established, and incorporated in a product or set of products, the frontier -- the place "where the action is" -- shifts from science and engineering to production and marketing. Instead of concentrating on making a single item work, the company concerned must learn to produce in quantity: to make the same item every time, and optimize the work flow. Customers must be acquired, and shown how to use the product. Service men must be trained -- much of the rapid post-war growth of "hi-fi" and TV equipment sales was spurred on by the training of radar technicians in the military. Ultimately the major benefits of a new technology accrue <u>not</u> to the technological innovator, but to those who solve the production and marketing problems.

Not only does the technology <u>change</u> over time, but it <u>moves</u>, and cannot be confined. Those whose command of a technology permits them to enjoy a position of monopoly have always tried to keep this advantage to themselves. Such attempts have invariably failed, and are doomed to failure by the very nature of things. The sale of any product embodying the technology necessarily reveals the most important item of information -- that the technology is possible. The processes of technical marketing also provide other data, and the more complex the product, the more information must be disseminated (concerning application and maintenance).

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* However, in order to ensure continued national economic health, a portion of the profits from a mature technology must be reinvested in new and efficient research and development; otherwise the technology well will run dry.

5. National Technological Strategy Options

There is more than one attractive strategy in playing the "technology game" on the international scene, and by no means all of the advantages lie with the innovative leader. Before attempting to discuss policy options for the United States, we must consider the implications of "leader" and "follower" roles. The discussion which follows is based upon an excellent summary by Horn, of the Institut für Weltwirtschaft in Kiel.*

> Technological progress continuously creates new products. Therefore, technological leads and lags are a steady source of international trade. A country which is able to generate a higher rate of innovations than other countries will be able to permanently produce a greater proportion of new goods. Countries which are less capable of producing technological innovations will have to specialize in the production of traditional goods.
>
> This leads to the question of which factors determine international differences in the innovative activity of countries. The answer to this question is suggested by the so-called product life cycle approach to international trade.** Simplified, the product life cycle hypothesis can be described as follows: Products and processes of production typically pass through a cycle which is characterized by an increasing degree of standardization (maturation). The most advanced countries possess comparative advantages in the production

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*Horn, Ernst-Jurgen, "International Trade and Technological Innovation: The German Position Vis-a-Vis Other Developed Market Economies", in Karl A. Stroetmann (Ed.) Innovation, Economic Change and Technology Policies, Bonn, Germany, 1976.

**Vernon, R., "International Investment and International Trade in the Product Cycle". In: Quarterly Journal of Economics, Vol. 80 (1966); and Hirsch, S., Location of Industry and International Competitiveness. Oxford: Clarendon Press, 1967, and Gruber, W. H., Mehta, D., Vernon, R., "The R&D Factor in International Trade and International Investment of United States Industries". In: Journal of Political Economy, Vol. 75 (1967), and Wells, L. T. Jr., "International Trade. The Product Life Cycle Approach". In: Idem (ed.), The Product Life Cycle and International Trade, Boston: Harvard University, 1972.

This option is open only to those nations/corporations whose technical level is similar to that of the innovator. The American Indian, for instance, could not imitate the settlers' firearms because he had no knowledge of the requisite skills in making and forming steel, casting lead, producing nitre, sulfur, etc. There are plentiful modern instances, also, where major problems have arisen due to disparities not only in a specific technology, but in the necessary supporting infrastructure and in a whole range of ancillary technologies.*

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* See for example
Baranson, Jack, Industrial Technology Transfer by U.S. Firms to Overseas Affiliates Under Licensing Agreements: Policies, Practices and Conditioning Factors (Arlington, Va.: Forecasting International, Ltd., 1975)

innovations. Says J. Fred Bucy, President of Texas Instruments:[*] "Today our toughest competition is coming from foreign companies whose ability to compete with us rests in part on their acquisition of U. S. technology... The time has come to stop selling our latest technologies, which are the most valuable things we've got." Horace D. McDonell, an executive vice president of Perkin-Elmer Corporation, sums it up more piquantly: "We want to sell more milk and fewer cows."[**]

Before we can evaluate the validity of this viewpoint, we wish to examine more closely the situation of the United States in the light of the technology flow pattern we have defined; given that our perception of our national role is that of a leader, what are our achievements relative to establishing, maintaining and capitalizing upon a technological lead?

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[*] An Analysis of Export Control of U. S. Technology: A DoD Perspective, Report of the Defense Science Board Task Force on Export of U. S. Technology, J. Fred Bucy, Jr., Chairman (Washington, D. C.: Office of the Director of Defense Research and Engineering, February 4, 1976).

[**] Langan, Patricia, op.cit.

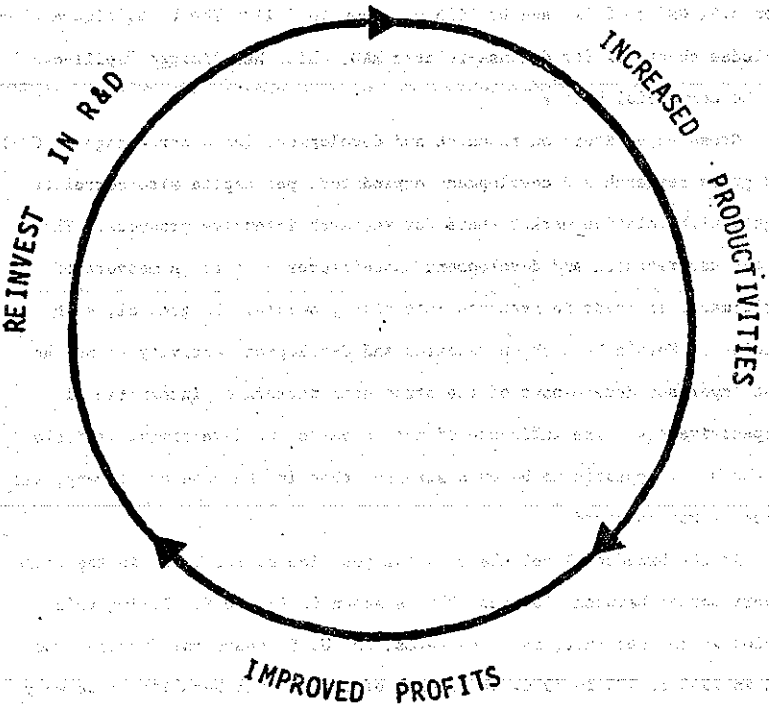

FIGURE 4. THE R&D CYCLE

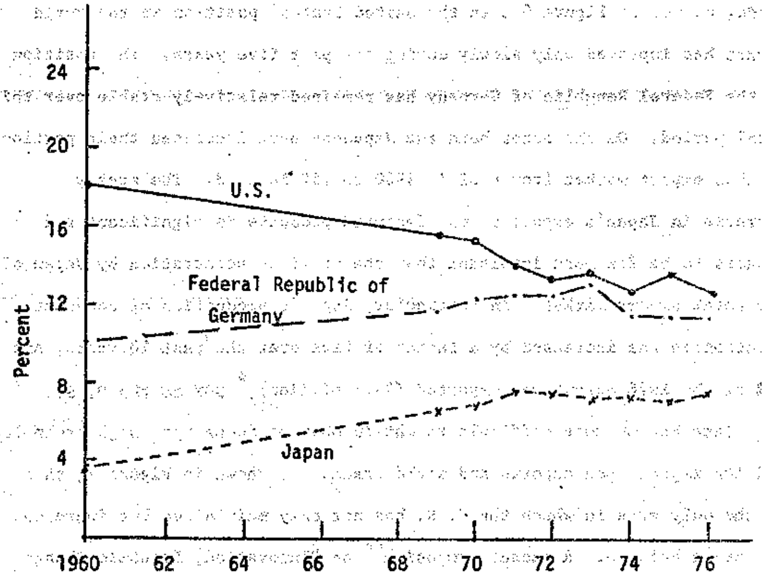

Figure 5. Share of the Total World Export Market (All products and raw materials)

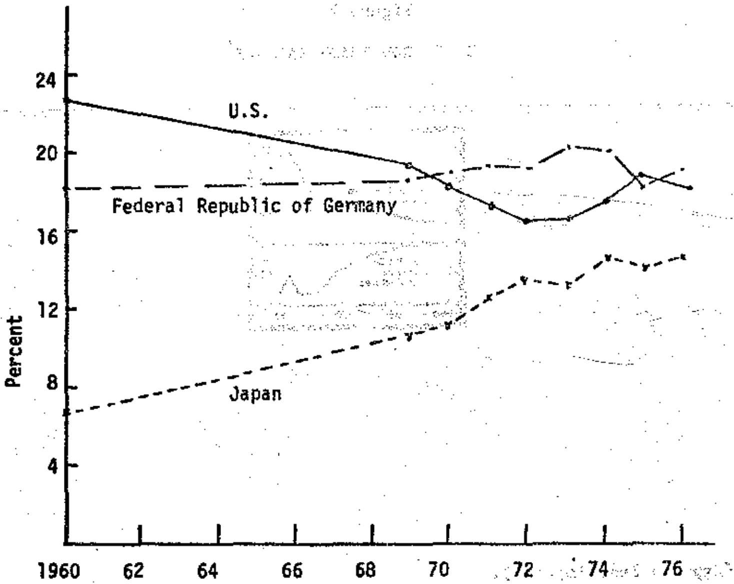

Figure 6. Share of the Total World Export Market (Manufactured Goods Only)

which he calls "revealed comparative advantage" (RCA)* provides insight into what is happening in the world arena concerning the international sale of high technology products.

Figure 8 shows RCA values for the United States, the Federal Republic of Germany and Japan for the periods 1963 through 1973 as well as a projection of these figures into the future. Note that the United States position has been eroding significantly, decreasing by about 30 units during the time period under examination; that the Federal Republic of Germany's position appears to have remained relatively constant although weakening somewhat; and that the Japanese position has improved, also by about 30 units. (In this figure a negative value means that they started at a disadvantage.) The cross-over between United States and Japan in this particular segment of the market would occur somewhere in the period 1980 through 1985, based upon extrapolation at the current rate of change.

A similar conclusion was presented in a document issued by the National Planning Association** in which a measure was defined of the lag*** between U. S. and Japanese technology, a graphic representation of which is shown in Figure 9. The relative lag impacts upon the future relative

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*This indicator measures the extent to which foreign trade surpluses (deficits) in one product group diverge from the trade position of this country in total manufactured goods. The measure has been normed so that it can assume values between + 100 and -100. High positive values of the measure indicate a high international competitiveness. For method of calculation the reader is referred to the article as cited, page 144 et seq.

**New International Realities, (National Planning Association, Washington, D. C., 1978).

***This is expressed in terms of the relative technological change over time: the rate of growth of output holding all inputs constant. For a precise definition of the measure, see Christensen, L. R., D. Cummings and D. W. Jorgenson, "Economic Growth, 1947-1973: An International Comparison," in J. W. Dendrick and B. Vaccara (Eds.), New Developments in Productivity Measurement, Studies in Income and Wealth, Vol. 41 (New York: Columbia University Press), forthcoming.

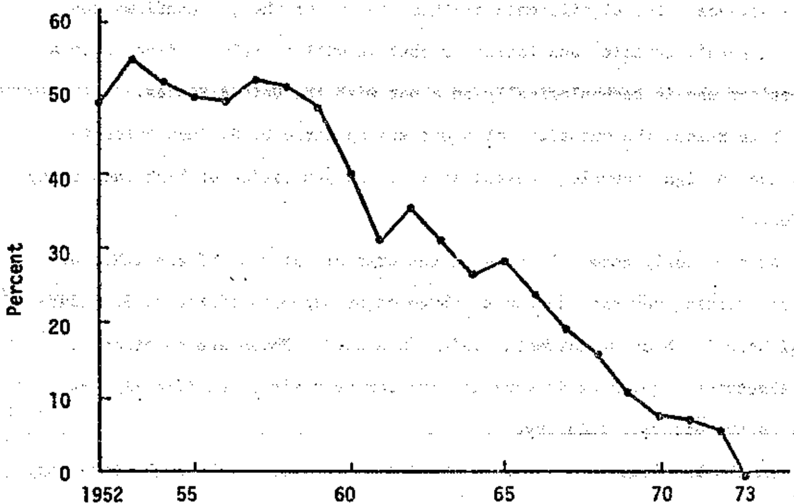

Figure 9. The U. S. - Japanese Technology Lag*

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*This is expressed in terms of the relative technological change over time: the rate of growth of output holding all inputs constant. For a precise definition of the measure, see Christensen, L. R., D. Cummings and D. W. Jorgenson, "Economic Growth, 1947-1973: An International Comparison," in J. W. Dendrick and B. Vaccara (Eds.), New Developments in Productivity Measurement, Studies in Income and Wealth, Vol. 41 (New York: Columbia University Press), forthcoming.

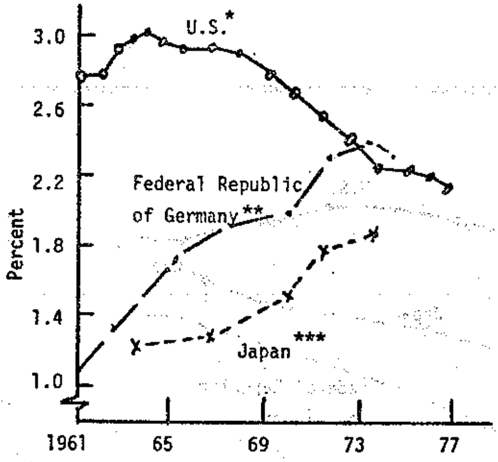

Figure 10. R & D Expenditures as a Percentage of National GNP

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[*] This includes about 50% defense-related R&D, most of which cannot be adopted to commercialization.

[**] This includes about 11% defense-related R&D.

[***] This includes about 2% defense-realated R&D.

"technical wizardry" are expanding their share of U. S. and world markets in those less technologically exciting goods which make up the bulk of world trade.*

The rationale for examining the high technology manufactured goods is based upon material previously generated for the U. S. Senate Committee on Finance.** Data were presented which indicated that high technology industries (that is, product industries whose products depend upon the application of high technology) provided for the U. S. a significant positive balance of trade as opposed to the lower technology manufactured goods or raw materials. This was previously shown also in Figure 7. A reproduction of the table for the period 1960 through 1971 is shown in Table 3. The specific industries categorized as high technology, medium technology and low technology are listed in Table 4 for reference, ranked in decreasing order of R&D investment as a percentage of shipments (1966 data)***

To bring the problem into focus, let us look at specific examples, as previously: in the semi-conductor industry the lead clearly has been with the United States for many years; the development of transistors, integrated circuits, etc. has placed the United States in a very strong position in this particular area. However, starting in about 1965 several developments occurred which ultimately must have serious consequences upon the balance of trade for the United States in this area. First, these semi-conductor

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*"The Science Olympics", loc.cit.

**Implications of Multinational Firms for World Trade and Investment and for U. S. Trade and Labor (Committee on Finance, U. S. Senate, February 1973).

***Based on U. S. Census of Manufactures.

High Technology Industries

Electrical machinery and apparatus, incl. household appliances
Drugs
Industrial chemicals
Instruments
Transportation equipment
Radio, T.V., electronic components
Farm machinery and equipment
Electronic computing equipment and miscellaneous nonelectrical machinery
Office machines

Medium Technology Industries

Soaps and cosmetics
Rubber products
Industrial machinery and equipment
Miscellaneous chemicals not included elsewhere
Stone, clay, and glass products
Primary and fabricated aluminum, plus misc. metal products
Fabricated metals (excl. aluminum, copper, and brass)
Miscellaneous electrical machinery not included elsewhere
Grain mill products
Plastics

Low Technology Industries

Primary metals (excl. aluminum)
Paper and allied products
Miscellaneous manufacturing (incl. ordnance, leather, and tobacco)
Lumber, wood products, and furniture
Miscellaneous food products (excl. grain mills)
Printing and publishing
Textiles and apparel

Table 4. Composition of Industrial Segments

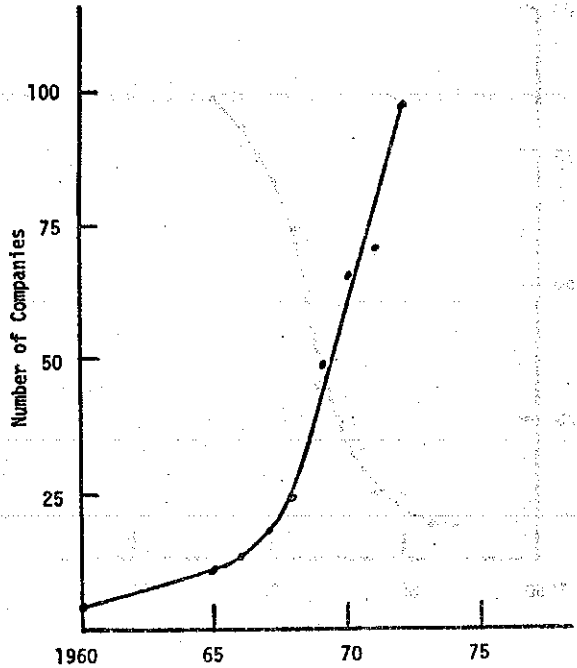

Figure 12. Number of U.S. Semiconductor Firms Establishing Overseas Operations

The implication of the long term effects focuses the need for our industrial structure to maintain a technological lead in the semi-conductor area. This means that we must encourage innovation and the application of leading-edge technology at an ever increasing rate.

The Institute recognizes the importance of this issue and the complexities involved in trying to evaluate the variety of impacts. To attack this problem, the IEEE is in the process of convening a study group which will bring together industrial, governmental and academic experts who will examine the causes, modes and consequences of the transfer of high technology from the U. S. to foreign sites. This task force will examine, to the extent possible, the technical, economic and socio-political aspects of these and related issues.

In the context of the present discussion, let us now examine the question of what is the relationship between funding of research and development and high technology, and the product output by that industry. To do that we will examine the computer industry where some statistics are available; this may give us some insight into at least one segment of the total high technology area.

In examining the research and development investment as a percentage of the total revenue of five major organizations in the computer industry, we produced the results shown in Figure 14. It is interesting to note that the National Cash Register (NCR) Company as well as Burroughs maintained a relatively stable input of research and development dollars as a percentage of their revenue over significant periods of time. On the other hand IBM increased its percentage of research and development from approximately 4% in the late 1950s to nearly 7% in the period 1970 through 1974.

The two remaining companies examined were CDC and the Digital Equipment Corporation. CDC shows a sporadic fluctuation in its research and development investment, particularly during the time period 1958 through 1964. From that period on it began to decrease its research and development investment although it was not until 1967 that the percentage dropped below the IBM level.

During the time period 1958 through 1967 CDC was applying high technology to its product line and developing very rapid penetration of the market for various new devices and systems which were produced.

DEC was utilizing approximately 16.6% of its revenues for research and development investment in 1964 and 15.2% in 1965. This appears to be decreasing asymptotically. However, during the time period when DEC was investing significant amounts of money in the research and development effort it was a recognized leader in developing mini-computers and micro-computers for sale in the United States. This penetration was successful and it is today one of the leading organizations in that particular sub-area of computers and computer applications.

Figure 15 provides additional information as to the impact of research and development upon the growth and viability of various organizations which can be classified as high technology, innovative and mature. In this figure we have presented the average annual growth of these three groups of organizations or companies. The specific growth rates spanned the time frame 1969 through 1974.

Another issue which relates to the questions posed by the Subcommittees concerns company size. Without external support, only large organizations can afford the huge research investments needed to practice innovation in

specialized high technology areas. Yet in the U. S., businesses with fewer than 1000 employees produce 17 times as many major innovations per research dollar, while "medium-size" companies appear to be about 4 times as innovative.[*] Organizations such as Bell and IBM register a patent a day throughout the year, but are often either too inflexible to exploit innovations, or are inhibited from doing so by Federal regulations.

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[*] "The Science Olympics", op.cit.

our large high speed computer system design technology not just to Fujitsu, but to Japan, because of the national solidarity of outlook. Japan has an integrated national policy designed to support its role as a modern industrial leader, and administered by MITI, the Ministry of International Trade and Industry. Because of this philosophy, there is no clear distinction between one firm and "Japan Inc." as far as relations with other nations are concerned.*

A second example is the LITEX light bulb case, where the inventor, Don Hollister, could not find funding for his new energy-conserving light bulb. The major U. S. manufacturers of light bulbs apparently were not interested in breaking down their production lines in their plants and starting a competitive business. Since venture capital was not available, in this instance the government intervened. ERDA (now the Department of Energy) agreed to underwrite the research and development costs ($310,000). The Government owns the patent, but Hollister has free licensing and use rights provided he exercises them. Otherwise, the patent lapses (similar to provisions of the Thornton Bill**) and the patent enters the public domain.

The third example is more general. It concerns the U. S. aircraft industry and its competitive position in the world market.***

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*See e.g. Oshima, Keichi, "Technology Transfer in Japan", in Cetron, M. J., H. F. Davidson and J. D. Goldhar (Eds.) Technology Transfer (Leiden, The Netherlands: Noordhoff, 1974).

**HR 6249 (95th Congress, First Session, 1977).

***A Study of How Technology Transfer Affects the Competitive Position of the United States in the World Aviation Market; Forecasting International, Ltd., Arlington, Va.; 1972; and A Study of the Key Aspects of Foreign Civil Aviation Competition; Forecasting International, Ltd., Arlington, Va.; 1976.

> DC-9. Other competition in this category is Britain's Rolls-Royce which is trying to put together an engine consortium with French, German, Swedish, Italian and Belgian manufacturers.*

The penetration of the American makret can take several forms. Not only can the foreign organization sell to American firms, it can invest and obtain access to the technology via that approach. A very insightful analysis of this area was published in 1971 by Business International S.A.** In that report, the author examines the value to the European organization of investing in the U. S.

> The biggest reason for the greatly expanded and expanding European corporate investment in the U. S. lies in the attractions of the market -- its size, its profitability, its research and development stream, its new products and industries, its new process development and applications engineering. As one group of observers have put it as regards the office equipment, electronic components, and computer industries: "Operating on the American market is no longer the natural consequence of success on other markets, but a precondition of success on the world market."
>
> Manufacturing in the U. S. brings far quicker and far closer access to the innovative stimuli of the U. S. business environment. The U. S. has played the role of technological and marketing bellwether for Europe and the world throughout the postwar era. True, the U. S. has no monopoly on invention or discovery of new products and processes. However, of 110 postwar first commercial introductions ("innovations") qualified as "significant" by the OECD***, 74 were first commercialized in the U. S. and practically all 74 were first marketed by U. S.-owned firms.

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*Cetron, M. J. and James L. Duda; "International Technology Transfer in One Industry - Aircraft", in Cetron, M. J., H. F. Davidson and J. D. Goldhar (Eds.) Technology Transfer (Leiden, The Netherlands: Noordhoff, 1974).

**"European Business Strategies in the United States"; Business International S.A., Geneva, Switzerland; 1971.

***Organization for Economic Cooperation and Development.

The majority of large European companies with U.S. operations are in relatively high-technology industries. 21 of the 49 firms examined - or nearly half - are in the "secteurs de pointe" in which Jean-Jacques Servan-Schreiber so feared American domination of European industry. These sectors are chemicals, pharmaceuticals, machinery, and electrical machinery. The average percentage of sales revenue spent by the 49 firms on research and development was an impressive 3.7%, without doubt a figure far above that of European companies not investing in the U.S. Indeed, if one compares this figure with the data available on most international U.S. corporations, it is still high.

Not only do European companies investing in the U.S. seem to have more technological competence than other European companies, but, within the former group, those companies that spend heavily on research and devlopment have done much better in terms of sales growth in the U.S. than those that do not. There is a significant correlation (.67) between the percentage of total revenue which companies in our sample spend on R&D and their rate of sales growth in the U.S. market between 1965 and 1969.* Almost all the European companies in our study that spent less than 1% of their total group sales revenue on R&D had stagnant or negative growth rates in the U.S. during those five years. Also, there appeared to be a relationship between total group revenue spent on R&D and U.S. profit growth over the 1965-69 period (the correlation coefficient was .7 for 10 companies for which we had sufficient information).

The primary reason for European companies' preference for wholly owned ventures in the U.S. (and incidentally for the high joint-venture divorce rate) seems to be related to the nature of the U.S. market. The desirability, perhaps the necessity, for a European company to do R&D in the U.S. has already been mentioned. Yet, insofar as "the management of technical innovation is much more than the maintenance of an R&D laboratory" but is rather "a corporate-wide task...too important to be left to any specialized functional department*... the subsidiary's response to the ever-changing U.S. market may require a closer coordination between marketing and R&D than is possible with a joint-venture relationship.

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*Based on 23 companies for which data were available. The reader should be warned that this and other correlations could be the result of other factors that, for one or another reason, could not be examined. They should be interpreted in the context of other qualitative evidence presented.

the advance of technology by investing money primarily in joint R&D ventures with industrial firms and also with private investors, and receives a fair commercial return on its investment. The Government gets a portion of the business and a percentage of the profits, and also has a seat on the Board of Directors. The profits derived from these ventures are reinvested in other high risk technological ventures. Two of the noteworthy successful projects were the Hovercraft and cephalosporins, one of the most significant groups of antibiotics discovered since penicillin. The latter was one of the largest royalty earners ever to have emerged from academic research, and represents an excellent example of the type of basic invention that NRDC was expected to handle when it was established. Not only has the Crown's initial investment been repaid but the revolving funds have brought about the funding of many other R&D projects in high risk technology. These include major contributions to the establishment of the electronic computer industry; development of selective herbicides; development and production of the first high speed linear motor hovertrain and of the first large superconducting electric motor; extensive research and development of fuel cells later used as the basis for the power plant in the Apollo moon-landing program; etc., etc.*

Attempts have been made to evaluate contributions of NRDC-supported innovations at the national level but appropriate techniques of measurement are still controversial. The Corporation believes that, unlike other

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*<u>Evidence Offered to the Committee to Review the Functioning of Financial Institutions</u> (The Wilson Committee), (London, England: NRDC, 1978).

sources of venture capital, its success will not be judged solely by reference to its balance sheet. It's aim is to continue to create new business opportunities in the U. K. from the research work and inventions available to it, with increased employment prospects and foreign currency earnings from exports or license income. The total NRDC investment in both private and institutional support is not large; the rationale is that:

> The cost of most of the civil development work in this country will continue to be met out of industry's own resources but there may be cases where individual firms are unable to undertake, entirely at their own expense, the development of potentially valuable projects. In the export field the need for the United Kingdom to develop and market technically advanced products against strong international competition puts a heavy development burden on much of the country's manufacturing industry. In such circumstances there may be merit in a collaboration between industry and NRDC.
>
> It is a natural consequence of the Corporation's statutory functions that it is prepared to undertake projects where the degree of risk is greater than that which a commercial undertaking would regard as justified.*

Having operated at a deficit for its first 27 years, the Corporation for the first time in 1975-76 was able to carry forward a net surplus. The total investment in external R&D support over that period (1949-76) was 48.2 million pounds sterling (about $87.4M at current exchange rates).** In 1977 alone it is estimated that the gross amount of new industrial production which the NRDC helped to generate was 100 million pounds sterling ($181.25M), with a ten year accumulated total of 600 million

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* National Research Development Corporation: An Introduction (NRDC, London, October 1970).

** 27th Annual Report and Statement of Accounts 1975-76 (London, England: NRDC, 1976).

Although generalizations are perilous, the case of a company that had a joint venture with its one-time U.S. importing agent during the first few years in which it manufactured in the U.S. seems typical. Prior to developing its own marketing competence under its own ownership umbrella, this subsidiary was effectively cut off from new developments in its marketplace and was not able to get information about new applications for the particular product it produced. After buying out its partner's sales network, it was able to reintegrate the marketing and R&D functions in the U.S., and went from rather dismal failure to quite considerable success over the subsequent five years.

Acquisition seems to provide the quickest way to learn U.S. technology and marketing skills that are new to a European group. This was a key reason for Plessey's acquisition of the U.S. company Alloys Unlimited. The acquisition by a European oil company of a small U.S. refinery had a similar motivation - but this time for purposes of learning marketing skills rather than technological skills. The European firm's executives remarked that they felt, in order to be a viable worldwide petroleum company, they had to learn marketing in the market where most of their major competitors came from. The company did not feel that its marketing was strong enough to enter the U.S. first by setting up an exploration company and then gradually working its way into competition in refining and distribution with other U.S. petroleum companies.

A pharmaceutical company, which originally entered the U.S. shortly after World War II by forming its own subsidiary, noted that it had recently taken over 100% of a U.S. hospital supply company. The company indicated that as far as possible it preferred to avoid acquisitions "and the digestion problems that acquisitions usually cause," but that in this particular case it felt that the pharmaceutical business was changing so rapidly that it could not take the time to learn medical electronics and hospital servicing without making such an acquisition.

One experiment designed to address the problem of technological lag and insufficiency of funds is the National Research Development Corporation (NRDC) in the United Kingdom. This is an independent public corporation, financed by government loans, established in 1948 under the Development of Inventions Act whereby new high risk R&D ventures can be funded. The fields covered are the biosciences, industrial chemistry, scientific equipment, mechanical engineering, production engineering, electrical engineering, electronics, computers and automation. NRDC assists the advance

Being inside the fast-changing and competitive U.S. market brings two advantages. First, new developments can be transmitted more rapidly to the European parent company, so that it can compete with U.S.-based and other European firms as new products and methods are introduced in Europe. Second, a corporate lead in high-income, labor-saving products in the U.S. prepares a European firm for competitive battles in Europe, as European markets take on "U.S." characteristics.

A good many European managers admit the need to learn-by-doing in the U.S. in order to face what U.S. companies (or more daring or lucky European competitors with U.S. operations) might employ on the European market in future.

Olivetti is one company that has not hidden its desire to learn from U.S. marketing and technology. Plessey is another European group that has publicly stated its desire to learn from U.S. practice. In its proposal to shareholders for the acquisition of the U.S. firm Alloys Unlimited, Plessey stated that the acquisition would allow it to "acquire immediately a number of products and know-how which are important to our successful development." Plessey's deputy chairman notes that it "would be uneconomic for us or any other European manufacturer to learn (on his own) the skills evident in the Alloys organization."

A similar rationale underlies part of Unilever's long-standing interest in U.S. operations. And managers of one European petroleum company commented that "in order to be really successful in Europe and elsewhere, we have to compete in the market where the greatest petroleum marketing advances are being made. We have to compete in the U.S. by direct investment operations because the quota system prevents us from simply exporting to the States."

In all, nearly 50% of the European company managers interviewed in this study emphasized the importance of being in the U.S. in order to "feed back" technical or marketing skills to the mother company.

In one of the most notable cases of a significant product breakthrough by a European firm in its U.S. subsidiary - Sandvik Steel's development of "throwaway" carbide cutting edges - perhaps the most significant factor was the fact that the Sandvik group's development director at headquarters had himself worked for two years in the U.S. and was receptive to new product improvements. He was able to convince group management of the usefulness of transferring this innovation from the U.S. to European operations. A development team from headquarters was sent to the U.S. to work with the U.S. R&D group and further develop the new product. These improvements have accounted for a great deal of Sandvik's impressive growth during the last decade and now account for no less than 40% of the group's worldwide sales.

> In the past (since 1925) the United States has contributed most of the significant technological advances in the field. Although 22% of the ideas for advances originated in Europe, less than 5% were implemented by European countries first. Clearly, the U. S. is very efficient at taking a working prototype and incorporating it into an actual flying component for military and commercial use. It is in making the transition from a model to a successful in-service system that the U. S. is particularly capable.

In order for a country to adapt a technology developed elsewhere, the process of technology transfer is of infinite importance. It is a well-known fact that the acceptance, production and utilization of an advancement is often delayed for long periods of time after the initial development of that advancement. The effects of the U. S. ability rapidly to apply these technical advances has contributed significantly to increases in performance capability of U. S. aircraft. In the past this has resulted in an increasingly advantageous market position for the United States.

The cancellations of both the SST and B-1 efforts have contributed to an erosion of our previous position. The recent sale of the French A-300's (AIRBUS) to Eastern Airlines indicates that the American aircraft industry may be on the verge of losing its monopoly here in the States in the medium haul aircraft area.

> U.S. aerospace firms are forming joint ventures with foreign countries. Boeing will join with Japan on a $600 million venture to build a small (150-200 passenger) wide-bodied, low-noise, short takeoff airbus for use on domestic Japanese routes. The General Electric Co. has joined forces with SNECMA, owned by the French government, to produce the CFM 56 aircraft engine for use in STOL aircraft. Pratt & Whitney will join forces with a German consortium, MTU, and an Italian group formed by Fiat and Alfa Romeo to produce the JTIOD, a competitive engine. These engines will compete to power the next generation of commercial aircraft replacing the Boeing 727 and 737 and the McDonnell-Douglas

8. Problem Summary

Let us examine the problem from a different standpoint -- what are the effects of the lack of adequate funding? Several examples and some quotations from competitive nations may help to place in proper focus the more important aspects of the subject.

Some consequences of the lack of available research funds within the U. S. will serve as typical case-studies. The first of these involved Dr. Amdahl, a computer research scientist who worked for IBM, having design responsibilities for IBM models 704, 709 and 7030, and who managed the architectural planning of IBM System 360. Amdahl left IBM in order to pursue a proposed design of a future large scale system, which would have involved a radical change from IBM's then "present generation" computers.

Since Dr. Amdahl believed he had a technological idea whose time had come, he established his own firm in 1970 and when sufficient financing was not available from American firms, or venture capital sources, he proceeded to negotiate financing from a Japanese Company, Fujitsu, which now owns 28% of the stock. Some domestic support was provided by a Chicago business development firm, Heizer Corporation, which owns 23%. The Board of Directors controls 8%. First revenues were recorded in late 1975 for the 470 V/6 computer which competes with the larger, faster IBM System 370's. By 1977, Amdahl announced a net income after taxes of $27 million, on a turnover of $189 million -- a better profit rate than that shown by the industry as a whole.* The need for foreign financing effectively transferred

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*"Europe's Chance of a Computer Revolution", Business International, The Economist, April 22, 1979, pp. 105, 106.

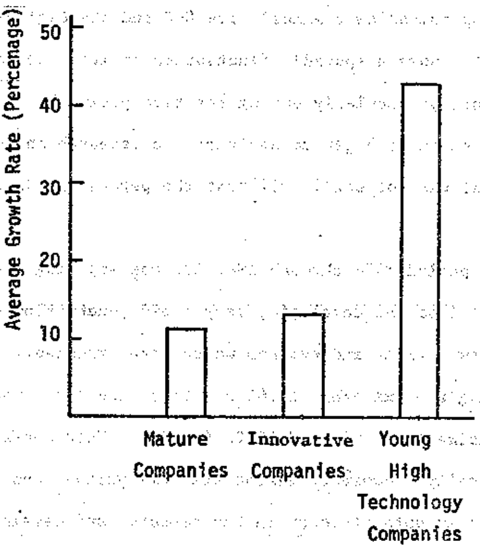

Figure 15. Comparison of Several Typical Companies - Annual Average Growth Versus Technological Classification From 1969 through 1977

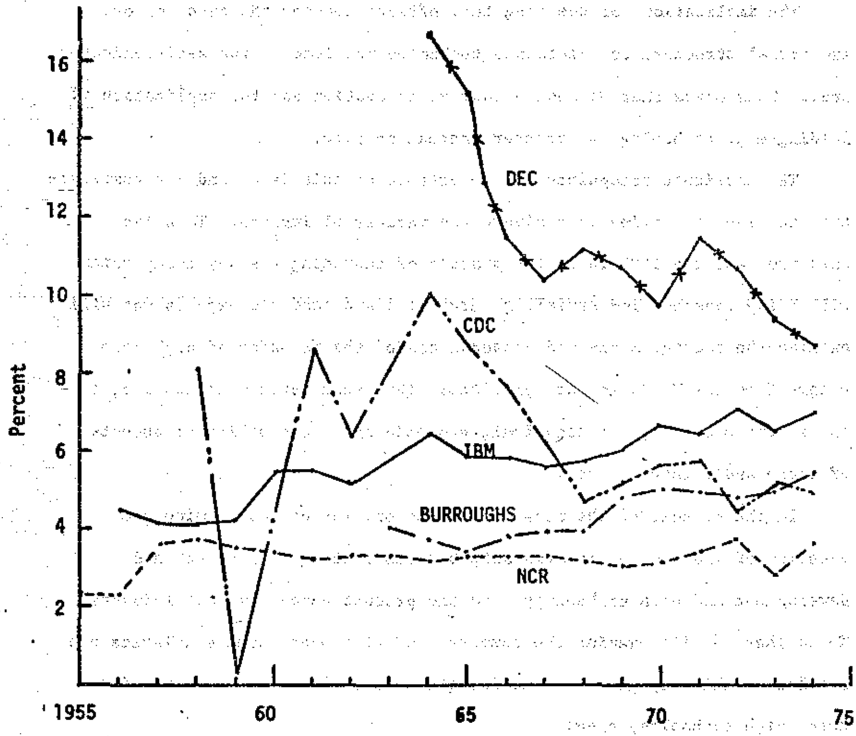

Figure 14. Computer Company R & D Investment as a Percentage of Revenue

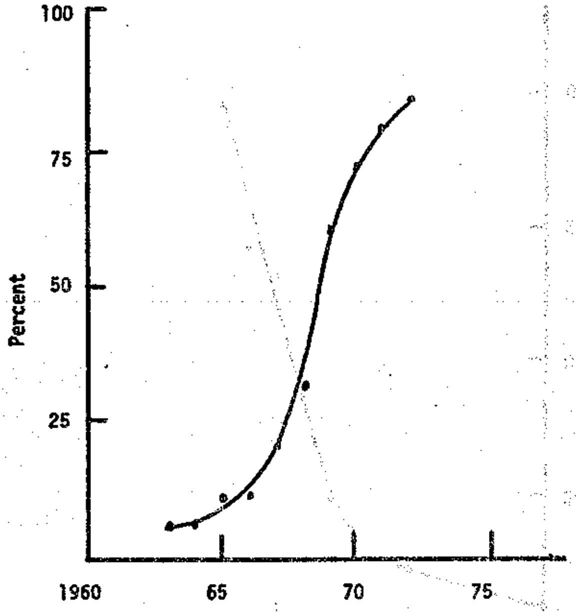

Figure 13. Cumulative Percentage of U.S. Semiconductor Companies Employing Off-Shore Assembly Facilities

companies begin to establish overseas operations. This is shown in Figure 12 which shows the number of firms who established overseas operations. Note that this number moved very rapidly from approximately 15 or 20 in 1966, to almost 100 in 1971. Further, we can examine the actual investment in overseas assembly facilities by the same semi-conductor industry. In Figure 13 we see the number of firms as a percentage of the total who established overseas assembly facilities. Starting in 1963 a very rapid development began of new overseas assembly plants by the semi-conductor industry, which reached a level of approximately 80% in 1972. Thus, most assembly or a significant portion of the assembly of semi-conductor products is currently being performed overseas by subsidiaries and joint ventures of U. S. semi-conductor organizations.

Several counterbalancing consequences of this action can be identified. On the positive side, the establishment of overseas production facilities has in several cases preempted the establishment of Japanese semi-conductor companies of production facilities in the area, and has also given the U. S. semi-conductor industry a local sales advantage. A second positive effect -- resulting from one of the probable primary reasons for the overseas movement, the availability of a large, semi-skilled labor force -- was the containment of total costs, resulting in consumer prices lower than could be achieved with U. S. production.

On the other side of the ledger, we must note the loss of employment opportunities here in the U. S. (at least in the short run) and the loss of national income (in the longer run) due to:

a. diversion of profits and tax income, and

b. establishment of potential competitive capability (through the transfer of the technology).

	Contribution in Billions of Current Dollars			
	1960	1965	1970	1971
High technology manufactured goods	+6.6	+9.1	+9.6	+8.3
Agricultural products	+1.0	+2.1	+1.5	+1.9
Low technology manufactured goods	-0.9	-2.9	-6.2	-8.3
Raw materials	-1.7	-2.8	-2.5	-4.1

Table 3. Contribution to the U.S. Balance of Payments by Industrial Segments

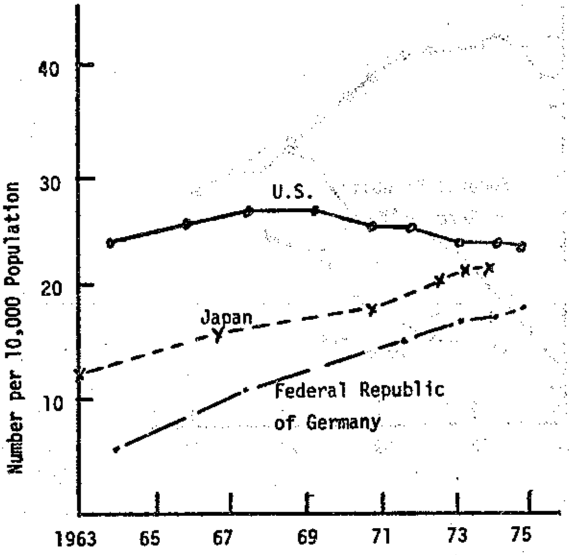

Figure 11. Scientists and Engineers Engaged in Research and Development

trade balance. The significance of this closing of the gap confirms the data in Horn's article, and indicates that we will shortly be faced with a competitor who is technologically on a par with the United States.

This raises the question of where are specific U. S. industries in relation to high technology development or the generation of high technology products?

As previously noted, because of the area of interest of the IEEE, we are restricting our examination to three major segments of the U. S. industrial base in which we currently maintain a lead. These are electronics and electrical equipment in general, the computer field specifically, as well as the aircraft industry.

In the broadest sense we must examine the inputs to the high technology segment of industry, by looking at the research and development expenditures as a percentage of the GNP (see Figure 10) as well as the number of scientists and engineers employed in the research and development areas, which is portrayed in Figure 11. Note that both of these Figures include the area of defense-related R&D, and this fact must be borne in mind in their interpretation. Half the total government outlay for R&D in the U. S. is related to defense, whereas the comparable figures for FRG and Japan are 11% and 2% respectively. The commercial emphasis in both Japan and Germany is paying off. These countries have led a huge increase in the number of foreign inventions being patented in the U. S.,* and by the addition of

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* Technology Assessment and Forecast, 7th Report (Washington, D. C.: U. S. Department of Commerce Patent and Trademark Office, March 1977).

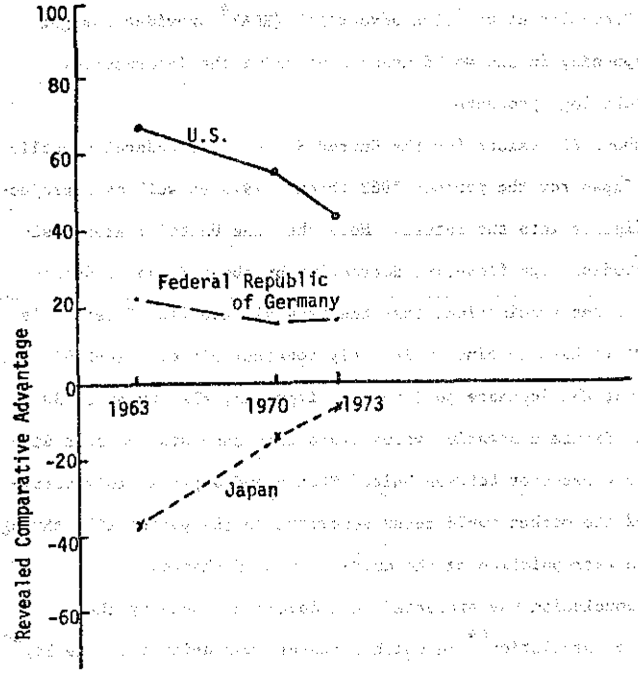

Figure 8. Revealed Comparative Advantage* Versus Time, for the U.S., Federal Republic Of Germany and Japan

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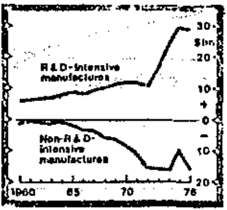
[*] This indicator measures the extent to which foreign trade surpluses (deficits) in one product group diverge from the trade position of this country in total manufactured goods. The measure has been normed so that it can assume values between + 100 and -100. High positive values of the measure indicate a high international competitiveness. For method of calculation the reader is referred to:

Horn, Ernst-Jurgen, "International Trade and Technological Innovation: The German Position Vis-a-Vis Other Developed Market Economies", in Karl A. Stroetmann (Ed.) Innovation, Economic Change and Technology Policies, Bonn, Germany, 1976, page 144 et seq.

Figure 7

U. S. R&D TRADE BALANCE*



*(Exports less imports).

Source: National Science Foundation Indicators, as depicted in "The Science Olympics", Business Brief, <u>The Economist</u>, May 20, 1978, pp. 86, 87.

goods, we see in Figure 6 that the United States' position in the world market has improved only slowly during the past five years. The position of the Federal Republic of Germany has remained relatively stable over this total period. On the other hand the Japanese have increased their portion of this export market from 6.5% in 1960 to 15% in 1978. The steady increase in Japan's export of manufactured products is significant and appears to be far more important than the previous penetration by Japan of the total export market. In particular, Japan's production of consumer electronics has increased by a factor of five over the past 10 years, and 62% of the 1976 output was exported ($4.8 billion),* 30% to the U. S.

Data become more difficult to obtain when we focus upon high technology and its impact upon exports and world trade. As shown in Figure 7, this is the only area in which the U. S. has not only maintained but increased its trade balance. A recent symposium** on "Innovation, Economic Change and Technology Policies" provides some insights in this area. This symposium, sponsored in part by the National Bureau of Standards, contains several presentations which provide some insights into the problem and possible solutions to that problem. Of particular note is a paper presented by Ernst-Jurgen Horn (pages 129-147), which was cited earlier.

Horn has developed a measure of the significance of high technology products upon the international competitiveness of nations. This measure,

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*"Japan's New Electronics Goodies", Business Brief, The Economist, April 22, 1978, pp. 84, 85.

**Stroetmann, Karl A. (Ed.) Innovation, Economic Change and Technology Policies (Bonn, Germany, 1976).

from 3.3% GNP to 2.6%, and by 1976 was down to 2.2%. The U. S. figure also includes about 50% for defense-related R&D, which has limited "spill-over" to the commercial sector.

Gross expenditure on research and development (as a percentage of GNP) and gross research and development expenditure per capita also correlate highly with relative market share for research intensive products. Thus we can use research and development expenditures as a rough measure of performance in trade in research intensive products. In general, such studies as Horn's have shown research and development activity to be the most important determinant of the structural pattern of international competitiveness. The influence of the research and development variable in the U. S. appeared to be even stronger than in the case of Germany, with which it was compared.*

At the broadest level the relative position of the U. S. in the world export market between 1960 and 1976 is shown in Figure 5. During this period we can see that, in round terms, the U. S. share has dropped from 18% in 1960 to 12% in 1976, while that of the Federal Republic of Germany has moved slightly upward from 10% to 11% of the total world market. On the other hand we find that the Japanese have improved their position from 4% of the total market in 1960 to 7.5% in 1976, approximately doubling their total export share.

This figure includes not only products based upon high technology and mature technology but also the exporting of raw materials, etc. It is useful only for presenting a broad overview. Focusing upon manufactured

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*U. S. Tariff Commission figures, and Horn, Ernst-Jurgen, op. cit.

7. The Current U. S. Status

There is no standard equation nor set of tables that can be employed to determine our current achievements in the application of technology to improving either the national well-being or the U. S. position in the export trade arena. Further, and probably of even greater importance, statistics that could be applied to examine this question are scattered and in some cases imperfect. However, we can begin to develop a feeling and in some cases gain both insights and indications by examining the information and data that are available. According to the product cycle hypothesis discussed in Section 5, innovative activities of countries depend on per capita income as a measure of the stage of the country in the development process. A study of 19 OECD member countries[*] showed a significant correlation between expenditure on research and development as a percentage of GNP, and per capita income. (At the level of the corporation, Mansfield[**] has demonstrated that a high level of research and development expenditure leads to increased productivity, and thence to improved gross profits, which permits and again tends to increase research and development funds. This relationship is depicted in Figure 4.) In response to this perceived relationship, both the U. S. and U. K. since 1945 have consistently spent over 2% of GNP on R&D.[***] However, German expenditures increased from 1.4% of GNP in 1963 to 2.1% in 1971, whereas U. S. expenditure dropped

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[*] Horn, Ernst-Jurgen, op.cit.

[**] Mansfield, E., "Research and Development and Economic Growth/Productivity", National Science Foundation Colloquium (Washington, D. C.: GPO, 1971).

[***] "The Science Olympics", loc. cit.

6. The United States Posture

Whatever the relative economic advantages and disadvantages, it appears to be the consensus of both government and industry opinion that the U. S. should strive to retain technological leadership, and both interests are concerned that the U. S. is unduly eroding its position by exporting technology without adequate safeguards/recompense. The concern of governmental policy-makers is manifested by such meetings as this present hearing, under the joint auspices of the Senate Science, Technology and Space Subcommittee and the International Finance Subcommittee. Other aspects of the problem are being examined by a House Subcommittee, the Congressional Office of Technology Assessment, the National Security Council, the Office of Science and Technology Policy, the International Trade Commission, the National Science Foundation, and the departments of State, Defense, Treasury, Commerce and Labor. In view of the widespread interest, we are hopeful that the outcome will be a systematic program designed to establish U. S. priorities and to define a responsive approach for achieving identified objectives.

Industrial representatives are also very much aware that a review of our policies and practices regarding the creation and transfer of high technology is an urgent requirement. Foreign products incorporating technology acquired from the U. S. are beating out American productions in markets around the world -- including the U. S. itself. Because of this, U. S. manufacturers are harvesting too little of the return from their own

> of new technologies, e.g. in R&D, and in the production of goods during the early phases of the cycle. On the one hand, these countries are relatively abundantly endowed with skilled manpower which is intensively used in the above mentioned activities and whose availability determines whether these activities can or cannot take place. Furthermore, risk capital to finance R&D activities is relatively abundant. On the other hand, a high per capita income provides domestic markets capable of absorbing new products, e.g. new consumer goods, labour-saving household devices and new labour-saving investment goods. When products become more mature, highly qualified manpower becomes less critical and the other factors of production gain influence in determining comparative advantage. In the course of increasing maturation of products or processes of production the comparative advantage shifts to less advanced industrial countries which can already handle the technology in question and are able to compete successfully with the innovating country because they enjoy the advantage of lower wages.* In the late phases of the cycle when products are mature and standardized, comparative advantage shifts to the developing countries.

Even in the high technology phase, there are advantages in occupying second place, in that the high risks and inevitable "false steps" will be taken by the leader. A nation which can maintain a minimal gap** can then be prepared to <u>buy</u> the products of leading edge technology, but produce and sell slightly less advanced products where the margins are less, but the volume is much greater. For example, Japan buys avionics and sells color television.

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*Haitani, K., "Low Wages, Productive Efficiency, and Comparative Advantage". In: <u>Kyklos</u>, Vol. 24 (1971).

**See for example
Hufbauer, G.C., <u>Synthetic Materials and the Theory of International Trade</u> (Cambridge, Mass.: Harvard University Press, 1966)
and
Vernon, Raymond (Ed.), <u>Big Business and the State</u> (Cambridge, Mass.: Harvard University Press, 1974)

The need to provide acceptable technical service requires that the local market supplier must understand the operation of the product, its virtues and limitations, and extends beyond this to require knowledge of the design and fabrication of the product as well as its mode of functioning such that one is able to diagnose field difficulties and make the requisite repairs or modifications.*

The transfer of technology and of intellectual property is perhaps accomplished most readily through the mobility of people. This process occurs not only through hiring practices deliberately designed to acquire advance technological information, but through the routine day-to-day mobility of the work force within and between companies, industries and nations.

It is of course undeniable that technology transfer is facilitated by foreign assembly, foreign manufacture of components, and complete foreign manufacture. But it is essential to understand that the absence of these may have other negative effects for the industry involved, including both the loss of foreign markets and the creation of new sources of foreign competition, and even so will not result in protection of the basic technology. The dissemination of technology cannot be stopped: it can only be controlled and slowed down.**

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* Steele, Lowell W., The Economics of International Technology Transfer, in Karl A. Stroetmann (Ed.) Innovation, Economic Change and Technology Policies, Bonn, Germany, 1976.

** How Technology Transfer Affects the Competitive Position of the U. S. in the World Aviation Market (Arlington, Va.: Forecasting International, Ltd., March 3, 1972).

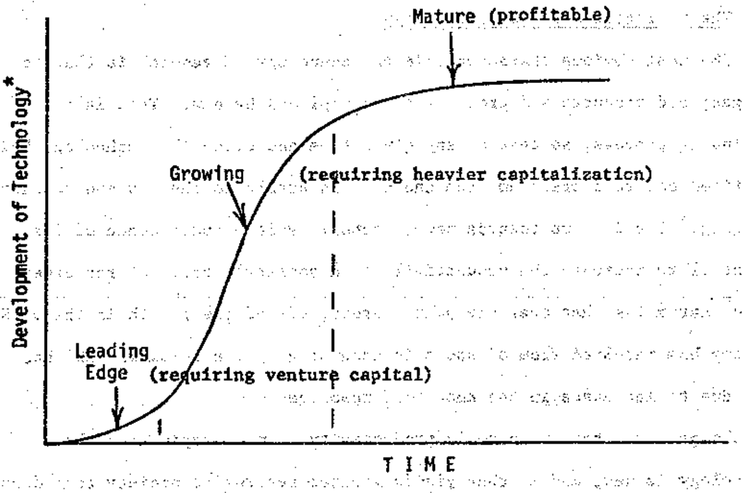

Figure 3. Technology Growth Curve

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*A typical measure is the percentage of firms in a particular product area which adopt the new technology.

However, the direct economic gains on the international scene resulting from the sale of technology-based products have been declining rapidly. In the area of semi-conductor electronics, where U. S. corporations have made nearly every technological breakthrough, the U. S. trade balance has been negative since 1968, and now stands at minus $2 billion, excluding only one category -- that of computers -- in which the U. S. retains a favorable balance.* Further comments concerning this particular situation will be made below, in section 6. An OECD report** cites the computer industry as one of only three areas in which the U. S. retains its technological lead, in terms of net export of the technology base. (The other two are aerospace and heavy electronics.)

Other studies have confirmed that the competitive strength of U. S. manufacturing industries in world markets is closely correlated with the performance in technological innovation.*** However, with regard to particular products, technological leads only temporarily provide comparative advantages, for the duration of the so-called imitation lag.****

In the following section, therefore, we will examine the characteristics of technology and its evolution, to assist in determining an optimum policy in controlling and/or capitalizing upon its development, application and dissemination.

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*Boretsky, Michael, U. S. Department of Commerce, as quoted in Fortune, May 22, 1978, p. 108.

**Gaps in Technology, Organization for Economic Cooperation and Development, 1970.

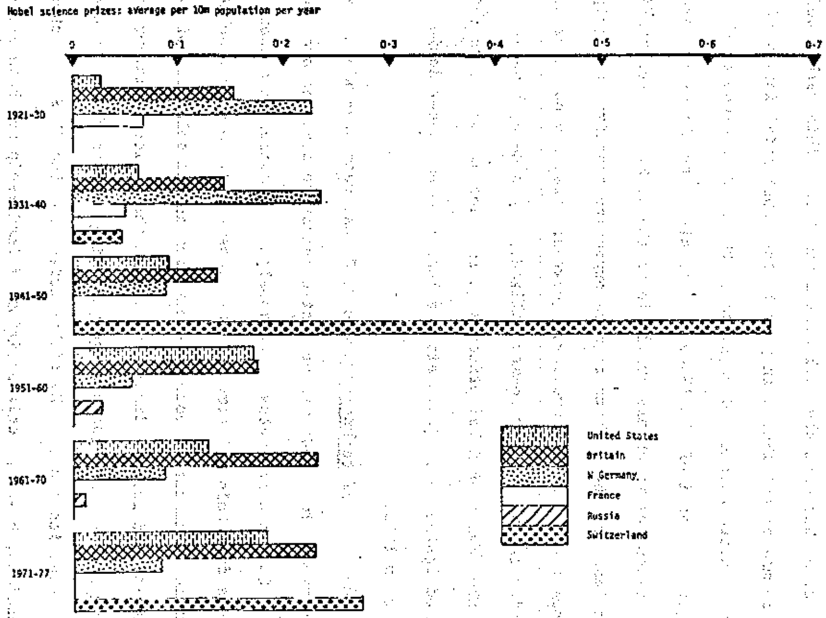
***See for example: Vernon, R., "International Investment and International Trade in the Product Cycle". In: Quarterly Journal of Economics, Vol. 80 (1966); Keesing, D. B., "The Impact of Research and Development on United States Trade". In: Journal of Political Economy, Vol. 75 (1967); Baldwin, R. E., "Determinants of the Commodity Structure of U. S. Trade". In: American Economic Review, Vol. 61 (1971).

****Posner, M. V., "International Trade and Technical Change". In: Oxford Economic Papers, Vol. 13 (1961).

countries. In the four high technology industries, aerospace, heavy electronics (including computers), chemicals and pharmaceuticals, the two areas where we lead are aerospace and electronics, where significant amounts of monies are funneled through government agencies by the Department of Defense, NASA, HEW, Department of Energy, etc. In the other two industries, chemistry and pharmaceuticals, since they are mature technological industries the bulk of their money comes from internal corporate funds or the stock market. This provides some indication that when the government funnels R&D money to private firms (as in electronics and aerospace), the industry prospers and we have a technological lead.

Figure 1

NOBEL SCIENCE PRIZES: AVERAGE PER 10 M POPULATION PER YEAR



Source: National Science Foundation, Science Indicators, as depicted in "The Science of Olympics", Business Brief, The Economist, May 20, 1978, pp. 86, 87.

Table 1

Nobel Prize Awards, by Country, 1901-1977

1901-1930		1931-1960		1961-1977	
Germany	27	United States	33	United States	53
England	15	England	18	England	20
France	11	Germany	14	Germany	6
Sweden	6	Switzerland	5	France	5
United States	6	Austria	4	Sweden	4
Holland	6	Sweden	2	USSR	3
Denmark	4	Italy	2	Austria	2
Austria	3	USSR	2	Belgium	2
				Denmark	2
				Argentina	1
				Australia	1
				Canada	1
				Italy	1
				Norway	1

Table 2

Selected Invention and Patent Rates, by Country*

	A Total Inventions on Selected List 1600-Present	B Average Annual Patenting Rate - 1930-1939	C** Annual Patenting Rate - 1975
United States	203	38,300	56,509
Great Britain	58	9,050	12,322
Germany	32	14,600	37,733#
France	29	9,550	13,386
Italy	14	3,900	—
Switzerland	—	3,130	4,369
Sweden	4	1,030	9,100##

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*Bode, H., Basic Research and National Goals, (Washington, D. C.: National Academy of Sciences, March 1965).

**Private Communication, U. S. Department of Commerce, Patent and Trademark Office, May 1978.

#West Germany only (FRG).

##This is made up of 7,233 foreign filings, and only 1867 by Swedish nationals.

relationships between research, technology, and economic growth, and assist in the definition of the appropriate role of Government in improving the international technological and economic standing of the United States.

5. R&D investments can be increased by direct government funding of long-range mission-oriented research, and by tax policies directed toward the encouragement of private-sector support. The many other obstacles to the maintenance of U. S. leadership are addressed at length in the body of this document.

6. Foreign investment in U. S. firms, while increasing rapidly, is at present only a minor factor in the erosion of our technological lead. The resulting transfer of technology need not be harmful if we ourselves act promptly and positively to capture and protect potential markets. However the extent of such investment needs to be monitored and, if necessary, controlled by a central authority.

7. Again, U. S. exports of technology and high technology products are not necessarily detrimental to our international stature. A two-way flow, and a coherent national policy, are essential to our well-being. On the other hand, it should be noted that our society is becoming service/information oriented. The sale of knowledge must be placed on a business basis.

8. Licensing and joint ventures abroad can be beneficial to the U. S. if we can maintain the two-way flow of technological innovation. Potential exports are being lost due to the export of technology, but this need not be the case with careful planning at the national level.

9. Our recommendations for improving export performance in high technology goods and services are given at the end of this document. It is our contention that this needs to be considered as an intrinsic component of a total technology policy which recognizes the need for balance and negotiation at an international level.

LIST OF FIGURES

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Acknowledgment

This statement was developed with the assistance of various individuals both within and outside the formal organization of The Institute of Electrical and Electronics Engineers, and was approved at a meeting of its Board of Directors on May 23, 1978. I wish to acknowledge especially the contributions of:

Dr. A. Astin

Dr. M. J. Cetron

Ms. Audrey Clayton

Dr. George Foster

Mr. Norman Nisenoff

Mr. J. Rabinow

Dr. S. Raff

Bruno O. Weinschel,
Vice President,
Professional Activities

The GAO effort to introduce an improved classification structure for the Federal R&D budget.

As part of a planned GAO study on the impact of various Federal policies on industrial capital formation, we will review the interrelations among Federal R&D activity, private R&D activity, and industrial capital formation. This study will consider the direct impact of Federal tax, patent, and regulatory policies on private R&D expenditures. In addition, the impact of various Federal policies on the business environment and the effect of this environment on industrial R&D expenditures will be investigated. More specifically, we will analyze the effects of Federal regulatory and economic stabilization policies on how businessmen perceive the riskiness of their environment and how changes in these perceptions affect the level and allocation of their R&D expenditures.

We also plan to analyze the impact of the level and composition of Federal R&D expenditures on industrial R&D expenditures and industrial capital formation. In this effort, we will attempt to develop more effective methods for allocating Federal R&D expenditures.

States, our principal foreign competitors have well-developed government-directed programs and special institutional structures for overcoming barriers to diffusion of existing manufacturing technology and for advancing the state-of-the-art through coordinated research and development programs.

In addition to improving traditional manufacturing methods, computers and numerically controlled machines are changing both the management and the engineering technology of manufacturing. There are indications that manufacturing methods are about to change—not incrementally but radically. The changes are already taking place in other countries where the productivity-improving institutions and mechanisms were created to recover from the adverse effects of war.

Such institutions exploit, develop, and diffuse the new computer-integrated manufacturing systems and are well-designed to continue development of their nations' manufacturing productive capabilities faster than that of the United States. Their success is evidenced by their increasing share of the international markets—in some cases at the expense of our own manufacturers.

But our principal concern is for the future. Short-term benefits are possible through improved diffusion of the available technology. For long-term sustained productivity increases, R&D is necessary to find new methods and to refine existing technology so that it can be economically used outside the few highly capitalized, high-technology firms.

In the most successful foreign countries, both programs and institutional models have involved joint public and private efforts. The United States has no comparable national program, although several Federal agencies are interested in this subject. A new organization has been created which could provide the central focus and leadership. This agency is the National Center for Productivity and Quality of Working Life, established by the Congress in November 1975.

We have recommended that the Center take the lead in developing a national policy and appropriate means for achieving balanced productivity growth in the industrial manufacturing base. Further, we propose that the Center, in carrying out this recommendation, seek the cooperation and assistance of the Department of Commerce and other agencies. The expertise within the Department of Commerce, particularly in the National Bureau of Standards and the National Technical Information Service, would allow that Department to play a major role in providing technological leadership and support.

The combination of expertise of the Center and of the Department of Commerce and their close coordination with other public and private organizations can provide the much-needed focal point to coordinate all the disparate Government and private work in developing, standardizing, and diffusing manufacturing technology, and assist the emerging State and regional productivity organizations to advance manufacturing technology.

A number of specific functions should be embraced by this central focus and leadership. Three of the major ones are:

Collect and evaluate manufacturing technology information from all available sources and establish means for disseminating state of the art knowledge to potential users.

Foster the development and acquisition of new technology in various ways.

Analyze public policy options and formulate recommendations that will improve Government-industry cooperation in stimulating productivity improvement.

WHAT CAN WE DO?

What can we do to improve the climate for Government-industry cooperation? I have no panacea to alleviate the attitudinal constraints that continue to retard the development of a more constructive partnership between Government and industry. It behooves all of us—individually and collectively—to make extraordinary efforts to achieve better communication and mutual understanding of our respective needs and interrelated goals in the context of our total responsibilities and obligations.

Continued studies and publication of resulting reports clarifying the issues and alternatives should help improve understanding. An excellent example is the July 9, 1975, report by Robert Gilpin, "Technology Economic Growth, and International Competitiveness," report prepared for use by the Subcommittee on Economic Growth of the Joint Economic Committee. Another good example is the 1973 report, "Barriers to Innovation in Industry: Opportunities for Public Policy Changes," based on study sponsored by the National Science Foundation and performed as a joint effort by Industrial Research Institute and Arthur D. Little.

be served when private industrial contractors, with a few provisos, are granted exclusive licenses for commercial development.

When developing and marketing commercial products, industry naturally prefers to exercise its own discretion independent of any Government assistance or influence unless it needs help to deal with serious threats from foreign competition or another domestic enterprise which it believes is exercising unfair competition. Industry is particularly concerned about the constraints of Government regulations which tend to divert capital from innovative R&D to R&D and other investments necessary to comply with regulatory requirements. Furthermore, some multi-national corporations may not be inclined to share strategic information with the Government and to plan and conduct their business in such a manner as to assure harmony with the international objectives of the United States.

As a final attitudinal concern, there are many in both Government and industry who are unwilling to assume responsibility for what others would judge to be reasonable and necessary risks for investment in exploratory research and development when the payoff is uncertain in terms of time or economic return.

Many factors have been identified as real or tangible constraints that tend to cause a decline in technology innovation. Among these are the uncertainty of the economy, the high cost of capital, and the slowdown during the last few years in Federal spending for research and development.

The myriad of regulations established by both Federal and State governments affect the cost of doing business and may involve conflicting requirements imposed by different agencies. For example, in Federal procurement of conventional commercial products, the public would be served better in many cases by best-buy competition based on superior or innovative performance and life-cycle costs, rather than by the prevalent procurement practice which tends to favor the lowest bidder who offers products meeting acceptable quality or minimal specifications.

In the larger sense, criticism is levied that the Government has not established a consistent national policy and strategy for Government-industry relations to balance incentives and constraints and assure a favorable climate for technology innovation by private enterprise. This contrasts sharply with other nations, notably Japan and West Germany, that have policies and special institutional arrangements to foster industrial technology innovation and improved manufacturing productivity.

Part of this issue is the question of whether our antitrust laws, established primarily on a domestic basis, need to be reexamined in an economy which is becoming increasingly world interdependent in market relationships and competition. This question is highlighted by the increasing number and size of multinational corporations and the fact that foreign corporations are growing faster than U.S. corporations.

Most of the other industrialized nations have developed closer relationships between government and the private sector on capital formation and R&D directed to the private economy. This is an area in which we perhaps should explore new perspectives for Government-private sector interaction within the framework of American institutions.

Improved productivity and advances in science and technology cannot take place separately from other aspects of national policy; advances made in the laboratory and on the testing grounds require adequate financial support obviously. However, these advances can be similarly flawed if such support does not go hand-in-hand with policies developed which will make it possible to use and develop these innovations. The Internal Revenue Service, Securities and Exchange Commission, Justice Department, and Department of Commerce all must play a part. Too frequently, these organizations go their individual ways for their own reasons and possibly for even socially desirable purposes. This does not mean, however, that their actions will coincide with adequate accounting as to their impact and consequences for risk-taking and technological innovation.

There is currently no procedure for measuring the effect of these Government decisions on science and technology. Thus, industrial risk-takers lean toward hedging and zero-risk decisions. Innovation under these conditions can be, at best, incremental. Hopefully, the new Office of Science and Technology Policy will recognize that innovation must come as the result of total Government policy—not the more frequently narrowly construed concept of science and technology.

[38] W. S. Comanor, "Market Structure, Product Differentiation and Industrial Research," *Quarterly Journal of Economics*, 81(4) (November 1967-1968), pp. 639-657.

[39] J. Jewkes, D. Sawers and R. Stillerman, *The Sources of Invention* (New York: St. Martin's Press, 1959).

[40] Hamberg, "Invention," pp. 95-115.

[41] W. F. Mueller, "The Origins of the Basic Inventions Underlying DuPont's Major Product and Process Innovations, 1920-1950," *The Rate and Direction of Economic Activity*, NBER Conference Report (Princeton: Princeton University Press, 1962), pp. 323-346.

[42] Hamberg, *Essays*.

[43] Hamberg, "Size of Enterprise," p. 48.

[44] E. F. Schumacher, *Small is Beautiful* (New York: Harper and Row, 1975).

[45] W. S. Comanor, "Research and Technical Change in the Pharmaceutical Industry," *Review of Economics and Statistics*, 47(2) (May 1965), pp. 182-190.

[46] Hamberg, "Size of Enterprise."

[47] A. C. Cooper, "R and D Is More Efficient in Small Companies," *Harvard Business Review* (3) (May/June 1964), pp. 75-83.

[48] Conversation with Richard O. Zerbe Sr., Patent Agent for Monsanto Chemical Company.

[49] Schmookler, "Bigness, Fewness and Research."

[50] Hamberg, "Size of Enterprise."

[51] Pavitt and Wald, "Conditions for Success."

[52] Kamien and Schwartz, "Market Structure and Innovation: A Survey," p. 13.

[53] F. M. Scherer, *Industrial Market Structure*, Ch. 15-16.

[54] Ibid., p. 351.

[55] J. A. Schumpeter, *Capitalism, Socialism and Democracy*, Third Edition (New York: Harper and Row, 1950), Ch. VII and VIII.

[56] J. K. Galbraith, *American Capitalism* (Boston: Houghton-Mifflin, 1956, revised and edited), pp. 86-87.

[57] Schumpeter, *Capitalism*, pp. 84-85.

[58] Kamien and Schwartz, "Market Structure and Innovation," p. 14.

[59] Comanor, "Market Structure," pp. 639-657.

[60] Galbraith, *American Capitalism*, pp. 86-87.

[61] R. H. Coase, "The Nature of the Firm," *Economica* (November 1937), pp. 386-405.

[62] Ibid.

[63] Scherer, *Industrial Market*, p. 395.

[64] Ibid., p. 398.

[65] Ibid.

[4] Donald B. Kessing, "The Impact of Research and Development on United States Trade," *Journal of Political Economy* (February 1967), pp. 38-48.

[5] K. Pavitt and S. Wald, "The Conditions for Success in Technological Innovation" (Paris: OECP, 1971).

[6] W. Gruber, D. Mehta and R. Vernon, "The R and D Factor in International Trade and International Investment of U.S. Industries," *Journal of Political Economy* (February 1967), p. 22.

[7] Calculated from data in a newsletter published by Economic Evaluation Associates (Chicago: 1975). With such a small sample, even if the correlation were perfect, the chi square distribution barely would be significant at the 5 percent level.

[8] The R and D figures are from U.S. National Science Foundation, *National Patterns of R and D Reserves: Funds and Manpower in the United States,* Reports for years 1958-1975 (Washington, D.C.).

[9] In 1965, a sample of firms in important industries showed that companies with less than 1,000 employees accounted for only 5.2 percent of industry R and D expenditures. This had fallen from 7.0 percent in 1957.

[10] J. M. Blair, *Economic Concentration: Structure, Behavior and Public Policy* (New York: Harcourt, Brace, Jovanovich, 1972).

[11] M. Kamien and N. Schwartz, "Market Structure and Innovation: A Survey," *Journal of Economic Literature* 12 (1) (March 1975), pp. 1-37.

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[14] D. Hamberg, *Essays on the Economics of Research and Development* (New York: Random House, 1966); ________, "Invention in the Industrial Research Laboratory," *Journal of Political Economy* (April 1963), pp. 95-115; ________, "Size of Enterprise and Technical Change," *Antitrust Law on Economics* (1) (July/August 1967), pp. 43-51.

[15] W. J. Smith and D. Creamer, "R and D and Small Company Growth, A Statistical Review and Company Case Studies," *The Conference Board, Studies in Business Economics,* No. 102 (New York: National Industrial Conference Board, 1968).

[16] D. C. Dearborn, R. W. Kneznek and R. N. Anthony, *Spending for Industrial Research 1951-52* (Boston, Mass.: Harvard University, 1953).

[17] McConnell and Peterson, "Research and Development." These percentages refer actually to those firms responding to the questionnaire. My feeling is that firms with formal R and D programs would be more likely to respond. If this is correct, the true percentage of small firms engaging in formal R and D would be lower than the 38 percent reported, but those with informal R and D could be either higher or lower.

[18] Smith and Creamer, "R and D and Small Company," from combining NSF and Census data, found that only 4 percent of firms with less than 1,000 employees had R and D programs compared with about 57 percent for firms with between 1,000 and 4,999 employees and about 91 percent for companies with more than 5,000 employees. Their figures for the smallest class of firms are almost certainly too low. Possibly the combining of NSF and Census data introduced inconsistency into the sample in the lowest size class; they themselves recognize the possibility of inconsistency.

expected value of a patent would be greater, reflecting greater immunity from legal attack and from "patenting around." The courts should not be called upon to so often make the distinction between weak and strong patents and between viable and nonviable patents. This would require a more careful comparison of pending patent applications with existing patents and, perhaps, a separation of inventions into categories for separate treatment on the basis of their importance as in Germany.[63] These changes would require a greater Patent Office budget as well as more experienced personnel.

Another approach might be to allow suit for treble damages in patent infringement cases. This clearly would increase the bargaining power of patent holders and, in so far as smaller firms have a comparative advantage in patenting, would increase their bargaining position.

A final proposal for patent reform is considerably more radical. This is that the patent system, and/or the proposed direct award system, discriminate between firms on the basis on size. The patent rights of smaller firms could be defined more broadly and the life of its patents could be greater.

Larger firms undoubtedly will react with indignation to proposals along such lines. Yet they have a considerable appeal even on the basis of equity. Most governmental regulations are disproportionately expensive for smaller firms. Except for possibilities of not getting caught, there are clear economies of scale in dealing with government regulations and bureaucracy. The type of change proposed would help balance the effect of other regulations. Moreover, this country has always put a premium on smallness. Large concentration of power in any areas are quite rightly mistrusted. Policies calculated to recognize this set of values command a certain force of their own.

Firms on their own can effect reform. Firms themselves can, and do, make purely internal arrangements that promote an efficient allocation of R and D by size. Research units can attempt to duplicate these conditions associated with the smaller firm that are most productive. In fact, larger firms sometimes fund research efforts and have a minority stockholder position in relatively small firms headed by a highly creative inventor. Such an arrangement may create a better work atmosphere, but it

Presumably, barriers should be low enough to present threat of competition, but high enough so that immediate entry would not eliminate the rewards of invention too quickly. Such monopoly power would presumably deteriorate over time in accord with Schumpeter's notion of creative destruction.

Schumpeter's thesis regarding firm size (as distinguished from monopoly) was taken up by Galbraith:

"There is no more pleasant fiction than that technical change is the product of the matchless ingenuity of a small man forced by competition to employ his wits to better his neighbor. Unhappily, it is a fiction. Technical development has long since become the preserve of the scientist and engineer. Most of the cheap and simple have, to put it bluntly and unpersuasively, been made---. Because development is costly, it follows that it can be carried on only by a firm that has the resources which are associated with considerable size."[60]

Galbraith's statement about the demise of cheap and simple inventions is reminiscent of the late nineteenth century patent commissioner who resigned on the grounds that all the important inventions had been made. Every year thousands of simple and important inventions are made by small firms or by individuals. Penicillin, the Polaroid camera and electrostatic duplicating were perhaps not simple inventions, or discoveries, but even these were the product of the single inventor or small firm. What Galbraith is doing is confusing the inventive function with the development function. Galbraith's confusion would result in a failure to seek means to combine more effectively the inventive efficiency of the smaller firms with the development efficiency of the larger firms. To this subject we now turn.

The direction in which solutions lie can be seen by considering a perfectly efficient patent system, the absence of uncertainty, a perfect capital market and sufficiently low transactions costs. In this situation, one would find an optimal allocation of R and D tasks among firms. Activities leading to original invention would tend to be concentrated in smaller firms, and developmental activities would be concentrated among medium-size or larger firms. Smaller firms could sell or contract original inventions to larger firms in an efficient market setting and the allocation of resources devoted to the various aspects of R and D small firms, which is also a view held by Pavitt and Wald. In an examination of empirical evidence from the 1960's, they concluded that larger and smaller firms play complementary roles in innovation. Smaller firms concentrated on smaller-scale, specialized and sophisticated equipment and made major innovations after larger firms had let the opportunity slip away.[51] Pavitt and Wald also found that "opportunities for small firms tend to be greatest in the earliest stages of the product cycle, when economies of scale are relatively unimportant, market shares volatile, and rates of entry and failure high."[52]

This view of the complementary tasks of the large and small firm is also suggested by the detailed examination of the development of important inventions by Jewkes, Sawyers, Stillerman, and by the investigation of Mueller and by other studies. These investigations show (implicitly, as the point is sometimes overlooked by the authors) that the initial patentable idea, which is of course an essential step, is one much less expensive than the steps transforming the original idea into a form that is commercially useful and marketable. The expenses involved in the stages of development after the original invention are, more often than not, prohibitive for the smaller firm.[53]

The patentable concept of electrostatic machine copying was developed by one man, Carlson. Since this was a new process substantially different from existing processes, a relatively small company (Haloid) could develop the process successfully and become the leading producer (Xerox) in the new field.[54] This is to be contrasted with, say, an innovation that improves the performance of existing copiers. Discovery of such an improvement by a laboratory becomes somewhat more probable, but it is much more likely that the development of work necessary to convert the invention into a useful final product will be performed by a larger firm. Even the expense of certain types of initial inventions are beyond the means of smaller firms. What is uncertain is the extent to which capital constraints, inherent riskiness of invention and the large costs of development discourage inventiveness by smaller firms. Chances are that this is a problem of considerable magnitude.

Just recognizing the problem is an important step since current mythology obscures it. The proposition that smaller firms have a comparative advantage in invention, while medium-size firms are usually sufficiently

This general pattern is borne out by the questionnaire survey of Cooper[47] who interviewed twenty-five people with experience in research and development, primarily in chemicals and electronics, most of whom had managed development in both large and small companies. The estimates derived from these interviews indicated that large companies must spend from three to ten times as much as small ones to develop a particular product. The reasons for this are presented below.

First, the average competence of technical people in smaller firms is higher than in large firms. Greater freedom of a smaller company apparently is attractive; research personnel may own significant amounts of the stock of small companies so that the incentives for successful invention or innovation may be significantly greater; and small companies are less likely both to tolerate unproductive personnel and to hire unseasoned people. Although Conner does not comment on this, apparently greater productivity of R and D personnel in smaller plants derives in part from their higher salaries--either because they are more experienced or more competent, or because of their direct ownership which acts as an incentive to produce. Nevertheless, if Connor estimates are correct, it would seem that the additional expenses are more than offset by the increased productivity. In so far as the increased financial incentive increases productivity, one may wonder why large companies do not adopt some incentive system. An experienced patent agent with a large chemicalcompany suggests that this is true because in a large R and D organization such a system would restrict information flow within the company and create difficult rivalries and jealousies.[48]

Second, technical people are much more cost conscious. Somehow the small firm is better able to achieve an atmosphere in which technical personnel are left alone to pursue work and, because of the closer identification of the personnel with the company, the personnel place a high priority on the way their efforts contribute to the company's success.

Third, in the small company there is greater ease of communication and reduced problems of coordination. In smaller companies, technical personnel are more likely to be sensitive to the needs of the market because of closer contact with people concerned with this area. To be sure, these various advantages must be weighted against disadvantages of breadth of experience and specialization, but Connor's study indicates that the advantage lies with small companies.

Support for the thesis that large firms in concentrated industries show greater evidence of technical change is furnished by A. Phillips.[34] In general, Phillips found that those industries "which had large-scale producing units in 1904 had significantly greater rates of decrease in the number of wage earners per unit of output between 1899 and 1939 than did the other industries." Phillips' results are too facile because they probably do not measure the effects of large size and concentration on invention or development. Greater technological opportunities probably exist for capital-intensive firms so that their capital/labor ratio naturally would tend to grow more quickly over time. Thus, the casual influence probably runs from technology to concentration rather than the reverse, and is shown by Phillips' own subsequent work[35] and by studies by Scherer[36], Philips[37] and Comanor.[38] Scherer and Philips found that differences in the scientific knowledge base accounted for as much of the total variance in corporate R and D as did interfirm differences in corporate sales; Comanor's results were supportive of Scherer and Philips' conclusions.

INVENTIVENESS AND THE SMALLER FIRM

An important and cogent argument can be made that, from the social point of view, smaller firms should invest more than they do in R and D and that they should invest more than larger firms in proportion to their size. This argument rests on the rather substantial amount of evidence which indicates that smaller firms have a greater efficiency in invention than larger ones.

Some evidence of this from works by McConnell and Peterson and Schmookler and Scherer already has been offered. However, none of these separates invention from development or invention or development from innovation. Scherer's results mainly concern patents and, therefore, relate to invention, but these are not only unweighted as measures of the importance of invention, but also are only for Fortune 500 firms.

The work most relevant for the present argument deals with the origins of invention. Jewkes, Sawers and Stillerman[39] in their analysis of the case histories of sixty-one important twentieth-century inventions found that less than one-third of these came from research laboratories. For a more restricted period, 1946-1955, Hamberg[40] found that only about one-fourth of a sample of major inventions were conceived in large

However, McConnell and Peterson's results are not duplicated in studies of larger firms. Typical results for larger firms are either that there is no relationship between firm size and R and D intensity or that R and D intensity increases up to a point and then diminishes. Some studies show a negative relationship between firm size and R and D intensity.

Smith and Creamer's results are somewhat typical.[27] One of the industries (scientific and measuring instruments) in Smith and Creamer's twelve-industry sample also shows a negative relationship for research intensity and firm size. For two additional industries (other chemicals and communication and electronic equipment), the intensity of the smallest firms (under 1,000 employees) was greater than for any other class when federal funds were excluded. In the categories of other chemicals, drugs and other medicine, and scientific instruments, the peak intensity occurred at less than the largest size class. Finally, in seven of the twelve industries, the peak intensity of the smallest size class was greater than that of the next largest class.

Schmookler's results for larger firms are fairly consistent with the relationships shown by Smith and Creamer.[28] For a six-industry sample, Schmookler found across four industries no relationship between firm size and R and D intensity. However, for two of the six industries, Schmookler data show that the R and D intensity of the smallest firms (49-499 employees in one case, 500-999 in another) was greater than that of any other size class. It is worth noting that these two industries (fabricated metal products and ordinance, and electrical equipment) are among those in the McConnell and Peterson sample. In two other industries, peak R and D intensity occurred at less than the largest size of more than 5,000 employees; for the professional and scientific instruments industry, peak intensity occurred at the second smallest size class (500-999 employees), in the food and kindred products industry, the peak intensity occurred at the next to largest size class (1,000-4,999 employees).[29]

Even for the chemical industry, the R and D intensity for the smallest size class (firms with less than 500 employees) was greater than for any size class, except for the largest. Strikingly, two of the industries found by Schmookler to exhibit peak research intensity at sizes of less than 1,000 employees (electrical equipment and professional instruments) small firm to capital problems, especially in view of the inherent risks of R and D. As R and D is spread among a larger number of projects, as is more likely the larger the firm, the risks of failure of any one project are reduced. Related to the question of small firm survival is the greater life expectancy of larger firms which allows them to assume R and D investments whose payoff period is longer. The greater diversity of large firms in increasing the likelihood of being able to use an invention, and the greater market concentration of large firms are also elements, though quite minor ones, in explaining the greater propensity for R and D programs among larger firms.

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R and D expenditures by small companies are distributed among approximately the same industries as for large companies. Smith and Creamer[19] show for 1965 that four of the top five industries in absorbing R and D spending by small firms were also among the top five for large firms. It would appear that the more capital-intensive industries have the higher percentages of firms engaging in R and D.[20] This probably reflects the greater potential for R and D in these industries and the fact that capital-intensive industries tend to have larger firms. It would be interesting to see what the regression of both firm size and capital intensity against the percentage of firms engaged in R and D would show.

Given the skewed distribution of R and D spending among small firms by industry and by size, it is not surprising that Smith and Creamer find the distribution of R and D spending among small firms also highly skewed.[21] Thirteen percent of manufacturing firms with less than 1,000 employees spent about 55 percent of total R and D spending by manufacturing in this size class. What is perhaps more interesting is that this 13 percent also showed a more continuous record of R and D spending.

Research Activity, Intensity and Firm Size

Firm size strongly influences the probability of a firm having a formal R and D program, but does firm size influence the *size* of the R and D program? One would expect a positive relationship as long as there were not strongly decreasing returns to scale in R and D. One also would expect a positive relationship simply on the basis of federal funding of R and D. The percentage of R and D funding from federal sources is enormous, though recently it has been declining. In 1959, federal funding advances may come from departments other than those for R and D. Changes in tax treatment of R and D can result in new, arbitrary classifications of personnel or activities into the category of research.[10] If these problems exist in attempts to study R and D for larger firms, how much more difficult is it to analyze R and D by smaller firms in which the data are less satisfactory or do not exist?

Aside from basic problems of data availability, current research suffers from two interrelated and important shortcomings. The first is that data are not examined on a sufficiently disaggregated basis. The second deficiency is that too few factors have been introduced that might help explain the structure of R and D. Kamien and Schwartz[11] observe "much of the evidence on the effect of size has not controlled for other factors that may be helpful in explaining innovational effort." The same may be said of evidence concerning innovational outcome. Few studies really have attempted to explain the structure of R and D, undoubtedly because to do this requires that the data and information be generated by narrowly focused studies working to build up a data base sufficiently rich to understand R and D structure.

In this regard, problems of R and D are reminiscent of problems of developing a general theory of oligopoly. The necessary basic research is tedious and perhaps less rewarding in the short run. Perhaps economists are less willing than researchers in the natural sciences to undertake the tedious and narrowly focused research upon which the advancement of science ultimately rests.

R AND D CHARACTERISTICS OF SMALL FIRMS

The most important studies of R and D in small firms are those of McConnell and Peterson,[12] McConnell and Ross,[13] Hamberg,[14] Smith and Creamer[15] and Dearborn, Kneznek and Anthony.[16] From these and other investigations, a number of limited and tentative, though important, conclusions emerge.

The Incidence of R and D Programs

Seems high

Probably about 20 to 40 percent of small firms engage in R and D in a relatively formal way. Among the more reliable estimates are those from the detailed and disaggregated questionnaire results of McConnell and between the investment-to-GNP ratio and real growth rates for seven OECD countries as measured by the Kendall coefficient of concordance is .92, with a chi square of 11.2. This is just significant at the 10 percent level, which is impressive for such a small sample.[8] Similarly for the 1967-1971 period, the United States ranked last in its growth of R and D expenditures, followed by the United Kingdom, France, West Germany and Japan. This matches the respective growth rates of these countries, except for the reversal of the United States and the United Kingdom.

For the United States, the fall in the investment-to-GNP ratio has occurred in large part because of the failure of the traditional sources of investment funds, retained earnings, debt and equity. Retained earnings in constant dollars have declined enormously during most of the 1960's and the 1970's. The "crowding out effect" has limited severely bond debt as a means of financing, and, until recently, the stock market has not been a very attractive place to go for financing. Financing problems of small businesses have been especially difficult.

One set of measures that undoubtedly are called for are policies that encourage greater capital formation. With such policies, R and D for both small and large firms undoubtedly would expand. However, the response of small firms probably would be greater because of their greater sensitivity to credit conditions. The phenomena is similar to the unemployment rate of minorities which increases proportionately more than for other groups during periods of contraction and which decreases more than proportionately during periods of expansion.

Economic growth is a matter of the efficiency as well as the magnitude of investment. In this regard, the distribution of R and D expenditures between large and small firms becomes especially relevant. After considering the relationship of R and D to smaller firms in the next section, the third section of this paper argues that efficiency requires a greater portion of R and D spending by smaller firms. The final section suggests conditions under which the improvements in efficiency might be brought about.

DATA LIMITATIONS FOR THE ANALYSIS OF SMALL FIRM R AND D

Small firms are those with less than 500 employees and probably account for less than 3 percent of total R and D expenditures.[9] Yet in terms of

APPENDIX XV

ARTICLE, "RESEARCH AND DEVELOPMENT BY SMALLER FIRMS," BY RICHARD O. ZERBE, JR., NORTHWESTERN UNIVERSITY AND UNIVERSITY OF WASHINGTON, JOURNAL OF CONTEMPORARY BUSINESS, 1976, PAGES 91–113

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Journal of Contemporary Business *Spring 1976*

RESEARCH AND DEVELOPMENT BY SMALLER FIRMS

Richard O. Zerbe, Jr.*
Northwestern University and University of Washington

THE IMPORTANCE OF RESEARCH AND DEVELOPMENT

Technical change arising from research and development (R and D) expenditures is exceedingly important. Solow,[1] in his pioneering work, found that between 1909 and 1949 about 81 percent of economic growth was attributable to technical change and changes in production practice. Dennison,[2] in a more disaggregated study, found that 36 percent of the rise in output per worker was attributable to advances in technical knowledge, and 42 percent was attributable to improved worker education. Only 9 percent of the rise was due to increases in the capital stock.

Research and development is also of major importance in determining comparative advantage, the balance of payments and the magnitude of U.S. exports.[3] Donald Kessing[4] found that there was a powerful correlation between the intensity of R and D activity in American industries and their export performance. Pavitt and Wald[5] found a high correlation between national industrial R and D expenditures and national technological performance across a sample of ten industrialized countries. In a sample of fourteen industries, Gruber, Mehta and Vernon[6] found that U.S. export strength was concentrated in the five industries with the greatest R and D effort, i.e., transportation, electrical machinery, instruments, chemicals and nonelectrical machinery. The remaining industries exhibited a net import balance for 1962, the year investigated.[7] From these and other studies there is little doubt that R and D and technical change play a major role both in economic growth and in determining relative economic position.

A crude comparison suggests that the fall in the U.S. growth rate of recent years and the concomitant absolute and relative decline in the ratio of R and D to GNP are not unrelated phenomena. The decline in R and D has been part of this decline in the United States in the investment-to-GNP ratio. See Figure 1. For the 1960-1973 period, the rank correlation

80.

Table 5-10. Distribution of employed doctoral scientists and engineers by employment sector, 1975

Employment sector	All doctoral scientists and engineers		Doctoral scientists[1]		Doctoral engineers	
	Number	Percent[2]	Number	Percent[2]	Number	Percent[2]
Total	262,411	100	219,055	100	43,356	100
Business and industry	65,876	25	43,341	20	22,535	52
Educational institutions	153,249	58	137,943	63	15,306	35
Four-year colleges and universities	147,633	56	132,504	61	15,129	35
Two-year colleges	3,674	1	3,497	2	177	([4])
Elementary and secondary schools	1,942	1	1,942	1	—	—
Hospitals and clinics	7,586	3	7,562	3	24	([4])
Nonprofit organizations	8,510	3	7,277	3	1,233	3
Government	26,755	10	22,538	10	4,217	10
Federal[3]	21,634	8	17,855	8	3,779	9
State	3,110	1	2,883	1	227	1
Other	2,011	1	1,800	1	211	([4])
Other employment sector	86	([4])	86	([4])	—	—
Employment sector unreported	349	—	308	—	41	—

[1] Includes 94 scientists or engineers whose field is unknown.

[2] Excluding those whose employer was unreported.

[3] Includes the military and the Commissioned Corps of the Public Health Service.

[4] Less than 0.5 percent.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States, 1975* (NSF 77-309), pp. 38-41.

See Figure 5-17 in text.

Table 5-11. Doctoral scientists and engineers by age and type of employer, 1975

Age	Business and industry		Four-year colleges and universities		Federal Government[1]	
	Number	Percent	Number	Percent	Number	Percent
Total	65,876	100	147,633	100	21,634	100
Under 30	2,129	3	5,772	4	773	4
30-34	15,117	23	30,862	21	4,121	19
35-39	14,113	21	30,903	21	4,734	22
40-44	10,274	16	23,687	16	3,646	17
45-49	8,090	12	19,833	13	3,081	14
50-54	7,476	11	16,146	11	2,398	11
55-59	4,610	7	10,774	7	1,533	7
60-64	2,734	4	6,461	4	953	4
65 or over	1,224	2	3,094	2	382	2
No report	109	([2])	101	([2])	13	([2])

[1] Includes the military and the Commissioned Corps.

[2] Less than 0.5 percent.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States, 197* (NSF 77-309), pp. 38-41.

See Figure 5-19 in text.

APPENDIX D

Selected Tables from Science Indicators, 1976, NSB 77-1, The National Science Board

OFFICE OF PLANNING AND RESOURCES MANAGEMENT

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
10/76	Computer Horizons Inc. Cherry Hill, N.J.	An Evaluation of University Research Productivity	7681724	Evaluation	$ 42,495
11/76	Computer Horizons Inc. Cherry Hill, N.J.	Review and Analysis of Importance and Utilization Measures Contained in Evaluative Bibliometrics	7682854	Evaluation	$ 18,318
9/77	Institute for Scientific Information Philadelphia, Pa.	A Citation and Publication Analysis of U.S. Industrial Organizations	7710048	Evaluation	$ 64,851

SCIENCE EDUCATION DIRECTORATE

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
9/77	Prism Productions Inc. Camarillo, Ca.	An Experimental Series of Science Programs for Commercial Television	7716196	Public Understanding of Science	$203,100
9/77	Exotech Inc. Gaithersburg, Md.	Data Processing Support to the Science Education Directorate	7726461	Special Studies	$124,854
9/77	Westat Inc. Rockville, Md	Program Evaluation in Science Education: CAUSE	7723940	Systems Approach	$ 9,900
2/77	Courseware Inc. Provo, Utah	Learner-Controlled Instructional Strategies: An Empirical Investigation	7601650	Technological Innovations in Education	$207,750
	Development & Evaluation Associates Syracuse, N.Y.	Evaluation of CAUSE	7723982	Systems Approach	$ 9,990

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
5/77	Technology Associates of Southern California, Inc. Monterey Park, CA	Investigation of the Design and Performance of a Simple Liquid Piston Heat Engine	77-07489	Exploratory Research	53,600
8/77	CONSAD Research Corp. Pittsburgh, PA	A Prototype Evaluation of the Program Output of the Research Applied to National Needs (RANN) Program	76-11438 A04	Research Evaluation	57,107
9/77	Operations Research, Inc. Silver Spring, MD	Research on Methods for Assessing the Utilization and Impact of RANN Projects	77-22190	Research Evaluation	63,500
9/77	Kappa Systems Arlington, VA	RFP 77-110: External Product Evaluation Management	77-26721	Research Applications	261,480
			Subtotal:		$ 7,599,535

Awards made via a purchase order:

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
7/77	Belt, Beranek & Newman Cambridge, MA	Evaluation of Basic Research Progress and Future Research Opportunities in Human Factors and Ergonomics	RN-1473 7SP0920	Productivity	3,609
6/77	Clinical Systems Associates, Inc. Washington, D.C.	Technological Needs of the Physically Handicapped	RN-1039 7SP0842	Productivity	9,850
9/77	Clinical Systems Associates, Inc. Washington, DC	Research Priorities to Aid the Productivity of the Physically Handicapped	RN-6096 7SP1121	Productivity	6,250
8/77	Dames & Moore San Francisco, CA	Implementation Measures to Reduce Earthquake Hazards of Dams	RN-6874 7SP1045	Environment	1,000

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
8/77	Oneida Materials Corp. Cucamonga, CA	Development and Testing CSMRI "A" Metal Process for Recycling Steelmaking Dust and Scale Waste for Industrial Adoption	76-84256	Indus. Prog./ Resources	75,000
2/77	Amber Laboratories Juneau, WI	Natural Red Food Colorant from Beets	76-24677	Resources	103,900
12/76	Anver Bioscience Design Sierra Madre, CA	Jojoba Seed Meal as an Animal Feed	76-23895	Resources	77,300
8/77	Roger Blobaum & Associates Creston, IA	An Assessment of the Potential for Applying Urban Wastes to Agricultural Lands	77-08280	Resources	92,100
9/77	Charles River Associates Cambridge, MA	An Analysis of Major Policy Issues Raised by the Commercial Development of Ocean Manganese Nodules	77-14453	Resources	191,900 (30,000 fro Bureau of Mines)
7/77	Collaborative Research, Inc. Waltham, MA	Synthesis and Applications of Nucleic Acids to Biological Nitrogen Fixation	77-10195	Resources	209,100
9/77	Collaborative Research, Inc. Waltham, MA	Enhancement of Animal Protein Production by Novel Genetic Technology	*77-19654	Resources	24,997
8/77	DASI Industries, Inc. Chevy Chase, MD	Evaluation of Free-Falling Film Ultra-High Temperature Processed Milk	77-04162	Resources	168,700
9/77	EIC Corporation Newton, MA	Recovery of Chromium from Nickeliferous Laterites	*77-19538	Resources	24,740
2/77	Experienced Resource Group, Inc. Baton Rouge, LA	Alternative Food Delivery Systems - An Exploratory Assessment	77-07184	Resources	25,000

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
4/77	Maurer Engineering, Inc. Houston, TX	Conference on Research in Excavation Technology	75-14405 A03	Productivity	36,900
9/77	Maynard Research Council Pittsburgh, PA	Study of a Mechanism to Foster University/Small Business Interaction	77-14151	Productivity	100,000
9/77	Multisystems, Inc. Cambridge, MA	Remote Employment of the Physically Handicapped	*77-19497	Productivity	24,948
9/77	Precision Instrument Co. Santa Clara, CA	Slidestore: Large Capacity Information Storage	*77-19528	Productivity	24,995
8/77	Radiation Monitoring Devices, Inc. Watertown, MA	Research on Uncooled Cadmium Telluride Gamma Detectors as Substitutes for Ultra-pure Germanium	77-10434	Productivity	198,100
9/77	Scientific Process and Research, Inc. Highland Park, NJ	Lowering of Energy Consumption in Plastics Processing	*77-19512	Productivity	25,000
9/77	Scientific Systems, Inc. Cambridge, MA	Microprocessor-Based Prosthetic Control	*77-19672	Productivity	23,670
6/77	Spectrum Research Denver, CO	Evaluating the Organization of Service Delivery: Public Health	74-08798 A01	Productivity	8,648
4/77	Stearns, Conrad, & Schmidt Consulting Engineers Long Beach, CA	Research on Equipment Technology Utilized by Local Government: Refuse Collection	77-04424	Productivity	40,272
6/77	Stearns, Conrad, & Schmidt Consulting Engineers Long Beach, CA	Research on Equipment Technology Utilized by Local Government: Refuse Collection	74-20560 A03	Productivity	13,800

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
9/77	Woodward-Clyde Consultants San Francisco, CA	Analysis of the Adoption and Implementation of Community Land Use Regulations for Flood Plains	77-13908	Environment	208,300
5/77	Advanced Research Resources Organization Silver Spring, MD	A Conference to Formulate Priorities for Research on Human Performance and Productivity	77-07886	Productivity	74,900
9/77	Agbabian Associates El Segundo, CA	Improved Design Procedures for Underground Structural Support Systems in Rock	76-80044	Productivity	179,900
9/77	Amtech, Inc. Newton, MA	Micro-Isotope Tool Wear Detection	*77-19517	Productivity	25,000
9/77	Block Engineering, Inc. Cambridge, MA	Single Ended Photoelectric Hazard Warning	*77-19478	Productivity	24,495
9/77	Ceramic Finishing Co. State College, PA	Control of Fragment Size Distribution and Damage Penetration During Machining of Ceramics	*77-19818	Productivity	24,942
4/77	Energy Research and Generation, Inc. Oakland, CA	Thermocorer for Rapid Excavation	73-03322 A06	Productivity	131,200
7/77	Ensco, Inc. Springfield, VA	Remote Sensing with Ground-Probing Radar	76-03300 A02	Productivity	10,700
3/77	Exotech, Inc. Gaithersburg, MD	Shaped-Pulse Rotary Percussion Drilling	75-16367 A01	Productivity	18,700
7/77	Exotech, Inc. Gaithersburg, MD	Shaped-Pulse Rotary Percussion Drilling	75-16367 A03	Productivity	12,900

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
7/77	Building Systems Development, Inc. San Francisco, CA	Building Configuration and Seismic Design	76-81821	Environment	199,400
4/77	Clement Associates, Inc. Washington, D.C.	An Evaluation of Toxicological Information Relevant to Future Testing Requirements for Hazardous Chemical Substances and Mixtures	77-15417	Environment	142,793
8/77	Clement Associates, Inc. Washington, D.C.	An Evaluation of Toxicological Information Relevant to Future Testing Requirements for Hazardous Chemical Substances and Mixtures	77-15417 A02	Environment	173,444
8/77	Collier Worm Ranch Santa Clara, CA	Conversion of Municipal Wastewater Treatment Plant Residual Sludges Into Earthworm Castings for Use as Topsoil	77-16832	Environment	9,700
5/77	Gurnham & Associates, Inc. Chicago, IL	Control of Heavy Metal Content of Municipal Wastewater Sludges	77-04355	Environment	110,900
3/77	Human Ecology Research Services, Inc. Boulder, CO	A Comparative Analysis of Public Response to Weather Modification	74-18613 A03	Environment	56,600
3/77	Human Ecology Research Services, Inc. Boulder, CO	Metromex: Social Impacts of Inadvertent Weather Modification: A Comparative Study	76-22041	Environment	60,300
9/77	Laser Analytics, Inc. Lexington, MA	Improved Sensitivity of Laser Absorption Techniques for Atmospheric Pollutant Monitoring	77-02124	Environment	211,500
6/77	Media Four Productions Hollywood, CA	Synthesis of a Municipal Wastewater Sludge Management System	76-82708 A01	Environment	49,640

ASTRONOMICAL, ATMOSPHERIC, EARTH, AND OCEAN SCIENCES DIRECTORATE

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
2/77	Scripta Technica Inc. Washington, D.C.	Publication of Polar Geography	7681106	Polar	$ 21,000
9/77	Compass Systems Inc. San Diego, Ca.	Assembly and Analysis of Oceanographic Data on the Surface Layer (0-150 M) in the Southern Hemisphere and Preparation of the Results for Publication in an Atlas	7724040	Atmospheric	$ 30,000
8/77	Compass Systems Inc. San Diego, Ca.	Assembly and Analysis of Oceanographic Data of the Surface Layer (0-150 M) in the Southern Hemisphere and Preparation of the Results for Publication in an Atlas	7709201	Atmospheric	$158,800

SCIENTIFIC, TECHNOLOGICAL, AND INTERNATIONAL AFFAIRS DIRECTORATE

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
1/77	Courtesy Travel Service Washington, D.C.	Travel and Administrative Services in Support of Intern'l Science Activities Sponsored by the NSF	7708322	Internat'l	$ 500,000
	Computer Horizons Inc. Cherry Hill, N.J.	Implementation of Evaluation Methodology for International Programs	7708484	Internat'l	$ 24,915
	Metrics Inc. Atlanta, Ga.	The Economics of the Unique Functions Associated with Information Analysis Center (IAC) Services	7718035	Science Information	$ 83,800
	Charles River Associates, Inc. Cambridge, Ma.	Development of a Discrete Choice Model for the Demand of Scientific and Technical Information	7718020	Science Information	$ 101,764
	Innovative Systems Research Pennsauken, N.J.	Electronic Information Exchange in Research on Devices for the Disabled	7717924	Science Information	$ 51,143
2/77	Capital Systems Group Inc. Rockville, Md.	A Planning Guide on Innovation in the Dissemination of Scientific Information	7701455	Science Information	$ 92,586
9/77	Capital Systems Group Inc. Rockville, Md.	A Planning Guide on Innovation in the Dissemination of Scientific Information	7720489	Science Information	$ 219,500
3/77	Westat Inc. Rockville, Md.	Relationship of Organization Climate to the Transfer of Scientific and Technical Information in Industrial Settings	7681946	Science Information	$ 10,017

FY 1977 GRANT AND CONTRACT AWARDS[1/]

TO SMALL BUSINESS

LISTED BY INDIVIDUAL AWARD BY

NSF DIRECTORATE

[1/] Includes programmatic grant and contract awards only. Excludes awards primarily for NSF logistics support and purchase orders except where noted in the Research Applications list.

FY 77 AWARDS TO INDUSTRY--BY NSF PROGRAM ELEMENT

MPE	No.	Amount
Other Math Sciences	1	$ 3,000
Engineering/Heat Transfer	1	63,700
Engineering Energetics	1	27,700
Engineering/Fluid Mechanics	1	73,400
Metallurgy	1	75,300
Ceramics	2	137,500
Materials Research	2	186,700
Chemical Analysis	1	60,000
Engineering	1	66,500
Other	1	24,535
TOTAL:	12	718,335
STI		
Policy Research & Analysis	5	217,847
Cooperative Science Program	1	500,000
Scientific Organization & Resources	1	24,915
Economics of Information	2	185,564
Access Improvement	3	363,229
User Requirement Program	3	146,186
Studies of Science Resources	6	534,269
TOTAL:	21*	1,972,010*
AEO		
Aeronomy	2	136,500
Solar-Terrestrial	2	148,800
Atmospheric Chemistry	2	119,900
Solar Terrestrial Physics	1	67,500
Information Services USARP	1	21,000
Contract Support USARP	5	7,059,825
Climate Dynamics	3	288,800
Research Ship Support	3	295,047
TOTAL:	19*	8,137,372*
BBS		
Regulatory Biology	3	164,856
Metabolic Bio.	1	80,500
Economics	1	12,500
History & Philosophy of Sci.	1	82,700
TOTAL:	6	340,556

RA	No.	Amount
Resources	87	2,122,800
Renewable Resources	1	35,000
Societal Response to Natural Hazards	2	920,000
Instrumentation Technology	3	198,600
Excavation Technology	19	1,732,800
Earthquake Engineering	12	2,013,100
Environment	94	2,293,600
Weather Modification	2	101,900
Regional Environmental Management	10	2,760,300
Chemical Threats to the Environment	13	3,592,400
Productivity	134	3,269,600
Regulation	2	929,000
Technology Assessment	25	1,115,675
Public Sector Productivity	1	5,000
Service Delivery Technology & Systems	5	664,025
National Productivity Measure.	2	192,000
Service Productivity & Intergovernmental Relations	1	59,500
Public Sector Productivity	2	121,600
Public Policy	1	260,400
Distribution & Equity	1	5,760
Systems Analysis	1	24,942
Biomass Utilization	1	280,000
Mineral Market Behavior & Shortages	1	190,000
Resources Development & Conservation	1	708,300
Advanced Processing Technology	1	89,700
Industrial Program	8	142,819
International Travel	1	978
TOTAL:	431	$23,829,799

BBS		
Genetic Biology	2	548,200
Ecosystem Studies	1	198,000
Regulatory Biology	2	112,100
Metabolic Biology	1	319,200
Biophysics	1	72,600
Memory & Cognitive Processes	1	63,100
Anthropology	1	112,500
Economics	1	16,200
History & Philosophy of Science	1	82,700
TOTAL:	11	1,524,600

APPENDICES

NASA patent policies appear not to be a serious deterrent to industry participation in NASA basic research activities. Patent rights start with NASA but companies often are assigned development rights if the government does not plan to use the patent. NASA's congressional supporters have emphasized that NASA supported research is beneficial to U.S. industry and the national economy. Moving research results to utilization is important in meeting those objectives.

NASA's publication policies in the basic research area generally resemble those of NSF. NASA encourages publication in refereed journals and staff spoke of an increasing emphasis on that mechanism as one of the evaluations of quality to be weighed when considering further research support. In addition, for NASA contracts, particularly those let in response to specific research needs, NASA requires a technical report addressed to NASA. In one of the research areas it was noted that research findings by private firms in the natural resources area sometimes are not published readily; some companies with large research programs and labs participate readily in certain of the basic research activities, and publish results in the open literature.

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

The Air Force Office of Scientific Research relies mainly on unsolicited proposals for initiation of new work through grants and contracts. Proposals are supported based on their originality, significance to science, the scientific competence of the investigator, the reasonableness of the research budget, and the appropriateness to the Air Force. Grants are limited to support of research at universities and not-for-profits. Contracts are used to support research in industry.

Research awards to industry vary according to the industry expertise and interest as these relate to the Air Force's research programs, and the interest of the Air Force in the industry expertise or the questions that a researcher may want to investigate. The AFOSR indicates that about 15% of its extramural basic research outlays go to industry, and estimates that about 10% of these awards are to small businesses.

Industry performance of basic research for AFOSR is more likely in high technology areas such as electromagnetic materials research and device concepts. In the microwave tube area, AFOSR has seven industrial research performers and because of a scarcity of trained researchers in this area Stanford University is training researchers in the field.

The AFOSR reports no special patent problems that appear to deter industrial basic researchers from Air Force work.

ONR does not have data permitting comparisons with NSF on proposal pressure. ONR interests are known generally and preliminary contact serves as a screen. Only proposals of some interest to ONR are submitted in most cases. There are few unsolicited proposals and their relative likelihood of support is not high.

In the nature of ONR relationships, contracts and negotiations, there are no serious administrative problems of a continuing sort involved with patents or publications. There are no cost-sharing requirements.

NATIONAL INSTITUTES OF HEALTH

NIH does not make grants to industry. Its awards to industry are in the form of contracts. Most of the contracts with industry are in response to requests for proposals. Within specific contracts it is sometimes necessary to perform some basic research, but such basic research is neither the major portion nor the primary purpose of the contract. This accounts for the fact that no industry basic research is reported by NIH in the annual Federal Funds report, since traditionally NIH has not split its awards for reporting purposes. Rather, the entire amount of any award has been allocated to the major research or development thrust.

There are relatively few unsolicited research proposals per year from industry. In FY 77, there were fewer than 10 active R&D contracts with industry resulting from unsolicited proposals, some new and some carryover from prior years.

In FY 76 there were about 300 R&D contracts awarded to for-profit organizations.

The determinations for awards to industry are made on the basis of competitive evaluation, with a very few awarded on the basis of "singular technical competency." NIH-supported research in industry is primarily in the life sciences.

NIH policies concerning both publications and patents resemble closely those of NSF. Researchers are encouraged to publish in the open literature and patent rights are dealt with on a deferred determination basis as with NSF. Cost-sharing is based on individual contract negotiations based on possible commercial advantage to the research performer.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Discussions were held with NASA Headquarters research management staff in three areas--engineering, life sciences, and space and terrestrial sciences. NASA's policies on the support of basic research are completely open. Anyone can apply. From one area to another, practices vary. Project announcements and knowledge of program thrusts in each field have a major influence on the support sought by research performers.

PART IV

Support of Basic Research in Industry by Five Other Federal Agencies

Directorate/Field/Program Area	No.	Amount
Science Education		
Science & Society	1	203,100
Science Education Development	4	484,648
Science Education Research	2	19,890
TOTAL:	7	$707,638
Administration	6	1,115,744
Office of Planning & Resources Management	6	295,999
Office of Government & Public Programs	2	28,055

[1] Appendix B provides more detailed list by program element.

[2] Includes Antarctic Research Program logistics support

Table III-4

FY 1977 GRANT AND CONTRACT AWARDS TO INDUSTRY[1]

Directorate	No. Awards	Amount	% of FY 77 Obligations	FY 77 Obligations
Mathematical & Physical Sciences & Engineering	12	$ 718,335	.32%	$224.4
Scientific, Technological & International Affairs	21	1,972,010	10.15	19.4[2]
Astronomical, Atmospheric, Earth & Ocean Sciences	19	8,137,372	3.48	233.5[3]
Research Applications	110	9,714,070	15.2	63.7[2]
Science Education	7	707,638	1.19	59.0[4]
Biological, Behavioral & Social Sciences	6	340,556	.27	126.6
Planning & Resources Management	6	295,999		
Administration	6	1,115,744		
Government & Public Programs	2	28,055		
TOTAL:	189	$23,029,779	3.2%	$726.6[5]

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[1] Excludes purchase orders

[2] These figures shown without $1.3 million transfer from RA to STIA for technology assessment as shown for FY 77 for consistency in the FY 1979 Budget request.

[3] Includes U.S. Antarctic Program

[4] Science Education total less Fellowships and Traineeships ($15.3m)

[5] FY 1977 Total NSF obligations ($791.8) less Special Foreign Currency ($4.4m), PD&M ($45.5m), and Fellowships and Traineeships ($15.3m).

GENERAL NOTE

During a fiscal year some awards will be to support proposals received in the prior fiscal year. Some proposals received during the current fiscal year will not be acted on finally until the following fiscal year. In categories of small numbers, particularly where contracts are included, it is possible that for a single fiscal year awards may exceed proposals.

Table III-3

FY 1977 PROPOSALS RECEIVED FROM INDUSTRY BY DIRECTORATE AND FIELD OF SCIENCE OR PROGRAM AREA WITHIN DIRECTORATE[1/]

Directorate/Field	No.	Amount
Mathematical & Physical Sciences & Engineering		
Math & Computer Sciences	2	$ 53,000
Engineering	5	769,316
Materials Research	8	926,600
Physics	2	212,500
Chemistry	4	509,750
Other	1	10,535
TOTAL:	22	$2,481,701
Scientific, Technological & International		
Policy Research & Analysis	8	701,039
International Science	6	1,623,600
Science Information	24	2,162,686
Science Resources Studies	7	488,613
TOTAL:	45	$4,975,938
Astronomical, Atmospheric, Earth & Ocean Sciences		
Atmospheric Sciences	9	1,746,600
Astronomy	5	398,700
Polar Programs	14[2/]	7,679,225
Ocean Sciences	1	40,700
TOTAL:	29	$9,865,225
Biological, Behavioral & Social Sciences		
Biological Sciences	7	1,250,100
Social Sciences	2	175,600
Behavioral & Neural Sciences	2	98,900
TOTAL:	11	$1,524,600

[1/] Appendix A provides more detailed list by program element.

[2/] Includes Antarctic Research Program logistics support.

Table III-1

TOTAL PROPOSALS RECEIVED BY NSF DIRECTORATES--FY 1977
FROM ALL SOURCES AND FROM PRIVATE INDUSTRY
(Data as of Sept. 30, 1977)

Directorate	Total From All Sources	Total From Private Industry
Mathematical, Physical & Engineering Sciences	7,984	22
Scientific, Technological & International Affairs	1,027	45
Astronomical, Atmospheric, Earth & Ocean Sciences	2,988	29
Research Applications	1,417	431
Biological, Behavioral & Social Sciences	7,231	11
Science Education	7,421*	17
Other (Administration; Office of Planning & Resources Management; Office of Government & Public Programs)	54	13
TOTAL:	28,122	568

*Excludes Fellowships and Traineeships.

The fiscal year 1977 data in Table III-3 show that more proposals were received in the materials research area than elsewhere in these three directorates, with atmospheric sciences, biological sciences, engineering, astronomy and chemistry all receiving four or more proposals. (Polar programs is considered to have received five research proposals when the nine for research support services are excluded).

The greatest number of basic research program awards were made to industry (Table III-5), in materials research, atmospheric sciences, engineering and biological sciences. (When Polar programs support awards are excluded, that program category drops to the low end of the group). Appendix B lists the grant and contract awards to industry by NSF directorate and program element.

The data for awards to small business, a subset of the data for all industry, are grouped by totals for each directorate and then are individually listed by award by Directorate in Appendix C. Review of the awards to small business made by the three basic research directorates in fiscal year 1977 shows that most of these awards are for analysis or evaluation of data on research materials.

The actual numbers of awards in these areas are too small to permit valid conclusions from statistical comparisons of these totals with the data on population characteristics and distribution of basic researchers in industry.

RESEARCH APPLICATIONS DIRECTORATE

Some 1417 proposals were received by the Research Applications Directorate in FY 1977. That directorate has accepted proposals from private firms without special criteria for qualification beyond the merit criteria used for consideration and support of proposals from other sectors. In addition, small business firms that have outstanding capabilities for scientific research or technology have been encouraged to submit proposals particularly because of special legislative provisions first added by the Congress in FY 1976. In FY 1977 the Research Applications directorate received 431 proposals from private industry, amounting to approximately 30% of the total received. Of the 431 there were 329 proposals that small businesses submitted in response to the "Small Business Innovation" solicitation. Research Application made 544 awards in FY 77; 110 awards were made to industry, nearly 20% of the RA total number of awards. Of the 110 RA awards to industry, 95 were to small business, 17.5% of the total number of RA awards.

RANN's proposals and awards are identified by field of program thrust rather than by the traditional fields of science or disciplinary area. In FY 1977 these grouped as follows (proposals from the solicitation are in the data, shown separately in parentheses):

The largest NSF obligations incurred in awards to businesses other than through program directorates occurred in the Administration Directorate for support of the Foundation's data center and computer operations.

Industrial proposal and award levels in NSF's basic research supporting directorates are discussed below.

BASIC RESEARCH ONLY

This section considers proposal pressures on NSF from industry for basic research support in terms of the data for NSF's three directorates in which nearly all of the obligations are in support of basic research--the Directorate for Mathematical, Physical Sciences and Engineering (MPE), the Directorate for Biological, Behavioral and Social Sciences (BBS), and the Directorate for Astronomical, Atmospheric, Earth and Ocean Sciences (AAEO).

The Foundation's policy on the support of basic research proposals from private industry has been expressed for many years in these words:

> "Private Profit Organizations: Commercial firms are infrequent recipients of awards for scientific research project support. However, in exceptional cases, unsolicited proposals for basic research will be considered from industrial organizations where: (a) the project is of special concern from a national point of view and shows promise of solving an important scientific problem; (b) unique resources are available in industry for the work; or (c) the project proposal is outstandingly meritorious."

This policy has been widely known. It also has been misunderstood by some who have thought that NSF never makes awards to commercial firms for support of basic research; such is not the case. Awards to private firms for basic research support have been relatively infrequent but have been made by NSF for many years.

Concerned that the long-standing wording of the basic research support policy may have been unduly negative in tone, the National Science Board on January 19, 1978, took the following action:

PART III

National Science Foundation
Proposals from Industry
Awards to Industry,
Fiscal Year 1977

Table II-11: Funds for Basic Research by Selected Industry for Firms With Less Than 1000 Employees, 1976

(Includes Company and Federal Funds)

Dollars in Millions

	1976 Preliminary	% of Total
TOTAL	68	100%
Food and kindred products	2	3
Chemicals and allied products	18	27
Industrial chemicals	3	4
Drugs and medicines	5	7
Other chemicals	10	15
Petroleum refining and extraction	1	2
Stone, clay, and glass products	4	6
Primary metals	1	2
Nonferrous metals and products	1	2
Machinery	4	6
Office, computing, and accounting machines	2	3
Electrical equipment and communications	14	21
Communication equipment and communication	4	6
Other electrical equipment	10	15
Transportation equipment other than motor vehicles and eqpt.	2	3
Other manufacturing industries	1	2
Nonmanufacturing industries	21*	31

*Including commercial research and development firms.

Source: National Science Foundation
Preliminary Data

Table II-9: Funds for Basic Research by Selected Industry
(Includes Company and Federal Funds)
1971 and 1976

(Dollars in millions)

	1971	% of Total	1976(Preliminary)	% of Total	Percent Change
Total	$581	100%	$786	100%	35%
Chemicals and Allied Products	216	37	322	41	49
Drugs & Medicines	77	13	125	16	62
Petroleum refining & extraction	21	4	45	6	114
Machinery	22	4	36	5	64
Electrical equipment & communication	143	25	148	19	4
Aircraft & Missiles	53	9	52	7	- 2
Nonmanufacturing	31	5	29	4	- 7
All other industries	95	16	154	20	63

Source: National Science Foundation
1/25/78

Table II-7: Funds for Basic Research by Size of Company

(Includes Company and Federal Funds)
1971 and 1976

(Dollars in millions)

	1971	% of Total	1976 (Preliminary)	% of Total	Percent Change
Total	$581	100%	$786	100%	35
Less than 1,000 employees	36	6	69	9	92
1,000 - 4,999 employees	51	9	38	5	-26
5,000 - 9,999 employees	72	12	112	14	56
10,000 or more employees	422	73	567	72	34

Source: National Science Foundation
1/25/78

NOTE: Since different companies comprise the specific size classes in each year, the data by size of company may not be entirely comparable.

Table II-5: Company Funded Basic Research as a Percent of Total Company R&D

1970 - 1978

1970	4.3%
1971	4.3
1972	4.0
1973	3.8
1974	3.6
1975	3.6
1976	3.5
1977(est)	3.4
1978(est)	3.3

Source: National Science Foundation
1/25/78

Table II-3

Share of Federal Basic Research Performed by Industry[1/] by Major Support Agency, with Percent Change, FY 1971 & FY 1976

Agency	Share of Total 1971	Share of Total 1976	Funding Percent Change 1971 - 76
NASA	63%	43%	-43%
ERDA	16	28	+45
DOD	19	21	- 9
NSF	.5	5	+700
OTHERS	2	3	+50

[1/] Includes federally funded research & development centers (FFRDC's) administered by this sector.

Source: Federal Funds surveys. NSF 1/25/78 sources of venture capital, its success will not be judged solely by reference to its balance sheet. It's aim is to continue to create new business opportunities in the U. K. from the research work and inventions available to it, with increased employment prospects and foreign currency earnings from exports or license income. The total NRDC investment in both private and institutional support is not large; the rationale is that:

> The cost of most of the civil development work in this country will continue to be met out of industry's own resources but there may be cases where individual firms are unable to undertake, entirely at their own expense, the development of potentially valuable projects. In the export field the need for the United Kingdom to develop and market technically advanced products against strong international competition puts a heavy development burden on much of the country's manufacturing industry. In such circumstances there may be merit in a collaboration between industry and NRDC.
>
> It is a natural consequence of the Corporation's statutory functions that it is prepared to undertake projects where the degree of risk is greater than that which a commercial undertaking would regard as justified.*

Having operated at a deficit for its first 27 years, the Corporation for the first time in 1975-76 was able to carry forward a net surplus. The total investment in external R&D support over that period (1949-76) was 48.2 million pounds sterling (about $87.4M at current exchange rates).** In 1977 alone it is estimated that the gross amount of new industrial production which the NRDC helped to generate was 100 million pounds sterling ($181.25M), with a ten year accumulated total of 600 million

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* National Research Development Corporation: An Introduction (NRDC, London, October 1970).

** 27th Annual Report and Statement of Accounts 1975-76 (London, England: NRDC, 1976).

> Although generalizations are perilous, the case of a company that had a joint venture with its one-time U.S. importing agent during the first few years in which it manufactured in the U.S. seems typical. Prior to developing its own marketing competence under its own ownership umbrella, this subsidiary was effectively cut off from new developments in its marketplace and was not able to get information about new applications for the particular product it produced. After buying out its partner's sales network, it was able to reintegrate the marketing and R&D functions in the U.S., and went from rather dismal failure to quite considerable success over the subsequent five years.
>
> Acquisition seems to provide the quickest way to learn U.S. technology and marketing skills that are new to a European group. This was a key reason for Plessey's acquisition of the U.S. company Alloys Unlimited. The acquisition by a European oil company of a small U.S. refinery had a similar motivation — but this time for purposes of learning marketing skills rather than technological skills. The European firm's executives remarked that they felt, in order to be a viable worldwide petroleum company, they had to learn marketing in the market where most of their major competitors came from. The company did not feel that its marketing was strong enough to enter the U.S. first by setting up an exploration company and then gradually working its way into competition in refining and distribution with other U.S. petroleum companies.
>
> A pharmaceutical company, which originally entered the U.S. shortly after World War II by forming its own subsidiary, noted that it had recently taken over 100% of a U.S. hospital supply company. The company indicated that as far as possible it preferred to avoid acquisitions "and the digestion problems that acquisitions usually cause," but that in this particular case it felt that the pharmaceutical business was changing so rapidly that it could not take the time to learn medical electronics and hospital servicing without making such an acquisition.

One experiment designed to address the problem of technological lag and insufficiency of funds is the National Research Development Corporation (NRDC) in the United Kingdom. This is an independent public corporation, financed by government loans, established in 1948 under the Development of Inventions Act whereby new high risk R&D ventures can be funded. The fields covered are the biosciences, industrial chemistry, scientific equipment, mechanical engineering, production engineering, electrical engineering, electronics, computers and automation. NRDC assists the advance

Being inside the fast-changing and competitive U.S. market brings two advantages. First, new developments can be transmitted more rapidly to the European parent company, so that it can compete with U.S.-based and other European firms as new products and methods are introduced in Europe. Second, a corporate lead in high-income, labor-saving products in the U.S. prepares a European firm for competitive battles in Europe, as European markets take on "U.S." characteristics.

A good many European managers admit the need to learn-by-doing in the U.S. in order to face what U.S. companies (or more daring or lucky European competitors with U.S. operations) might employ on the European market in future.

Olivetti is one company that has not hidden its desire to learn from U.S. marketing and technology. Plessey is another European group that has publicly stated its desire to learn from U.S. practice. In its proposal to shareholders for the acquisition of the U.S. firm Alloys Unlimited, Plessey stated that the acquisition would allow it to "acquire immediately a number of products and know-how which are important to our successful development." Plessey's deputy chairman notes that it "would be uneconomic for us or any other European manufacturer to learn (on his own) the skills evident in the Alloys organization."

A similar rationale underlies part of Unilever's long-standing interest in U.S. operations. And managers of one European petroleum company commented that "in order to be really successful in Europe and elsewhere, we have to compete in the market where the greatest petroleum marketing advances are being made. We have to compete in the U.S. by direct investment operations because the quota system prevents us from simply exporting to the States."

In all, nearly 50% of the European company managers interviewed in this study emphasized the importance of being in the U.S. in order to "feed back" technical or marketing skills to the mother company.

In one of the most notable cases of a significant product breakthrough by a European firm in its U.S. subsidiary - Sandvik Steel's development of "throwaway" carbide cutting edges - perhaps the most significant factor was the fact that the Sandvik group's development director at headquarters had himself worked for two years in the U.S. and was receptive to new product improvements. He was able to convince group management of the usefulness of transferring this innovation from the U.S. to European operations. A development team from headquarters was sent to the U.S. to work with the U.S. R&D group and further develop the new product. These improvements have accounted for a great deal of Sandvik's impressive growth during the last decade and now account for no less than 40% of the group's worldwide sales.

> In the past (since 1925) the United States has contributed most of the significant technological advances in the field. Although 22% of the ideas for advances originated in Europe, less than 5% were implemented by European countries first. Clearly, the U. S. is very efficient at taking a working prototype and incorporating it into an actual flying component for military and commercial use. It is in making the transition from a model to a successful in-service system that the U. S. is particularly capable.

In order for a country to adapt a technology developed elsewhere, the process of technology transfer is of infinite importance. It is a well-known fact that the acceptance, production and utilization of an advancement is often delayed for long periods of time after the initial development of that advancement. The effects of the U. S. ability rapidly to apply these technical advances has contributed significantly to increases in performance capability of U. S. aircraft. In the past this has resulted in an increasingly advantageous market position for the United States.

The cancellations of both the SST and B-1 efforts have contributed to an erosion of our previous position. The recent sale of the French A-300's (AIRBUS) to Eastern Airlines indicates that the American aircraft industry may be on the verge of losing its monopoly here in the States in the medium haul aircraft area.

> U.S. aerospace firms are forming joint ventures with foreign countries. Boeing will join with Japan on a $600 million venture to build a small (150-200 passenger) wide-bodied, low-noise, short takeoff airbus for use on domestic Japanese routes. The General Electric Co. has joined forces with SNECMA, owned by the French government, to produce the CFM 56 aircraft engine for use in STOL aircraft. Pratt & Whitney will join forces with a German consortium, MTU, and an Italian group formed by Fiat and Alfa Romeo to produce the JTIOD, a competitive engine. These engines will compete to power the next generation of commercial aircraft replacing the Boeing 727 and 737 and the McDonnell-Douglas

8. Problem Summary

Let us examine the problem from a different standpoint -- what are the effects of the lack of adequate funding? Several examples and some quotations from competitive nations may help to place in proper focus the more important aspects of the subject.

Some consequences of the lack of available research funds within the U. S. will serve as typical case-studies. The first of these involved Dr. Amdahl, a computer research scientist who worked for IBM, having design responsibilities for IBM models 704, 709 and 7030, and who managed the architectural planning of IBM System 360. Amdahl left IBM in order to pursue a proposed design of a future large scale system, which would have involved a radical change from IBM's then "present generation" computers.

Since Dr. Amdahl believed he had a technological idea whose time had come, he established his own firm in 1970 and when sufficient financing was not available from American firms, or venture capital sources, he proceeded to negotiate financing from a Japanese Company, Fujitsu, which now owns 28% of the stock. Some domestic support was provided by a Chicago business development firm, Heizer Corporation, which owns 23%. The Board of Directors controls 8%. First revenues were recorded in late 1975 for the 470 V/6 computer which competes with the larger, faster IBM System 370's. By 1977, Amdahl announced a net income after taxes of $27 million, on a turnover of $189 million -- a better profit rate than that shown by the industry as a whole.* The need for foreign financing effectively transferred

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*"Europe's Chance of a Computer Revolution", Business International, The Economist, April 22, 1979, pp. 105, 106.

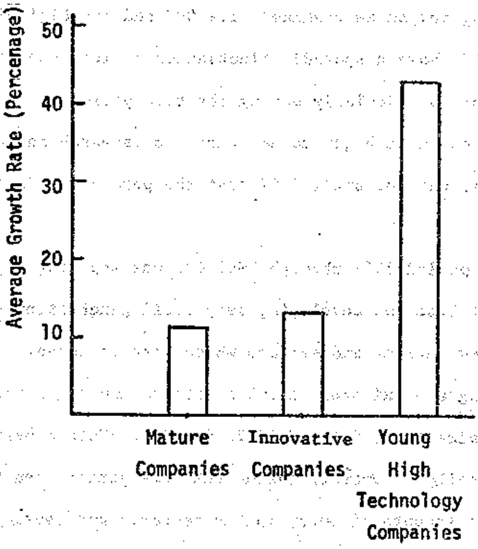

Figure 15. Comparison of Several Typical Companies - Annual Average Growth Versus Technological Classification From 1969 through 1977

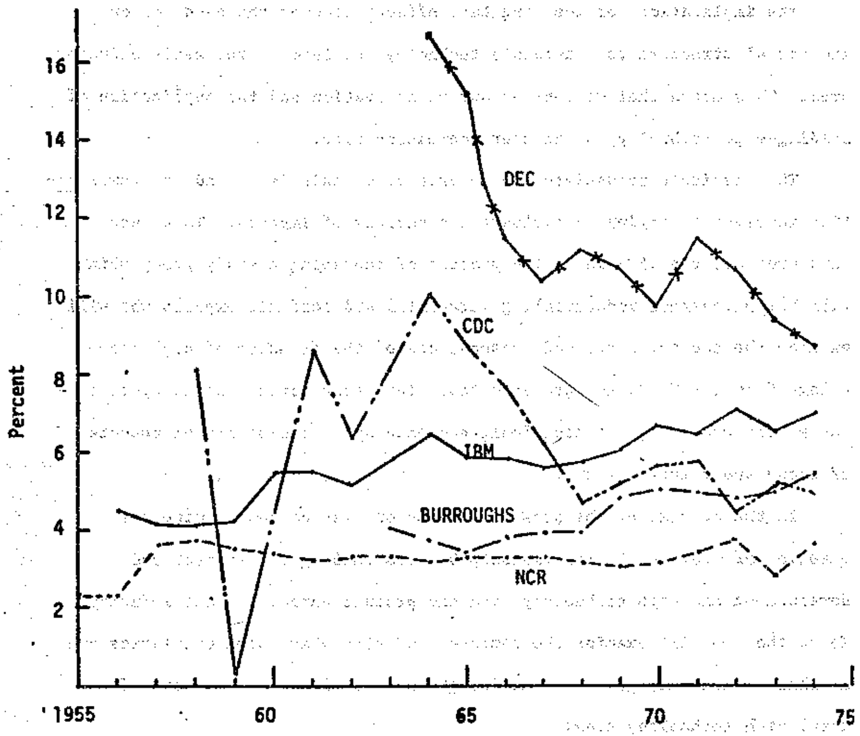

Figure 14. Computer Company R & D Investment as a Percentage of Revenue

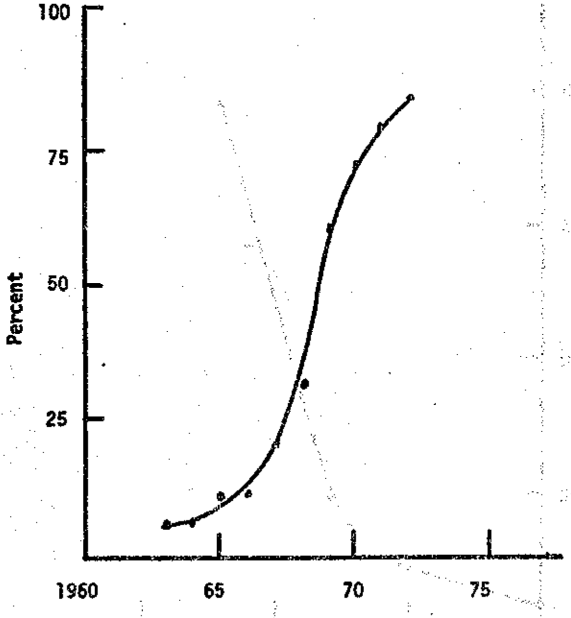

Figure 13. Cumulative Percentage of U.S. Semiconductor Companies Employing Off-Shore Assembly Facilities

companies begin to establish overseas operations. This is shown in Figure 12 which shows the number of firms who established overseas operations. Note that this number moved very rapidly from approximately 15 or 20 in 1966, to almost 100 in 1971. Further, we can examine the actual investment in overseas assembly facilities by the same semi-conductor industry. In Figure 13 we see the number of firms as a percentage of the total who established overseas assembly facilities. Starting in 1963 a very rapid development began of new overseas assembly plants by the semi-conductor industry, which reached a level of approximately 80% in 1972. Thus, most assembly or a significant portion of the assembly of semi-conductor products is currently being performed overseas by subsidiaries and joint ventures of U. S. semi-conductor organizations.

Several counterbalancing consequences of this action can be identified. On the positive side, the establishment of overseas production facilities has in several cases preempted the establishment of Japanese semi-conductor companies of production facilities in the area, and has also given the U. S. semi-conductor industry a local sales advantage. A second positive effect — resulting from one of the probable primary reasons for the overseas movement, the availability of a large, semi-skilled labor force — was the containment of total costs, resulting in consumer prices lower than could be achieved with U. S. production.

On the other side of the ledger, we must note the loss of employment opportunities here in the U. S. (at least in the short run) and the loss of national income (in the longer run) due to:

a. diversion of profits and tax income, and

b. establishment of potential competitive capability (through the transfer of the technology).

	Contribution in Billions of Current Dollars			
	1960	1965	1970	1971
High technology manufactured goods	+6.6	+9.1	+9.6	+8.3
Agricultural products	+1.0	+2.1	+1.5	+1.9
Low technology manufactured goods	-0.9	-2.9	-6.2	-8.3
Raw materials	-1.7	-2.8	-2.5	-4.1

Table 3. Contribution to the U.S. Balance of Payments by Industrial Segments

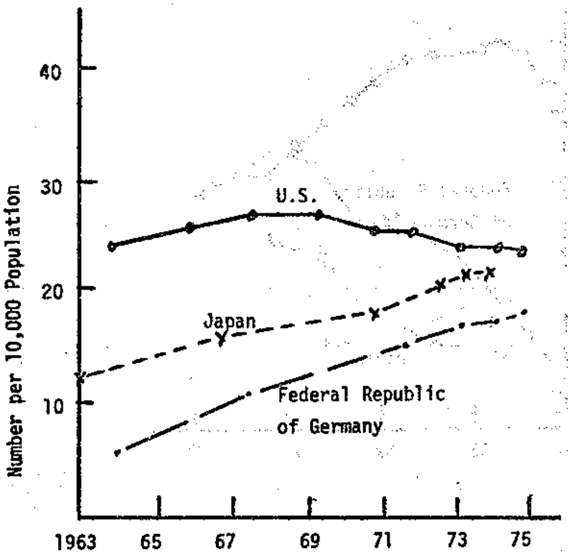

Figure 11. Scientists and Engineers Engaged in Research and Development

trade balance. The significance of this closing of the gap confirms the data in Horn's article, and indicates that we will shortly be faced with a competitor who is technologically on a par with the United States.

This raises the question of where are specific U. S. industries in relation to high technology development or the generation of high technology products?

As previously noted, because of the area of interest of the IEEE, we are restricting our examination to three major segments of the U. S. industrial base in which we currently maintain a lead. These are electronics and electrical equipment in general, the computer field specifically, as well as the aircraft industry.

In the broadest sense we must examine the inputs to the high technology segment of industry, by looking at the research and development expenditures as a percentage of the GNP (see Figure 10) as well as the number of scientists and engineers employed in the research and development areas, which is portrayed in Figure 11. Note that both of these Figures include the area of defense-related R&D, and this fact must be borne in mind in their interpretation. Half the total government outlay for R&D in the U. S. is related to defense, whereas the comparable figures for FRG and Japan are 11% and 2% respectively. The commercial emphasis in both Japan and Germany is paying off. These countries have led a huge increase in the number of foreign inventions being patented in the U. S.,* and by the addition of

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*Technology Assessment and Forecast, 7th Report (Washington, D. C.: U. S. Department of Commerce Patent and Trademark Office, March 1977).

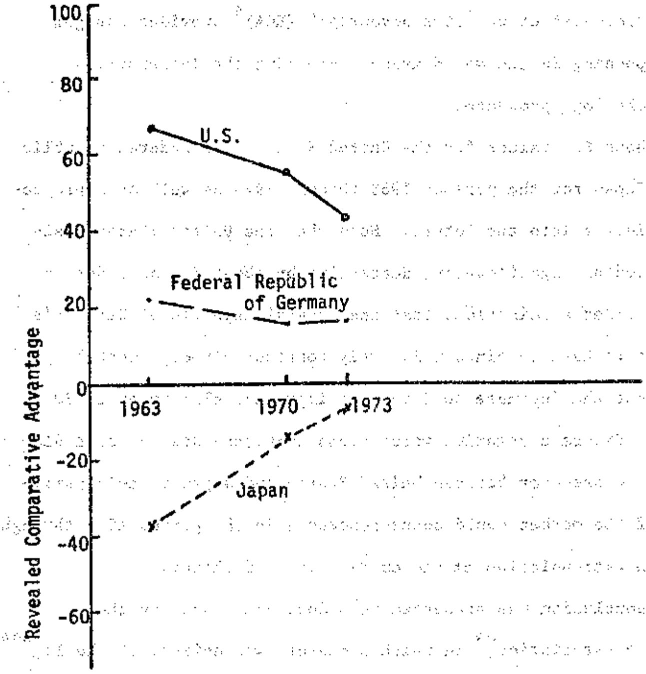

Figure 8. Revealed Comparative Advantage* Versus Time, for the U.S., Federal Republic Of Germany and Japan

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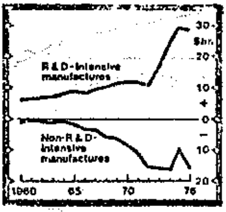
[*] This indicator measures the extent to which foreign trade surpluses (deficits) in one product group diverge from the trade position of this country in total manufactured goods. The measure has been normed so that it can assume values between + 100 and -100. High positive values of the measure indicate a high international competitiveness. For method of calculation the reader is referred to:

Horn, Ernst-Jurgen, "International Trade and Technological Innovation: The German Position Vis-a-Vis Other Developed Market Economies", in Karl A. Stroetmann (Ed.) Innovation, Economic Change and Technology Policies, Bonn, Germany, 1976, page 144 et seq.

Figure 7

U. S. R&D TRADE BALANCE[*]



[*] (Exports less imports).

Source: National Science Foundation Indicators, as depicted in "The Science Olympics", Business Brief, The Economist, May 20, 1978, pp. 86, 87.

goods, we see in Figure 6 that the United States' position in the world market has improved only slowly during the past five years. The position of the Federal Republic of Germany has remained relatively stable over this total period. On the other hand the Japanese have increased their portion of this export market from 6.5% in 1960 to 15% in 1978. The steady increase in Japan's export of manufactured products is significant and appears to be far more important than the previous penetration by Japan of the total export market. In particular, Japan's production of consumer electronics has increased by a factor of five over the past 10 years, and 62% of the 1976 output was exported ($4.8 billion),* 30% to the U. S.

Data become more difficult to obtain when we focus upon high technology and its impact upon exports and world trade. As shown in Figure 7, this is the only area in which the U. S. has not only maintained but increased its trade balance. A recent symposium** on "Innovation, Economic Change and Technology Policies" provides some insights in this area. This symposium, sponsored in part by the National Bureau of Standards, contains several presentations which provide some insights into the problem and possible solutions to that problem. Of particular note is a paper presented by Ernst-Jurgen Horn (pages 129-147), which was cited earlier.

Horn has developed a measure of the significance of high technology products upon the international competitiveness of nations. This measure,

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*"Japan's New Electronics Goodies", Business Brief, <u>The Economist</u>, April 22, 1978, pp. 84, 85.

**Stroetmann, Karl A. (Ed.) <u>Innovation, Economic Change and Technology Policies</u> (Bonn, Germany, 1976).

from 3.3% GNP to 2.6%, and by 1976 was down to 2.2%. The U. S. figure also includes about 50% for defense-related R&D, which has limited "spill-over" to the commercial sector.

Gross expenditure on research and development (as a percentage of GNP) and gross research and development expenditure per capita also correlate highly with relative market share for research intensive products. Thus we can use research and development expenditures as a rough measure of performance in trade in research intensive products. In general, such studies as Horn's have shown research and development activity to be the most important determinant of the structural pattern of international competitiveness. The influence of the research and development variable in the U. S. appeared to be even stronger than in the case of Germany, with which it was compared.*

At the broadest level the relative position of the U. S. in the world export market between 1960 and 1976 is shown in Figure 5. During this period we can see that, in round terms, the U. S. share has dropped from 18% in 1960 to 12% in 1976, while that of the Federal Republic of Germany has moved slightly upward from 10% to 11% of the total world market. On the other hand we find that the Japanese have improved their position from 4% of the total market in 1960 to 7.5% in 1976, approximately doubling their total export share.

This figure includes not only products based upon high technology and mature technology but also the exporting of raw materials, etc. It is useful only for presenting a broad overview. Focusing upon manufactured

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*U. S. Tariff Commission figures, and Horn, Ernst-Jurgen, op. cit.

7. The Current U. S. Status

There is no standard equation nor set of tables that can be employed to determine our current achievements in the application of technology to improving either the national well-being or the U. S. position in the export trade arena. Further, and probably of even greater importance, statistics that could be applied to examine this question are scattered and in some cases imperfect. However, we can begin to develop a feeling and in some cases gain both insights and indications by examining the information and data that are available. According to the product cycle hypothesis discussed in Section 5, innovative activities of countries depend on per capita income as a measure of the stage of the country in the development process. A study of 19 OECD member countries* showed a significant correlation between expenditure on research and development as a percentage of GNP, and per capita income. (At the level of the corporation, Mansfield** has demonstrated that a high level of research and development expenditure leads to increased productivity, and thence to improved gross profits, which permits and again tends to increase research and development funds. This relationship is depicted in Figure 4.) In response to this perceived relationship, both the U. S. and U. K. since 1945 have consistently spent over 2% of GNP on R&D.*** However, German expenditures increased from 1.4% of GNP in 1963 to 2.1% in 1971, whereas U. S. expenditure dropped

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*Horn, Ernst-Jurgen, op.cit.

**Mansfield, E., "Research and Development and Economic Growth/Productivity", National Science Foundation Colloquium (Washington, D. C.: GPO, 1971).

***"The Science Olympics", loc. cit.

6. The United States Posture

Whatever the relative economic advantages and disadvantages, it appears to be the consensus of both government and industry opinion that the U. S. should strive to retain technological leadership, and both interests are concerned that the U. S. is unduly eroding its position by exporting technology without adequate safeguards/recompense. The concern of governmental policy-makers is manifested by such meetings as this present hearing, under the joint auspices of the Senate Science, Technology and Space Subcommittee and the International Finance Subcommittee. Other aspects of the problem are being examined by a House Subcommittee, the Congressional Office of Technology Assessment, the National Security Council, the Office of Science and Technology Policy, the International Trade Commission, the National Science Foundation, and the departments of State, Defense, Treasury, Commerce and Labor. In view of the widespread interest, we are hopeful that the outcome will be a systematic program designed to establish U. S. priorities and to define a responsive approach for achieving identified objectives.

Industrial representatives are also very much aware that a review of our policies and practices regarding the creation and transfer of high technology is an urgent requirement. Foreign products incorporating technology acquired from the U. S. are beating out American productions in markets around the world — including the U. S. itself. Because of this, U. S. manufacturers are harvesting too little of the return from their own

> of new technologies, e.g. in R&D, and in the production of goods during the early phases of the cycle. On the one hand, these countries are relatively abundantly endowed with skilled manpower which is intensively used in the above mentioned activities and whose availability determines whether these activities can or cannot take place. Furthermore, risk capital to finance R&D activities is relatively abundant. On the other hand, a high per capita income provides domestic markets capable of absorbing new products, e.g. new consumer goods, labour-saving household devices and new labour-saving investment goods. When products become more mature, highly qualified manpower becomes less critical and the other factors of production gain influence in determining comparative advantage. In the course of increasing maturation of products or processes of production the comparative advantage shifts to less advanced industrial countries which can already handle the technology in question and are able to compete successfully with the innovating country because they enjoy the advantage of lower wages.* In the late phases of the cycle when products are mature and standardized, comparative advantage shifts to the developing countries.

Even in the high technology phase, there are advantages in occupying second place, in that the high risks and inevitable "false steps" will be taken by the leader. A nation which can maintain a minimal gap** can then be prepared to buy the products of leading edge technology, but produce and sell slightly less advanced products where the margins are less, but the volume is much greater. For example, Japan buys avionics and sells color television.

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*Haitani, K., "Low Wages, Productive Efficiency, and Comparative Advantage". In: Kyklos, Vol. 24 (1971).

**See for example
Hufbauer, G.C., Synthetic Materials and the Theory of International Trade (Cambridge, Mass.: Harvard University Press, 1966)
and
Vernon, Raymond (Ed.), Big Business and the State (Cambridge, Mass.: Harvard University Press, 1974)

The need to provide acceptable technical service requires that the local market supplier must understand the operation of the product, its virtues and limitations, and extends beyond this to require knowledge of the design and fabrication of the product as well as its mode of functioning such that one is able to diagnose field difficulties and make the requisite repairs or modifications.*

The transfer of technology and of intellectual property is perhaps accomplished most readily through the mobility of people. This process occurs not only through hiring practices deliberately designed to acquire advance technological information, but through the routine day-to-day mobility of the work force within and between companies, industries and nations.

It is of course undeniable that technology transfer is facilitated by foreign assembly, foreign manufacture of components, and complete foreign manufacture. But it is essential to understand that the absence of these may have other negative effects for the industry involved, including both the loss of foreign markets and the creation of new sources of foreign competition, and even so will not result in protection of the basic technology. The dissemination of technology cannot be stopped: it can only be controlled and slowed down.**

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*Steele, Lowell W., The Economics of International Technology Transfer, in Karl A. Stroetmann (Ed.) Innovation, Economic Change and Technology Policies, Bonn, Germany, 1976.

**How Technology Transfer Affects the Competitive Position of the U. S. in the World Aviation Market (Arlington, Va.: Forecasting International, Ltd., March 3, 1972).

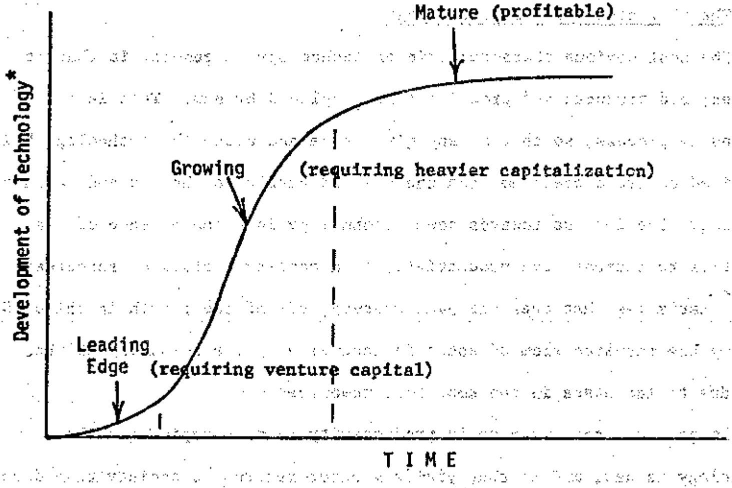

Figure 3. Technology Growth Curve

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[*] A typical measure is the percentage of firms in a particular product area which adopt the new technology.

However, the direct economic gains on the international scene resulting from the sale of technology-based products have been declining rapidly. In the area of semi-conductor electronics, where U. S. corporations have made nearly every technological breakthrough, the U. S. trade balance has been negative since 1968, and now stands at minus $2 billion, excluding only one category -- that of computers -- in which the U. S. retains a favorable balance.* Further comments concerning this particular situation will be made below, in section 6. An OECD report** cites the computer industry as one of only three areas in which the U. S. retains its technological lead, in terms of net export of the technology base. (The other two are aerospace and heavy electronics.)

Other studies have confirmed that the competitive strength of U. S. manufacturing industries in world markets is closely correlated with the performance in technological innovation.*** However, with regard to particular products, technological leads only temporarily provide comparative advantages, for the duration of the so-called imitation lag.****

In the following section, therefore, we will examine the characteristics of technology and its evolution, to assist in determining an optimum policy in controlling and/or capitalizing upon its development, application and dissemination.

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*Boretsky, Michael, U. S. Department of Commerce, as quoted in Fortune, May 22, 1978, p. 108.

**Gaps in Technology, Organization for Economic Cooperation and Development, 1970.

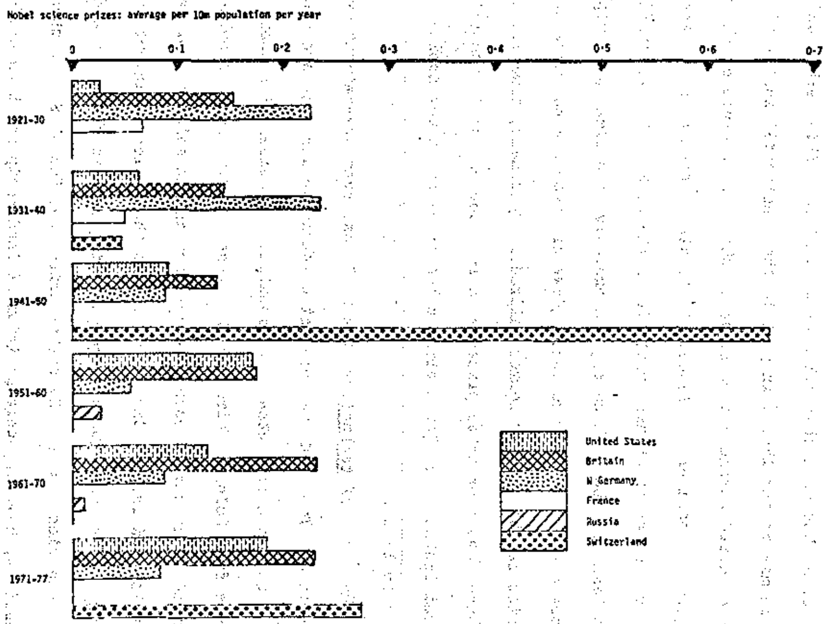
***See for example: Vernon, R., "International Investment and International Trade in the Product Cycle". In: Quarterly Journal of Economics, Vol. 80 (1966); Keesing, D. B., "The Impact of Research and Development on United States Trade". In: Journal of Political Economy, Vol. 75 (1967); Baldwin, R. E., "Determinants of the Commodity Structure of U. S. Trade". In: American Economic Review, Vol. 61 (1971).

****Posner, M. V., "International Trade and Technical Change". In: Oxford Economic Papers, Vol. 13 (1961).

countries. In the four high technology industries, aerospace, heavy electronics (including computers), chemicals and pharmaceuticals, the two areas where we lead are aerospace and electronics, where significant amounts of monies are funneled through government agencies by the Department of Defense, NASA, HEW, Department of Energy, etc. In the other two industries, chemistry and pharmaceuticals, since they are mature technological industries the bulk of their money comes from internal corporate funds or the stock market. This provides some indication that when the government funnels R&D money to private firms (as in electronics and aerospace), the industry prospers and we have a technological lead.

Figure 1

NOBEL SCIENCE PRIZES: AVERAGE PER 10 M POPULATION PER YEAR



Source: National Science Foundation, Science Indicators, as depicted in "The Science of Olympics", Business Brief, <u>The Economist</u>, May 20, 1978, pp. 86, 87.

Table 1

Nobel Prize Awards, by Country, 1901-1977

1901-1930		1931-1960		1961-1977	
Germany	27	United States	33	United States	53
England	15	England	18	England	20
France	11	Germany	14	Germany	6
Sweden	6	Switzerland	5	France	5
United States	6	Austria	4	Sweden	4
Holland	6	Sweden	2	USSR	3
Denmark	4	Italy	2	Austria	2
Austria	3	USSR	2	Belgium	2
				Denmark	2
				Argentina	1
				Australia	1
				Canada	1
				Italy	1
				Norway	1

Table 2

Selected Invention and Patent Rates, by Country[*]

	A Total Inventions on Selected List 1600-Present	B Average Annual Patenting Rate - 1930-1939	C[**] Annual Patenting Rate - 1975
United States	203	38,300	56,509
Great Britain	58	9,050	12,322
Germany	32	14,600	37,733[#]
France	29	9,550	13,386
Italy	14	3,900	--
Switzerland	--	3,130	4,369
Sweden	4	1,030	9,100[##]

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[*] Bode, H., Basic Research and National Goals, (Washington, D. C.: National Academy of Sciences, March 1965).

[**] Private Communication, U. S. Department of Commerce, Patent and Trademark Office, May 1978.

[#] West Germany only (FRG).

[##] This is made up of 7,233 foreign filings, and only 1867 by Swedish nationals.

relationships between research, technology, and economic growth, and assist in the definition of the appropriate role of Government in improving the international technological and economic standing of the United States.

5. R&D investments can be increased by direct government funding of long-range mission-oriented research, and by tax policies directed toward the encouragement of private-sector support. The many other obstacles to the maintenance of U. S. leadership are addressed at length in the body of this document.

6. Foreign investment in U. S. firms, while increasing rapidly, is at present only a minor factor in the erosion of our technological lead. The resulting transfer of technology need not be harmful if we ourselves act promptly and positively to capture and protect potential markets. However the extent of such investment needs to be monitored and, if necessary, controlled by a central authority.

7. Again, U. S. exports of technology and high technology products are not necessarily detrimental to our international stature. A two-way flow, and a coherent national policy, are essential to our well-being. On the other hand, it should be noted that our society is becoming service/information oriented. The sale of knowledge must be placed on a business basis.

8. Licensing and joint ventures abroad can be beneficial to the U. S. if we can maintain the two-way flow of technological innovation. Potential exports are being lost due to the export of technology, but this need not be the case with careful planning at the national level.

9. Our recommendations for improving export performance in high technology goods and services are given at the end of this document. It is our contention that this needs to be considered as an intrinsic component of a total technology policy which recognizes the need for balance and negotiation at an international level.

LIST OF FIGURES

LIST OF TABLES

Acknowledgment

This statement was developed with the assistance of various individuals both within and outside the formal organization of The Institute of Electrical and Electronics Engineers, and was approved at a meeting of its Board of Directors on May 23, 1978. I wish to acknowledge especially the contributions of:

Dr. A. Astin
Dr. M. J. Cetron
Ms. Audrey Clayton
Dr. George Foster
Mr. Norman Nisenoff
Mr. J. Rabinow
Dr. S. Raff

Bruno O. Weinschel,
Vice President,
Professional Activities

The GAO effort to introduce an improved classification structure for the Federal R&D budget.

As part of a planned GAO study on the impact of various Federal policies on industrial capital formation, we will review the interrelations among Federal R&D activity, private R&D activity, and industrial capital formation. This study will consider the direct impact of Federal tax, patent, and regulatory policies on private R&D expenditures. In addition, the impact of various Federal policies on the business environment and the effect of this environment on industrial R&D expenditures will be investigated. More specifically, we will analyze the effects of Federal regulatory and economic stabilization policies on how businessmen perceive the riskiness of their environment and how changes in these perceptions affect the level and allocation of their R&D expenditures.

We also plan to analyze the impact of the level and composition of Federal R&D expenditures on industrial R&D expenditures and industrial capital formation. In this effort, we will attempt to develop more effective methods for allocating Federal R&D expenditures.

States, our principal foreign competitors have well-developed government-directed programs and special institutional structures for overcoming barriers to diffusion of existing manufacturing technology and for advancing the state-of-the-art through coordinated research and development programs.

In addition to improving traditional manufacturing methods, computers and numerically controlled machines are changing both the management and the engineering technology of manufacturing. There are indications that manufacturing methods are about to change—not incrementally but radically. The changes are already taking place in other countries where the productivity-improving institutions and mechanisms were created to recover from the adverse effects of war.

Such institutions exploit, develop, and diffuse the new computer-integrated manufacturing systems and are well-designed to continue development of their nations' manufacturing productive capabilities faster than that of the United States. Their success is evidenced by their increasing share of the international markets—in some cases at the expense of our own manufacturers.

But our principal concern is for the future. Short-term benefits are possible through improved diffusion of the available technology. For long-term sustained productivity increases, R&D is necessary to find new methods and to refine existing technology so that it can be economically used outside the few highly capitalized, high-technology firms.

In the most successful foreign countries, both programs and institutional models have involved joint public and private efforts. The United States has no comparable national program, although several Federal agencies are interested in this subject. A new organization has been created which could provide the central focus and leadership. This agency is the National Center for Productivity and Quality of Working Life, established by the Congress in November 1975.

We have recommended that the Center take the lead in developing a national policy and appropriate means for achieving balanced productivity growth in the industrial manufacturing base. Further, we propose that the Center, in carrying out this recommendation, seek the cooperation and assistance of the Department of Commerce and other agencies. The expertise within the Department of Commerce, particularly in the National Bureau of Standards and the National Technical Information Service, would allow that Department to play a major role in providing technological leadership and support.

The combination of expertise of the Center and of the Department of Commerce and their close coordination with other public and private organizations can provide the much-needed focal point to coordinate all the disparate Government and private work in developing, standardizing, and diffusing manufacturing technology, and assist the emerging State and regional productivity organizations to advance manufacturing technology.

A number of specific functions should be embraced by this central focus and leadership. Three of the major ones are:

Collect and evaluate manufacturing technology information from all available sources and establish means for disseminating state of the art knowledge to potential users.

Foster the development and acquisition of new technology in various ways.

Analyze public policy options and formulate recommendations that will improve Government-industry cooperation in stimulating productivity improvement.

WHAT CAN WE DO?

What can we do to improve the climate for Government-industry cooperation? I have no panacea to alleviate the attitudinal constraints that continue to retard the development of a more constructive partnership between Government and industry. It behooves all of us—individually and collectively—to make extraordinary efforts to achieve better communication and mutual understanding of our respective needs and interrelated goals in the context of our total responsibilities and obligations.

Continued studies and publication of resulting reports clarifying the issues and alternatives should help improve understanding. An excellent example is the July 9, 1975, report by Robert Gilpin, "Technology Economic Growth, and International Competitiveness," report prepared for use by the Subcommittee on Economic Growth of the Joint Economic Committee. Another good example is the 1973 report, "Barriers to Innovation in Industry: Opportunities for Public Policy Changes," based on study sponsored by the National Science Foundation and performed as a joint effort by Industrial Research Institute and Arthur D. Little.

be served when private industrial contractors, with a few provisos, are granted exclusive licenses for commercial development.

When developing and marketing commercial products, industry naturally prefers to exercise its own discretion independent of any Government assistance or influence unless it needs help to deal with serious threats from foreign competition or another domestic enterprise which it believes is exercising unfair competition. Industry is particularly concerned about the constraints of Government regulations which tend to divert capital from innovative R&D to R&D and other investments necessary to comply with regulatory requirements. Furthermore, some multi-national corporations may not be inclined to share strategic information with the Government and to plan and conduct their business in such a manner as to assure harmony with the international objectives of the United States.

As a final attitudinal concern, there are many in both Government and industry who are unwilling to assume responsibility for what others would judge to be reasonable and necessary risks for investment in exploratory research and development when the payoff is uncertain in terms of time or economic return.

Many factors have been identified as real or tangible constraints that tend to cause a decline in technology innovation. Among these are the uncertainty of the economy, the high cost of capital, and the slowdown during the last few years in Federal spending for research and development.

The myriad of regulations established by both Federal and State governments affect the cost of doing business and may involve conflicting requirements imposed by different agencies. For example, in Federal procurement of conventional commercial products, the public would be served better in many cases by best-buy competition based on superior or innovative performance and life-cycle costs, rather than by the prevalent procurement practice which tends to favor the lowest bidder who offers products meeting acceptable quality or minimal specifications.

In the larger sense, criticism is levied that the Government has not established a consistent national policy and strategy for Government-industry relations to balance incentives and constraints and assure a favorable climate for technology innovation by private enterprise. This contrasts sharply with other nations, notably Japan and West Germany, that have policies and special institutional arrangements to foster industrial technology innovation and improved manufacturing productivity.

Part of this issue is the question of whether our antitrust laws, established primarily on a domestic basis, need to be reexamined in an economy which is becoming increasingly world interdependent in market relationships and competition. This question is highlighted by the increasing number and size of multinational corporations and the fact that foreign corporations are growing faster than U.S. corporations.

Most of the other industrialized nations have developed closer relationships between government and the private sector on capital formation and R&D directed to the private economy. This is an area in which we perhaps should explore new perspectives for Government-private sector interaction within the framework of American institutions.

Improved productivity and advances in science and technology cannot take place separately from other aspects of national policy; advances made in the laboratory and on the testing grounds require adequate financial support obviously. However, these advances can be similarly flawed if such support does not go hand-in-hand with policies developed which will make it possible to use and develop these innovations. The Internal Revenue Service, Securities and Exchange Commission, Justice Department, and Department of Commerce all must play a part. Too frequently, these organizations go their individual ways for their own reasons and possibly for even socially desirable purposes. This does not mean, however, that their actions will coincide with adequate accounting as to their impact and consequences for risk-taking and technological innovation. There is currently no procedure for measuring the effect of these Government decisions on science and technology. Thus, industrial risk-takers lean toward hedging and zero-risk decisions. Innovation under these conditions can be, at best, incremental. Hopefully, the new Office of Science and Technology Policy will recognize that innovation must come as the result of total Government policy—not the more frequently narrowly construed concept of science and technology.

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[45] W. S. Comanor, "Research and Technical Change in the Pharmaceutical Industry," *Review of Economics and Statistics*, 47(2) (May 1965), pp. 182-190.

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[50] Hamberg, "Size of Enterprise."

[51] Pavitt and Wald, "Conditions for Success."

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[53] F. M. Scherer, *Industrial Market Structure*, Ch. 15-16.

[54] Ibid., p. 351.

[55] J. A. Schumpeter, *Capitalism, Socialism and Democracy*, Third Edition (New York: Harper and Row, 1950), Ch. VII and VIII.

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[58] Kamien and Schwartz, "Market Structure and Innovation," p. 14.

[59] Comanor, "Market Structure," pp. 639-657.

[60] Galbraith, *American Capitalism*, pp. 86-87.

[61] R. H. Coase, "The Nature of the Firm," *Economica* (November 1937), pp. 386-405.

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[64] Ibid., p. 398.

[65] Ibid.

[4] Donald B. Kessing, "The Impact of Research and Development on United States Trade," *Journal of Political Economy* (February 1967), pp. 38-48.

[5] K. Pavitt and S. Wald, "The Conditions for Success in Technological Innovation" (Paris: OECP, 1971).

[6] W. Gruber, D. Mehta and R. Vernon, "The R and D Factor in International Trade and International Investment of U.S. Industries," *Journal of Political Economy* (February 1967), p. 22.

[7] Calculated from data in a newsletter published by Economic Evaluation Associates (Chicago: 1975). With such a small sample, even if the correlation were perfect, the chi square distribution barely would be significant at the 5 percent level.

[8] The R and D figures are from U.S. National Science Foundation, *National Patterns of R and D Reserves: Funds and Manpower in the United States,* Reports for years 1958-1975 (Washington, D.C.).

[9] In 1965, a sample of firms in important industries showed that companies with less than 1,000 employees accounted for only 5.2 percent of industry R and D expenditures. This had fallen from 7.0 percent in 1957.

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[17] McConnell and Peterson, "Research and Development." These percentages refer actually to those firms responding to the questionnaire. My feeling is that firms with formal R and D programs would be more likely to respond. If this is correct, the true percentage of small firms engaging in formal R and D would be lower than the 38 percent reported, but those with informal R and D could be either higher or lower.

[18] Smith and Creamer, "R and D and Small Company," from combining NSF and Census data, found that only 4 percent of firms with less than 1,000 employees had R and D programs compared with about 57 percent for firms with between 1,000 and 4,999 employees and about 91 percent for companies with more than 5,000 employees. Their figures for the smallest class of firms are almost certainly too low. Possibly the combining of NSF and Census data introduced inconsistency into the sample in the lowest size class; they themselves recognize the possibility of inconsistency.

expected value of a patent would be greater, reflecting greater immunity from legal attack and from "patenting around." The courts should not be called upon to so often make the distinction between weak and strong patents and between viable and nonviable patents. This would require a more careful comparison of pending patent applications with existing patents and, perhaps, a separation of inventions into categories for separate treatment on the basis of their importance as in Germany.[63] These changes would require a greater Patent Office budget as well as more experienced personnel.

Another approach might be to allow suit for treble damages in patent infringement cases. This clearly would increase the bargaining power of patent holders and, in so far as smaller firms have a comparative advantage in patenting, would increase their bargaining position.

A final proposal for patent reform is considerably more radical. This is that the patent system, and/or the proposed direct award system, discriminate between firms on the basis on size. The patent rights of smaller firms could be defined more broadly and the life of its patents could be greater.

Larger firms undoubtedly will react with indignation to proposals along such lines. Yet they have a considerable appeal even on the basis of equity. Most governmental regulations are disproportionately expensive for smaller firms. Except for possibilities of not getting caught, there are clear economies of scale in dealing with government regulations and bureaucracy. The type of change proposed would help balance the effect of other regulations. Moreover, this country has always put a premium on smallness. Large concentration of power in any areas are quite rightly mistrusted. Policies calculated to recognize this set of values command a certain force of their own.

Firms on their own can effect reform. Firms themselves can, and do, make purely internal arrangements that promote an efficient allocation of R and D by size. Research units can attempt to duplicate those conditions associated with the smaller firm that are most productive. In fact, larger firms sometimes fund research efforts and have a minority stockholder position in relatively small firms headed by a highly creative inventor. Such an arrangement may create a better work atmosphere, but it

Presumably, barriers should be low enough to present threat of competition, but high enough so that immediate entry would not eliminate the rewards of invention too quickly. Such monopoly power would presumably deteriorate over time in accord with Schumpeter's notion of creative destruction.

Schumpeter's thesis regarding firm size (as distinguished from monopoly) was taken up by Galbraith:

"There is no more pleasant fiction than that technical change is the product of the matchless ingenuity of a small man forced by competition to employ his wits to better his neighbor. Unhappily, it is a fiction. Technical development has long since become the preserve of the scientist and engineer. Most of the cheap and simple have, to put it bluntly and unpersuasively, been made---. Because development is costly, it follows that it can be carried on only by a firm that has the resources which are associated with considerable size."[60]

Galbraith's statement about the demise of cheap and simple inventions is reminiscent of the late nineteenth century patent commissioner who resigned on the grounds that all the important inventions had been made. Every year thousands of simple and important inventions are made by small firms or by individuals. Penicillin, the Polaroid camera and electrostatic duplicating were perhaps not simple inventions, or discoveries, but even these were the product of the single inventor or small firm. What Galbraith is doing is confusing the inventive function with the development function. Galbraith's confusion would result in a failure to seek means to combine more effectively the inventive efficiency of the smaller firms with the development efficiency of the larger firms. To this subject we now turn.

The direction in which solutions lie can be seen by considering a perfectly efficient patent system, the absence of uncertainty, a perfect capital market and sufficiently low transactions costs. In this situation, one would find an optimal allocation of R and D tasks among firms. Activities leading to original invention would tend to be concentrated in smaller firms, and developmental activities would be concentrated among medium-size or larger firms. Smaller firms could sell or contract original inventions to larger firms in an efficient market setting and the allocation of resources devoted to the various aspects of R and D small firms, which is also a view held by Pavitt and Wald. In an examination of empirical evidence from the 1960's, they concluded that larger and smaller firms play complementary roles in innovation. Smaller firms concentrated on smaller-scale, specialized and sophisticated equipment and made major innovations after larger firms had let the opportunity slip away.[51] Pavitt and Wald also found that "opportunities for small firms tend to be greatest in the earliest stages of the product cycle, when economies of scale are relatively unimportant, market shares volatile, and rates of entry and failure high."[52]

This view of the complementary tasks of the large and small firm is also suggested by the detailed examination of the development of important inventions by Jewkes, Sawyers, Stillerman, and by the investigation of Mueller and by other studies. These investigations show (implicitly, as the point is sometimes overlooked by the authors) that the initial patentable idea, which is of course an essential step, is one much less expensive than the steps transforming the original idea into a form that is commercially useful and marketable. The expenses involved in the stages of development after the original invention are, more often than not, prohibitive for the smaller firm.[53]

The patentable concept of electrostatic machine copying was developed by one man, Carlson. Since this was a new process substantially different from existing processes, a relatively small company (Haloid) could develop the process successfully and become the leading producer (Xerox) in the new field.[54] This is to be contrasted with, say, an innovation that improves the performance of existing copiers. Discovery of such an improvement by a laboratory becomes somewhat more probable, but it is much more likely that the development of work necessary to convert the invention into a useful final product will be performed by a larger firm. Even the expense of certain types of initial inventions are beyond the means of smaller firms. What is uncertain is the extent to which capital constraints, inherent riskiness of invention and the large costs of development discourage inventiveness by smaller firms. Chances are that this is a problem of considerable magnitude.

Just recognizing the problem is an important step since current mythology obscures it. The proposition that smaller firms have a comparative advantage in invention, while medium-size firms are usually sufficiently

This general pattern is borne out by the questionnaire survey of Cooper[47] who interviewed twenty-five people with experience in research and development, primarily in chemicals and electronics, most of whom had managed development in both large and small companies. The estimates derived from these interviews indicated that large companies must spend from three to ten times as much as small ones to develop a particular product. The reasons for this are presented below.

First, the average competence of technical people in smaller firms is higher than in large firms. Greater freedom of a smaller company apparently is attractive; research personnel may own significant amounts of the stock of small companies so that the incentives for successful invention or innovation may be significantly greater; and small companies are less likely both to tolerate unproductive personnel and to hire unseasoned people. Although Conner does not comment on this, apparently greater productivity of R and D personnel in smaller plants derives in part from their higher salaries--either because they are more experienced or more competent, or because of their direct ownership which acts as an incentive to produce. Nevertheless, if Connor estimates are correct, it would seem that the additional expenses are more than offset by the increased productivity. In so far as the increased financial incentive increases productivity, one may wonder why large companies do not adopt some incentive system. An experienced patent agent with a large chemicalcompany suggests that this is true because in a large R and D organization such a system would restrict information flow within the company and create difficult rivalries and jealousies.[48]

Second, technical people are much more cost conscious. Somehow the small firm is better able to achieve an atmosphere in which technical personnel are left alone to pursue work and, because of the closer identification of the personnel with the company, the personnel place a high priority on the way their efforts contribute to the company's success.

Third, in the small company there is greater ease of communication and reduced problems of coordination. In smaller companies, technical personnel are more likely to be sensitive to the needs of the market because of closer contact with people concerned with this area. To be sure, these various advantages must be weighted against disadvantages of breadth of experience and specialization, but Connor's study indicates that the advantage lies with small companies.

Support for the thesis that large firms in concentrated industries show greater evidence of technical change is furnished by A. Phillips.[34] In general, Phillips found that those industries "which had large-scale producing units in 1904 had significantly greater rates of decrease in the number of wage earners per unit of output between 1899 and 1939 than did the other industries." Phillips' results are too facile because they probably do not measure the effects of large size and concentration on invention or development. Greater technological opportunities probably exist for capital-intensive firms so that their capital/labor ratio naturally would tend to grow more quickly over time. Thus, the casual influence probably runs from technology to concentration rather than the reverse, and is shown by Phillips' own subsequent work[35] and by studies by Scherer[36], Philips[37] and Comanor.[38] Scherer and Philips found that differences in the scientific knowledge base accounted for as much of the total variance in corporate R and D as did interfirm differences in corporate sales; Comanor's results were supportive of Scherer and Philips' conclusions.

INVENTIVENESS AND THE SMALLER FIRM

An important and cogent argument can be made that, from the social point of view, smaller firms should invest more than they do in R and D and that they should invest more than larger firms in proportion to their size. This argument rests on the rather substantial amount of evidence which indicates that smaller firms have a greater efficiency in invention than larger ones.

Some evidence of this from works by McConnell and Peterson and Schmookler and Scherer already has been offered. However, none of these separates invention from development or invention or development from innovation. Scherer's results mainly concern patents and, therefore, relate to invention, but these are not only unweighted as measures of the importance of invention, but also are only for Fortune 500 firms.

The work most relevant for the present argument deals with the origins of invention. Jewkes, Sawers and Stillerman[39] in their analysis of the case histories of sixty-one important twentieth-century inventions found that less than one-third of these came from research laboratories. For a more restricted period, 1946-1955, Hamberg[40] found that only ~~about~~ one-fourth of a sample of major inventions were conceived in large

However, McConnell and Peterson's results are not duplicated in studies of larger firms. Typical results for larger firms are either that there is no relationship between firm size and R and D intensity or that R and D intensity increases up to a point and then diminishes. Some studies show a negative relationship between firm size and R and D intensity.

Smith and Creamer's results are somewhat typical.[27] One of the industries (scientific and measuring instruments) in Smith and Creamer's twelve-industry sample also shows a negative relationship for research intensity and firm size. For two additional industries (other chemicals and communication and electronic equipment), the intensity of the smallest firms (under 1,000 employees) was greater than for any other class when federal funds were excluded. In the categories of other chemicals, drugs and other medicine, and scientific instruments, the peak intensity occurred at less than the largest size class. Finally, in seven of the twelve industries, the peak intensity of the smallest size class was greater than that of the next largest class.

Schmookler's results for larger firms are fairly consistent with the relationships shown by Smith and Creamer.[28] For a six-industry sample, Schmookler found across four industries no relationship between firm size and R and D intensity. However, for two of the six industries, Schmookler data show that the R and D intensity of the smallest firms (49-499 employees in one case, 500-999 in another) was greater than that of any other size class. It is worth noting that these two industries (fabricated metal products and ordinance, and electrical equipment) are among those in the McConnell and Peterson sample. In two other industries, peak R and D intensity occurred at less than the largest size of more than 5,000 employees; for the professional and scientific instruments industry, peak intensity occurred at the second smallest size class (500-999 employees), in the food and kindred products industry, the peak intensity occurred at the next to largest size class (1,000-4,999 employees).[29]

Even for the chemical industry, the R and D intensity for the smallest size class (firms with less than 500 employees) was greater than for any size class, except for the largest. Strikingly, two of the industries found by Schmookler to exhibit peak research intensity at sizes of less than 1,000 employees (electrical equipment and professional instruments) small firm to capital problems, especially in view of the inherent risks of R and D. As R and D is spread among a larger number of projects, as is more likely the larger the firm, the risks of failure of any one project are reduced. //? Related to the question of small firm survival is the greater life expectancy of larger firms which allows them to assume R and D investments whose payoff period is longer. The greater diversity of large firms in increasing the likelihood of being able to use an invention, and the greater market concentration of large firms are also elements, though quite minor ones, in explaining the greater propensity for R and D programs among larger firms.

R and D expenditures by small companies are distributed among approximately the same industries as for large companies. Smith and Creamer[19] show for 1965 that four of the top five industries in absorbing R and D spending by small firms were also among the top five for large firms. It would appear that the more capital-intensive industries have the higher percentages of firms engaging in R and D.[20] This probably reflects the greater potential for R and D in these industries and the fact that capital-intensive industries tend to have larger firms. It would be interesting to see what the regression of both firm size and capital intensity against the percentage of firms engaged in R and D would show.

Given the skewed distribution of R and D spending among small firms by industry and by size, it is not surprising that Smith and Creamer find the distribution of R and D spending among small firms also highly skewed.[21] Thirteen percent of manufacturing firms with less than 1,000 employees spent about 55 percent of total R and D spending by manufacturing in this size class. What is perhaps more interesting is that this 13 percent also showed a more continuous record of R and D spending.

Research Activity, Intensity and Firm Size

Firm size strongly influences the probability of a firm having a formal R and D program, but does firm size influence the size of the R and D program? One would expect a positive relationship as long as there were not strongly decreasing returns to scale in R and D. One also would expect a positive relationship simply on the basis of federal funding of R and D. The percentage of R and D funding from federal sources is enormous, though recently it has been declining. In 1959, federal funding advances may come from departments other than those for R and D. Changes in tax treatment of R and D can result in new, arbitrary classifications of personnel or activities into the category of research.[10] If these problems exist in attempts to study R and D for larger firms, how much more difficult is it to analyze R and D by smaller firms in which the data are less satisfactory or do not exist?

Aside from basic problems of data availability, current research suffers from two interrelated and important shortcomings. The first is that data are not examined on a sufficiently disaggregated basis. The second deficiency is that too few factors have been introduced that might help explain the structure of R and D. Kamien and Schwartz[11] observe "much of the evidence on the effect of size has not controlled for other factors that may be helpful in explaining innovational effort." The same may be said of evidence concerning innovational outcome. Few studies really have attempted to explain the structure of R and D, undoubtedly because to do this requires that the data and information be generated by narrowly focused studies working to build up a data base sufficiently rich to understand R and D structure.

In this regard, problems of R and D are reminiscent of problems of developing a general theory of oligopoly. The necessary basic research is tedious and perhaps less rewarding in the short run. Perhaps economists are less willing than researchers in the natural sciences to undertake the tedious and narrowly focused research upon which the advancement of science ultimately rests.

R AND D CHARACTERISTICS OF SMALL FIRMS

The most important studies of R and D in small firms are those of McConnell and Peterson,[12] McConnell and Ross,[13] Hamberg,[14] Smith and Creamer[15] and Dearborn, Kneznek and Anthony.[16] From these and other investigations, a number of limited and tentative, though important, conclusions emerge.

The Incidence of R and D Programs

Seems high

Probably about 20 to 40 percent of small firms engage in R and D in a relatively formal way. Among the more reliable estimates are those from the detailed and disaggregated questionnaire results of McConnell and between the investment-to-GNP ratio and real growth rates for seven OECD countries as measured by the Kendall coefficient of concordance is .92, with a chi square of 11.2. This is just significant at the 10 percent level, which is impressive for such a small sample.[8] Similarly for the 1967-1971 period, the United States ranked last in its growth of R and D expenditures, followed by the United Kingdom, France, West Germany and Japan. This matches the respective growth rates of these countries, except for the reversal of the United States and the United Kingdom.

For the United States, the fall in the investment-to-GNP ratio has occurred in large part because of the failure of the traditional sources of investment funds, retained earnings, debt and equity. Retained earnings in constant dollars have declined enormously during most of the 1960's and the 1970's. The "crowding out effect" has limited severely bond debt as a means of financing, and, until recently, the stock market has not been a very attractive place to go for financing. Financing problems of small businesses have been especially difficult.

One set of measures that undoubtedly are called for are policies that encourage greater capital formation. With such policies, R and D for both small and large firms undoubtedly would expand. However, the response of small firms probably would be greater because of their greater sensitivity to credit conditions. The phenomena is similar to the unemployment rate of minorities which increases proportionately more than for other groups during periods of contraction and which decreases more than proportionately during periods of expansion.

Economic growth is a matter of the efficiency as well as the magnitude of investment. In this regard, the distribution of R and D expenditures between large and small firms becomes especially relevant. After considering the relationship of R and D to smaller firms in the next section, the third section of this paper argues that efficiency requires a greater portion of R and D spending by smaller firms. The final section suggests conditions under which the improvements in efficiency might be brought about.

DATA LIMITATIONS FOR THE ANALYSIS OF SMALL FIRM R AND D

Small firms are those with less than 500 employees and probably account for less than 3 percent of total R and D expenditures.[9] Yet in terms of

APPENDIX XV

ARTICLE, "RESEARCH AND DEVELOPMENT BY SMALLER FIRMS," BY RICHARD O. ZERBE, JR., NORTHWESTERN UNIVERSITY AND UNIVERSITY OF WASHINGTON, JOURNAL OF CONTEMPORARY BUSINESS, 1976, PAGES 91–113

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Journal of Contemporary Business *Spring 1976*

RESEARCH AND DEVELOPMENT BY SMALLER FIRMS

Richard O. Zerbe, Jr.*
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THE IMPORTANCE OF RESEARCH AND DEVELOPMENT

Technical change arising from research and development (R and D) expenditures is exceedingly important. Solow,[1] in his pioneering work, found that between 1909 and 1949 about 81 percent of economic growth was attributable to technical change and changes in production practice. Dennison,[2] in a more disaggregated study, found that 36 percent of the rise in output per worker was attributable to advances in technical knowledge, and 42 percent was attributable to improved worker education. Only 9 percent of the rise was due to increases in the capital stock.

Research and development is also of major importance in determining comparative advantage, the balance of payments and the magnitude of U.S. exports.[3] Donald Kessing[4] found that there was a powerful correlation between the intensity of R and D activity in American industries and their export performance. Pavitt and Wald[5] found a high correlation between national industrial R and D expenditures and national technological performance across a sample of ten industrialized countries. In a sample of fourteen industries, Gruber, Mehta and Vernon[6] found that U.S. export strength was concentrated in the five industries with the greatest R and D effort, i.e., transportation, electrical machinery, instruments, chemicals and nonelectrical machinery. The remaining industries exhibited a net import balance for 1962, the year investigated.[7] From these and other studies there is little doubt that R and D and technical change play a major role both in economic growth and in determining relative economic position.

A crude comparison suggests that the fall in the U.S. growth rate of recent years and the concomitant absolute and relative decline in the ratio of R and D to GNP are not unrelated phenomena. The decline in R and D has been part of this decline in the United States in the investment-to-GNP ratio. See Figure I. For the 1960-1973 period, the rank correlation

Table 5-10. Distribution of employed doctoral scientists and engineers by employment sector, 1975

Employment sector	All doctoral scientists and engineers		Doctoral scientists[1]		Doctoral engineers[1]	
	Number	Percent[2]	Number	Percent[2]	Number	Percent[2]
Total	262,411	100	219,055	100	43,356	100
Business and industry	65,876	25	43,341	20	22,535	52
Educational institutions	153,249	58	137,943	63	15,306	35
Four-year colleges and universities	147,633	56	132,504	61	15,129	35
Two-year colleges	3,674	1	3,497	2	177	(4)
Elementary and secondary schools	1,942	1	1,942	1	—	—
Hospitals and clinics	7,586	3	7,562	3	24	(4)
Nonprofit organizations	8,510	3	7,277	3	1,233	3
Government	26,755	10	22,538	10	4,217	10
Federal[3]	21,634	8	17,855	8	3,779	9
State	3,110	1	2,883	1	227	1
Other	2,011	1	1,800	1	211	(4)
Other employment sector	86	(4)	86	(4)	—	—
Employment sector unreported	349	—	308	—	41	—

[1] Includes 94 scientists or engineers whose field is unknown.
[2] Excluding those whose employer was unreported.
[3] Includes the military and the Commissioned Corps of the Public Health Service.
[4] Less than 0.5 percent.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States, 1975* (NSF 77-309), pp. 38-41.

See Figure 5-17 in text.

Table 5-11. Doctoral scientists and engineers by age and type of employer, 1975

Age	Business and industry		Four-year colleges and universities		Federal Government[1]	
	Number	Percent	Number	Percent	Number	Percent
Total	65,876	100	147,633	100	21,634	100
Under 30	2.129	3	5,772	4	773	4
30-34	15,117	23	30,862	21	4,121	19
35-39	14,113	21	30,903	21	4,734	22
40-44	10,274	16	23,687	16	3,646	17
45-49	8,090	12	19,833	13	3.081	14
50-54	7.476	11	16,146	11	2,398	11
55-59	4,610	7	10,774	7	1,533	7
60-64	2,734	4	6,461	4	953	4
65 or over	1,224	2	3,094	2	382	2
No report	109	(2)	101	(2)	13	(2)

[1] Includes the military and the Commissioned Corps.
[2] Less than 0.5 percent.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States, 1975* (NSF 77-309), pp. 38-41.

See Figure 5-19 in text.

APPENDIX D

Selected Tables from Science Indicators, 1976, NSB 77-1, The National Science Board

OFFICE OF PLANNING AND RESOURCES MANAGEMENT

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
10/76	Computer Horizons Inc. Cherry Hill, N.J.	An Evaluation of University Research Productivity	7681724	Evaluation	$ 42,495
11/76	Computer Horizons Inc. Cherry Hill, N.J.	Review and Analysis of Importance and Utilization Measures Contained in Evaluative Bibliometrics	7682854	Evaluation	$ 18,318
9/77	Institute for Scientific Information Philadelphia, Pa.	A Citation and Publication Analysis of U.S. Industrial Organizations	7710048	Evaluation	$ 64,851

SCIENCE EDUCATION DIRECTORATE

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
9/77	Prism Productions Inc. Camarillo, Ca.	An Experimental Series of Science Programs for Commercial Television	7716196	Public Understanding of Science	$203,100
9/77	Exotech Inc. Gaithersburg, Md.	Data Processing Support to the Science Education Directorate	7726461	Special Studies	$124,854
9/77	Westat Inc. Rockville, Md	Program Evaluation in Science Education: CAUSE	7723940	Systems Approach	$ 9,900
2/77	Courseware Inc. Provo, Utah	Learner-Controlled Instructional Strategies: An Empirical Investigation	7601650	Technological Innovations in Education	$207,750
	Development & Evaluation Associates Syracuse, N.Y.	Evaluation of CAUSE	7723982	Systems Approach	$ 9,990

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
5/77	Technology Associates of Southern California, Inc. Monterey Park, CA	Investigation of the Design and Performance of a Simple Liquid Piston Heat Engine	77-07489	Exploratory Research	53,600
8/77	CONSAD Research Corp. Pittsburgh, PA	A Prototype Evaluation of the Program Output of the Research Applied to National Needs (RANN) Program	76-11438 A04	Research Evaluation	57,107
9/77	Operations Research, Inc. Silver Spring, MD	Research on Methods for Assessing the Utilization and Impact of RANN Projects	77-22190	Research Evaluation	63,500
9/77	Kappa Systems Arlington, VA	RFP 77-110: External Product Evaluation Management	77-26721	Research Applications	261,480
			Subtotal:		$ 7,599,535

Awards made via a purchase order:

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
7/77	Belt, Beranek & Newman Cambridge, MA	Evaluation of Basic Research Progress and Future Research Opportunities in Human Factors and Ergonomics	RN-1473 7SP0920	Productivity	3,609
6/77	Clinical Systems Associates, Inc. Washington, D.C.	Technological Needs of the Physically Handicapped	RN-1039 7SP0842	Productivity	9,850
9/77	Clinical Systems Associates, Inc. Washington, DC	Research Priorities to Aid the Productivity of the Physically Handicapped	RN-6096 7SP1121	Productivity	6,250
8/77	Dames & Moore San Francisco, CA	Implementation Measures to Reduce Earthquake Hazards of Dams	RN-6874 7SP1045	Environment	1,000

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
8/77	Oneida Materials Corp. Cucamonga, CA	Development and Testing CSMRI "A" Metal Process for Recycling Steelmaking Dust and Scale Waste for Industrial Adoption	76-84256	Indus. Prog./ Resources	75,000
2/77	Amber Laboratories Juneau, WI	Natural Red Food Colorant from Beets	76-24677	Resources	103,900
12/76	Anver Bioscience Design Sierra Madre, CA	Jojoba Seed Meal as an Animal Feed	76-23895	Resources	77,300
8/77	Roger Blobaum & Associates Creston, IA	An Assessment of the Potential for Applying Urban Wastes to Agricultural Lands	77-08280	Resources	92,100
9/77	Charles River Associates Cambridge, MA	An Analysis of Major Policy Issues Raised by the Commercial Development of Ocean Manganese Nodules	77-14453	Resources	191,900 (30,000 fro Bureau of Mines)
7/77	Collaborative Research, Inc. Waltham, MA	Synthesis and Applications of Nucleic Acids to Biological Nitrogen Fixation	77-10195	Resources	209,100
9/77	Collaborative Research, Inc. Waltham, MA	Enhancement of Animal Protein Production by Novel Genetic Technology	*77-19654	Resources	24,997
8/77	DASI Industries, Inc. Chevy Chase, MD	Evaluation of Free-Falling Film Ultra-High Temperature Processed Milk	77-04162	Resources	168,700
9/77	EIC Corporation Newton, MA	Recovery of Chromium from Nickeliferous Laterites	*77-19538	Resources	24,740
2/77	Experienced Resource Group, Inc. Baton Rouge, LA	Alternative Food Delivery Systems - An Exploratory Assessment	77-07184	Resources	25,000

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
4/77	Maurer Engineering, Inc. Houston, TX	Conference on Research in Excavation Technology	75-14405 A03	Productivity	36,900
9/77	Maynard Research Council Pittsburgh, PA	Study of a Mechanism to Foster University/Small Business Interaction	77-14151	Productivity	100,000
9/77	Multisystems, Inc. Cambridge, MA	Remote Employment of the Physically Handicapped	*77-19497	Productivity	24,948
9/77	Precision Instrument Co. Santa Clara, CA	Slidestore: Large Capacity Information Storage	*77-19528	Productivity	24,995
8/77	Radiation Monitoring Devices, Inc. Watertown, MA	Research on Uncooled Cadmium Telluride Gamma Detectors as Substitutes for Ultra-pure Germanium	77-10434	Productivity	198,100
9/77	Scientific Process and Research, Inc. Highland Park, NJ	Lowering of Energy Consumption in Plastics Processing	*77-19512	Productivity	25,000
9/77	Scientific Systems, Inc. Cambridge, MA	Microprocessor-Based Prosthetic Control	*77-19672	Productivity	23,670
6/77	Spectrum Research Denver, CO	Evaluating the Organization of Service Delivery: Public Health	74-08798 A01	Productivity	8,648
4/77	Stearns, Conrad, & Schmidt Consulting Engineers Long Beach, CA	Research on Equipment Technology Utilized by Local Government: Refuse Collection	77-04424	Productivity	40,272
6/77	Stearns, Conrad, & Schmidt Consulting Engineers Long Beach, CA	Research on Equipment Technology Utilized by Local Government: Refuse Collection	74-20560 A03	Productivity	13,800

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
9/77	Woodward-Clyde Consultants San Francisco, CA	Analysis of the Adoption and Implementation of Community Land Use Regulations for Flood Plains	77-13908	Environment	208,300
5/77	Advanced Research Resources Organization Silver Spring, MD	A Conference to Formulate Priorities for Research on Human Performance and Productivity	77-07886	Productivity	74,900
9/77	Agbabian Associates El Segundo, CA	Improved Design Procedures for Underground Structural Support Systems in Rock	76-80044	Productivity	179,900
9/77	Amtech, Inc. Newton, MA	Micro-Isotope Tool Wear Detection	*77-19517	Productivity	25,000
9/77	Block Engineering, Inc. Cambridge, MA	Single Ended Photoelectric Hazard Warning	*77-19478	Productivity	24,495
9/77	Ceramic Finishing Co. State College, PA	Control of Fragment Size Distribution and Damage Penetration During Machining of Ceramics	*77-19818	Productivity	24,942
4/77	Energy Research and Generation, Inc. Oakland, CA	Thermocorer for Rapid Excavation	73-03322 A06	Productivity	131,200
7/77	Ensco, Inc. Springfield, VA	Remote Sensing with Ground-Probing Radar	76-03300 A02	Productivity	10,700
3/77	Exotech, Inc. Gaithersburg, MD	Shaped-Pulse Rotary Percussion Drilling	75-16367 A01	Productivity	18,700
7/77	Exotech, Inc. Gaithersburg, MD	Shaped-Pulse Rotary Percussion Drilling	75-16367 A03	Productivity	12,900

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
7/77	Building Systems Development, Inc. San Francisco, CA	Building Configuration and Seismic Design	76-81821	Environment	199,400
4/77	Clement Associates, Inc. Washington, D.C.	An Evaluation of Toxicological Information Relevant to Future Testing Requirements for Hazardous Chemical Substances and Mixtures	77-15417	Environment	142,793
8/77	Clement Associates, Inc. Washington, D.C.	An Evaluation of Toxicological Information Relevant to Future Testing Requirements for Hazardous Chemical Substances and Mixtures	77-15417 A02	Environment	173,444
8/77	Collier Worm Ranch Santa Clara, CA	Conversion of Municipal Wastewater Treatment Plant Residual Sludges Into Earthworm Castings for Use as Topsoil	77-16832	Environment	9,700
5/77	Gurnham & Associates, Inc. Chicago, IL	Control of Heavy Metal Content of Municipal Wastewater Sludges	77-04355	Environment	110,900
3/77	Human Ecology Research Services, Inc. Boulder, CO	A Comparative Analysis of Public Response to Weather Modification	74-18673 A03	Environment	56,600
3/77	Human Ecology Research Services, Inc. Boulder, CO	Metromex: Social Impacts of Inadvertent Weather Modification: A Comparative Study	76-22041	Environment	60,300
9/77	Laser Analytics, Inc. Lexington, MA	Improved Sensitivity of Laser Absorption Techniques for Atmospheric Pollutant Monitoring	77-02124	Environment	211,500
6/77	Media Four Productions Hollywood, CA	Synthesis of a Municipal Wastewater Sludge Management System	76-82708 A01	Environment	49,640

ASTRONOMICAL, ATMOSPHERIC, EARTH, AND OCEAN SCIENCES DIRECTORATE

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
2/77	Scripta Technica Inc. Washington, D.C.	Publication of Polar Geography	7681106	Polar	$ 21,000
9/77	Compass Systems Inc. San Diego, Ca.	Assembly and Analysis of Oceanographic Data on the Surface Layer (0-150 M) in the Southern Hemisphere and Preparation of the Results for Publication in an Atlas	7724040	Atmospheric	$ 30,000
8/77	Compass Systems Inc. San Diego, Ca.	Assembly and Analysis of Oceanographic Data of the Surface Layer (0-150 M) in the Southern Hemisphere and Preparation of the Results for Publication in an Atlas	7709201	Atmospheric	$158,800

SCIENTIFIC, TECHNOLOGICAL, AND INTERNATIONAL AFFAIRS DIRECTORATE

DATE OF AWARD	FIRM NAME	PROJECT TITLE	AWARD NUMBER	PROGRAM AREA	AMOUNT
1/77	Courtesy Travel Service Washington, D.C.	Travel and Administrative Services in Support of Intern'l Science Activities Sponsored by the NSF	7708322	Internat'l	$ 500,000
	Computer Horizons Inc. Cherry Hill, N.J.	Implementation of Evaluation Methodology for International Programs	7708484	Internat'l	$ 24,915
	Metrics Inc. Atlanta, Ga.	The Economics of the Unique Functions Associated with Information Analysis Center (IAC) Services	7718035	Science Information	$ 83,800
	Charles River Associates, Inc. Cambridge, Ma.	Development of a Discrete Choice Model for the Demand of Scientific and Technical Information	7718020	Science Information	$ 101,764
[illegible]	Innovative Systems Research Pennsauken, N.J.	Electronic Information Exchange in Research on Devices for the Disabled	7717924	Science Information	$ 51,143
2/77	Capital Systems Group Inc. Rockville, Md.	A Planning Guide on Innovation in the Dissemination of Scientific Information	7701455	Science Information	$ 92,586
9/77	Capital Systems Group Inc. Rockville, Md.	A Planning Guide on Innovation in the Dissemination of Scientific Information	7720489	Science Information	$ 219,500
3/77	Westat Inc. Rockville, Md.	Relationship of Organization Climate to the Transfer of Scientific and Technical Information in Industrial Settings	7681946	Science Information	$ 10,017

FY 1977 GRANT AND CONTRACT AWARDS[1/]

TO SMALL BUSINESS

LISTED BY INDIVIDUAL AWARD BY

NSF DIRECTORATE

[1/] Includes programmatic grant and contract awards only. Excludes awards primarily for NSF logistics support and purchase orders except where noted in the Research Applications list.

APPENDIX B

FY 77 AWARDS TO INDUSTRY--BY NSF PROGRAM ELEMENT

MPE	No.	Amount
Other Math Sciences	1	$ 3,000
Engineering/Heat Transfer	1	63,700
Engineering Energetics	1	27,700
Engineering/Fluid Mechanics	1	73,400
Metallurgy	1	75,300
Ceramics	2	137,500
Materials Research	2	186,700
Chemical Analysis	1	60,000
Engineering	1	66,500
Other	1	24,535
TOTAL:	12	718,335
STI		
Policy Research & Analysis	5	217,847
Cooperative Science Program	1	500,000
Scientific Organization & Resources	1	24,915
Economics of Information	2	185,564
Access Improvement	3	363,229
User Requirement Program	3	146,186
Studies of Science Resources	6	534,269
TOTAL:	21*	1,972,010*
AEO		
Aeronomy	2	136,500
Solar-Terrestrial	2	148,800
Atmospheric Chemistry	2	119,900
Solar Terrestrial Physics	1	67,500
Information Services USARP	1	21,000
Contract Support USARP	5	7,059,825
Climate Dynamics	3	288,800
Research Ship Support	3	295,047
TOTAL:	19*	8,137,372*
BBS		
Regulatory Biology	3	164,856
Metabolic Bio.	1	80,500
Economics	1	12,500
History & Philosophy of Sci.	1	82,700
TOTAL:	6	340,556

RA	No.	Amount
Resources	87	2,122,800
Renewable Resources	1	35,000
Societal Response to Natural Hazards	2	920,000
Instrumentation Technology	3	198,600
Excavation Technology	19	1,732,800
Earthquake Engineering	12	2,013,100
Environment	94	2,293,600
Weather Modification	2	101,900
Regional Environmental Management	10	2,760,300
Chemical Threats to the Environment	13	3,592,400
Productivity	134	3,269,600
Regulation	2	929,000
Technology Assessment	25	1,115,675
Public Sector Productivity	1	5,000
Service Delivery Technology & Systems	5	664,025
National Productivity Measure.	2	192,000
Service Productivity & Intergovernmental Relations	1	59,500
Public Sector Productivity	2	121,600
Public Policy	1	260,400
Distribution & Equity	1	5,760
Systems Analysis	1	24,942
Biomass Utilization	1	280,000
Mineral Market Behavior & Shortages	1	190,000
Resources Development & Conservation	1	708,300
Advanced Processing Technology	1	89,700
Industrial Program	8	142,819
International Travel	1	978
TOTAL:	431	$23,829,799

BBS		
Genetic Biology	2	548,200
Ecosystem Studies	1	198,000
Regulatory Biology	2	112,100
Metabolic Biology	1	319,200
Biophysics	1	72,600
Memory & Cognitive Processes	1	63,100
Anthropology	1	112,500
Economics	1	16,200
History & Philosophy of Science	1	82,700
TOTAL:	11	1,524,600

APPENDICES

NASA patent policies appear not to be a serious deterrent to industry participation in NASA basic research activities. Patent rights start with NASA but companies often are assigned development rights if the government does not plan to use the patent. NASA's congressional supporters have emphasized that NASA supported research is beneficial to U.S. industry and the national economy. Moving research results to utilization is important in meeting those objectives.

NASA's publication policies in the basic research area generally resemble those of NSF. NASA encourages publication in refereed journals and staff spoke of an increasing emphasis on that mechanism as one of the evaluations of quality to be weighed when considering further research support. In addition, for NASA contracts, particularly those let in response to specific research needs, NASA requires a technical report addressed to NASA. In one of the research areas it was noted that research findings by private firms in the natural resources area sometimes are not published readily; some companies with large research programs and labs participate readily in certain of the basic research activities, and publish results in the open literature.

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

The Air Force Office of Scientific Research relies mainly on unsolicited proposals for initiation of new work through grants and contracts. Proposals are supported based on their originality, significance to science, the scientific competence of the investigator, the reasonableness of the research budget, and the appropriateness to the Air Force. Grants are limited to support of research at universities and not-for-profits. Contracts are used to support research in industry.

Research awards to industry vary according to the industry expertise and interest as these relate to the Air Force's research programs, and the interest of the Air Force in the industry expertise or the questions that a researcher may want to investigate. The AFOSR indicates that about 15% of its extramural basic research outlays go to industry, and estimates that about 10% of these awards are to small businesses.

Industry performance of basic research for AFOSR is more likely in high technology areas such as electromagnetic materials research and device concepts. In the microwave tube area, AFOSR has seven industrial research performers and because of a scarcity of trained researchers in this area Stanford University is training researchers in the field.

The AFOSR reports no special patent problems that appear to deter industrial basic researchers from Air Force work.

ONR does not have data permitting comparisons with NSF on proposal pressure. ONR interests are known generally and preliminary contact serves as a screen. Only proposals of some interest to ONR are submitted in most cases. There are few unsolicited proposals and their relative likelihood of support is not high.

In the nature of ONR relationships, contracts and negotiations, there are no serious administrative problems of a continuing sort involved with patents or publications. There are no cost-sharing requirements.

NATIONAL INSTITUTES OF HEALTH

NIH does not make grants to industry. Its awards to industry are in the form of contracts. Most of the contracts with industry are in response to requests for proposals. Within specific contracts it is sometimes necessary to perform some basic research, but such basic research is neither the major portion nor the primary purpose of the contract. This accounts for the fact that no industry basic research is reported by NIH in the annual Federal Funds report, since traditionally NIH has not split its awards for reporting purposes. Rather, the entire amount of any award has been allocated to the major research or development thrust.

There are relatively few unsolicited research proposals per year from industry. In FY 77, there were fewer than 10 active R&D contracts with industry resulting from unsolicited proposals, some new and some carryover from prior years.

In FY 76 there were about 300 R&D contracts awarded to for-profit organizations.

The determinations for awards to industry are made on the basis of competitive evaluation, with a very few awarded on the basis of "singular technical competency." NIH-supported research in industry is primarily in the life sciences.

NIH policies concerning both publications and patents resemble closely those of NSF. Researchers are encouraged to publish in the open literature and patent rights are dealt with on a deferred determination basis as with NSF. Cost-sharing is based on individual contract negotiations based on possible commercial advantage to the research performer.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Discussions were held with NASA Headquarters research management staff in three areas--engineering, life sciences, and space and terrestrial sciences. NASA's policies on the support of basic research are completely open. Anyone can apply. From one area to another, practices vary. Project announcements and knowledge of program thrusts in each field have a major influence on the support sought by research performers.

PART IV

Support of Basic Research in Industry by Five Other Federal Agencies

Directorate/Field/Program Area		No.	Amount
Science Education			
Science & Society		1	203,100
Science Education Development		4	484,648
Science Education Research		2	19,890
	TOTAL:	7	$707,638
Administration		6	1,115,744
Office of Planning & Resources Management		6	295,999
Office of Government & Public Programs		2	28,055

1/Appendix B provides more detailed list by program element.

2/Includes Antarctic Research Program logistics support

Table III-4

FY 1977 GRANT AND CONTRACT AWARDS TO INDUSTRY[1]

Directorate	No. Awards	Amount	% of FY 77 Obligations	FY 77 Obligations
Mathematical & Physical Sciences & Engineering	12	$ 718,335	.32%	$224.4
Scientific, Technological & International Affairs	21	1,972,010	10.15	19.4[2]
Astronomical, Atmospheric, Earth & Ocean Sciences	19	8,137,372	3.48	233.5[3]
Research Applications	110	9,714,070	15.2	63.7[2]
Science Education	7	707,638	1.19	59.0[4]
Biological, Behavioral & Social Sciences	6	340,556	.27	126.6
Planning & Resources Management	6	295,999		
Administration	6	1,115,744		
Government & Public Programs	2	28,055		
TOTAL:	189	$23,029,779	3.2%	$726.6[5]

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[1] Excludes purchase orders

[2] These figures shown without $1.3 million transfer from RA to STIA for technology assessment as shown for FY 77 for consistency in the FY 1979 Budget request.

[3] Includes U.S. Antarctic Program

[4] Science Education total less Fellowships and Traineeships ($15.3m)

[5] FY 1977 Total NSF obligations ($791.8) less Special Foreign Currency ($4.4m), PD&M ($45.5m), and Fellowships and Traineeships ($15.3m).

GENERAL NOTE

During a fiscal year some awards will be to support proposals received in the prior fiscal year. Some proposals received during the current fiscal year will not be acted on finally until the following fiscal year. In categories of small numbers, particularly where contracts are included, it is possible that for a single fiscal year awards may exceed proposals.

Table III-3

FY 1977 PROPOSALS RECEIVED FROM INDUSTRY
BY DIRECTORATE AND FIELD OF
SCIENCE OR PROGRAM AREA WITHIN DIRECTORATE[1]

Directorate/Field	No.	Amount
Mathematical & Physical Sciences & Engineering		
Math & Computer Sciences	2	$ 53,000
Engineering	5	769,316
Materials Research	8	926,600
Physics	2	212,500
Chemistry	4	509,750
Other	1	10,535
TOTAL:	22	$2,481,701
Scientific, Technological & International		
Policy Research & Analysis	8	701,039
International Science	6	1,623,600
Science Information	24	2,162,686
Science Resources Studies	7	488,613
TOTAL:	45	$4,975,938
Astronomical, Atmospheric, Earth & Ocean Sciences		
Atmospheric Sciences	9	1,746,600
Astronomy	5	398,700
Polar Programs	14[2]	7,679,225
Ocean Sciences	1	40,700
TOTAL:	29	$9,865,225
Biological, Behavioral & Social Sciences		
Biological Sciences	7	1,250,100
Social Sciences	2	175,600
Behavioral & Neural Sciences	2	98,900
TOTAL:	11	$1,524,600

[1] Appendix A provides more detailed list by program element.

[2] Includes Antarctic Research Program logistics support.

Table III-1

TOTAL PROPOSALS RECEIVED BY NSF DIRECTORATES--FY 1977
FROM ALL SOURCES AND FROM PRIVATE INDUSTRY
(Data as of Sept. 30, 1977)

Directorate	Total From All Sources	Total From Private Industry
Mathematical, Physical & Engineering Sciences	7,984	22
Scientific, Technological & International Affairs	1,027	45
Astronomical, Atmospheric, Earth & Ocean Sciences	2,988	29
Research Applications	1,417	431
Biological, Behavioral & Social Sciences	7,231	11
Science Education	7,421*	17
Other (Administration; Office of Planning & Resources Management; Office of Government & Public Programs)	54	13
TOTAL:	28,122	568

*Excludes Fellowships and Traineeships.

The fiscal year 1977 data in Table III-3 show that more proposals were received in the materials research area than elsewhere in these three directorates, with atmospheric sciences, biological sciences, engineering, astronomy and chemistry all receiving four or more proposals. (Polar programs is considered to have received five research proposals when the nine for research support services are excluded).

The greatest number of basic research program awards were made to industry (Table III-5), in materials research, atmospheric sciences, engineering and biological sciences. (When Polar programs support awards are excluded, that program category drops to the low end of the group). Appendix B lists the grant and contract awards to industry by NSF directorate and program element.

The data for awards to small business, a subset of the data for all industry, are grouped by totals for each directorate and then are individually listed by award by Directorate in Appendix C. Review of the awards to small business made by the three basic research directorates in fiscal year 1977 shows that most of these awards are for analysis or evaluation of data on research materials.

The actual numbers of awards in these areas are too small to permit valid conclusions from statistical comparisons of these totals with the data on population characteristics and distribution of basic researchers in industry.

RESEARCH APPLICATIONS DIRECTORATE

Some 1417 proposals were received by the Research Applications Directorate in FY 1977. That directorate has accepted proposals from private firms without special criteria for qualification beyond the merit criteria used for consideration and support of proposals from other sectors. In addition, small business firms that have outstanding capabilities for scientific research or technology have been encouraged to submit proposals particularly because of special legislative provisions first added by the Congress in FY 1976. In FY 1977 the Research Applications directorate received 431 proposals from private industry, amounting to approximately 30% of the total received. Of the 431 there were 329 proposals that small businesses submitted in response to the "Small Business Innovation" solicitation. Research Application made 544 awards in FY 77; 110 awards were made to industry, nearly 20% of the RA total number of awards. Of the 110 RA awards to industry, 95 were to small business, 17.5% of the total number of RA awards.

RANN's proposals and awards are identified by field of program thrust rather than by the traditional fields of science or disciplinary area. In FY 1977 these grouped as follows (proposals from the solicitation are in the data, shown separately in parentheses):

The largest NSF obligations incurred in awards to businesses other than through program directorates occurred in the Administration Directorate for support of the Foundation's data center and computer operations.

Industrial proposal and award levels in NSF's basic research supporting directorates are discussed below.

BASIC RESEARCH ONLY

This section considers proposal pressures on NSF from industry for basic research support in terms of the data for NSF's three directorates in which nearly all of the obligations are in support of basic research--the Directorate for Mathematical, Physical Sciences and Engineering (MPE), the Directorate for Biological, Behavioral and Social Sciences (BBS), and the Directorate for Astronomical, Atmospheric, Earth and Ocean Sciences (AAEO).

The Foundation's policy on the support of basic research proposals from private industry has been expressed for many years in these words:

> "Private Profit Organizations: Commercial firms are infrequent recipients of awards for scientific research project support. However, in exceptional cases, unsolicited proposals for basic research will be considered from industrial organizations where: (a) the project is of special concern from a national point of view and shows promise of solving an important scientific problem; (b) unique resources are available in industry for the work; or (c) the project proposal is outstandingly meritorious."

This policy has been widely known. It also has been misunderstood by some who have thought that NSF never makes awards to commercial firms for support of basic research; such is not the case. Awards to private firms for basic research support have been relatively infrequent but have been made by NSF for many years.

Concerned that the long-standing wording of the basic research support policy may have been unduly negative in tone, the National Science Board on January 19, 1978, took the following action:

PART III

National Science Foundation
Proposals from Industry
Awards to Industry,

Fiscal Year 1977

Table II-11: Funds for Basic Research by Selected Industry for Firms With Less Than 1000 Employees, 1976

(Includes Company and Federal Funds)

Dollars in Millions

	1976 Preliminary	% of Total
TOTAL	68	100%
Food and kindred products	2	3
Chemicals and allied products	18	27
Industrial chemicals	3	4
Drugs and medicines	5	7
Other chemicals	10	15
Petroleum refining and extraction	1	2
Stone, clay, and glass products	4	6
Primary metals	1	2
Nonferrous metals and products	1	2
Machinery	4	6
Office, computing, and accounting machines	2	3
Electrical equipment and communications	14	21
Communication equipment and communication	4	6
Other electrical equipment	10	15
Transportation equipment other than motor vehicles and eqpt.	2	3
Other manufacturing industries	1	2
Nonmanufacturing industries	21*	31

*Including commercial research and development firms.

Source: National Science Foundation
Preliminary Data

Table II-9: Funds for Basic Research by Selected Industry
(Includes Company and Federal Funds)
1971 and 1976

(Dollars in millions)

	1971	% of Total	1976(Preliminary)		Percent Change
				% of Total	
Total	$581	100%	$786	100%	35%
Chemicals and Allied Products	216	37	322	41	49
Drugs & Medicines	77	13	125	16	62
Petroleum refining & extraction	21	4	45	6	114
Machinery	22	4	36	5	64
Electrical equipment & communication	143	25	148	19	4
Aircraft & Missiles	53	9	52	7	- 2
Nonmanufacturing	31	5	29	4	- 7
All other industries	95	16	154	20	63

Source: National Science Foundation
1/25/78

Table II-7: Funds for Basic Research by Size of Company
(Includes Company and Federal Funds)
1971 and 1976

(Dollars in millions)

	1971	% of Total	1976 (Preliminary)	% of Total	Percent Change
Total	$581	100%	$786	100%	35
Less than 1,000 employees	36	6	69	9	92
1,000 - 4,999 employees	51	9	38	5	-26
5,000 - 9,999 employees	72	12	112	14	56
10,000 or more employees	422	73	567	72	34

Source: National Science Foundation
1/25/78

NOTE: Since different companies comprise the specific size classes in each year, the data by size of company may not be entirely comparable.

Table II-5: Company Funded Basic Research as a Percent of Total Company R&D

1970 - 1978

1970	4.3%
1971	4.3
1972	4.0
1973	3.8
1974	3.6
1975	3.6
1976	3.5
1977(est)	3.4
1978(est)	3.3

Source: National Science Foundation
1/25/78

Table II-3

Share of Federal Basic Research Performed by Industry[1] by Major Support Agency, with Percent Change, FY 1971 & FY 1976

Agency	Share of Total 1971	Share of Total 1976	Funding Percent Change 1971 - 76
NASA	63%	43%	-43%
ERDA	16	28	+45
DOD	19	21	- 9
NSF	.5	5	+700
OTHERS	2	3	+50

[1] Includes federally funded research & development centers (FFRDC's) administered by this sector.

Source: Federal Funds surveys. NSF
1/25/78