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STRUCTURE OF INTERNATIONAL COLLABORATION IN SCIENCE - PART II: COMPARISONS OF PROFILES IN COUNTRIES USING A LINK INDICATOR*

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In this article, the behaviors of countries in scientific production activities are investigated using an asymmetrical matrix system to analyze data collected from the *Science Citation Index*. Examination of international collaboration, intercountry relationships, and domestic scientific output patterns structured by 98 countries in eight principal fields of science reveal diverse aspects of country behaviors. Three asymmetrical matrixes are established and the multidimentional Minimum Spanning Tree technique is applied to classify, visualize and determine the distinctive characteristics of country profiles. Investigations are conducted at both a macro (country behavior) and a micro (particular city behavior) level in order to demonstrate the applicability of the methodology and to obtain global observations of country behaviors. It is argued that these methods contribute to reveal traditions and policies of countries, universities and research organizations as well as that of the international network of scientific exchange. Further usage of these methodologies is advocated for policy analysis.

Introduction

This article is the extension of our series of scientific activity studies exploiting the asymmetrical matrix system. The methodology presented in our previous article related to international scientific collaboration is extended to practical applications.[1]

Conducting collaborative research and communicating its results is perpetuating a long scientific tradition. Modern science has always been linked to knowledge diffusion and to cooperation between specialists.[2] Nevertheless, as *Touscoz* has emphasized, even though international cooperation has developed in all areas of social activity, international scientific cooperation, whatever may be its forms or modes, is characterized by a specificity of purpose and the originality of its participants.[3]

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In the international network of scientific exchange, each partner country behaves differently, and such diversities in behavior are determined by numerous social, economic, political, and cultural factors. These include the priorities set by scientists and policy-makers to invest in one particular field rather than another, the strategies of individual scientists to pursue research through collaboration with one university rather than another, and the varying need to share costly facilities and equipment.

The scientific size of a participating country, when measured in terms of article performance, is one of the specificities of its behavior in the international community. Scientific sizes are a reflection of differences in economic strengths, scientific infrastructures, manpower, and educational systems. As a consequence, the size of the total national scientific activity of a country influences its capability to collaborate internationally. Quantitative comparisons of the domestic and international outputs of countries are significant measurements of levels of scientific strength and international activity. Such strengths and activities may be measured in one particular field or in all fields taken together. The measurements result in the ranking of countries, but do not reveal the *scientific characteristics of individual countries relative to different scientific disciplines.*

Other particular characteristic in the behaviors of a country is its preferences toward scientific disciplines in production and in international exchange. The distribution of activities into scientific disciplines in a country may indicate such specificity in field preferences. They can be determined by developing a method that "neutralizes" the influence of country size. One such method involves the classification of countries according to *profile* proximities through the use of an asymmetrical matrix. The distribution of scientific activity into eight large scientific disciplines determines the profile of each country and of the entire world. A basic principle is that *specific country behaviors can be revealed by comparing them with the behavior of the world profile.* Classification of countries according to profile proximities is made possible by the use of multidimentional classification techniques, such as the Correspondence Factorial Analysis and the Minimum Spanning Tree. These methods were applied to the international behaviors of countries in our earlier article.[4]

In the work of *Schubert, Glänzel* and *Braun*, which investigates comparisons between a given country and the rest of the world, a field's share relative to the world's output is considered a standard for the field.[5] The size of the share of a given field is related, country by country to the standard. *Bonitz, Bruckner* and *Scharnhorst* extended the principle and compared a country's science activities in all fields with corresponding activities of other countries.[6]

The present investigation focuses on the *profiles* in countries and of the world determined by the distribution of the major scientific disciplines. We extend the application of the methodology to analyses of (a) domestic production profiles in countries, (b) international collaboration profiles in countries, and (c) profiles of bi-country relationships. It thereby identifies distinctive features in science output and in international cooperation. Each country has its own profiles. The underlying assumption of the approach is that the different distributions of the fields in different countries reflect significant characteristics of country behaviors which stem from both explicit and implicit science policies. The differences between various patterns of domestic production and international cooperation may be quantified and compared.

Investigations are conducted at both a macro and a micro level in order to demonstrate the applicability of the methodologies. In the macro level analysis, three countries France, Japan, and Sweden are taken as examples of profile types. In the micro level analysis, the scientific behavior patterns of one particular French city, Strasbourg, are examined. By comparing the profile of Strasbourg to that of the whole of France, the scientific particularities of the city are identified. A micro level analysis helps demonstrate the role of the scientific units of one locality in the overall cooperation activities of the country of which it is a part.

Application of these methodologies should reveal the state of art of research organizations as viewed both from within the context of the countries in which they are situated, and from within the context of their relationships in international science. The data derived from this investigation should help bring about an understanding of the role of social and cultural traditions in forming science policies.

Materials and methods

The basic data in this paper are derived from the *Science Citation Index* (SCI) of the Institute for Scientific Information (ISI). We have used the fixed journal set composed by CHI Research, which covers over 3000 scientific journals in the 1981 collection of the ISI. The 1986 CD-ROM published by the ISI[7] has also been used. Only articles, notes, and reviews have been incorporated in our investigations. The data cover the period 1981–1986.[8]

For the purposes of our study, we have created the following two definitions:

(1) Throughout this article, *publications* which include affiliations of only one country are the "Domestic Scientific Publications" (DSPs) of the country. Publications by a single-author and those by several authors all having affiliations in the same country fall under this category. In the "World",[9] defined here as 98 countries, there were 2,114,561 Domestic Scientific Publications (DSPs) produced during the period 1981–1986.

We have not included international coauthorships i.e. publications having affiliations of two or more countries in the category of domestic science production. This is because we aim to analyze "purely domestic" publication patterns, those which are not affected by international supply and demand. As a result, in the present study the ranking of countries in order of domestic publication size differs from that indicated in the NSF classification which includes international coauthorships in its national production figures.[10] In the investigation of "purely domestic" publications, for example, the USSR ranks second, following the USA and leading the UK, for the period 1981–1986, whereas in the NSF classification the USSR ranks third, following the USA and the UK. This reversal stems from the fact that during the period under study internationalization was exceptionally low in the USSR but strong in the UK. For similar reasons, other reversals occur in rankings of West and East European countries.

(2) We have defined each *cooperative tie* established between any country and any other country participating in an international coauthorship as a "cooperative linkage" (LINK). There were 382,179 LINKs in the World during the period under study. The combined LINKs show scientific relationships between 98 countries in the matrix.[11] These world LINKs are therefore the sum of the total scientific linkages *emanating from each of the 98 countries* in the World as well as the sum of the linkages in all of the *bi-country relationships* in the 98 countries i.e. the sum of 9,506 country-country combinations (98 x 97).

All publications and LINKs have been classified into the following eight large fields of science: mathematics (MAT), physics (PHY), chemistry (CHM), engineering & technology (ENT), earth & space sciences (EAS), biology (BIO), biomedicine (BIM) and clinical medicine (CLI). The data thereby make up the *three asymmetrical matrixes* shown below: (1) the domestic scientific publication matrix, (2) the international collaboration linkage matrix, and (3) the bi-country relationship linkage matrix.

Table 1
Domestic scientific publication matrix.
98 countries, 8 scientific fields, 1981 – 1986

	Matrix 1								
	MAT %	PHY %	CHM %	ENT %	EAS %	BIO %	BIM %	CLI %	Total 100% (Nbr. of Pub.)
USA	2.6	10.5	8.4	7.7	5.6	10.1	17.6	37.5	(769555)
SUN	1.1	26.9	28.3	5.2	4.5	3.1	18.1	12.8	(177212)
GBR	1.9	9.2	10.6	6.9	4.3	10.6	16.2	40.3	(173101)
...									
...									
SLE	–	–	5.4	–	1.7	50.0	5.4	37.5	(56)
World	2.3	12.9	14.4	7.3	4.4	9.4	16.4	32.9	(2114577)

Each *row* in the matrixes of Table 1 and Table 2a reveals a country profile, i.e. the distribution into eight large scientific fields of the domestic publications (Table 1) or of the international collaboration linkages (Table 2a) emanating from each country. In Table 2b each row indicates the distribution into the eight fields of the linkages in each bi-country relationship. The last row in each matrix, indicating the total of the data in the matrix, reveals *the profile of the World*. This row, therefore, is used as a *reference*.

Each *column* of the matrixes indicates the specificities of the countries or of the bi-country relationships in *one of the eight large scientific disciplines*.

It must be stressed that the profile of the "World" is particular to each set of 98 countries or 9,506 bi-country combinations and to the eight fields in the matrix. Adding or omitting a single country could alter the structure of the World profiles. The Matrices 2 and 3 are "pair matrices" based on the same World linkage profile.

The methodologies can be summarized as follows:

Profile of the World:

$$w_1/T_w + w_2/T_w + w_3/T_w \ldots + w_8/T_w = 1$$

Profile of country *A**:

$$a_1/T_a + a_2/T_a + a_3/T_a \ldots + a_8/T_a = 1$$

* Country can be replaced by bi-country relationship.

where: T_w: Total number of publications* of the World,
$w_1, w_2, w_3 .... w_8$: Number of World publications in each of eight fields 1, 2, 3...8,
T_a: Total number of publications of country A,
$a_1, a_2, a_3 .... a_8$: Number of country A publications in each of eight fields 1, 2, 3,....8.

Table 2a
International collaboration linkage matrix.
98 countries x 8 scientific fields, 1981 – 1986 combined

					Matrix 2				
	MAT %	PHY %	CHM %	ENT %	EAS %	BIO %	BIM %	CLI %	Total 100% (Nbr. of Linkages)
USA	4.9	19.7	8.3	6.3	9.7	7.4	18.8	25.1	(84216)
SUN	1.5	38.9	17.9	3.3	9.7	3.3	17.3	8.2	(6685)
GBR	3.2	19.9	11.2	5.1	9.9	7.0	18.2	25.5	(36763)
...									
...									
SLE	–	–	15.0	–	–	25.0	5.0	55.0	(20)
World	3.6	23.4	10.8	5.3	8.4	7.4	16.9	24.2	(382179)

Table 2b
Bi-country relationship linkage matrix.
9,506 country-combinations, 8 scientific fields, 1981 – 1986

					Matrix 3				
	MAT %	PHY %	CHM %	ENT %	EAS %	BIO %	BIM %	CLI %	Total 100% (Nbr. of Linkages)
USAxSUN	2.1	33.0	8.2	4.6	18.9	4.9	19.7	8.6	(569)
USAxGBR	4.4	17.2	9.8	5.5	11.9	5.4	22.2	23.6	(10432)
USA									
...									
SLExUSA	–	–	16.7	–	–	16.7	–	66.6	(6)
SLExSUN	–	–	–	–	–	–	–	–	(0)
...									
World	3.6	23.4	10.8	5.3	8.4	7.4	16.9	24.2	(382179)

* Publications can be replaced by domestic publications, country cooperative linkages or bi-country relationship linkages.

Consequently, the comparison between the distribution of the fields in country *A* and the distribution of the fields in the World can be expressed as:

$$(a_1/T_a)/(w_1/T_w)\ ,\ (a_2/T_a)/(w_2/T_w),\ ...\ ,\ (a_8/T_a)/(w_8/T_w)$$

Analysis carried out with the asymmetrical matrix reveals the distinguishing features in overall science production activities in any country, as well as the comparative orientations toward any given field in different countries. It becomes possible to determine the fields in which a country is more or less active relative to the activities of the same fields in the World. This rationale brings about an understanding of country behaviors in function of field choices.

The greatest advantage of using an *asymmetrical matrix* is that elements of different nature, in this case "countries" and "fields", can be classified according to *countries* by fields and according to *fields* by countries. One thus obtains a double classification. When the matrix is applied to multi-dimentional Minimum Spanning Tree (MST) technique based on X^2, *diverse correlations can be extracted.* The technique generates a 2-Dimensional planar graph from the normalized 8-Dimensional data table that best describes the "nearest-neighbor relationships" among the 8 fields of all countries. To do this, the row data matrix is first converted into a symmetric semi-matrix of the X^2 distances separating each pair of countries. From this starting point, in which each of the *n* countries can be considered a group, a series of mergers are operated by single-link clustering that terminates with a single group constituted of all *n* countries arranged in a network. This network spans all items by a set of straight links joining pairs of points whose lengths are equal to the appropriate interpoint distances.

Correlations may thus be obtained between "countries and countries", between "fields and fields" as well as between "countries and fields". *The diversity and the all-inclusiveness of the information* distinguish analyses using an asymmetrical matrix from that using a symmetric semi-matrix (country/country matrix) alone.[12]

By using the matrix system and referring to the World models, it becomes possible to compare overall country patterns revealed by the distribution of all eight fields (rows). It is also possible to examine the variations in country specificities according to the patterns revealed in any particular field (columns). Any particular country, bi-country relationship, or field in the matrixes can thus be studied.

This method consequently makes it possible to compare the scientific behaviors of countries regardless of scientific sizes. Furthermore, the disproportional representation of journals in the various scientific fields is no longer a hindrance to investigation.

Results

In the following sections the scientific characteristics of countries revealed by means of the methodologies described above are indicated.

1. Macro level analysis : scientific behavior patterns in countries

Domestic scientific publication profiles

In Figure 1, the domestic publication profiles in the fields of clinical medicine and physics of the 36 largest producers of science are related to the World profile in the corresponding two fields.[13]

It can be seen that in clinical medicine most of the countries having higher proportional shares (>1) in clinical medicine than the World model are either situated geographically in Northern Europe or have been influenced historically or culturally by Great Britain. The Scandinavian countries have particularly high positions.

The histogram in physics is somewhat of a reversal to the clinical medicine pattern. It is clear that there are strong contrasts between different fields in the domestic scientific production behaviors of countries, particularly in clinical medicine and physics.

The pattern formed by ranking the EC countries in order of decreasing share sizes in clinical medicine is shown in Fig. 2. The contrasts between patterns of countries in clinical medicine and physics out of the totality of the Domestic Scientific Publications (DSPs) in each country show that there is a North-South geographical correlation. In the ranking of countries according to field preferences, there is an evident order and there are large variances in the sizes of the shares. In Denmark, clinical medicine makes up 59% of the DSPs, whereas in Spain the corresponding percentage is only 20%. Inversely, physics makes up 12% of the DSPs in Spain and only 7% of the domestic production in Denmark. Italy is the only exception to the North-South geographical correlation, as it is positioned between Northern EC countries in the middle of the alignment.

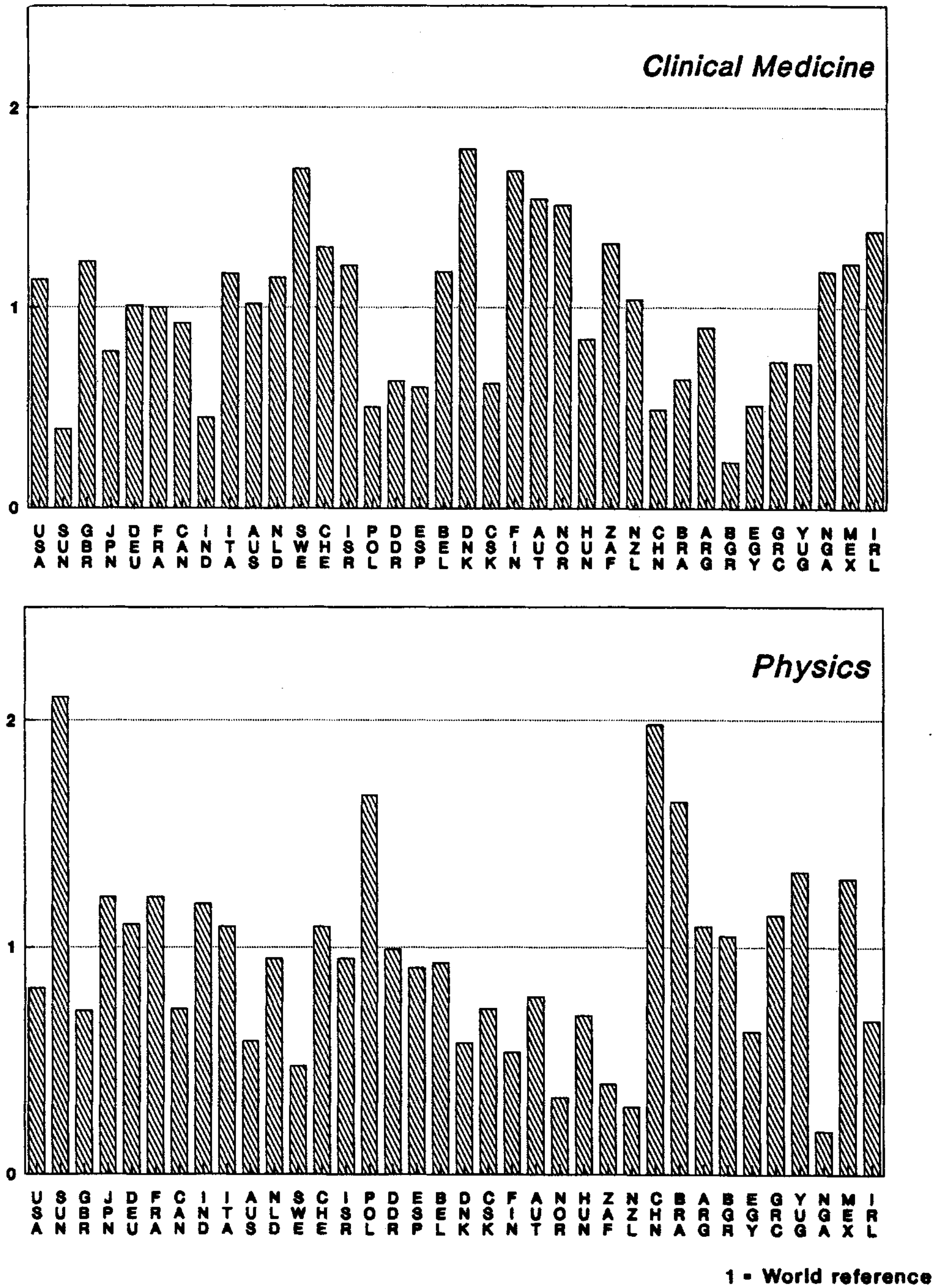

Fig. 1. Comparisons with World in weight of Clinical Medicine and Physics. Domestic Scientific Publications, 1981–86

Figure 2 also manifests the long standing traditional attachments to fundamental physics in European "non-Protestant Latin" countries such as France, Italy and Portugal.[14]

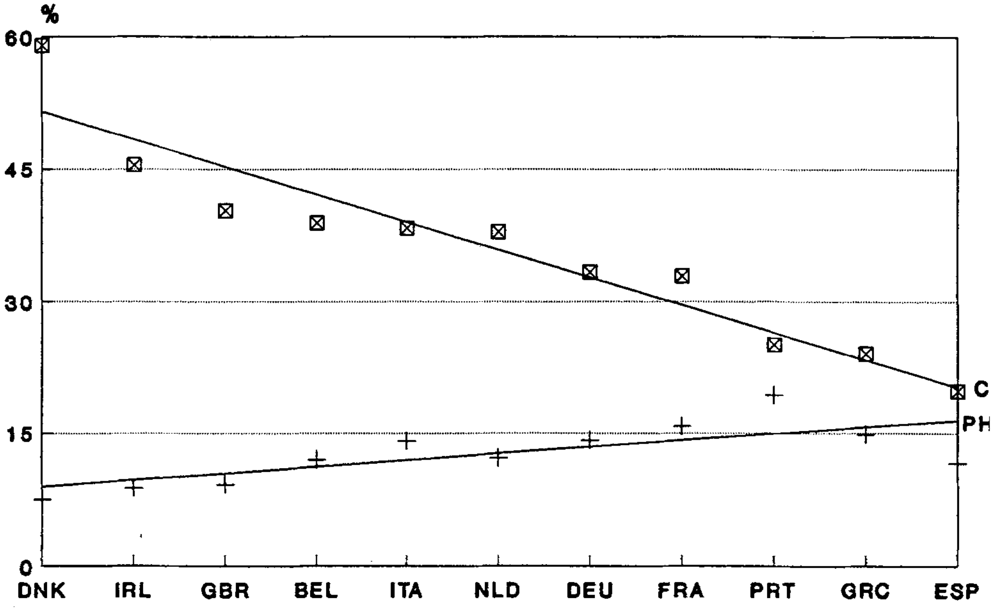

Fig. 2. Proportions of Clinical Medicine and Physics in the EC countries, 1981 – 1986

Proximities in country profiles: The Minimum Spanning Tree technique

In Figure 3 the profiles of the 36 largest producers of domestic scientific publications are structured by means of the Minimum Spanning Tree (MST) technique. Country profiles in domestic publication are situated graphically, according to their relative similarities to each other. Profiles vary least between a country and its neighbor on the Tree.[15] Figure 3 thus provides an overview of the relative "proximities" in the profiles of these countries.

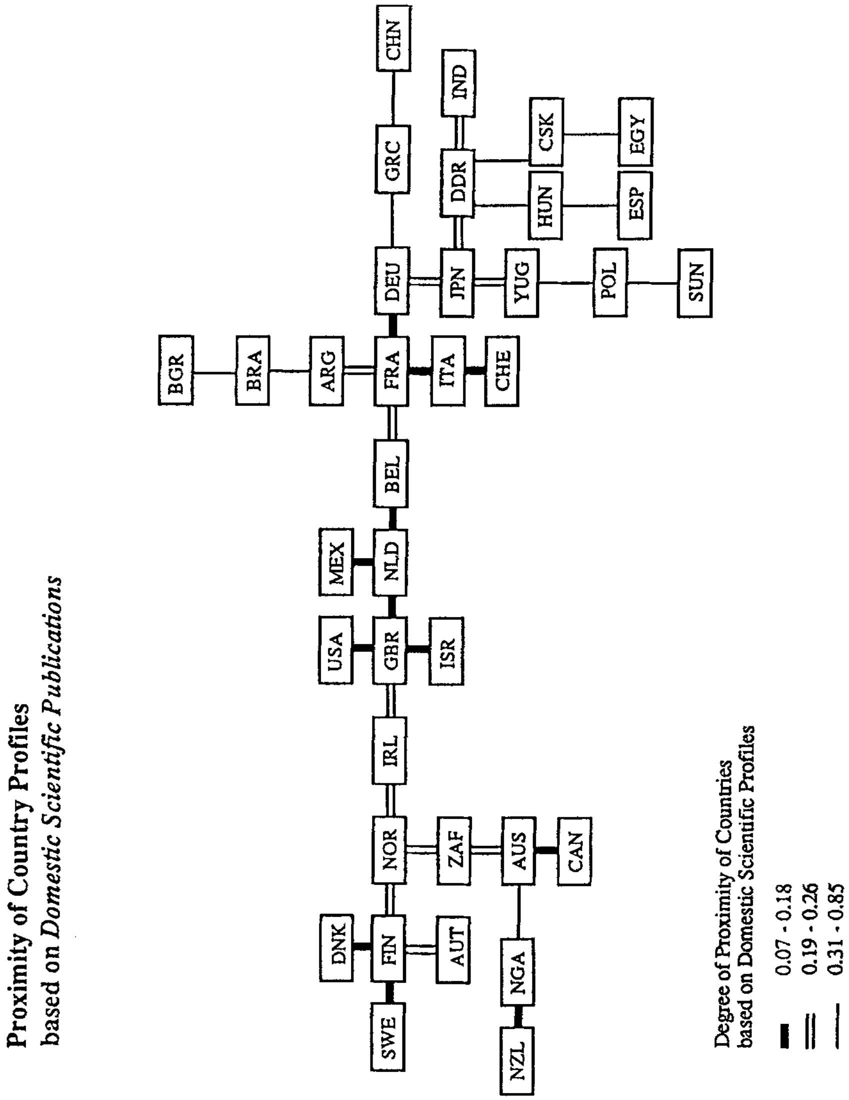

Fig. 3. Minimum Spanning Tree. The first 36 producers of science, 1981 – 1986

It can be seen on the Tree that the profiles of the East European countries contrast with those of North European countries. The history of twentieth century science has resulted in creating profiles in East European countries which are more similar to those of other countries of continental Europe than to those of the United Kingdom or Scandinavia. East European countries produce high proportions of the physical sciences, physics and chemistry, and low proportions of life sciences. Such orientations often reflect efforts linked to industrialization and large investments in disciplines which could contribute to rapid economic growth. Orientations toward the physical sciences are also characteristic of countries which have been isolated from world contacts for political or cultural reasons, such as Spain and Japan. Long-dated field priorities persist in modern science.

In countries which have been culturally influenced by Great Britain, such as the USA, Canada, Australia, South Africa, Nigeria, and New Zealand, there are strong contrasts between "old" and "new" countries. Australia, Canada, Nigeria and New Zealand are markedly different from the United Kingdom, having research propensities more strongly oriented toward basic and applied biology than to the medical sciences. For example, biological research makes up 17.6% of the total Canadian domestic production, which is 1.9 times the World reference in the field (x1.9). The strong investment in science in these countries is not particularly bound to British traditions, but is notably devoted to the development of natural resources, agriculture, and biotechnologies.

In Latin American countries such as Brazil and Argentina, the trend toward physics, remarkably similar to European "Latin" countries, demonstrates the power of cultural traditions in the choice of investments.[16] These preferences sometimes result in a neglect of the needs for engineers and engineering research for economic development.

On the Minimum Spanning Tree Japan is situated in the midst of continental and East European countries, reflecting the century-old nature of this country. The scientific and technological infrastructures of Japan were influenced by European countries, and Japanese science policy priorities were set on industrialization.[17, 18] It is especially interesting to see that Japan is situated between West (DEU) and East (DDR) Germany on the Tree. The profile of Japan is closest to that of West Germany (proximity of 0.23). Similarities in the general cultural trends in Japan and in the two Germanies, have been perceived and analyzed by many scientists.[19, 20] The graph confirms the hypothesis that the culture of a country, which includes the ways of thinking and the choices in research orientations of its scientists, has an obvious effect on science behavior patterns. The fact that Japan is situated between the two Germanies on the Tree demonstrates that country profiles indeed reflect the preferences and policies of a country and also confirms the power of the Minimum Spanning Tree technique in revealing overall trends.

In comparison to other industrialized countries, the patterns in Japan are still unstable in the world of mainstream science.[21] Large endeavors were performed in the medical sciences during the 1980s, resulting in alterations of the profile of Japan during the period 1981–1986. The changing pattern of Japan appears even more when observed over ten-year intervals. In 1973, Japanese efforts focused strongly on the physical sciences. Over 45% of the Japanese-authored papers appearing in the SCI for that year were in either physics or chemistry.[22] Ten years later, the proportion in these fields had dropped to 35%, whereas for the same years the World percentages of the same fields decreased by only 1.8%.[23]

Domestic and International Scientific Activities in France and Sweden

The Scientific Activities of France. Profile analysis also indicate the scientific characteristics of specific countries. Figure 4 shows the domestic production profile of France related to the World profile.

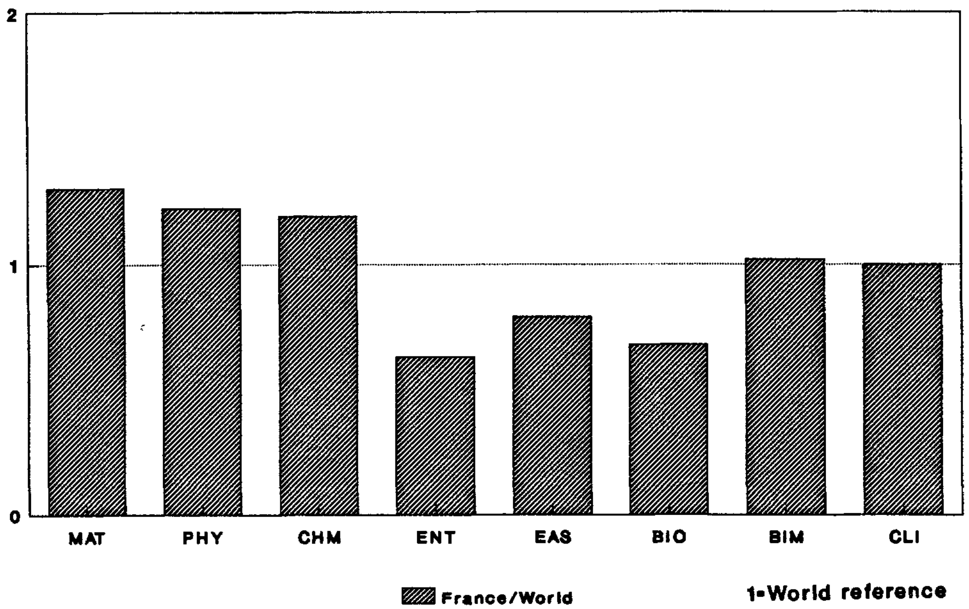

Fig. 4. Comparison of profiles between France and World. Domestic Scientific Publications, 1981–86

In French publication the differences in the field distributions is above the World reference in mathematics (x1.3), in physics (x1.2) and in chemistry (x1.2) and below the World reference in engineering & technology (x0.6), in fundamental and applied biology (x0.7). The differences with the World are small which is a characteristic of scientifically developed countries.[24]

Let us first consider the fields having "lower" positions (< 1) relative to the World reference, engineering & technology and biology. In the case of France, these disciplines also correspond to the "weaker" fields of scientific activity when measured in terms of World production shares. The *citation impact* of scientific papers from France grew constantly from 1981 to 1990 in engineering, technology, and applied sciences as well as in agriculture, biology, and environmental sciences.[25, 26] In spite of the growing French impact in quality, the volume of productivity and the numbers of students and engineers trained in these disciplines through research remained relatively low. Engineering schools have comparatively small research laboratories and limited international programs. In industry, developmental research remains concentrated within a few spheres and a few groups of activities. Furthermore, cooperation between university and industrial science, public and private, is still new compared to other free-trade industrialized countries.

It may also be worthwhile to analyze the situation concerning publication in biology, both fundamental and applied, related to animal, vegetable, and agro-nutritional production, and leading to the development of the agricultural and food industries. Agriculture is more and more conditioned by biotechnologies (production and transformation), and the sciences associated with such subjects do not seem to have received priority in France in the years under analysis.

It can be seen in Fig. 4 that physics, with mathematics, is by far the most preference field in France. Physics is also a very internationalized discipline. The international site for large scale instruments in this field stimulates international cooperation and brings together scientists from around the world. Investments certainly bear on the scientific budget of a host nation. Nonetheless, providing international scientific facilities does not necessarily seem to produce a negative effect on the economy of a country.[27]

The pattern of France remained relatively stable over the entire period under study. The stability may have been due to the persisting disproportion between the numbers of French scientists going abroad and of foreign researchers coming to France.[28] Even today, for every French scientist abroad there are more than five foreign researchers from industrialized countries in France. The amounts spent on

French research abroad have consequently been inferior to the expenditures for foreign researchers in France. Moreover, statistical data at the CNRS indicate that the only relative equality in the numbers of French scientists in a foreign country and of foreign scientists from the same country in France is in exchanges between France and the USA.[29] Considering the strength of the USA in science and the usual attraction of this country to foreign researchers, this equality confirms the low rate of French scientists going abroad. If French science attempted to stimulate its weaker fields by adhering them to excellence abroad, some changes would most likely appear in the balance of the fields after a period of several years. Even non-interventionist government policies which encourage a free market of scientific enterprise may allow for readjustments in the balance between fields, especially where there are urgent needs to develop new industries or specific areas of research.

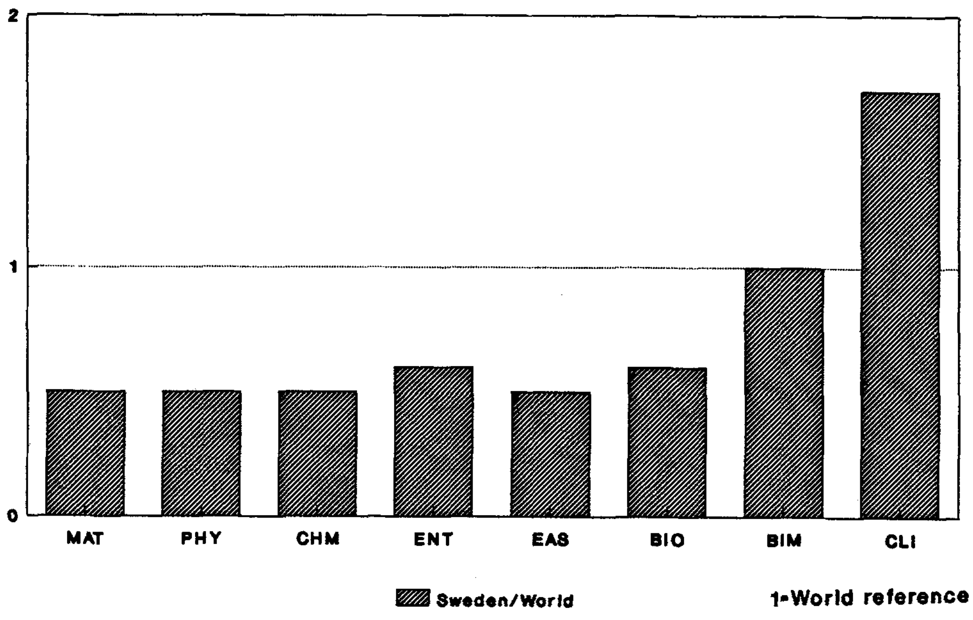

Fig. 5. Comparison of profiles between Sweden and World. Domestic Scientific Publications, 1981–86

The Scientific Activities of Sweden.

Figure 5 shows the domestic production profile of Sweden and compares it to the World reference. The high propensity toward clinical research in this country is one of the most conspicuous features in the 98-country matrix, not only in domestic research (x1.7), but in international activities (x1.7) as well. The considerable weight of clinical medicine results in the "lower" positions (<1) of all the other fields as compared to the World. Swedish leanings toward this discipline may be a manifestation of traditional cultural preferences.[30-32]

Swedish science contains an important "correcting factor", its policy of providing opportunities for young Swedish scientists to spend long periods of time abroad. Furthermore, Sweden has traditionally been aware, on an informal basis, of research undertaken in other countries. The Nobel Foundation has kept abreast of discussions, congresses, and scientific journals in order to discover creative and structured research. This Foundation has always kept data on the state of art of all fields and the development of new areas. As a result, Sweden has developed a tradition of analyzing science in the world, and notably, of inviting foreign scientists to meetings and of sending its own scientists abroad. Moreover, scientists in Sweden have maintained their decision-making powers in research. At present, in the Swedish Research Councils only the administrative work is left to a small number of individuals and the evaluation committees allocate the funds to laboratories.

In spite of the awareness of international science, there is a strong "unbalance" in favor of the medical fields in Sweden. Investment in state health care in Sweden, which is higher than in most other industrialized countries parallels the strong priorities given to clinical medicine in this country.[33]

International Scientific Activities in Japan. Comparing country profiles to a World model may contribute to an understanding of the various aspects of international cooperative research in a specific country. The profile of Japan is taken as an example for investigation.

Table 3
Comparisons of profiles between Japan and World.
Domestic scientific publications and international collaboration, 1981 – 1986

	MAT	PHY	CHM	ENT	EAS	BIO	BIM	CLI
Japan/World in Domestic Scientific Publications:								
	0.7	1.2	1.5	1.4	0.4	0.9	0.9	0.8
Japan/World in International Collaboration:								
	0.8	0.8	1.1	1.5	0.7	1.1	1.2	1.0

The field preferences of Japan in relation to the World references in domestic scientific publications and in international collaboration are presented in Table 3.

It has been demonstrated above that domestic scientific production in Japan is oriented toward the physical sciences. Table 3 clearly confirms that the domestic orientations of Japan are in chemistry (x1.5), engineering & technology (x1.4), and physics (x1.2). The variance is large between the fields as figures range from x1.5 to x0.4. Domestic publication is relatively weak in the medical sciences and in mathematics. In comparison to the World profile, the earth & space sciences appear to be particularly disadvantaged in Japanese production (x0.4).

The international collaboration profile of Japan contrasts with its domestic profile. The distribution of the fields is more balanced in international research, as figures only range from x1.5 to x0.7. Moreover, domestic production positions are reversed in international collaboration in several of the fields. All the life science fields, below 1 in domestic production, indicates above 1 in the international profile. Physics, inversely, switches from >1 to <1, being x0.8 the World reference in international research. In spite of the high Japanese domestic productivity of this field as compared to the World share, physics was only the fourth internationalized field in Japan. Only 7.2% of the entire scientific production in physics in Japan was issued from international collaborative projects.[34] This situation is strikingly different in countries such as France or West Germany, where nearly one third of the productivity in physics stems from international collaborative works.[35]

Examination of Japan's science production behavior reveals the relative weaknesses of Japanese domestic productivity, in relation to overall scientific strengths, as well as the nature of Japanese participation in international cooperation.

Engineering & technology and, to a lesser extent chemistry, priviledged fields in domestic production, remained so in international research, due, in part, to the Japanese excellence in these disciplines. In international research, the numbers of collaborative works and of collaborative partners grew in both of these fields. Japan reinforced strong scientific ties with non-industrialized countries, most particularly with other Asian and Pacific nations, which resulted in growing numbers of coauthorships.[36]

This movement toward the exterior parallelled, in 1978, the inauguration by the Japanese government of special bilateral exchange programs designed to develop scientific cooperation between Japan and Southeast Asian countries.[37] By 1989, the numbers of scientists from other Asian and Pacific countries going to Japan and of Japanese scientists going to these countries had increased considerably.[38] The mobility of researchers toward Japan and the change in Japanese "cultural homogeneity" provoked by the sudden increase of Asian students and researchers in

Japanese university laboratories is eloquently expressed in *Science*.[39] In addition to benefitting geographical proximities, Asian researchers seem to have the advantage of being able to acquire the Japanese language more easily than scientists from non-Asian countries.[40] Language and geographical isolation may have remained major barriers to the full participation of Japan in the international scientific community, but these obstacles between Japanese and other Asian researchers are not nearly as large as those between Japanese and Western researchers.[41]

The bi-country relationships created by collaborative links in scientific research

The relationship between any two given countries created by scientific cooperative links may be investigated. The distribution into fields of all the LINKs between the two countries are related to the World LINK model, and the differences in the balances of fields are perceived.

Table 4a
Country profiles.
The bi-country relationships Japan-Sweden and France-Japan,
1981 - 1986

	MAT	PHY	CHM	ENT	EAS	BIO	BIM	CLI	
World reference based on cooperative links:									
	3.6	23.1	10.8	5.3	8.4	7.4	16.9	24.2	100%
Cooperative linkage profile of the Japan-Sweden relationship compared to the World reference:									
	–	0.6	1.0	0.8	0.1	0.6	1.5	1.6	
Collaboration linkage profile of Japan compared to the World reference:									
	0.8	0.8	1.1	1.5	0.7	1.1	1.2	1.0	
Collaboration linkage profile of Sweden compared to the World reference:									
	0.3	0.8	0.6	0.5	0.6	0.5	1.3	1.7	
Cooperative linkage profile of the France-Japan relationship compared to the World reference:									
	2.1	1.3	1.2	0.6	0.9	0.8	1.2	0.6	
Collaboration linkage profile of Japan compared to the World reference:									
	0.8	0.8	1.1	1.5	0.7	1.1	1.2	1.0	
Collaboration linkage profile of France compared to the World reference:									
	0.9	1.3	1.2	0.6	1.0	0.7	1.0	0.8	

Table 4a indicates the cooperative linkage profile of the specific bi-country relationship Japan-Sweden as compared to the World reference based on cooperative links. The Table also presents the overall collaboration profiles of Japan and of Sweden in terms of cooperative links. The exceptionally high orientation toward clinical medicine in the Swedish international collaboration pattern (x1.7) is particularly apparent and is manifested, although to a smaller degree, in the Japan-Sweden relationship (x1.6). The cooperative efforts between Japan and Sweden, however, show levels of activity in biomedicine (x1.5), chemistry (x1.0), and engineering & technology (x0.8) which are higher than in the overall Swedish collaboration pattern with the World in the same fields (x1.3, x0.6, and x0.5, respectively). Seen from a Japanese point of view, the Japan-Sweden relationship is clearly oriented toward biomedicine (x1.5) and clinical medicine (x1.6), as these weights are significantly higher than in overall Japanese research with the World in the same fields (x1.2 and x1.0, respectively).[42, 43]

Table 4a demonstrates a considerably different collaborative pattern between the France-Japan relationship and in the Japan-Sweden relationship. In the profile of the cooperation Japan maintains with France, the strong weights of mathematics (x2.1 the World reference), physics (x1.3 the World reference), and chemistry (x1.2 the World reference) can be seen. The importance of French mathematics, physics, and chemistry to Japan becomes apparent in comparing these weights to the weights of the same three fields in the overall Japanese collaborative profile with the World (x0.8, x0.8, and x1.1, respectively). From a French point of view, the France-Japan relationship is predominantly oriented toward mathematics (x2.1 in the relationship but only x0.9 in the overall collaboration profile of France), and secondarily toward biomedicine (x1.2 in the relationship but x1.0 in the French overall collaborative profile).

The profile of a collaborative relationship between two countries can, therefore, be compared to the overall international collaboration patterns of each one of the countries with the World and can also be compared to other collaborative relationship patterns. The interpretation of field preferences in the relationship can be clarified by examining the weights of the fields in the overall collaboration of each one of the countries with the World.

Another mode of relationship-analysis can be carried out by observing the bi-country relationship behaviors in *one particular field* and comparing them to the levels of activity of the field in different countries.

Table 4b
Comparisons with World in weight of chemistry in bi-country relationships, 1981 – 1986

Partner	Comparison with the world			Number of Links		
Countries	FRA	JPN	SWE	FRA	JPN	SWE
USA	0.8	0.9	0.4	563	591	131
GBR	1.2	1.3	0.4	316	110	47
JPN	1.2	–	1.0	74	–	20
DEU	0.8	1.2	0.6	247	141	53
FRA	–	1.2	1.0	–	74	68
CAN	1.2	1.2	0.5	221	86	14
IND	1.2	3.4	0.4	24	95	4
ITA	1.3	0.7	0.9	253	11	42
AUS	0.9	0.7	2.2	32	14	36
NLD	0.7	1.0	0.3	64	20	11
SWE	1.0	1.0	–	68	20	–
CHN	0.7	1.7	1.6	15	51	11
Comparison between the world and Country Profiles	FRA/WRD 1.2	JPN/WRD 1.1	SWE/WRD 0.6			
Weight of chemistry in the world		10.8%				

Table 4b shows the relationships which each of the countries France, Japan, and Sweden maintained with other nations in research in chemistry during the period under study. The relative weight of each bi-country relationship in this field can thus be seen. The number of cooperative LINKs in chemistry between two countries, expressed as a percentage of the total number of LINKs between the two countries in all fields, is compared to the World model in which the balance of the fields of LINKs in chemistry is 10.8%.

In France, high levels of cooperation in chemistry can be observed with the U.S.A. (563 LINKs), Great Britain (316 LINKs), Italy (253 LINKs), West Germany (247 LINKs) and Canada (221 LINKs). In absolute numbers France conducted three times as much collaboration with Canada (221 LINKs) than it did with Japan (74 LINKs). However, related to the World model, the difference in the weights of chemistry in the France-Canada and the France-Japan relationships are identical (x1.2). The indicator reveals comparative degrees of propensity toward a given field in the relationships France maintained with partner countries within the context of total cooperation in the same field in the World.

The cooperative linkage profile of chemistry in Japan related to the World reference of 10.8% shows a difference in the balance of the fields of x1.1. It can be seen that chemistry in the India-Japan relationship is a particularly dominating feature (x3.4) and well above the overall chemistry in Japan of x1.1. Comparisons of bi-country relationship profiles, therefore, has revealed the specificity of chemistry in India-Japan collaboration relative to both the overall Japanese pattern and to the World pattern.

A remarkable result seen in Table 4b is the high propensity for chemistry in the relationship between Sweden and Australia, with an indication of x2.2 above the World model. The predominance of this field in Australia-Sweden research is even more striking as, in chemistry, Sweden and Australia each produce overall cooperative linkage profiles below the World model (x0.6 and x0.9, respectively).

2. Micro level analysis: The international activities of the city of Strasbourg

In the following section an approach to examining the activities of the research units of a particular locality is presented. A micro level analysis of the characteristics of the international scientific activities of the French city of Strasbourg is taken as a prototype. In micro level analysis, the "model" or "reference" can be a single country, in this case France, rather than the World of 98 countries. The profile under study can be that of a single locality, in this case Strasbourg, rather than that of an entire country.

Relationships between research units in Strasbourg and research units in 45 partner countries (out of 97 countries) were identified by means of affiliations in the SCI CD-ROM. The cooperation patterns were observed in order to determine the behavior of the city in international science. By comparing the collaborative linkage pattern of Strasbourg to that of the whole of France, scientific particularities of the city were revealed. This type of analysis helps demonstrate the role of the scientific units of one locality in the total context of the country of which it is a part. At the same time, it provides complementary information contributing to the understanding of the mechanisms of the behavior of a country in international science.

Strasbourg registered 1,180 publications (articles, notes and reviews) in the CD-ROM Science Citation Index in 1986, which represented approximately 5% of the total scientific production of France in that year. 28% of the publications were the output of collaboration with other French research units and 27.5% were produced through bi-national (22.2%) and multi-national (5.3%) collaborative projects. Only 7 projects involved more than five countries. The internationalization rate in Strasbourg was higher than in overall France (21.0%) in 1986. A comparison of the profiles of Strasbourg and of France is shown in Table 5.

Table 5

Comparison of international profiles between France and Strasbourg, 1986

Cooperative links between Strasbourg and 97 countries

	MAT	PHY	CHM	ENT	EAS	BIO	BIM	CLI	Total
USA		16	12	3	3	3	34	4	75
DEU		26	2	1	2	2	23	7	63
GBR	1	9	8		1	4	17	2	42
ITA	1	11	10			2	8	6	38
CAN		1	3			1	6		11
CHE		17			2	2	14	5	40
BEL	1	7	3			1	4		16
ESP	1	10	10			1	4		26
NLD		3	2				5		10
SWE		6	1				5	2	14
...	...	...	...	...	...	...	...	...	...
OTH					1		3	1	5
No. of Links	4	158	57	11	20	21	142	28	441
Profile of Strasbourg (a)	0.9	35.8	12.9	2.5	4.5	4.8	32.2	6.4	100%
Profile of France (b)	2.7	30.7	11.8	3.2	8.3	4.3	18.0	21.0	100%
Comparison of Profiles (a/b)	0.3	1.2	1.1	0.8	0.5	1.1	1.8	0.3	

Source: SCI CD-ROM 1986 (articles, notes, and reviews).

As can be seen, there is a proportionally large share of collaborative linkages in physics in Strasbourg (35.8%), and in the whole of France (30.7%). The weight of physics in the international relationships of Strasbourg is therefore slightly above the analogous weight in overall France (x1.2). The importance of this field in Strasbourg is a normal consequence of the large facilities related to physical research located in the city. The participation of Strasbourg in projects conducted at CERN is another factor contributing to this propensity. CERN represents 23% of the output of international co-authored articles in physics in Strasbourg and the city alone accounts for 20% of the French participation at the Center.[44]

The exceptionally high proportion of international activities in Strasbourg devoted to biomedical research (32.2%) is another particularly outstanding feature. The weight of biomedical international cooperation in Strasbourg, x1.8 the overall French reference (18.0%), demonstrates the significant role of Strasbourg biomedicine in France. This international cooperation is due to the activities of several specialized laboratories of international reknown (genetic engineering and molecular biology, cellular molecular biology, and neurobiology, among others) and to two industrial institutions (Transgene and Merrell-Dow).

The weight of international research in clinical medicine in Strasbourg (6.4%), in contrast to biomedical research, is particularly low when related either to the overall international activities of the city or to clinical medicine in the whole of France.

Comparing the profiles of France and Strasbourg results in a clear perception of the contribution of a city to its nation, and the same process may be applied to any other particular mass in science. Establishing a matrix and deriving a "reference" make it possible to define particular units in a fixed sphere. The cognitive structures of the international activities of research units may be correlated to the function of the overall activities of a country.

As in the macro-analysis, the data in the micro-analysis have been derived from only three types of publications: articles, notes, and reviews. However, more than 12% of the international coauthorships of Strasbourg were "meeting abstracts", all of these in biomedicine or clinical medicine. Such a high level of activity in medical fields may, if included, result in a different structure in the overall balance between fields in Strasbourg and possibly in France and of the World. If other micro-level analyses of cities are to be conducted, it might be advisable to consider the inclusion of less formal publications such as meeting abstracts, letters, and discussions, which often reveal essential international contacts between scientists.

Conclusion

Further to our previous article on the comprehensive treatment of a matrix of 98 countries in eight large scientific disciplines, we have presented ways of perceiving and comparing the science production behaviors of countries. World models have been determined to serve as references and behavior profiles of countries have been compared to the models. Weights of each of the eight large fields relative to the world models have thereby been determined in specific countries. Science behavior patterns in a French city have been examined in order to demonstrate the application of the methodologies to micro-level analysis.

Application of the methodologies should be able to create a better understanding of the science policies of any country. Domestic and international activity patterns indicate the orientations of a country in terms of internal efforts and of policies and strategies in international research. The methodologies may be applied to measurements of the domestic publication and international collaboration patterns of any country, to specific bi-country relationship patterns, and either to large-scale or to local situations. An investigation of patterns should contribute to an awareness of deliberate and undeliberate traditions, strategies, and priorities, determined in any particular laboratory, university, locality, or nation participating in mainstream science.

Further investigations could take the form of analyses of the international activities between specific research units through the use of measures for quantitative volumes, affinities, and equilibria between fields. Cross-references between the scientific behavior patterns of the "World", specific countries, and specific bi-country, bi-university, or bi-laboratory relationships may nurture discussions on the choices of subjects and the adequacies of local policies or cooperation agreements.

Preferences for particular fields do not arise or alter drastically overnight and country profiles take form over long periods of time. Patterns emerge from diverse influences, including the cultural, social, and political aspects of a country, traditional ways of thinking, the motivations of researchers, and the choices of research methodologies. A reequilibrium between fields is often desirable in a country but not at the expense of its scientific traditions and excellencies. Restructuring involves the training of scientists and adaptations in budgetary distributions. New forms of training and new programs, therefore, reflect changes. The restructuring factor of international cooperation can also reduce gaps between fields. In particular, the "weaker" discipline of a country can be strengthened by sending researchers in such fields to the most advanced specialized laboratories in the world. Nevertheless, it is only after long periods that changes become visible.

It remains to be seen whether internationalization in science will lead to homogeneity in profiles, or whether, on the contrary, the role of complementarity in cooperative work will accentuate country differences.

The NSF/Carpenter field classification and its extension to the SCI CD-ROM have been vital to our investigations. However, in order to fully develop and exploit the methodologies, it will be necessary to standardize the correlations between journals and fields and to determine the classification of articles from multidisciplinary journals. For such purposes, it is crucial to establish agreements between scientists from different countries. Such cooperation is left to the future.

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