Articles

Science and Technology Policies and Priorities: A Comparative Analysis

LEONARD L. LEDERMAN

This article compares the science and technology strategies and priorities of France, Germany, Japan, Sweden, the United Kingdom, and the United States. An analysis is given of similarities and differences, historical settings, research and development allocations, coordinating mechanisms, outputs, dissatisfactions, and recent changes. Also presented are data on performers and funding sources, the character and objectives of work, the industries involved, employment of scientists and engineers, and degrees by field. This comparison provides a way of understanding the advantages and disadvantages of different strategies and an opportunity for one country to learn from the others.

THE PURPOSE OF THIS ARTICLE IS TO HIGHLIGHT THE similarities and differences in the science and technology (S&T) "systems" of four European countries (France, Germany, Sweden, and the United Kingdom), Japan, and the United States. In making this comparison, we hope to understand better what each country might learn from the others in considering options for S&T organization, policies, and strategies. Each country has had its own tradition of science and technology organization, and some discussion of the historical setting is useful in analyzing present and future policy. These countries have used different means of allocating financial and human resources, coordinating S&T programs, and assessing the effectiveness of S&T systems. These six countries are now each facing a variety of pressures to change their S&T structures in response to the demands of an increasingly competitive, and yet interdependent, world.

Each of the following sections could usefully be the subject of a lengthy paper in its own right. The space limitations for this article make it impossible to include details that are presented in other publications. References to such publications are provided for the reader who wishes to pursue a particular point in greater depth.

Traditions That Have Shaped Science and Technology

To a much greater extent than the U.S., the other five countries have a long tradition of central government support for higher education and research as a part of their culture. Such support includes (i) general operating funds for higher education and research, the distribution of which is left to academic institutions; (ii) competitively awarded, investigator-initiated, peer-reviewed project and program support; and (iii) strategically targeted mission research. National university systems are the norm, supported by central or central and regional governments. In the Federal Republic of Germany (FRG) for example, regional government support for academic research is of considerable significance. Most faculty members in countries other than the U.S. are lifetime civil servants whose salaries are paid from general funds and not from project or program support. Academic facilities, major research equipment, and some support services are also provided from general funds. As a part of this tradition, research support tends to be longer term (except for the FRG) and more programmatic in these countries than the more usual shorter term project support in the U.S. (*1–3*).

Except for the U.S., the higher education of students in these countries is supported by the central government as a social overhead; all qualified students have a right to higher education—often in the field and institution of their choice if space is available—with low or zero tuition costs and often with stipends. Nonetheless, a smaller proportion of the college-aged population in European countries participates in higher education than in the U.S. and Japan. Research and education are less often coupled in the other countries than in the U.S. and the FRG, with education having more of a pedagogical and less of a research orientation (*1–4*).

All governments support research and development (R&D) for general knowledge and government needs and missions. In the U.S. central government support for R&D performed by industry is for mission purposes rather than as a contribution to economic development. About 90% of U.S. federal government R&D funds going to industry are for defense, space, and energy. In the other countries, however, there is a broader social and political agreement that the central government has an important role in supporting science and technology for economic development. The other countries directly and/or indirectly support R&D for new and improved industrial products, processes, and services. This partly arises from the need for economic reconstruction following World War II and a belief that their smaller size and limited domestic markets require such government support (*1–3*).

In all of the countries, government (national and regional) is by far the major supporter of basic research. Each country relies heavily on academia for the performance of basic or fundamental research and for the higher education of scientists and engineers. Important fundamental research is also performed in industry, federally funded R&D centers, and the national laboratories of each country. Such institutions are especially important in areas of research that require large facilities or serve special government interests such as defense, space, and nuclear research. Opinions differ on the overall importance of nonacademic institutions in the performance of basic research, but agreement is widespread that academic institutions constitute the major performer (*2, 4*).

In each country, the performance of applied research and technological development is conducted primarily by industry. The bulk of

The author is head of the Special Analytical Studies Section, Division of Science Resources Studies, National Science Foundation, Washington, DC 20550.

privately funded R&D comes from a relatively small number of large firms in a handful of industries. The extent to which industry uses its own funds or government funds is variable. Industrial R&D in Japan receives the least direct government funding (contrary to popular misconceptions) of any other country; Sweden and the FRG also are low in this regard, and the U.S., the U.K., and France provide the highest proportion of government funding. Much of the difference between the U.S., the U.K., and France and the other countries in direct industrial R&D support from the national government is accounted for by the relatively large defense R&D efforts (*3, 5*).

The role of government-owned industrial enterprises in R&D performance and funding is probably greatest in France, least in the U.S. and FRG, and somewhere in the middle for the other countries. The Organization for Economic Cooperation and Development (OECD) data collection system categorizes R&D performance as being in industry if the government-owned enterprise mainly engages in the production and selling of the kind of goods and services that are often produced by business enterprises; other government-owned R&D enterprises are categorized under government.

In each of these other countries there is greater emphasis than in the U.S. on focusing or targeting national R&D efforts on areas believed to be important for future economic development. These areas include electronics, computers, informatics, biotechnology, materials, and robotics. Support in these areas for academic research and education, and industrial R&D and commercial activities, is considered "strategic," and increasing government and private resources are being provided in such areas (*1, 4–6*).

Relations between academia and industry have tended to be weaker in the other countries than in the U.S. Historic distrust and disinterest have existed, with academia feeling that research of industrial interest is less desirable, and industry feeling that academia could contribute little to its needs. Recently this distrust and disinterest has lessened, and numerous bridges are being built, in part as a result of government policies and incentives. In some of the countries (for example, France and the FRG) there was less government reliance on academia where unique facilities or large research group arrangements are required, and therefore there has been greater reliance on specially created institutions (*3, 4*). Historically, engineers have been accorded higher status in some of these countries (for example, Japan, the FRG, France, and Sweden) than in the U.S. or the U.K. This is changing in the U.S. and the U.K. partly as a result of the pressure of international competition and trade.

The mobility of faculty members and industrial and government researchers is relatively low in the other countries as compared to the U.S. It is not unusual in these other countries for faculty members and R&D personnel in other sectors to spend all or most of their careers in one organization. Greater effort and central government incentives have been applied recently to encourage more mobility between sectors and movement to strategically important R&D areas (*4, 5*).

Each of the other countries places much greater emphasis than the U.S. on international cooperation in research, both bilateral (for example, Japan) and multilateral (as in the European countries' projects for cooperation in high technology, or Eureka, and the strategic program for research in information technology, or ESPRIT). A considerably higher proportion of central government funds supports such cooperation than in the U.S. A much higher proportion of graduate students and postdoctoral researchers do their work in other countries (often in the U.S.), and significantly greater effort is made to keep up with progress and literature from other countries (*2, 3*).

Data on the Allocation of Financial and Human Resources

This subject is best addressed in the form of Tables 1, 2, and 3, which display data for each country. Although efforts have been made to institute uniform definitions and concepts, such data have the usual frailties of comparability across countries in the application of definitions, collection procedures, and decisions as to the category appropriate for each activity. The data showing percentage allocations by country are particularly useful in considering different policies, strategies, and priorities and avoid the problems of size, differential exchange rates, and inflation. These data will be referred to throughout this paper (*7–11*).

Table 1 shows indicators of the science and engineering (S&E) effort relative to the size of each country. For the six countries, total R&D as a percent of gross national product (GNP) is of similar magnitude ranging from 2.2% for the U.K. to 2.8% for the U.S. and Japan. For nondefense R&D as a percent of GNP the range is greater, from 1.5% for the U.K. and 1.9% for the U.S. and France to 2.3% for Sweden, 2.6% for the FRG, and 2.8% for Japan. In the U.S. almost 70% of government R&D funding is for defense. Because development accounts for about 90% of U.S. defense R&D, the importance of this emphasis on research is much less.

The U.S. and Japan have the highest number of R&D scientists and engineers per 10,000 persons in the labor force, 69 and 63, respectively, with France, the U.K., and Sweden at the low end of about 40. For GNP, R&D funding, and the number of R&D scientists and engineers, the U.S. is larger than the total of the other five countries combined.

Table 2 shows the percent distribution of R&D expenditures by performing and funding sectors. For industry performance of R&D, industry itself is the major source of funds in all countries, ranging from 82% to 98% in the FRG, Sweden, and Japan to 61% to 73% in the U.K., the U.S., and France. Clearly, government defense R&D funding accounts for most of this difference. For the performance of R&D in academic institutions, the government is the major provider of funds, ranging from 64% in Japan, 73% in the U.S., and 80% in the U.K. to over 90% in Sweden, the FRG, and France.

Table 3 shows, for each country the percent distribution of R&D funds by source, performer, government objectives, industry, and government support by industry. It also shows the distribution of R&D scientists and engineers by sector, first-university and doctoral degrees by field, and shares of technology-intensive exports. These data, which are used throughout the article, clearly show priorities within each country and differences between them.

Allocation of Government Funding

In each country, government funds are provided by organizations whose primary mission is to promote and support science, and by mission agencies that support R&D related to other national objectives. The bulk of national government support for academic research is provided by a central science or education ministry, except in the U.S. The importance of mission agencies in funding academic research is especially pronounced in the U.S.; it is less important in the other nations because of the greater prominence of their central support agencies. Each of the countries uses mission agencies to provide guidance and support for more applied or industrially oriented research related to their objectives (for example, defense, space, energy, agriculture, health). Unlike the U.S., the other nations have a single ministry such as trade, industry, and commerce, that performs such functions in areas of industrially oriented science and technology considered important for economic

Table 1. Indicators of the S&E effort relative to country size for a year in the 1983–1986 period, depending upon country. Data from NSF and OECD.

Indicator	U.S.	Japan	FRG	France*	U.K.†	Sweden*,†
GNP (in billion constant 1982 dollars)	3680.7	1231.1	682.7	561.3	530.2	115.7
R&D (in billion constant 1982 dollars)	102.5	35.4	18.7	13.5	11.8	2.2
R&D/GNP ratio	2.8%	2.8%	2.7%	2.4%	2.2%	2.5%
Nondefense R&D/GNP ratio	1.9%	2.8%	2.6%	1.9%	1.5%	2.3%
Labor force (in millions)	119.5	60.3	27.7	23.8	27.4	4.3
R&D scientists and engineers‡ (in thousands)	825	406	135	98	90	17
R&D scientists and engineers‡ per 10,000 labor force	69	63.2	49.1	41.2	32.8	39.0

*Data for France and Sweden use gross domestic product. †Data for the U.K. and Sweden are for natural sciences and engineering only. ‡Scientists and engineers engaged in research and development on a full-time basis except Japan, whose data include persons primarily employed in natural science and engineering research and development and the U.K. whose data include only the government and industry sectors.

development (*2, 3*).

In contrast to U.S. practice, the other governments use a dual system of support for academic research in which general funding is supplemented with project or program funds. Under these systems, general funding is the primary source for the salaries of academic investigators and some technical and support staff; standard equipment; support services; supplies; and the construction, repair, maintenance, and operation of facilities. General support is supplemented with competitively awarded funds for the other costs of specific research projects or programs such as special equipment, travel, and support personnel (*1–3*).

The dual support system for academic research is being modified in practice, as increasingly complex and costly research instrumentation and support needs are straining limited general support budgets and are forcing a shift of some general support costs to project or program budgets. For example, the Research Councils in the U.K. have had to assume a larger share of research costs that previously were paid from general support, including instrumentation and technicians' salaries. In the FRG, to overcome problems with insufficient academic facilities, equipment, and research support, attempts are under way to better integrate academic research with the work of the Max Planck Institutes. Moreover, as the European nations have shifted toward greater targeting of research and greater reliance on strategic programs of research in support of economic needs, overall growth in academic research budgets has been curtailed or shifted away from general support and investigator-initiated research toward more strategically focused efforts (*3, 4*).

In contrast to the U.S. practice of relying on project awards, funding elsewhere tends to support research groups, programs, or laboratories through block grants, senior investigator awards, or special collaborative efforts. Except for the U.S. and the FRG, this support tends to be for periods from 3 to 5 years and may range to 10 years or longer (*2–4*).

The central government in France provides a higher proportion of total R&D funds than in any of the other countries (54%). About 20% of this central government funding is disbursed through the National Center for Scientific Research (CNRS) under the Ministry of Research and Higher Education. CNRS laboratories are the main locations for the conduct of academic research and most of these laboratories are associated with and located on higher education campuses. The Ministry of Industry, Telecommunications, and Tourism supports industrial R&D. Research funds are also provided by the mission agencies, for example, CNES (space), CEA (atomic energy), INSERM (health and medicine), IFREMER (oceans and fisheries), INRA (agriculture), and AFME (energy conservation and renewable energy). The French system relies on block grants to the laboratories and research groups rather than on specific project grants to individual researchers (*2–4, 9, 10*).

In the FRG, 38% of total R&D funding is provided by government. The FRG relies heavily on joint funding of major performers and R&D programs by Federal and Länder (or State) governments. The Research and Technology Ministry (BMFT) provides the bulk of federal funds, with additional resources coming from the ministries of defense, economics, education, and science. Several autonomous organizations jointly funded by Federal and Länder governments allocate government science funds: the German Research Society (DFG) to academia; and Max Planck (MPG) and Fraunhofer (FhG) Societies (half of the latter funds come from industry) to their research institutes. Federal funds predominate for major national laboratories, Länder funds for regional applied research institutes. As in other nations, industry is not a major source of support for research conducted in other sectors [see Table 2 and (*2–4, 12, 13*)].

In the U.K., about 48% of total R&D funding is provided by the government. Major performers are the universities, government laboratories, and private industry. Academic research is supported largely by the central government through two funding mechanisms. Block grants from the University Grants Council are supplemented by competitively awarded research grants from five autonomous Research Councils, which also operate government-supported laboratories to which academic scientists have access. The Department of Trade and Industry supports a number of R&D activities of

Table 2. Percent distribution of R&D expenditures by performer and source. Columns may not total 100% because of rounding. Data from NSF and OECD.

Source	Performer			
	Industry	Government	Higher education	Private nonprofit
United States (1986)*				
Industry	67	—	4	11
Government	33	100	73	71
Higher education	—	—	18	—
Private nonprofit	—	—	5	18
Foreign	—	—	—	—
Japan (1983)				
Industry	98	2	2	66
Government	2	98	64	21
Higher education	—	—	34	—
Private nonprofit	—	—	—	12
Foreign	—	—	—	1
Federal Republic of Germany (1985)†				
Industry	82	3	7	16
Government	16	95	93	80
Higher education	—	—	—	—
Private nonprofit	—	1	—	1
Foreign	1	1	—	3
France (1983)‡				
Industry	73	1	1	12
Government	22	96	98	41
Higher education	—	—	1	3
Private nonprofit	—	—	—	43
Foreign	5	3	—	2
United Kingdom (1981)§				
Industry	61	10	3	31
Government	30	82	80	54
Higher education	—	—	9	3
Private nonprofit	—	3	6	13
Foreign	9	5	2	2
Sweden (1983)§				
Industry	88	7	4	7
Government	10	92	91	38
Higher education	—	—	1	—
Private nonprofit	—	—	3	40
Foreign	2	1	1	15

*In the U.S. the government sector is federal only; in other countries government includes all levels. †In the FRG the Max Planck Institutes are classified as government. ‡In France research and development funded by CNRS is classified as being performed in the higher education sector, but with government as the source. §Data for Sweden and the U.K. are for natural sciences and engineering research only.

industrial relevance with industrial cost sharing. Special joint efforts involving industry, academia, and government are growing (for example, the Alvey Program in manufacturing and information technology, JOERS in opto-electronics) (*2–4, 17*).

In Sweden, government provides 40% of total R&D funding. Swedish S&T policy and organization may be characterized as decentralized, pluralistic, and sector specific. The government performs relatively little of its own research, although some mission agencies maintain their own laboratories. There are no national laboratories, and the national universities are the main performers of research and house large laboratories. Government support to the universities for specific research awards flows through three Research Councils. The mechanisms are both general support and project or program support. The National Swedish Board for Technical Development (STU) provides funds for applied academic research and applied R&D in industry (*3, 14, 15*).

Japan has the lowest government proportion of total R&D funding—22%. In Japan, government S&T funding is provided by the Ministry of Education, Science, and Culture (Monbusho), the Science and Technology Agency (STA), the Ministry for International Trade and Industry (MITI), and other mission agencies. Monbusho provides most academic research funding, principally to national universities and their affiliated laboratories. Recently, greater attention is being paid to increasing basic research. Noteworthy among STA supported programs is Exploratory Research for Advanced Technologies (ERATO). It supports teams of scientists from industry, academia, and government that are led by key individuals in programs of interdisciplinary breakthrough R&D. MITI supports an elaborate system in support of industrial R&D, carried out in its own labs and through active promotion of privately supported research institutes that perform nonproprietary R&D in certain product areas such as semiconductors and new synthetics, as well as focused R&D initiatives and low interest loans. Industry in Japan is more important than elsewhere as a supporter of R&D—67% of total R&D [see Table 3 and (*1, 3, 16*)].

In the U.S., federal government R&D funding—47% of total R&D—is dispersed across many agencies. Recently the Department of Defense (DOD) share has significantly increased to about 65% of all federal R&D funds. Other agencies of importance include the Department of Energy (DOE), 9%—more than half of this serves the defense objective; the National Institutes of Health (NIH), 9%; the National Aeronautics and Space Administration (NASA), 7%; the National Science Foundation (NSF), 3%; and the Department of Agriculture (DOA), 2%. NIH, NSF, DOD, and DOE account for about 85% of the total federal government support of academic R&D. DOD, NASA, and DOE account for over 95% of federal government support of industrial R&D.

Mechanisms for Coordination of Science and Technology

Coordination of the components of national science and technology is everywhere made difficult by the diversity of performers and support institutions, varying time horizons of the different activities, and the intrinsic difficulty in predicting and planning R&D. Coordination is not synonymous with greater centralization and can be achieved by other mechanisms. Some coordinating functions are often performed by the central budget organizations—for example, the Finance Ministry or Office of Management and Budget—in each of the countries (*3*).

There has been much discussion and some literature attempting to classify the organization and coordination of R&D in different countries. For present purposes, it may be enough to say that there is general agreement that the U.S. R&D system and organization are at the pluralistic, less centralized, and market-oriented end of the spectrum; the French system and organization are at the more centralized, planned, and strategically targeted end of the spectrum; and the U.K., the FRG, Sweden, and Japan are somewhere in between, depending on who is looking at what part of the system (*1, 5, 6*).

French government research and technology priorities and directions are stated in 5-year R&D plans put forth by the central government in power. The Ministry for Research and Higher Education coordinates higher education research and also funds CNRS, which is the principal organization for the support of basic research. The Ministry of Industry, Telecommunications, and Tourism does the same for government support of industrial S&T. Coordination may be facilitated by the use of longer term block support, joint operation of big-science laboratories by mission agencies, and government involvement in industrial R&D through subsidiaries or direct participation. CNRS, as well as other research agencies, has several mechanisms for closer coordination between CNRS-funded work and the R&D needs of French industry (for example, prime agreements with industrial firms, mobility of researchers) (*2, 3*).

The FRG achieves a degree of coordination of basic research without direct government control, largely as a result of the efforts of autonomous associations in its science system: the DFG, which provides academic project support and science advice; and the MPG, which conducts research and operates about 50 research institutes. A Science Council advises the government as well as DFG and MPG. The BMFT and mission agencies take a more directive stance for applied research and work in the national laboratories. The organization of Big Science Establishments (AGF) participates in setting research directions and receives funds from the Federal and Länder governments. No formal government-industry coordinating bodies exist, but the BMFT is the major source of federal funds and plays a coordinating role. Federal, Länder, and industry funds support the applied institutes of the FhG, whose work reflects both government and industry needs. There is industry-government collaboration in the work of the national laboratories (*2, 3, 12, 13*).

No strong central coordinating body exists in the U.K. science and technology system, whose major elements operate with considerable autonomy. The establishment of the decade-old offices of Chief Scientists in major government agencies is believed to have improved government coordination, and a Cabinet Chief Science Adviser and staff produce an annual review of government-funded R&D and perform coordinating functions (*17*). The Advisory Board for Research Councils (ABRC) advises the Secretary of Education and Science; efforts are under way to increase its role in decisions about resource allocation across the Councils. A number of coordinating bodies exist for applied research and development: the Advisory Council on Applied Research and Development (ACARD) directs attention to emerging areas of commercial importance; a Department of Industry Requirements Board identifies and recommends support of R&D linked to industrial needs, as do similar boards in the mission agencies; and the National Research and Development Corporation, a quasi-governmental body, identifies and promotes inventions that may have industrial applications (*2, 3, 17*).

In 1979, the Swedish government began a number of steps to increase the coordination of the R&D it supports. Comprehensive S&T legislation created a Council for Planning and Coordination of Research to coordinate the research of three councils that support fundamental research. The government periodically formulates comprehensive science policy plans that are enacted by the Parliament (the latest is the 1987 Research Policy Bill). It has undertaken two major initiatives: encouraging the universities to conduct more industrially relevant research; and providing funds, loans, and technical assistance to industry directly through the STU, which also supports applied academic research (*3, 14, 15*).

The most fundamental coordinating mechanism in Japan's S&T system is the setting of national policy through an emerging consensus judgment. The most important formal coordinating body is the Council for Science and Technology in the Prime Minister's Office, composed of ministers, senior educators, industrial managers, scientists, and engineers. Special councils are formed periodically to assess progress in different fields and recommend priorities. The DELPHI technique is sometimes relied upon to seek the views of researchers from a broad range of government, university, and industrial organizations. Government agencies including MITI and STA operate research institutes whose work is planned and conducted in cooperation with industry. STA also performs important coordinating and advisory services in the national government. Monbusho is the central agency for the coordination and support of academic research. Each agency acts independently, and STA and MITI employ an array of advisory councils and industry associations to ensure that government-conducted and government-sponsored research will be consonant with private sector research interests. MITI's National Project System focuses R&D in national priority areas: and the programs are carried out primarily with industry participation and costs are shared by industry and government. Little university-industry coordination exists, although considerable emphasis has been placed recently on strengthening this linkage (*2, 3, 16*).

In the U.S., the Science Advisor to the President and his Office of Science and Technology Policy (OSTP) have responsibility for coordinating federal R&D activities. In addition to the work of the OSTP staff, the White House Science Council (made up of external advisors) and the Federal Coordinating Council for Science, Engineering, and Technology (made up of key federal agency R&D officials) assist as coordinating mechanisms. The required *Annual S&T Report* (now biennial) and the annual *Special Analysis of the Budget* on R&D prepared by the Office of Management and Budget are important documents in this area. But the pluralistic nature of the U.S. system frequently makes coordination efforts difficult.

Assessment of Effectiveness of Science and Technology

In principle, research assessments can be carried out at all levels. But assessments of the performance of national S&T systems are rare, and empirical evidence to address system performance is minimal and often of questionable value. More frequently, attention is given to determining the quality of science in a given discipline or laboratory and, less frequently, in groups of institutions or broad fields of science or application (*2–4*).

Such assessments are largely based on variants of the peer review system. Each of the countries is trying to supplement this mechanism with other methods that involve the retrospective mapping of scientific advances by means of various bibliometric methods in order to provide additional inputs for quality evaluation or resource allocation decisions, especially as resources become more limited (*2–4*).

Peer review methods function better for assessing the quality of work in scientific disciplines than for assessments of cross-disciplinary work, for programs that mix fundamental and applied research elements, or for comparisons of dissimilar areas of R&D. A further problem in conducting assessments arises from the difficulty of tracing cause-and-effect relationships in the S&T process.

In the quality of science assessments, there is some evidence that the U.S. devotes more effort to determining the promise and quality at the proposal review stage than do some of the other nations, where more emphasis is placed on assessing progress and outputs. This may reflect other nations' greater reliance on longer term support to entire institutions or research programs, as contrasted with the preponderance of shorter-term project support in the U.S., as well as the larger size of the U.S. effort (*3, 4*).

Perhaps the most ambitious assessment efforts exist in Sweden. Peer evaluations cover programs, research teams, institutions, and fields of science, and they span both basic and applied research. Results feed into the formulation of comprehensive R&D strategies as well as decisions on future research directions and support levels. The focus of these assessments is on particular fields of R&D and application. Comparison is made with other countries, and foreign scientists and engineers play a key role as members of the peer review teams. The results of such reviews are available to all (*4, 14*).

Table 3. Selected comparative data (in percent) primarily for a year in the 1983–86 period, depending on country and item. Columns may not add to totals because of rounding. Data from NSF, EEC, and OECD. NA, not available.

Item	U.S.	Japan	FRG	France	U.K.	Sweden*
Total R&D by source of funds	100	100	100	100	100	100
Industry	50	67	61	41	42	58
Government†	47	22	38‡	54	48	40
Other	3	11	1	5	10	2
Total R&D by performer	100	100	100	100	100	100
Industry	73	65	72	57	63	65
Government†	12	9	12‡	29	21	5
Higher education	12	22	15	14‡	13	30
Private nonprofit	3	4	—	—	3	—
Total R&D by character	100	100*	100	100	100*	100
Basic research	12	13	20	21	12	22
Applied research	21	25	{ 80	34	25	17
Development	67	62		45	63	61
Research expenditures by performer	100	100		100	100*	100
Industry	51	51		35	39	25
Higher education	30	34	NA	29‡	28	65
Government†	13	{ 15		35	30	10
Nonprofit	5			2	2	—
Basic research expenditures by performer	100	100	100	100	100*	100
Higher education	57	59	58	67‡	55	89
Industry	21	29	17	9	13	7
Government†	14	{ 12	24‡	22	30	4
Private nonprofit	8		1	3	2	—

*Natural sciences and engineering only; all other figures include social science and humanities; the U.S. excludes humanities. †In the U.S., the government sector is federal only; in other countries, government includes all levels. ‡In France, the CNRS R&D is classified as higher education in performance data but as government in source of funds data; in the FRG the Max Planck Institutes are classified as government. §General purpose research; including an estimated portion of general university funds (except U.S.). For the U.S., only general research not supported for the other objectives is reported here. ||Includes mathematics and computer scientists/specialists. #Engineering degrees are master's level. **Included in natural sciences. ††Reflects information from 24 reporting countries on exports to and imports from each of nearly 200 partner countries. Technology-intensive products are defined as those for which R&D expenditures exceed 2.36% of value-added.

Results of Research, Education, and Technology

Indicators exist that permit rough comparisons of S&E research and training. For research, the number of publications by a nation's scientists and engineers in various fields can serve as a measure of the quantity of output, whereas references to these publications in the literature provide some basis for quality indicators. These measures are rough due to possible bias toward the English language, possible different time lags in the citation of foreign language publications relative to English, and the difficulty of measuring importance. For training, numbers of college and university S&E graduates, that is, additions to a nation's human capital base for S&E, are the most frequently used quantitative output indicator.

For all fields combined, the U.S. accounts for about 35% of the publications included in the Science Citation Index set of S&T Journals. The U.S. share of these publications exceeds the combined total of the five other nations. Japan, France, the FRG, and the U.K. contribute between 5% and 9% each, and Sweden less than that, reflecting its smaller science establishment. The U.S. proportion of publications ranges from about 40% or greater for earth and space sciences, clinical medicine, biomedicine, and engineering and technology, to 37% in mathematics, 27% in physics, 21% in chemistry, and 11% in biology. The overall U.S. share has remained roughly stable since 1973 (*8, 11*).

A rough initial impression of the quality of a nation's contribution to a field or discipline of science can be derived by examining whether the share of references to that nation's published output falls short of, approximates, or exceeds its share of the published output. In each major discipline, the U.S. share of references exceeds the U.S. share of publications, except in medicine where it is equal, with substantial variation among disciplines. In a number of S&E specialties, including physical chemistry, solid-state catalysis, and organic synthetic chemistry, the U.K., FRG, and Japan appear to hold leadership positions.

The number of degrees granted by institutions of higher education generally reflects the position of the U.S. in world science. The U.S. awards more first-university degrees in the natural sciences than the other five nations combined (over 120,000 in 1985). Data on advanced degrees are broadly consistent with data on undergraduate degrees. In the U.S., FRG, and U.K., the number of first-university-degree graduates in the natural sciences exceeds that in engineering. In contrast, the number of engineering graduates exceeds that in the natural sciences by a considerable margin in Japan and Sweden and a smaller margin in France (see Table 3). Engineering degrees constitute a smaller portion of total first-university degrees in the U.S. and Sweden than is the case for the other countries. Japan graduates slightly fewer first-degree holders in engineering than does the U.S., although it has only about half the population. Universities in the U.S. graduate more doctorate-level engineers than such institutions in Japan. More than half of the recipients of U.S. engineering doctorates are foreigners, 57% in 1985 (*8, 11*).

There is a dearth of acceptable measures of technological outputs. Measures such as patent counts and license fees provide little information about their technological or economic importance, and international comparisons are greatly affected by the different laws, regulations, and exchange rates in each of the countries. One relative measure is shown in Table 3. It shows the shares of technology-intensive exports for each of these countries. In recent years the U.S. share has declined some to 24%. Japan has increased to 19%, the FRG 15%, and the other countries less than 10%. Relative to the size of their respective economies, the other countries export a higher percent than the U.S.

Table 3 (continued).

Item	U.S.	Japan	FRG	France	U.K.	Sweden*
Government† R&D funding by objective	100	100	100	100	100	100
Defense	69	3	12	31	52	26
Advancement of knowledge§	4	54	44	27	22	43
Space	5	5	5	6	2	3
Energy	4	14	11	7	5	6
Health	10	3	3	4	4	1
Industrial growth	0.2	6	14	13	7	6
Agriculture	2	11	2	4	5	3
All other	6	4	9	8	3	12
Industrial R&D expenditures by industry*	100	100	100	100	100	100
Electrical equipment	22	27	24	25	31	24
Machinery, computers	14	12	14	8	15	11
Chemicals, allied products	11	16	22	16	21	12
Motor vehicles	9	14	15	11	6	{ 23
Aerospace	22	—	5	17	17	
Instruments	7	3	2	1	2	2
All other	15	28	18	22	8	28
Percent of government† support of industrial R&D expenditures						
Electrical equipment	40	2	21	30	46	11
Machinery, computers	14	2	9	10	10	4
Chemicals, allied products	3	2	4	4	1	6
Motor vehicles	14	2	2	2	4	{ 15
Aerospace	76	2	65	65	68	
Instruments	13	2	11	11	4	11
Scientists and engineers engaged in R&D by sector	100	100*	100	100		100
Industry	74	62	62	41		57
Higher education	14	30	23	37	NA	34
Government	8	{ 8	14	21		9
Private nonprofit	4		1	1		—
First-university degrees by field	100	100	100	100	100	100
Natural sciences‖	12	3	16	20	24	4
Engineering	8	19	14	28#	14	9
Agriculture	2	4	4	NA**	2	1
All other	78	74	66	52	60	86
Doctoral degrees by field	100	100	100	100	100	100
Natural sciences‖	24	11	21	48	42	12
Engineering	10	17	9	9	16	13
Agriculture	3	8	3	NA**	4	1
All other (includes M.D.)	63	64	67	42	39	74
Shares of technology-intensive exports††	24	19	15	8	9	2

*Natural sciences and engineering only; all other figures include social science and humanities; the U.S. excludes humanities. †In the U.S., the government sector is federal only; in other countries, government includes all levels. ‡In France, the CNRS R&D is classified as higher education in performance data but as government in source of funds data; in the FRG the Max Planck Institutes are classified as government. §General purpose research; including an estimated portion of general university funds (except U.S.). For the U.S., only general research not supported for the other objectives is reported here. ‖Includes mathematics and computer scientists/specialists. #Engineering degrees are master's level. **Included in natural sciences. ††Reflects information from 24 reporting countries on exports to and imports from each of nearly 200 partner countries. Technology-intensive products are defined as those for which R&D expenditures exceed 2.36% of value-added.

Criticisms of Existing Science and Technology Policies

All of these countries are advanced in science, technology, and socioeconomic development. Nonetheless, all are attempting to improve their situation. Despite general satisfaction with their R&D situation, criticisms of certain aspects have been rising recently, due in part to other problems. The following is a listing of some of the dissatisfactions or criticisms that have recently been expressed in most or all of the countries, varying with the different needs perceived and the degrees to which self-criticism is openly stated:

1) There is inadequate cooperation between academia and industry in research, education, and exchange of information. Academics prefer to "do their own thing" with insufficient attention to industrial needs, and industry tends to be too short-term oriented to take advantage of the longer term possibilities of more fundamental research (*4, 5*). Academic and government research institutions stress stability too much and lack flexibility and responsiveness to economic needs (*4*).

2) Except in the U.S., there is relatively little mobility of researchers, who tend to remain in one institution for long periods of time, thereby reducing the transfer of research skills and technical information (*4, 5*). An insufficient number of younger researchers can find faculty positions, and the average age of faculty continues to increase with relatively small numbers ready to retire (*2, 4*).

3) Academic research is not sufficiently coupled with education or industrial needs, with the result that graduates are not equipped to operate close to the state-of-the-art (*2, 4*). Academic institutions lack

sufficient state-of-the-art facilities and equipment. The quality and relevance of the work of some large government laboratories is insufficient (*4, 5*).

4) The number of new, small, high-technology firms being started is insufficient for several reasons: Technical professionals are reluctant to take risks, capital markets are ineffective, and social attitudes are adverse. In the U.S., there have been a relatively large number of new, small high-technology firms each year partly because of the availability of venture capital, favorable tax treatment, and a tradition of technical entrepreneurship. Only a small proportion survive with most failing or bought out. Much attention is paid to the relatively small proportion that succeed, and their importance to a dynamic high-technology society is high (*4, 5*).

Suggested Major Changes

A number of major changes have recently been made or are under active consideration. Greater emphasis is being placed on strategically targeted R&D in areas designed to improve future economic development and international competitiveness. More emphasis is being placed on a market or user orientation in government supported R&D (*4–6*). In a number of countries, real growth in funding of general academic support and of investigator-initiated, peer-reviewed projects has been reduced or stopped in favor of strategically targeted program support by government agencies. Japan and the U.S. are in the process of significantly increasing central government support for basic research (*3–5*).

Governments are trying to provide increased incentives for university-industry-government laboratory cooperation and mobility of research personnel from one sector to another. In the U.S. almost all of the states, hundreds of local authorities, and the federal government are attempting to build new high-technology partnerships. The role of the public sector in these relationships tends to be that of a catalyst with some funds supplied. These newer technical-development partnership programs are mostly experimental in design, and it will take several more years of experience, data, and study to determine their effectiveness (*4, 5, 18*).

Governments are adopting special programs to provide academic positions for younger researchers, although at a very low rate thus far. In the FRG a large part of this problem has eased (*2, 4*). They are trying to increase their support for industrial R&D, utilizing both direct mechanisms such as funding or loans and indirect mechanisms such as tax incentives or research parks, especially for small- and medium-sized enterprises (*4, 5*). Governments are also undertaking more assessments and evaluations of the quality of research in specific fields of science and engineering, and areas of application, relative to other countries (*4, 5*).

In the U.S., greater attention and funding are now provided to program-oriented centers (Engineering Research Centers, Industry-University Cooperative Research Centers, Supercomputer Centers are examples) especially in interdisciplinary areas that may render assistance in the competitive international arena.

Future Considerations

Before addressing the question of what one country can learn from the others, the following cautions should be noted: (i) The elements of a system for supporting and conducting S&T are interrelated with each other and with the broader national context and individual elements should fit into this context. They are not necessarily transferable from one country to another. (ii) While each country is looking at the policies and strategies of other countries with a view to what can be learned and possibly applied, the other countries are doing the same. As noted above, several changes have been introduced that could move the countries closer together in their policies and strategies. The organization and resource allocations, however, remain very different. (iii) The advantages and disadvantages of optional policies and strategies are not clear. There is little objective assessment information revealing what works better or worse under what circumstances and why. The positive and negative consequences of a particular option frequently depend on how it is implemented.

With these cautions in mind, it is nonetheless useful to consider some of the questions or issues in light of changing objectives and needs. This can be useful even if it serves the purpose of reinforcing commitment to current policies and strategies, with or without some modifications. The following list of questions is offered for consideration:

1) Should the U.S. and the FRG move toward more longer term or aggregate programmatic support for science and engineering and away from the predominant reliance on shorter term project support? This is one of the most striking differences between the policies and strategies of the other countries and the U.S. and FRG (*2–4*).

2) Is it as desirable to focus graduate support on fields where demand is growing strongly and is greater than supply? For the U.S., there is also the question of whether it should shift toward more direct support for graduate students. Most U.S. S&E graduate students receiving financial assistance from the federal government are supported as a part of projects grants; most graduate students in the other countries are supported by low or no tuition costs and often stipends (*4–6*).

3) Should alternative mechanisms be considered for supporting academic research facilities and equipment? All countries are facing problems of obsolescence of academic research facilities and equipment. In the other countries, government support for such facilities and equipment is treated as a social capital investment; in the U.S. they are chargeable to indirect project costs or are partially paid for under project support and some special facilities or equipment programs. This problem may be especially difficult for the U.S. because of the greater reliance upon support from mission agencies (*2, 3*).

4) Should these countries (and especially the U.S.) move further toward greater government support for nonproprietary S&T in support of industrial needs, especially in areas of increasing international technological competition? Each of the other countries accepts this as a part of the responsibility of the central government and has employed both direct and indirect mechanisms to discharge it. In the U.S. no such consensus exists, and debate continues about the advantages and disadvantages of such a strategy, with differences of views in the political, academic, and industrial communities (*5, 6*).

5) Should the countries encourage more cooperative research activities regionally within the country and internationally among countries, especially where the costs of facilities and equipment are high? As discussed above, each of the other countries allocates proportionately more resources to such cooperative ventures than does the U.S. With regard to international cooperation, there are some indications that participation by U.S. scientists may not be as high as it was in earlier periods. The advantages and disadvantages of the forms of cooperation (for example, bilateral, multilateral) in particular fields of science need to be carefully considered (*2, 3*).

6) Should the countries move toward greater centralization or coordination of government S&T activities and needs? This question has frequently been raised in the U.S., most recently by a recommendation that a Cabinet-level Department of Science and

Technology be established (*19*). Other, more limited proposals, with similar intent, include formation of a Department of Science, a National Technology Foundation, a National Institute for Research and Advanced Studies, and a National Applied Science Administration. As stated above, centralization is not synonymous with coordination or quality, and no good evidence can be drawn from the experiences of the countries examined to support the greater efficacy of more centralized versus more pluralistic systems. These countries run the gamut in this regard, and several countries have shifted along this spectrum in both directions (*1–3*).

Conclusions

This article demonstrates that there are many similarities and differences in the S&T policies, strategies, priorities, and practices among the six countries. In analyzing the comparative advantages and disadvantages it appears as if some of the advantages when carried to an extreme can become liabilities. For example, the U.S. reliance on project support contributes to greater flexibility, mobility, and market-orientation. It also results in less stability, less proportionate investment in infrastructure, and less general support for graduate students. Such advantages and disadvantages tend to be reversed in the other countries, although there are some notable exceptions.

It is not surprising that some of the more important recent changes appear to be designed to lessen the disadvantages while maintaining the advantages. In this way we can indeed learn from each other, adopt that which serves our individual country needs, while seeking to preserve our unique advantages.

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The Discovery of a Class of High-Temperature Superconductors

K. ALEX MÜLLER AND J. GEORG BEDNORZ

The exceptional interest in the new class of oxide superconductors and the importance of these materials are discussed together with the concepts that led to their discovery. The discovery itself and its early confirmation are summarized, including the work until the beginning of 1987. The observation of a superconductive glass state in percolative samples is also discussed.

The authors are in the IBM Research Division, Zurich Research Laboratory, 8803 Rüschlikon, Switzerland.

HIGH TRANSITION TEMPERATURE SUPERCONDUCTIVITY IN the Ba-La-Cu oxide system (*1*) was discovered by Bednorz and Müller at the IBM Zurich Research Laboratory and confirmed in early fall of 1986 (*2*). For this reason we were asked to review the progress for this special issue on "Science in Europe." Since this invitation, the work and interest in the field have been exceptional. Figure 1 shows the progression of the superconducting transition temperatures (T_c) from the discovery of the phenomenon in mercury by H. K. Onnes in 1911 (*3*) until February 1987. One notices a more or less linear increase in maximal T_c's until the 75th anniversary of the discovery. This led to the expectation of T_c's near