Changing National Origins of Materials Research

Implications for Science and Technology Policy

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The analysis of scientific trends we present here is intended as an initial element in the development of indicators for science and technology policymaking. New science indicators are becoming increasingly necessary, especially to explore the variables that could affect economic competitiveness.

Because publications are a major immediate outcome of scientific enterprise, we chose to quantify certain publication trends. We analyzed the recent publications output of five leading scientific nations—the United States, Japan, United Kingdom, U.S.S.R., and West Germany. The focus was on seven areas of materials research, which are identified later and also listed in Table III.

Analysis of the number of journal publications and conference papers in seven areas of materials research, originating in five leading scientific nations, indicated the following:

1. Japan's share in every field has increased over the past 20 years. The U.S. has remained roughly the same, as has the Soviet Union when publication policies are taken into account.

2. Work in ferrous metals and alloys has increased worldwide in the last 20 years, but the trend since 1979 is clearly downward. For other fields, trends vary from country to country.

3. Comparing U.S. and Japanese data in the 1980s, the Japanese emphasis is most pronounced in ferrous metals, ceramics, and extractive metallurgy, in decreasing order of dominance. In cement, concrete, and related building materials, the publications of the two nations are nearly equal. Of the seven fields considered, the U.S. has double the publication rate of Japan in nonferrous metals, catalysis, and chemical and phase equilibria.

20-Year Trends in Chemical Literature

In the 1970s the output of scientists and engineers working in the United States, as measured by published papers, accounted for approximately 37% of the total world scientific literature. According to *Science Indicators*,[1] published by the U.S. National Science Foundation (NSF), the U.S. share of chemical literature was 21%. Using data collected between 1976 and 1980, *Chemical Abstracts* service obtained a similar figure of 26.3% of the world total.[2]

As Table I shows, the percentages for sources of chemical papers fell in all major industrialized nations included in the sample except for Japan and for developing countries (included in the "others" category).

Data drawn from *Chemical Abstracts* indicate that between 1962 and 1983 Japanese output for publications in chemistry rose 3.7%, from 6.9 to 10.6% of world publications (see Table I). Of that 10.6%, 4.4% of the papers were published in Japanese. This makes Japanese the third most widely used language, though it substantially trails the 68.6% published in English and the 15.8% in Russian.

Although concern has recently been expressed about access to Japanese-language scientific and technological literature, English abstracts are available. With a will to do so, U.S. scientists can easily locate relevant materials for translation.[4] The Japanese Information Center for Science and Technology is an open source, and comprehensive coverage is within reach for the U.S. scientific and business community. Given the areas of Japanese contribution to science, it is not surprising that users of the *Chemical Abstracts* computer service most frequently ask for information from Japa-

Table I: Sources of Papers Abstracted in *Chemical Abstracts*, Percent of World Publications, 1962-1983.[2]

Nation	1962	1966	1972	1977	1983
U.S.	28.4%	30.0%	28.0%	25.9%	27.0%
U.S.S.R.	23.0	21.3	24.0	23.2	17.0
Japan	6.9	6.4	7.9	8.2	10.6
U.K.	8.6	6.8	6.4	6.2	5.8
W. Germany	8.5	6.8	6.2	7.2	7.3
France	4.8	5.0	4.4	4.2	4.1
Others	19.8	23.7	23.1	25.1	28.2

Table II: Combined Support and Trends for Solid State Chemistry and Polymers in the U.S.

FY 1972	Current FY 1981	Constant FY 1981	Real Growth
$2.1M	$10.5M	$5.4M	160%

Source: NSF Program Report on Materials Research[9]

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Table III: Percent Internal Change Between 1979 and 1984 for Selected Materials Research Subfields.

		Extractive Metallurgy	Ferrous Metals and Alloys	Nonferrous Metals and Alloys	Ceramics	Cements and Related Materials	Catalysis	Chemical and Phase Equilibria
1979	U.S.	189	650	1,056	433	131	481	499
1984		245	655	1,215	665	114	763	372
Change		29.6%	0.76%	15%	53.6%	-12.9%	58.6%	-25.4%
1979	U.K.	71	380	393	128	71	205	85
1984		77	278	270	136	81	189	58
Change		8.4%	-26.8%	-31.3%	6.2%	14%	-7.8%	-18.8%
1979	U.S.S.R.	1,217	2,853	2,560	911	459	926	1,723
1984		947	1,901	1,768	756	448	962	1,196
Change		-22.2%	-33.4%	-31%	-17%	-2.4%	3.9%	-30.6%
1979	Japan	197	1,338	751	424	166	302	193
1984		274	1,097	817	649	150	285	220
Change		39%	-18%	8.8%	53%	-0.6%	-5.6%	13.2%
1979	W. Germany	94	473	525	176	67	114	100
1984		71	462	374	216	75	111	141
Change		-24.5%	-2.3%	-28.7%	22.7%	11.9%	-2.6%	41%

Table IV: Percent Internal Change Between 1979 and 1986 of Publications in Ceramics and in Cements and Related Materials.

	Ceramics		Cements and Related Materials	
	1986	Change	1986	Change
United States	739	70%	144	12%
U.K.	173	24%	63	-11%
U.S.S.R.	611	-33%	293	-36%
Japan	818	92%	112	-33%
W. Germany	253	44%	83	24%

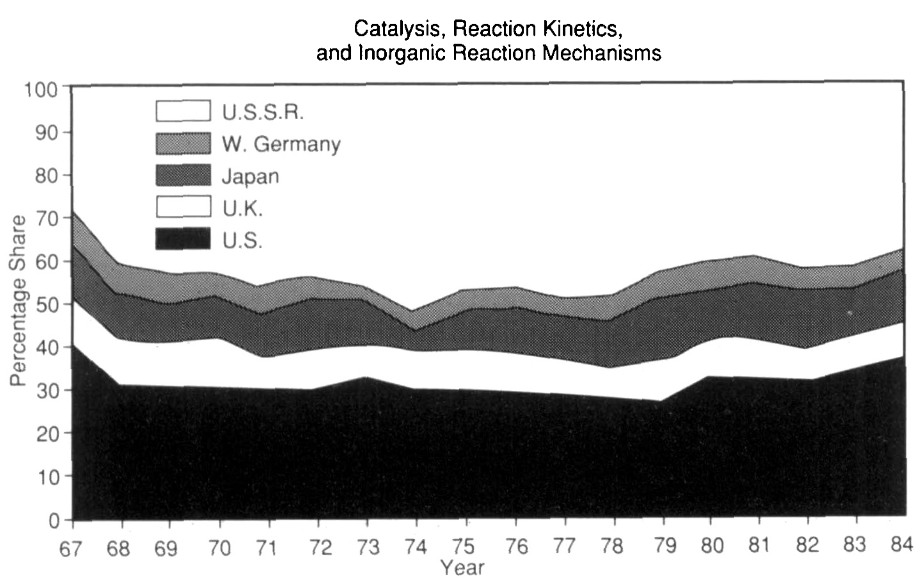

Figure 1. Production of papers in catalysis, reaction kinetics, and inorganic mechanisms research; relative contributions of six countries.

nese publications on electric phenomena, photography, metals and alloys, and plastics.[5]

Papers abstracted from the Soviet Union held at approximately 23% of the world's total until five years ago, when it dropped 6%. It is not altogether clear how this came about, but the drop probably reflects a new publishing policy rather than a drop in scientific research.[6] In 1979 the Soviet government adopted a resolution regulating the size of press runs and reducing the number of periodical publications approximately 10%.[7] The Soviet Union ranks second, behind the U.S., in total production of chemical papers (see Table I). However, in the materials research areas selected for this study, the Soviet Union still leads in quantitative output, as the following discussion indicates.

Of the 80 subject sections in *Chemical Abstracts* (CA), worldwide growth in publications in the last decade is strongest in applied chemistry and chemical engineering, which include the fields of our study. Applied chemistry and chemical engineering papers grew at an average annual rate of 4.6% from 1976 to 1980. All CA-abstracted literature, which includes patents, grew 9.4% in the same period.[8]

This healthy growth in scientific publications has led to complaints about the size of the literature professionals must be conversant with. But given the growth in numbers of scientists, more than doubling from 1976 to 1986 according to NSF statistics, it would have been worrisome if this growth in output had not occurred.

Although biochemistry remains the largest subdiscipline, applied chemistry is growing most rapidly, and the data signal changes in chemical R&D emphasis. Funding from the NSF's Division of Materials Research for solid state chemistry and polymers is one example. Table II documents increased support for these two "maverick subfields" within the academic community, which in 1972 "were struggling to gain greater recognition and acceptance"[9] and are now well established.

Trends in Seven Materials Research Fields

In order to examine trends more definitively and provide more discriminating policy choices, we disaggregated the chemical publications data. Looking at fields that seem promising for technology applications and commercialization, we focused on seven subfields in materials research, as categorized in *Chemical Abstracts:*

- extractive metallurgy;
- ferrous metals and alloys;
- nonferrous metal and alloys;
- ceramics;

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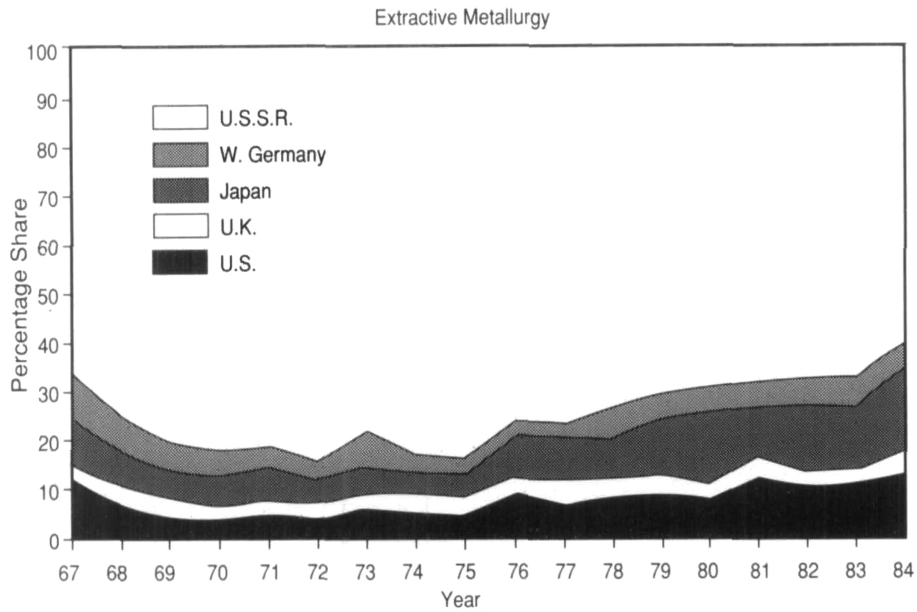

Figure 2. Production of papers in extractive metallurgy research; relative contributions of six countries.

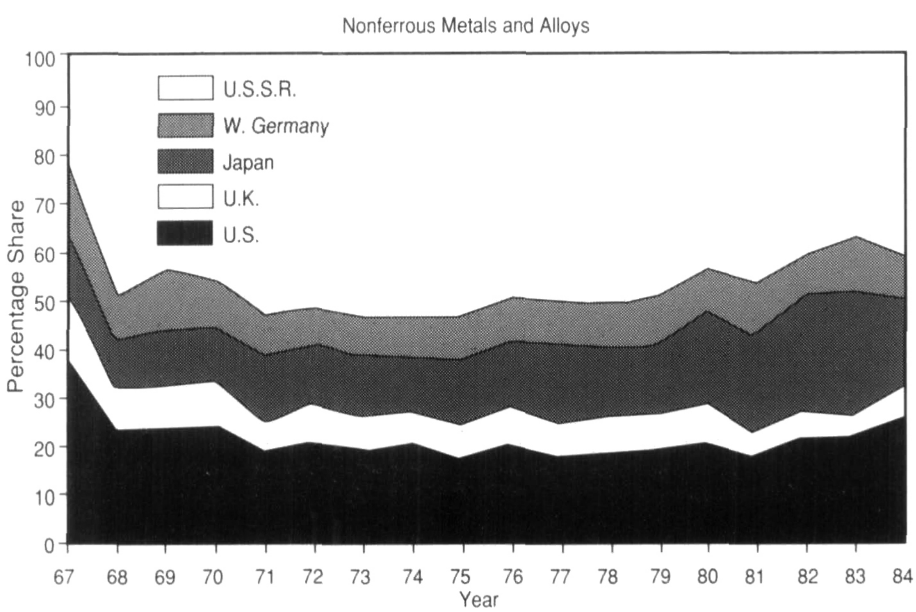

Figure 3. Production of papers in nonferrous metals and alloys research; relative contributions of six countries.

- cement, concrete, and related building materials;
- catalysis, reaction kinetics, and inorganic reaction mechanisms; and
- phase equilibria, chemical equilibria, and solutions.

Using the *Chemical Abstracts* database we determined the numbers of publications and their secular variances in these subfields.

Historically, nations have specialized in subfields and such specialization continues. Changes in the U.S. position relative to other countries is very different depending on the field. Table III indicates the percentage change between 1979 and 1984 in five fields for the United States, United Kingdom, the U.S.S.R., Japan, and West Germany.

In the category of catalysis, reaction kinetics and inorganic reaction mechanisms, the United States' 58.6% increase is the largest in any of the fields analyzed. Except for the Soviet Union's 3.9% increase, the change in any other country's share is negative. However, looking at the almost 20-year period in Figure 1, the United States now commands approximately the same world share as in 1967, after a slight decline in the seventies.

In extractive metallurgy the 22% decrease in Soviet output (Table III) cannot be accounted for only by a changed publication policy, but represents an alteration in emphasis. Still, this is an area of specialization for the U.S.S.R. The combined efforts of the United States, Japan, United Kingdom, and West Germany only account for between 30 and 40% of publications and papers over the period indicated in Figure 2. Japan gave roughly the same scientific attention to extractive metallurgy as the United States during that period. In 1984, the Japanese published 274 papers and the U.S. 245, while the Soviets put out 947, down from 1,217 in 1979 (Table III).

Taking 1968 as the base year, the five nations have maintained an approximately equal share in nonferrous metals and alloys publications (Figure 3), and in phase and chemical equilibria and solutions (Figure 4). The Soviets dominate quantitatively with 40 and 60% of those areas, respectively. Japan noticeably increased its emphasis in nonferrous metals and alloys, from 10% of world publications in 1968 to 18% in 1984. Its share of phase and chemical equilibria and solutions increased more slowly from 7 to 11%.

During 1968-1984 the United States increased its share in nonferrous metals from 23 to 27%, and decreased from a 23 to 18% share in chemical and phase equilibria. Given the fluctuation in Soviet output, this change is not significant. However, using internal reference as seen in Table III, the drop in numbers of publications issuing from U.S. science in chemical and phase equilibria between 1979 and 1984 was a substantial 25%. This is far more than the only other decrease in U.S. activity, which was a temporary decrease in the cement and related materials field. Though internal emphasis on chemical and phase equilibria became stronger in West Germany and Japan, the United States and Soviet Union are still the two countries of major output.

Looking at the numbers of publications in 1986 for cement and related materials (Table IV), we see the United States pick up once again with a 12% increase since 1979. The Soviets decrease 36% and the Japanese decrease by one third. West Germany has been slowly increasing its publications

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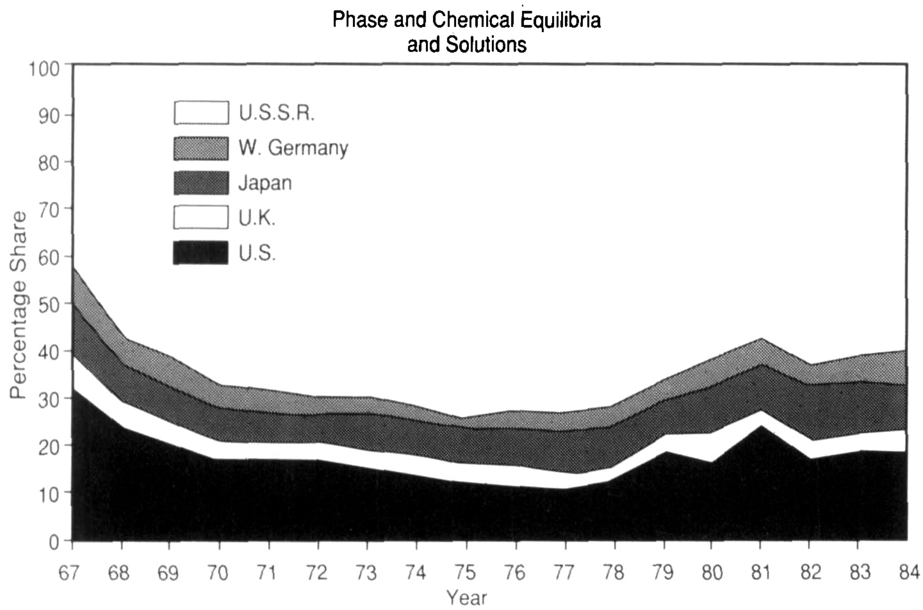

Figure 4. Production of papers in phase and chemical equilibria and solutions research; relative contributions of six countries.

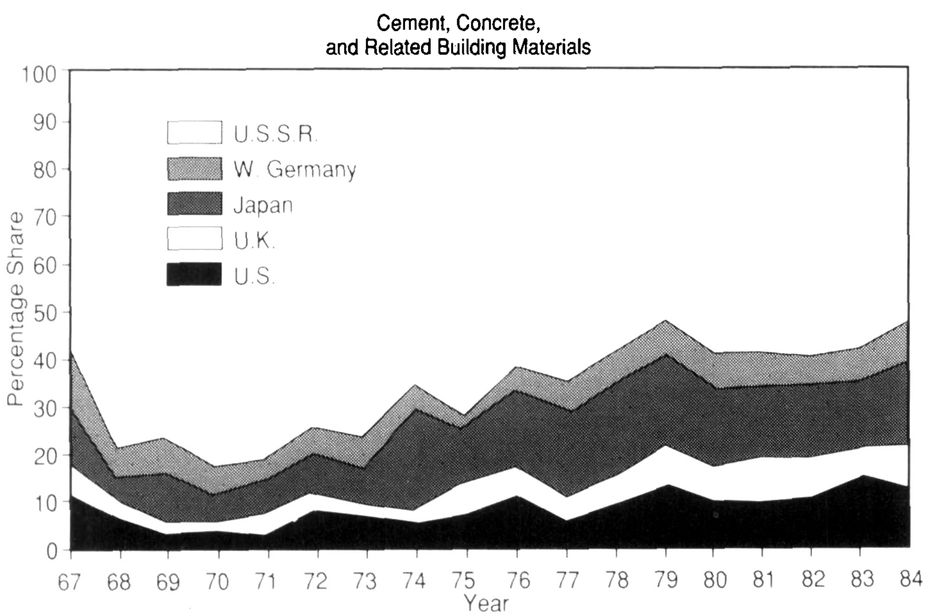

Figure 5. Production of papers in cement, concrete, and related building materials research; relative contributions of six countries.

in this area over the last 10 years. Clearly the United States has chosen to specialize, though in quantity the Soviets put out roughly 50% more papers (293 to 144). As Figure 5 indicates, over a nearly 20-year period Japan and the United States have increased their world shares, and, since the early seventies, Japan has emphasized the cement field more than has the United States and is second in the world share of publications.

In ferrous metals and alloys, research output has gone down throughout the world. Between 1979 and 1984 (Table III) U.S. output increased less than 1%. The United Kingdom dropped about 27%; the Soviet Union, 33%; Japan, 18%; and West Germany, 2%. In world share, Japan increased in the late seventies and early eighties (Figure 6) as the share of the Soviet Union decreased and others held steady.

Japan and the United States: The Ceramics Race

Calculating the U.S./Japan ratio of publishing frequency in the four fields of ceramics, catalysis, ferrous metals, and nonferrous metals (Figure 7), the ceramics trend is outstanding. As Figure 8 illustrates, beginning in the seventies and accelerating into the eighties the Japanese have placed a large emphasis on ceramic science. They increased from 8% of the world share in 1967 to 31% in 1986. During the same period, the United States was nearly stable, beginning in 1967 with 29% and ending in 1986 with 28%. The numbers of publications in each country are now roughly equal. Note, however, that production from U.S. ceramics scientists increased 70% between 1979 and 1986 (Table IV). As the Red Queen told Alice, the United States must now run very fast to keep in the same place.

Faced with patent data, which make it clear that the Japanese are worrisome international competition to the United States, commentators have usually hastened to point out that the United States is still superior in "basic" science.[10] Japanese scientists, no doubt with an eye to funding, often concur in highlighting Japanese weaknesses in producing basic science. Although patent studies are limited as an indicator of scientific creativity, it is unhelpful to dismiss the Japanese prowess in science. Though it is perhaps understandable that we have eased into a recognition of Japanese scientific competition, the argument that the Japanese are only adaptors of science, not creators, is outdated, as our data show.

One method in constructing effective science policy is to look individually, as we have, at various science subfields that have commercial potential on the horizon. Ceramics is an area where allocation of resources, and management of existing resources, should continue to be of concern so that potential problems can be foreseen and handled. It has been a general assumption of science policy that "timing and direction of R&D payoffs are not predictable."[11] Thus, the aim of policy, at least at the federal level, has been to build pluralism—that is, fund a wide variety of basic research endeavors and get a wide variety of funders to foot the bill. It was hoped that this would maximize the possibility that no good bets would be overlooked. This approach may have served in

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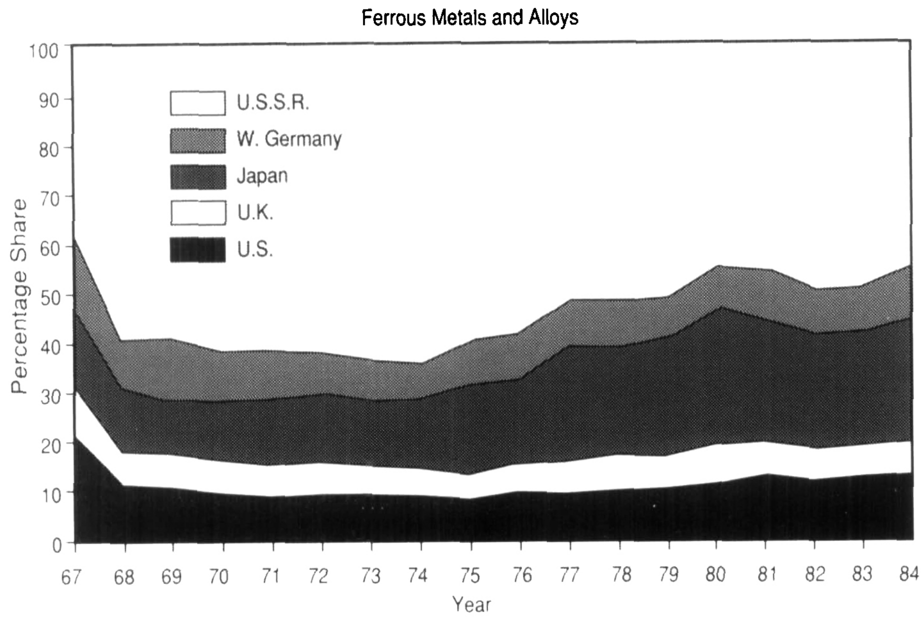

Figure 6. Production of papers in ferrous metals and alloys research; relative contributions of six countries.

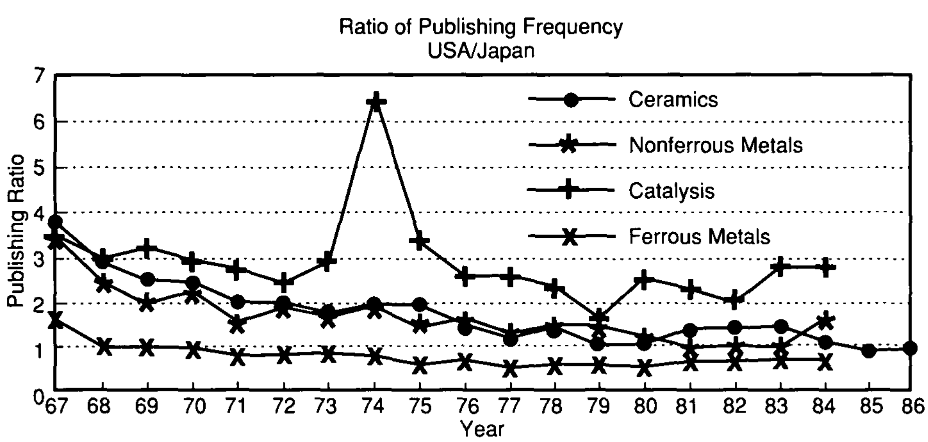

Figure 7. U.S./Japan ratio of publishing frequency in ceramics, catalysis, ferrous metals, and nonferrous metals research.

a time of affluence, but today the arguments for funding need to rest on a more discriminating database.[12]

Policymaking and the Limitations of Science Indicators

One major immediate outcome of scientific enterprise is publication of findings. It is a major part of the progress in science and has also become a measure of success for individual scientists. It has been (until the recent interjection of international economic competition as foremost) an objective measure used by funders. In the materials field, for example, the NSF's *Program Report: Materials Research*, 1979, states the following objectives:

1. To support research directed at a basic understanding of principles, concepts, and phenomena which underlie the properties of materials;

2. To provide insight into how we can optimize known materials properties or produce novel ones;

3. *To insure the broadest diffusion of this new scientific understanding to others.*[13]

Although the publications output discussed above is only one ingredient necessary to policymaking, it represents trends that can be used to chart future paths. The above analysis is especially useful since it represents publications data that are nearly the total universe for five leading nations. The quantity of publications is a useful indicator of the productivity in a scientific field. The index-indicand relationship is generally viewed as direct and strong. Further, the time series data is useful to policy because of possible predictive extrapolation.

Quality is more complex, of course, and it is unlikely that quantitative measures, such as ours, can be a wholly satisfactory index of quality. Although to some extent—and rapidly decreasing in "hot" fields like superconductor research—poor or repetitive science work is supposed to be eliminated from publication by the peer review system, other measures of output (citation indexing, awards, patents, and production increase in industry) need to be added to the endeavor to measure the output of "science" and to make policy.[14] Further, with the utility of science a premium in global competition, and with funding agencies seeking some assurance about commercial potential, quality in science is taking on nontraditional meanings. New science indicators will be required to explore the variables necessary to economic competitiveness. In the United States there has been a "continuing effort to identify valid indicators of science and technology as cognitive and social activities."[15] But the measures are not simply of science, of the changing state of science and technology, but of the changing state of society ... of what is demanded by society from science and technology.

The demands placed upon scientific endeavors during World War II had the effect of testing the arguments of the physical sciences (made earlier in the century) that they could be useful and, thus, worthy of public funding. Similarly, without slighting the work done in past decades in trying to demonstrate a link between science and economic growth, clearly we are now entering a new, intensive era of demand for useful science. Indicators aiding policymaking will be developed to measure the production function for research, a complex task in which this analysis is an initial element.

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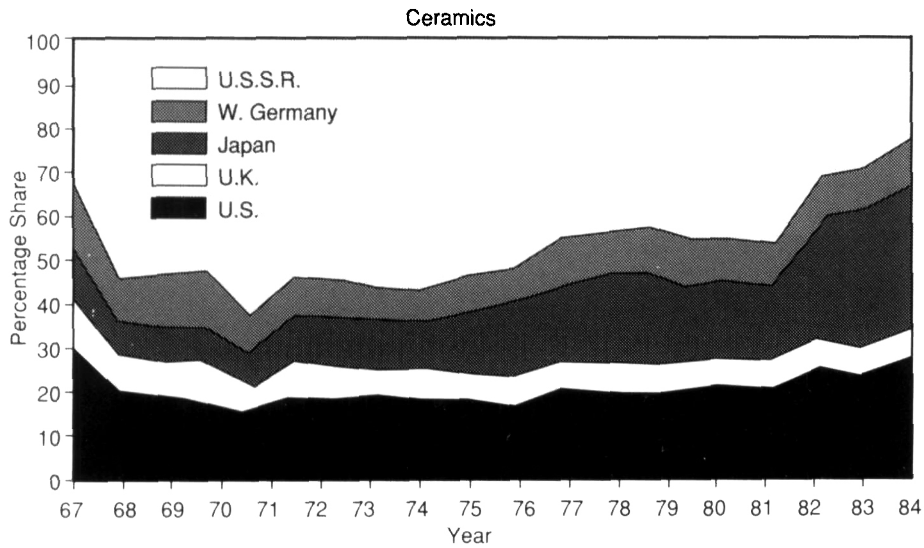

Figure 8. Production of papers in ceramics research; relative contributions of six countries.

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6. Baker, *op.cit.*; also, Montagu Hyams, "Chemical Patents Information: The Challenge of Change," *J. Chem. Information and Computer Science* **25** (1985).

7. Hyams, *op.cit.*

8. Baker, *op.cit.*, p. 29, 31.

9. National Science Foundation, *Program Report, Materials Research* **6** (2) (March 1982) p. 5.

10. The derivative claim that the "basic" work indicates greater "creativity" on the part of those doing it, is, of course, absurd and will no doubt change as the national shares change.

11. Harvey Averch, "Science Indicators and Policy Analysis," *Scientometrics* **2** (5-6) (1980) p. 341.

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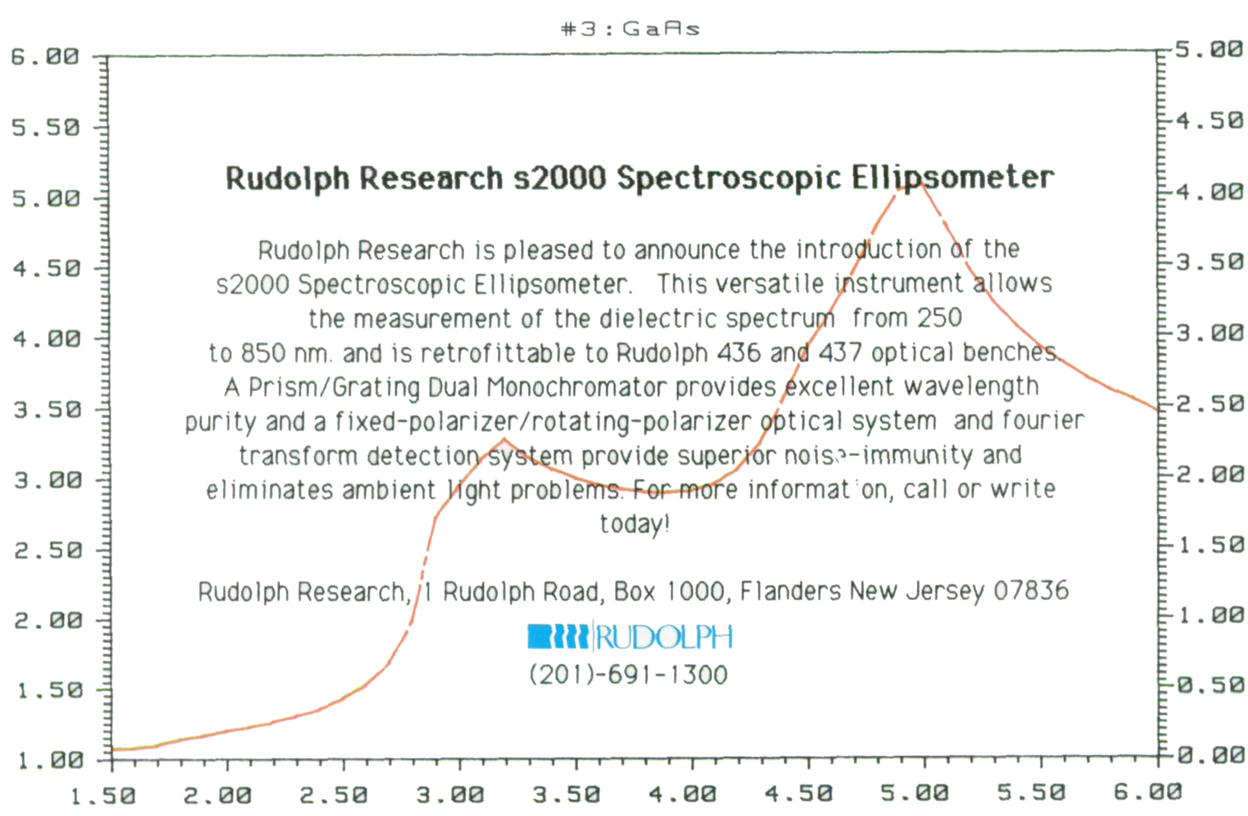

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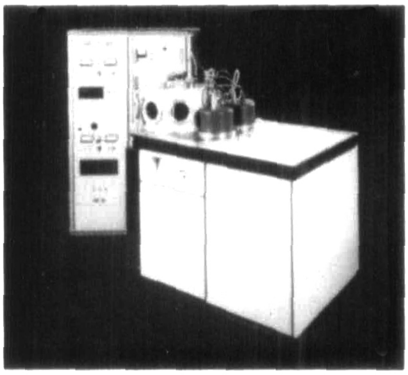

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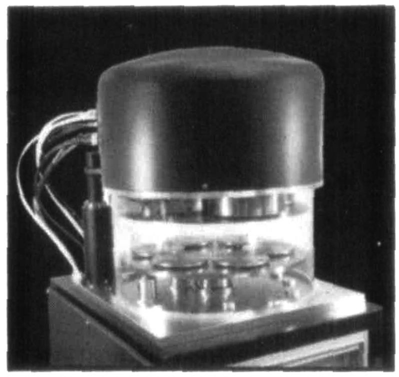

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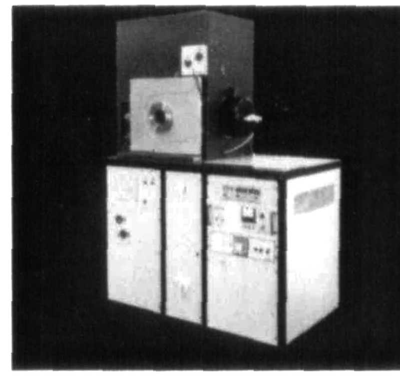

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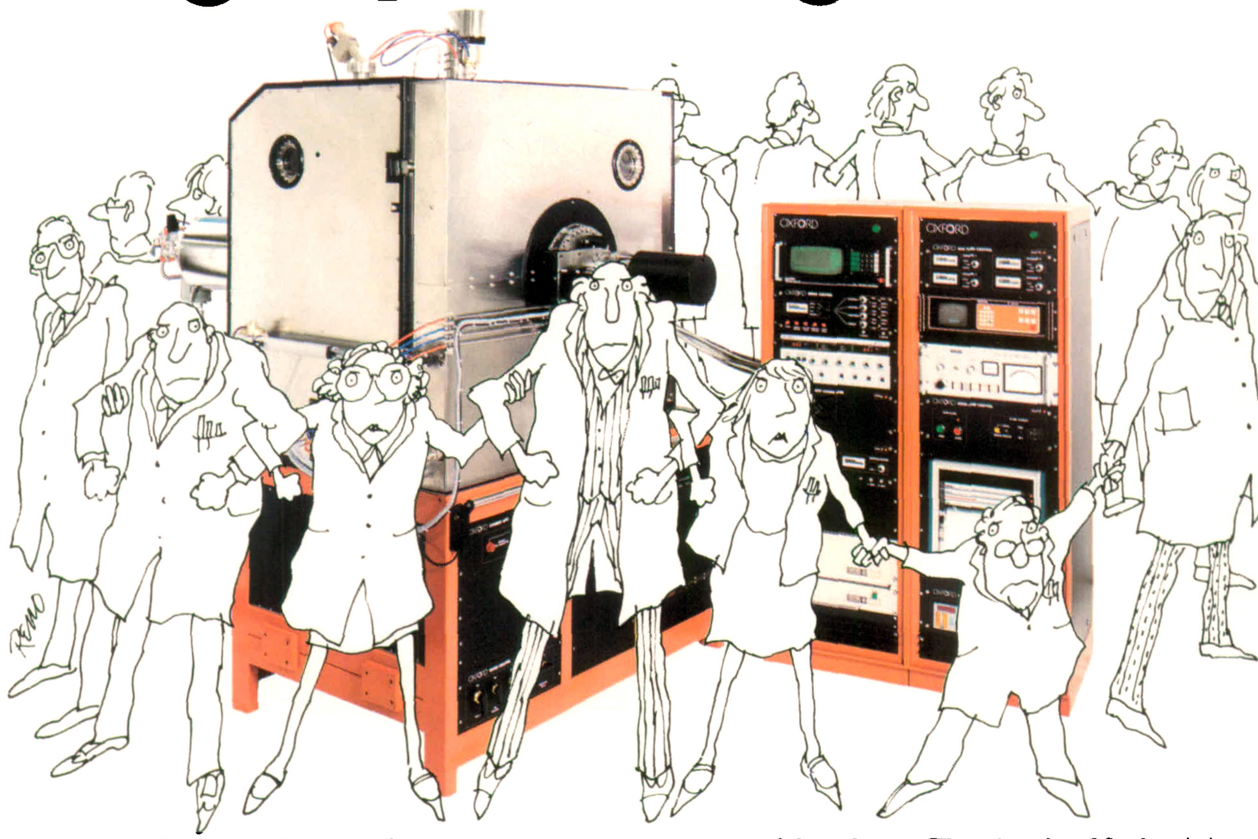

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