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POLICY REPORT

A Strategic Assessment of the Scientific Performance of Five Countries

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Abstract

This report compares the concentration of effort among subfields of science across five industrialized nations, as shown in numbers of publications. The analysis is based on the PASCAL database maintained by the French Centre National de la Recherche Scientifique (CNRS) for the years 1980 to 1983. Japan and Germany show strong concentrations in areas of strategic basic research such as new materials, biotechnology, and communications technology. The United States effort is concentrated in environmental and space sciences as well as health sciences and technologies. France and the United Kingdom concentrate on the health sciences.

Editor's Note: Policy Reports in S&TS are an experimental form of communication between the worlds of science studies and science policy. They call the attention of S&TS readers to results of studies commissioned with direct policy applications in mind. Volunteers or nominations for contributors to this series are invited, and comments on its usefulness are welcome.

Analysis of national scientific performance is part of the strategic assessment of science policy which is, explicitly or implicitly, performed by all governments. Such an assessment is needed because ever more difficult decisions about resource allocation among scientific fields have to be made . Furthermore, those decisions can obviously have farreaching consequences for industrial and economic performance. Part of basic research is sometimes labelled "strategic," as opposed to "curiosity-oriented," in that it can relate directly to innovations in the scientifically-driven "core technologies," which in turn can affect a broad spectrum of activities.[1]

Such allocation decisions determine a *flow* of resources which is aimed at changing the scientific level or strength of the nation (which is a *stock*), as compared to other nations. Year after year, the allocation decisions, whether explicit or implicit, centralized or decentralized, determine the relative level of the country, in each field and sub-field of science: it determines its *scientific profile*, which can be seen as the "sedimentation" of all past resource allocations. For these science policy decisions, a knowledge of the national scientific profile is clearly needed both to ground the allocation decisions and to assess their results in terms of modified scientific strength over a period of time.[2]

The indicators published by the United States National Science Foundation (NSF) provide very useful information in this respect, especially the bibliometric indicators based on the *Science Citation Index* or CHI-NSF database.[3] Nevertheless, they do not solve the problem because the results are reported in a rigid classification of fields and subfields, unchanged for a decade, which may—or may not—be suitable to perform strategic assessment.

Because of the lack of alternative data, M. R. Chabbal from the French Ministry of Science and Technology commissioned the bibliometric study reported here[4] to identify the scientific profile of various countries according to subfields considered meaningful for a strategic assessment of science in those countries. Such an enterprise was all the more needed because a law passed in 1985 made it compulsory for the Ministry of Science and Technology "to present a yearly assessment to the Parliament of the 'strategic choices' of national science and technology policy, presenting the position of France in international competition in comparison with major foreign countries."[5]

Methodology

The PASCAL database

Two points set our study apart from the *Science Indicators* data. First, we chose to work with the PASCAL data base for the study. This multidisciplinary data base, which is produced by the Centre National de la Recherche Scientifique (CNRS), is drawn from about 9,000 scientific and technical journals which are chosen to represent the core of the world's scientific activity, even though, like the SCI (and therefore the CHI-NSF), it underrepresents sci-

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ence published in non-Roman alphabets. A disadvantage of PASCAL is that it does not include citations; this is why we did only publication counts and could not perform any impact analysis.

An advantage of PASCAL, on the other hand, is that it includes keywords with each article. This feature enabled us to define subfields which were meaningful in terms of science policymaking and strategic assessment. This is the second distinctive feature of this study.

Definition of the subfields

In order to be meaningful in terms of strategic assessment of science policy, yet manageable for the PASCAL database, the subfields of interest were determined through a discussion among policymakers, their scientific advisors, and PASCAL data base specialists. This led to the identification of 145 subfields. For various reasons, mathematics, particle physics, clinical medicine, and the social sciences were excluded. Each subfield is accessible without ambiguity or overlap through the classification scheme or the PASCAL keywords, and all subfields taken together cover about 85% of PASCAL.

Constitution and validation of the data base

The number of articles contained in PASCAL for each one of the 145 subfields was then computed for France, the United States, the Federal Republic of Germany (FRG), the United Kingdom (U.K.), and Japan[6]; in order to increase the reliability of the results, the numbers were computed as a total over 4 years (1980 to 1983). This being done, we retained subfields for analysis if they met all of the following criteria:

—The world total of articles had to be greater than 200 per year, in order to avoid subfields which were too narrowly defined.

—The proportion of articles without country affiliation had to be less than 30%. We assumed that articles without country affiliations were randomly distributed among countries. The 30% criterion gave us some assurance that even if this assumption were false, the impact would not be significant.

Then we computed the number of articles for each subfield which appeared in another data base, chosen case by case according to the subfield (e.g., *Chemical Abstracts* for chemistry). At this stage we added a third criterion: similarity in relative importance of the different countries when computed with PASCAL and the other data base.

In the end, selection by these criteria left us with 103 subfields out of the 145 initially defined. Most of the subfields we had to drop were applied sciences and technology. We still have very good coverage of basic research and fair coverage of the applied sciences, but poor coverage for technology. To simplify matters, these 103 subfields will be referred to as "science" in what follows.

Table 1:
Scientific Profiles of the Countries (on the macro-profile fields

	Field	F	FRG	UK	USA	JPN
I	Theoretical physics and chemistry	93	110	97	100	119
II	Life sciences, basic research	98	101	107	147	143
III	Semiconductors; analytic and electro-chemistry; catalysis; condensed matter	94	95	81	68	166
IV	Materials science plus applied and organic chemistry	57	127	80	59	126
V	Physics and technology of electronic components, integrated circuits, "Group III-V" semiconductors, photocmemistry	74	91	86	116	255
VI	Computer science and imaging technology	78	102	101	106	84
VII	Technology for pollution treatment, energy storage, civil engineering, plus machine tool research	71	136	74	72	59
VIII	Earth sciences	98	62	83	77	52
IX	Environmental sciences and space sciences	68	84	88	114	55
X	Renewable resources	129	78	97	83	45
XI	Agronomy, food production, biotechnology for agriculture	98	69	97	90	67
XII	Life sciences: health and drugs	155	114	130	121	69
XIII	Other applied life sciences	109	99	142	143	70
	Mean	100	100	100	100	100

Each number is the mean for each field of the value of the relative specialization index of its sub-fields; each number therefore represents a macro-specialization index. Details on the subfields included in each field are available from the author.

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Our PASCAL-profiles data base thus comprises a matrix of 103 lines (subfields) and 6 columns (5 countries plus rest of the world). The total number of articles recorded in the 103 subfields (for 4 years, world total, including nonaffiliated articles) is 1,452,500, the number of articles and world share per country being the following:[7]

France	107,001 (6.1%)
United Kingdom	118,603 (6.8%)
Germany	106,632 (6.1%)
USA	511,764 (29.4%)
Japan	105,916 (6.1%)

The mean number of articles for the 4 years, per subfield is 14,000, with a minimum of 800 and a maximum of 9,500.

Scientific and geographic profiles

Each country was given an overall "scientific weight": its share of world scientific articles. Each country also has a weight relative to each subfield, which is simply its share of the world articles in that subfield. For a country, the ratio of its weight in a subfield to its overall scientific weight measures the relative specialization of the country in that subfield.

The "scientific profile of a country" is the set of measures of its relative specialization for each subfield—a vector of 103 elements. If Aij is the number of articles of a country *i* in subfield *j*, then the relative specialization of *i* in *j* is: Aij/A.j : Ai./A.. = Kij. The scientific profile of country *i* is the vector Vi = (Ki1, Ki2, ... Kij, ... Ki103).

In exactly the same way, each subfield has a profile of countries, which we call the "geographic profile of a subfield." It is made up of the relative concentration in each country, the concentration being the ratio of the weight of subfield j in country i to the overall weight of subfield j in world science (Aij/Ai. : A.j/A.. = Kij). Therefore the geographic profile of subfield j is the vector Vj = (K1j, K2j, .. Kij .... K6j).

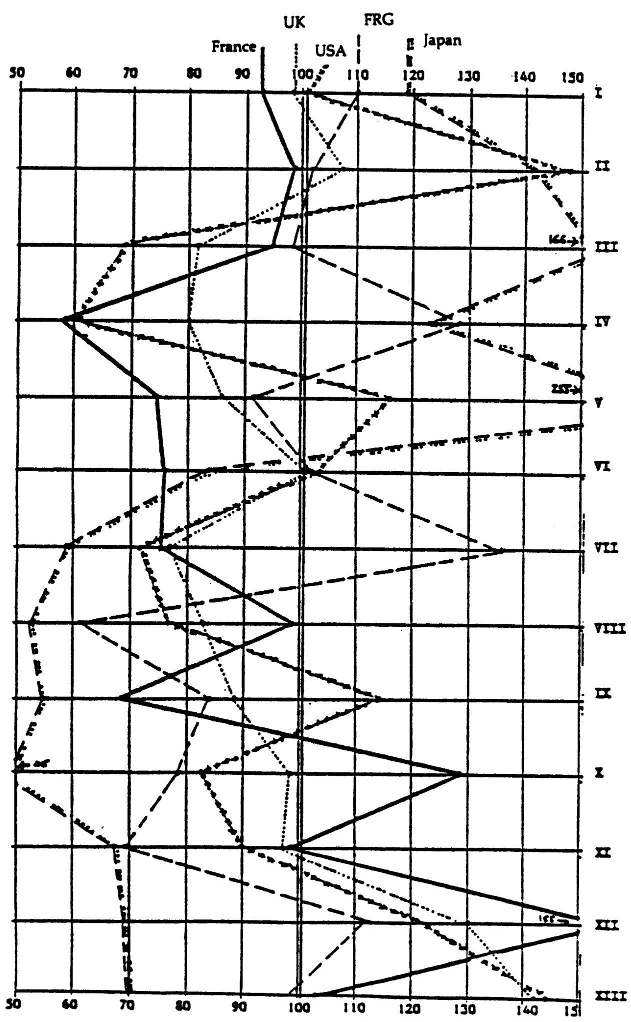

Figure 1. Scientific profiles of the five countries on the 13 macro-profile fields. The mean weight of each country is 100. For each field, the relative specialization index is shown.

Definition of the macro-profile fields

Comparing the scientific profiles of the countries (that is, vectors made up of 103 numbers) is no easy task; some sort of aggregation of the subfields into a dozen or so major fields has to be done if we want to be able to interpret the figures. A common way to aggregate such vectors is to put together the subfields considered to belong to the same area of science in terms of the disciplinary categories (chemistry, physics, biology...); but each one of those fields would contain about 10 subfields which have no reason to have the same profile. Therefore the profile of the field, being an average of the profiles of the subfields, would mask the diversity of the sub-profiles. In other words we would lose all the information gathered at subfield level and end up at a high level of generality. As an alternative, we clustered the subfields which had a similar geographic profile. Those sets of subfields, called the "macro-profile fields" or simply "fields" enable us to simplify the interpretation of the scientific profiles while minimizing the amount of information loss in the process.

In practice, to determine the macro-profile fields we clustered the subfields from the PASCAL-profiles matrix, which gave us nine algorithmically-defined clusters. If at this point our macro-profile fields had consisted of unrelated subfields in terms of scientific disciplines, characterization of the macro-profiles would have been difficult. In fact, it appeared that with only minor modifications of the initial nine clusters to ease interpretation, we got 13 well-characterized macro-profile fields.

The ease of interpreting these groups suggests that subfields having the same geographic profile are also related in terms of scientific discipline. Thus, to the extent that discipline concentrations are shaped by a nation's economic system, national or macro patterns of scientific specialization can be interpreted in terms of science policy and

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the socio-economic objectives which underlie them. This leads us to the interpretation of each field:

—**Field I** is theoretical physics and chemistry, including controlled fusion.

—**Field II** is basic research in the life sciences (molecular biochemistry and genetics, molecular and cell basis of pharmacology, biotechnology).

—**Fields III to VI** are basic and applied research in areas such as new materials, solid-state physics, electronics, chemistry, computer and communication.

*Field III is physics of semi-conductors and components, analytic and electro-chemistry, catalysis, and the science of condensed matter.

*Field IV is materials science plus applied and organic chemistry.

*Field V is physics and technology of electronic components, integrated circuits, "group III-V" semiconductors and photochemistry.

*Field VI is computer science plus imaging technology.

—**Field VII** is research on technology and devices for applications such as water and pollution treatment, energy storage, civil engineering, and new materials, plus research on machine tools and their automation.

—**Field VIII** is earth sciences.

—**Field IX** is environmental sciences and space sciences.

—**Field X** is research on renewable resources: forestry, wood and wood pulp, biomass for nutrition and energy, fisheries, ecology and marine ecology.

—**Field XI** is agronomy in a broad sense, including food production and biotechnology applied to agriculture

—**Fields XII and XIII** are health sciences from pharmacetical products to medical technologies;

In summary, Field I is theoretical physics and chemistry; fields II to VI are the areas of strategic basic reseach, that is, fields with a clear potential, on a long time scale, for wide-ranging applications (communication technology, new materials and biotechnology); Field VII is about techniques and machines; Fields VIII and IX are earth, environmnental and space sciences; and Fields X to XIII are linked to various sectors of economic activity dealing with living matter, respectively renewable resources, agriculture and health.

Results

The results of the study—that is, the scientific profiles for the five countries in the 13 fields—are given in numerical and graphical form in Table 1 and Figure 1).

Overall comparison of the profiles

It is possible to define the distance between two profiles as the sum of the squares of the differences of their relative specialization indices over the 13 fields. Given such distances for all pairs of countries, it is possible to visualize their relative similarity with a "hierarchical tree" which embodies as well as possible all the distances among countries. (See Figure 2.) Clearly, the scientific profiles of Japan

Table 2
Fields of relative strength and weakness for the countries

	Important relative weakness	Relative weakness	Around the mean of the country	Relative strengh	Important relative strength
France		I, II, IV, V, IX XI	III, VI, VII, XIII	VIII, X	XII
FRG	XI	II, VIII, X, XIII	I, III, V, IX, XII		IV, VI, VII
UK		I, III	II, IV, V, VII, VIII, IX, X, XI	VI, XII, XIII	
USA		I, III, IV, VIII, X, XI	XII	V, VII, XIII	II, VI, IX
Japan	VIII, IX, X, XI, XII, XIII	VII	I, VI	II	III, IV, V

The numbers from I to XIII refer to the 13 macro-profile fields.
If A is the value of the macro-specialization index of a country on a field, then we have the following scheme:
$A \leq 70$: field of important relative weakness
$70 < A \leq 90$: field of relative weakness
$90 < A \leq 110$: field of around the mean position of the country
$110 < A \leq 130$: field of relative strength
$A \leq 130$: field of important relative strength

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and Germany are relatively similar, and very different from the three other countries; those three countries (U.S., U.K., and France), in turn, have very similar profiles, France and the U.K. being closest.

Let us now describe those similarities and differences more precisely. (See Table 2.)

The profiles of **Germany** and **Japan** show clearly-differentiated strengths and weaknesses, in other words clear-cut scientific priorities:

—Fields II, III, IV, V and VI (materials sciences, electronics, solid-state physics, chemistry), all parts of what we call strategic basic research, are never below the mean. In fact, four of them for Japan and two for Germany are indeed areas of important relative strength. (The third area of important relative strength for Germany—machine tools—might also be considered strategic.)

—Fields VIII, X, XI and XIII (earth sciences, renewable resources, agronomy, and part of the health sciences) are relatively weak.

—Fundamental research is around average. We note, however, that in the life sciences (Field II), another area of strategic research, Japan has a relative strength, while Germany exhibits a relative weakness.

—Japan shows an important relative weakness for Fields IX and XII (space and environmental sciences plus medical sciences, including pharmaceticals) while Germany is around its average for these.

France and the **United Kingdom** have much more homogeneous profiles, showing almost no important relative strengths nor weakness.

—Among the fields of strategic research (II to VI), none is above average, except field VI (computer science) for the U.K..

—Fields XII and XIII (health sciences) are the (rare) relative strengths.

—Fields VIII and X (earth sciences and renewable resources) are at average or just above.

—Fundamental research is a relative weakness, except for life sciences where the U.K. is at average.

—For France, Fields IX and XI (space and environmental sciences, plus agronomy) are areas of relative weakness.

Even though it is not very different from the profiles of France and the United Kingdom, the scientific profile of the **United States** shows some interesting particularities.

—Fields V and VI (electronics and computer science) are respectively areas of relative and important relative strength, showing here a focus even sharper than that of Japan and Germany. Fields III and IV (materials science, solid-state physics, chemistry) , unlike Japan and Germany, are areas of relative weakness for the U.S., as they are for France and the U.K..

—Field II (fundamental research in the life sciences) is an area of important relative strength. This is another sharp focus in a strategic research area, again sharper than Japan. (In Germany, Field II is an area of relative weakness.)

—Field IX (space and environemental sciences) is another area of important relative strength, all the more remarkable since the U.S. is the only country where this field stands above average.

—Fields XII and XIII (health sciences) are, as in France and the U.K., areas at or above average.

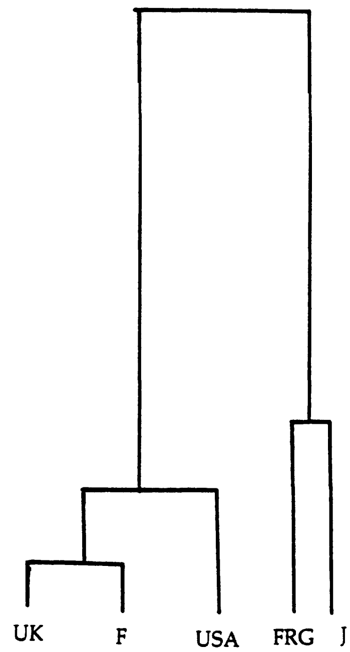

Figure 2. The distances of the scientific profiles of the five countries. The higher one must go to link two countries, the more different their scientific profiles are. UK = United Kingdom F = France FRG = West Germany J = Japan.

Comparing strengths and weaknesses in absolute terms

Using the same definition of the fields, we now compare the absolute weights (world shares) of each country. This amounts simply to calculating the percentage of total articles in the field produced in each country. This being done, we arbitrarily set the value for France at 100 for each field. (See Table 3 and Figure 3).

The United States compared to the other countries. The U.S. is dominant in all fields without exception; but the level of dominance varies widely from field to field.

—For Fields III and IV (material sciences, solid-state physics, chemistry), where Japan and Germany have a strength and the U.S. a weakness, the U.S. dominance is only between 2.0 and 2.2 , that is, the U.S. share is twice as great as Japan's and twice as great as Germany's (3.5 as much for Field III)

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—For Field V (electronics) the dominance is also only 2.2 with Japan, even though this is an area of relative U.S. strength. The reason is that the Japanese focus is much sharper here; European countries for which this is not a strength are dominated by factors of 6.0 to 7.5 times in this field by the U.S.

—For all other fields the U.S. dominance is at least by a factor of 3; it is particularly striking for Field II (fundamental research in life sciences) where dominance is by a factor of 5 to second-place Japan, even though it is an area of relative Japanese strength. For Field IX (space and environmental sciences), the U.S. dominance is by a factor of 5.6 to second-place U.K. The U.S. dominance is not as strong in the health sciences (around a factor of 4).

—Japan is in second place in Fields I to V, the U.K. for Fields VI, IX, XI and XIII, France for Fields VIII, X and XII and Germany for Fields IV and VII.

Europe as compared to the United States and Japan. An aggregation of the relative scientific specialization indices of the U.K., Germany and France gives an idea of where Europe would stand[9] as compared to the U.S. and Japan.

—Europe is dominant over Japan in all fields except Field V (electronics), where the shares are approximately equal. In Fields I to VII the dominance is moderate (a factor 3 to 4). In Fields VIII to XIII the dominance is stronger (factors greater than 5).

—Europe is never dominant over the U.S.; nevertheless, its scientific weight is similar to the U.S. in Fields III and IV (materials sciences), which are strategic research areas. It is also similar for Fields VII, VIII, X, XI and XII. On the contrary, the U.S. has dominance over Europe in Fields II, V, and VI (life sciences, electronics, information sciences) which are also strategic research areas, as well as in Field IX (space and environmental).

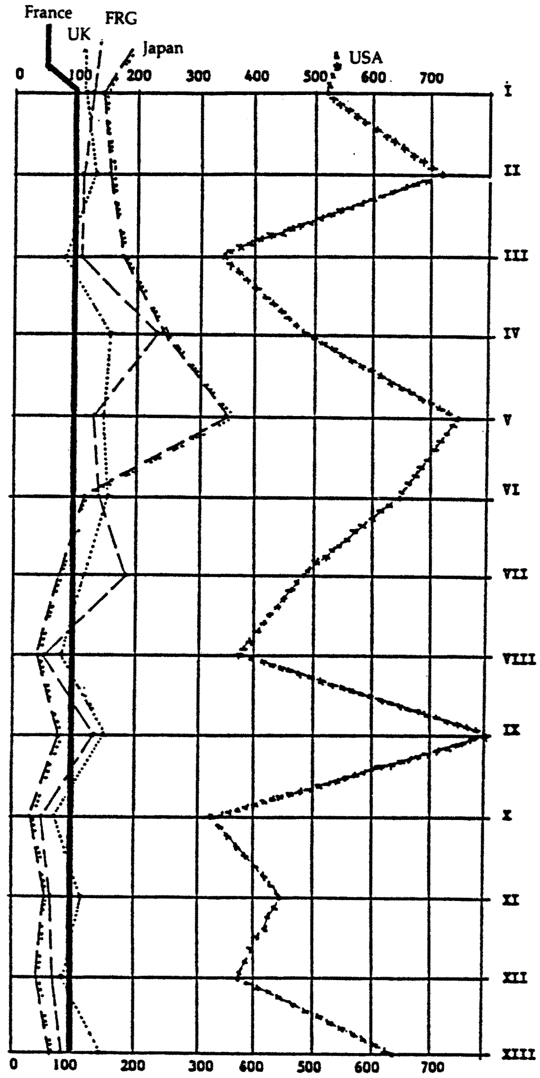

Figure 3. Absolute scientific weight of the five countries on the 13 macro-profile fields. By convention, the weight of France has been set at 100.

Summary of the results

Japan and Germany share a marked focus on all areas of strategic basic research. The only exception is biotechnology for Germany, but the German profile includes a focus on Field VII, which includes machine-tool automation and could also be labelled "strategic." Almost all other areas of science are below average for these two countries. (The exception is environmental and health sciences which are at average for Germany.)

The U.S. is focused on some of the strategic areas (biotechnology and computer science plus electronics) but below average on others (material sciences, chemistry). The U.S., however, is highly concentrated on environmental and space sciences, as well as health sciences and technologies.

France and the U.K. share a profile which shows little contrast among fields; furthermore the contrasts apparently have little to do with the concept of strategic basic research. On the contrary, France has no areas of strategic basic research above its average but three below; and the U.K. has only one above (computer science) and one below. The relative emphasis in both counties is in health sciences, as well as, for France, earth sciences and renewable resources.

The fields of relative strength for the U.S. are totally dominated by it (by a factor of 4 or more as compared to the next strongest country), with the exception of Field V (physics and technology of electronic components) where Japan is even more highly focused. In fields where the U.S. is not focused, while Japan and Germany are, dominance by the U.S. again is only by a factor of 2.0 to 2.5. This applies to several areas of strategic basic research.

Europe (as represented by its three major countries) has a scientific weight which is comparable to the U.S. in areas of strategic basic research such as materials sciences, chemistry, some aspects of electronics, machinery and machine tools. This holds true also for some aspects of the health sciences. In all fields European levels of effort are significantly above Japanese, sometimes by a wide margin

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Table 3:
Absolute Scientific Weight of the Countries on the Macro-profile Fields

	Field	F	FRG	UK	USA	JPN
I	Theoretical physics and chemistry	109	118	116	518	128
II	Life sciences, basic research	100	103	121	722	146
III	Semiconductors; analytic and electro-chemistry; catalysis; condensed matter	100	101	96	349	177
IV	Materials science plus applied and organic chemistry	100	223	156	498	221
V	Physics and technology of electronic components, integrated circuits, "Group III-V" semiconductors, photocmemistry	100	123	128	755	345
VI	Computer science and imaging technology	100	131	144	655	108
VII	Technology for pollution treatment, energy storage, civil engineering, plus machine tool research	100	192	116	489	83
VIII	Earth sciences	100	63	94	378	53
IX	Environmental sciences and space sciences	100	124	144	807	81
X	Renewable resources	100	61	84	310	35
XI	Agronomy, food production, biotechnology for agriculture	100	71	110	443	69
XII	Life sciences: health and drugs	100	74	93	376	45
XIII	Other applied life sciences	100	91	145	632	64
	Mean	100	100	100	100	100

(as in renewable resources, health, and earth sciences). The notable exception is electronics, where Japan and Europe are about equal.

Notes and References

1. For a more detailed definition of "strategic research" or "strategic basic research" see J. Irvine & B. Martin, *Foresight in science: picking the winners* (London: Frances Pinter, 1984), 1-13.

2. This leads to the concept of strategic management; see R. Barré, "Science and technology in France: from planning to strategy", *Futures*, April 1986, 298-308.

3. These indicators appear in *Science Indicators*, a biennial volume prepared for the National Science Board. The CHI-NSF data base, from which many of the bibliometric indicators in the volume are drawn, is prepared under contract at CHI, Inc.

4. This study was been done by R. Barré with J. P. Bordet from Applications Scientifiques Statistiques et Informatiques (ASSI) Company and D. Pelissier from Centre de Documentation Scientifique et Techniques (CDST) of the Centre National de la Recherche Scientifique (CNRS).

5. Law No. 85-1376, 23 December 1985, concerning research and technological development, Article 16.

6. In fact, the work was done with a total of 11 countries (the five already mentionned, plus Canada, The Netherlands, Sweden, Italy, India, and Australia); the clustering of the subfields discussed later in the article was done according to the profiles of those 11 countries and not on the five countries only.

7. These figures for world share of scientific articles per country are underestimates, since the articles which do not mention a country of origin (about 15%) are counted with "rest of the world." It is interesting to compare those figures with those published recently for 1982 by D. C. Smith, P. M. D. Collins, D. M. Hicks and S. Wyatt, "National performance in basic research," *Nature* 323 (1986), 681-684. They get the following results with the CHI-NSF data base: USA, 37.2%; UK, 8.3%; Japan, 7.3%; West Germany, 6.3%; France, 5.4%. It is to be noted first that the figures are comparable to those found with the PASCAL data base, and, second, that what could be interpreted as an overrepresentation of France in PASCAL has little importance for our study which deals with profiles and not with absolute levels (except in the last section).

8. The clustering was done with a hierarchical ascendant classification of the subfields using a CHI-square distance. The modifications of the clusters we introduced to ease interpretation are the following: 2 clusters have been split in two and one split in three; five subfields have been shifted from one cluster to another.

9. Germany, the U.K. and France together account for 80% of the total R&D spending of the 12 countries which belong to the European Economic Community.

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