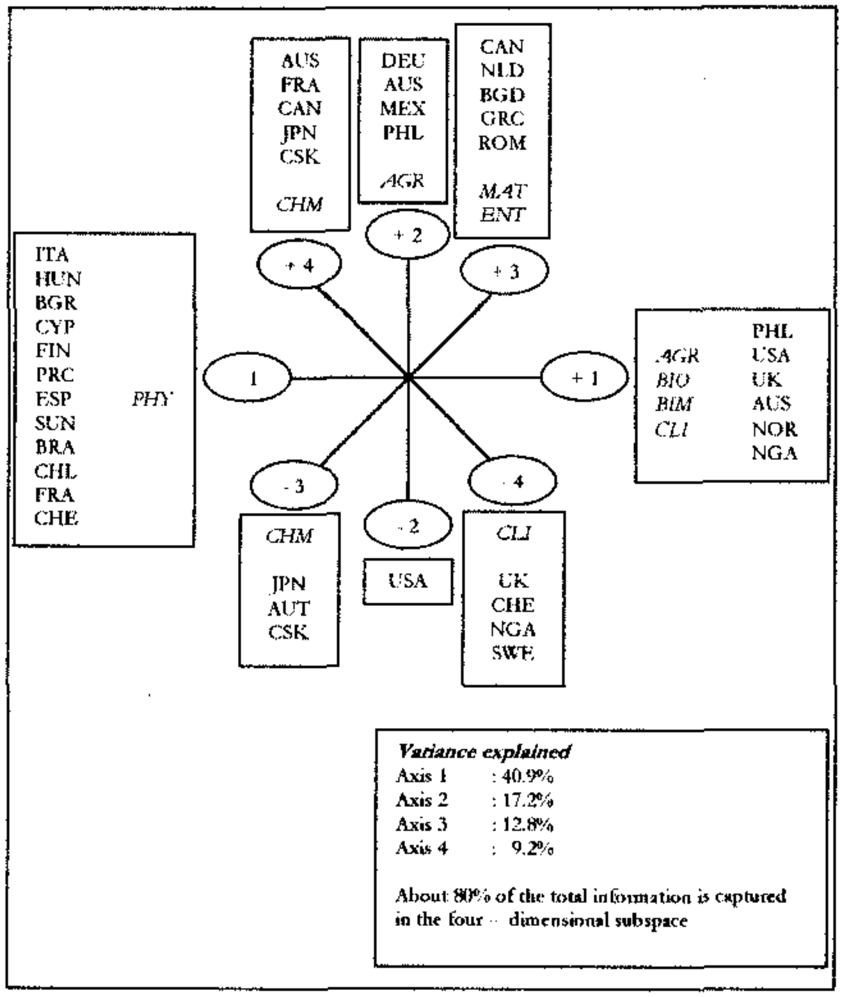
Science beyond Institutional Boundaries

Mapping of Transnational Linkages of Indian Science



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Preface

International cooperation is playing a far greater role in scientific research today than ever in the past. The volume of international cooperation is growing much faster than the production of scientific knowledge. This means that the domestic framework of science is no longer dissociable from the external elements which condition it. As a result, international cooperation in science has become one of the major and recurrent themes of national science policy. In this context, the following issues are of crucial importance.

1. What is India's status in the global network of science?
2. What is the role of international cooperation in India's research output in different fields and subfields of science and which are its significant partners?

This study, sponsored by the National Information System for Science and Technology (NISSAT), Department of Scientific and Industrial Research (research grant # NI/SS/068/94) addresses these issues. A number of quantitative indicators, based on coauthorship links of research papers, have been constructed and used in the analysis. The analysis is carried out at two levels - macrofields and subfields. State of the art statistical techniques and computer software have been used in the analysis. Major findings of the study are reported in the *Executive Summary*.

Several colleagues at National Institute of Science, Technology and Development Studies (NISTADS) have helped me in different phases of the study, right from conceptualization through data collection and analysis, up to the final processing of the manuscript. I am indebted to Shri Sujit Bhatacharya for downloading of the data from *SCI* CD - ROMs and experimenting with the transformation of the downloaded data into a usable database, using the *CDS - ISIS* software. However this experiment had to be aborted due to technical and logistic reasons. I am particularly grateful to Ms. Lalita Sharma who collected the data on dyadic linkages among 45 countries for six years: 1982 - 1984 and 1992 - 1994. She also provided valuable help in data analysis and graphics for the first six chapters of the report. I am also grateful to Ms. Madhu Sheopuri for data analysis, graphics and preparation of manuscript through several drafts.

I am particularly indebted to Dr. Ashok Jain, Director, NISTADS and his colleagues for intellectual, moral and infrastructural support, without which this study could not have been undertaken.

Finally, I wish to express my gratitude to Dr. A. Lahiri, Adviser and Ms. Kamini Mishra, Principal Scientific Officer, Department of Scientific and Industrial Research for their active support and encouragement.

(P.S. Nagpaul)
Principal Investigator
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CONTENTS

0 Executive Summary

This study examines:

(i.) The patterns of research output and transnational cooperation links of Indian science in different fields and subfields during the five – year period: 1990 – 1994.

(ii.) India's status in the global network of science and the changes that have occurred in the ten – year interval between 1982 – 1984 and 1992 – 1994.

1. Methodology

Indicators of Cooperations

Scientific cooperation is measured by coauthorships of articles, which signify a formal acknowledgement of joint research. International coauthorship is defined in terms of articles cosigned by authors located in different countries, irrespective of their nationalities. If an article is cosigned by six authors, one in India, two in Japan and three in France, it counts as one internationally coauthored article (*ICOA*) and three transnational cooperation links (*COP*): (1) between India and Japan; (2) between India and France; and (3) between Japan and France. From these two basic indicators (*ICOA* and *COP*), we have constructed the following four indices for inter – field and inter – country comparisons of transnational cooperation:

(i.) Internationalization Index (*INI*)

(ii.) *Transnational Cooperation Index (COP)* (iii.) Cooperation Extensiveness Index (*CEI*)

(iv.) Affinity Index (*AFI*)

These indices are defined in Figure 1.

Data

(i.) Downloaded from CD - ROM version of *Science Citation Index* for five indexing years 1990 – 1994. Further processed for 'cleaning' and classification of articles into 125 subfields and 11 macrofields: *Mathematics*, *Physics*, *Chemistry*, *Biology*, *Earth & Atmospheric Sciences*, *Food & Agriculture Research*, *Clinical Medicine*, *Biomedical Research*, *Engineering & Technology*, *Computer Science* and *Materials Science*.

(ii.) Dyadic searches for cooperation links among 45 major countries from CD – ROMs for indexing years 1992 – 1994 and 1982 – 1984.

We have used ISO trilateral codes to identify the countries (Appendix 1) and abbreviations to identify the subfields / fields (Appendix 2).

Analyses

Levels: Macrofields, Subfields. Macrolevel analysis provides an overview of the topology of India's cooperation links; subfields – level analysis indicates its fine – grained structure.

Statistical Techniques: Correspondence Analysis; Network Analysis.

Graphics: Component bar charts; sunray plots; two - dimensional factorial maps, depicting the relationships between India's major partners and their preferred fields (subfields) of cooperation; *Infographic Maps* summarizing the results of Correspondence Analysis.

2. Global Network of Science

International cooperation is playing a far greater role today in the generation of scientific knowledge than in the past. The volume of international cooperation is growing faster than research output (i.e. output of articles).

Internationalization Index (*INI*)

This index measures the output of internationally coauthored articles in a given field or country compared to that of all articles (*ICOA* + non *ICOA*) in that given field (or country).

$$INI = \frac{\text{Number of internationally coauthored articles}}{\text{Number of all articles}} \times 100$$

Cooperation Index (*COI*)

This index measures the incidence of cooperation links in a given field compared to the publication output in that field.

$$COI = \frac{\text{Number of cooperation links}}{\text{Number of all articles}} \times 100$$

Cooperation Extensiveness Index (*CEI*)

This index measures the incidence of cooperation links in a field compared to the output of internationally coauthored articles in that field.

$$CEI = \frac{\text{Number of cooperation links}}{\text{Number of internationally coauthored articles}} \times 100$$

If the value of *CEI* is close to 1, it means that all the internationally coauthored articles are based on bilateral cooperation. If the value of $CEI > 1$, it means greater incidence of multilateral cooperation.

Affinity Index (*AFI*)

Affinity Index (*AFI*) is a measure of the amount of collaboration between a given country *A* and another country *B* compared to the total collaboration of the given country *A* with the entire world (*WRD*) in a given field of science during a given period of time. *AFI* is therefore the number of links between *A* and *B* divided by the total links *A* has with the rest of the world (*WRD*) in a given field and during a given period of time. It indicates the scientific affinity of *A* toward *B* ($A \rightarrow B$).

$$AFI\,(\mathrm{A}\rightarrow\mathrm{B}) = \frac{COP\,(\mathrm{A}\leftrightarrow\mathrm{B})}{OP\,(\mathrm{A}\leftrightarrow\mathrm{WRD})} \times 100$$

Affinity index can be used to find how *B* situates in *A*'s international activity with the world and *vice versa*.

Fig. 1: Indicators of transnational cooperation

	1982 - 1984	*1992 - 1994*	*Annual growth rate*
Articles	1,598,479	2,069,460	2.6%
Cooperation links	213,782	615,422	11.1%

India had almost zero growth rate in the output of articles and less than (world) average growth rate in transnational cooperation.

In 1982 – 1984, India had accounted for 1.19% of all transnational cooperation links in the world; *in 1992 – 1994, it accounted for 0.93% of all transnational cooperation links.* Some other countries, for example, China, Korea, Taiwan, Japan and Spain had very steep growth rates, both in research output and transnational cooperation links.

Growth Rates in Publication Output and Cooperation Links of Selected Countries

Country	*Publication Output*	*Links*
IND	-0.4%	8.9%
PRC	11.4%	17.0%
JPN	4.6%	13.6%
CAN	3.0%	9.4%
FRA	3.5%	11.7%
AUS	2.8%	9.6%
ESP	12.7%	17.6%
KOR	22.0%	23.2%
TWN	21.5%	17.5%
SGP	15.4%	20.8%
USA	1.8%	9.5%
UKD	3.3%	9.1%
World	*2.6%*	11.1%

India's status in the global network of science may be visualized from the networks presented in Figures 2 and 3. In these networks, the arcs between the nodes indicate links above a certain threshold (*Jaccard index* > .010).

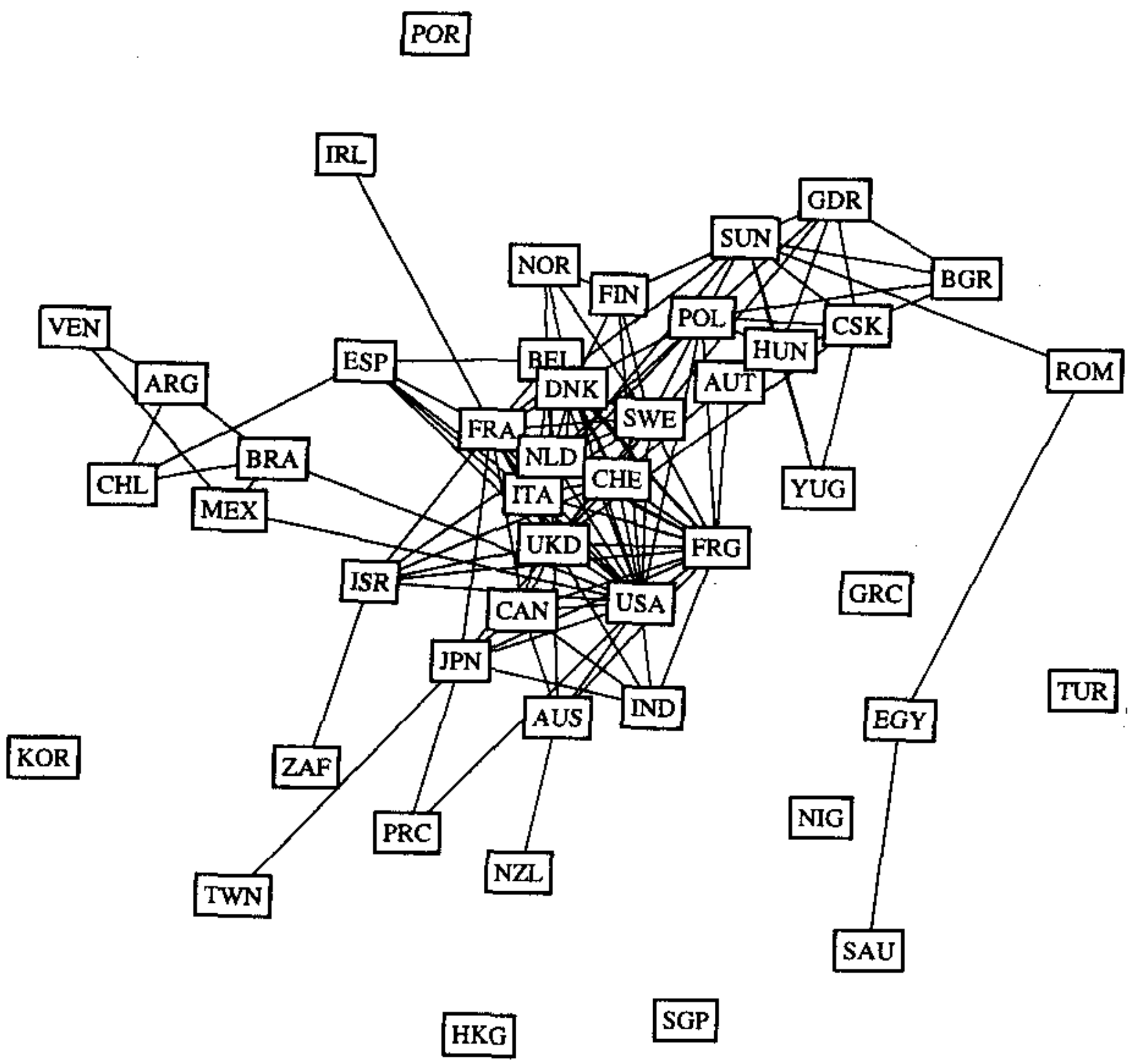


Fig. 2: Network of transnational cooperation in science (1982 – 1984)

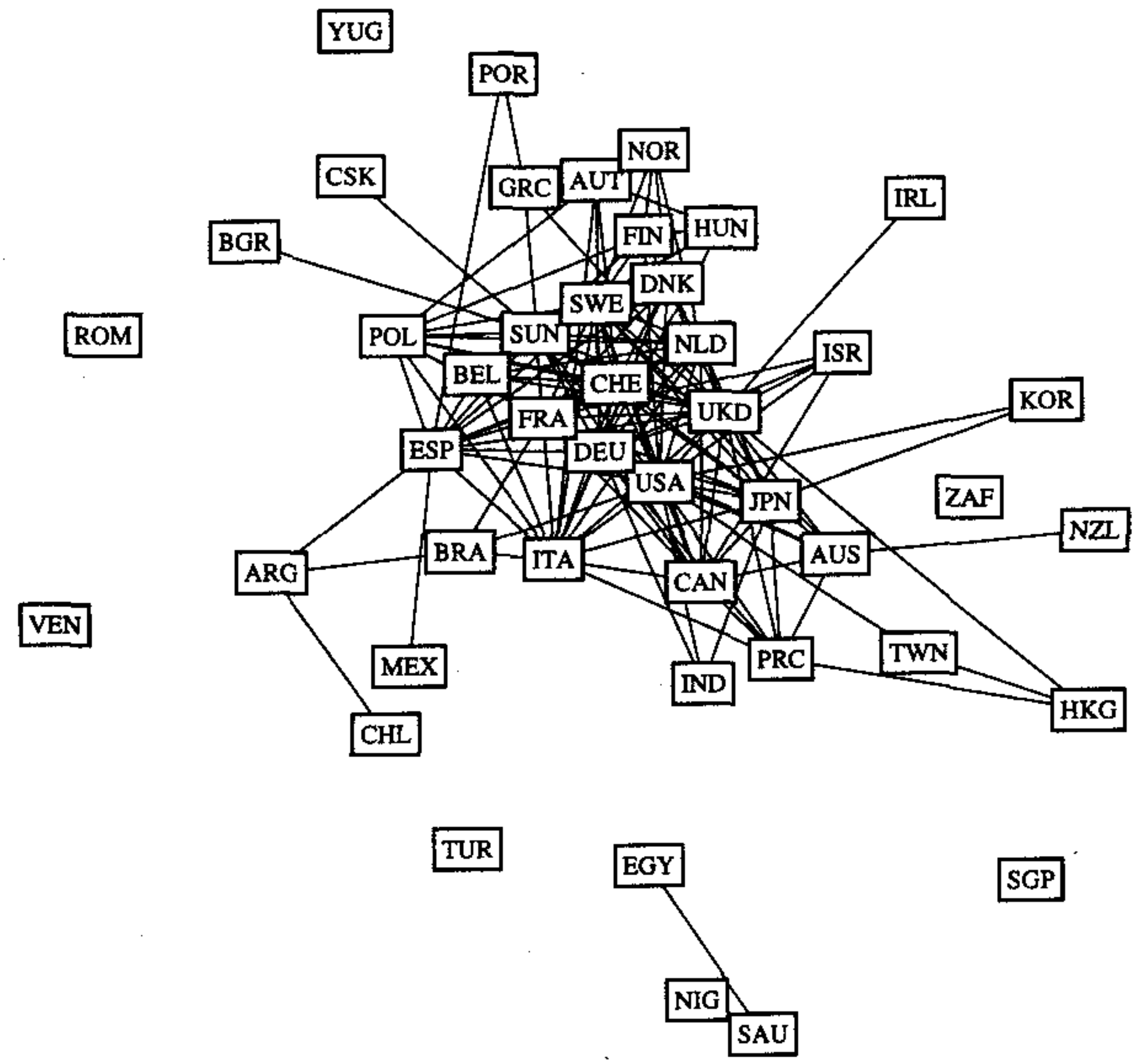


Fig. 3: Network of transnational cooperation in science (1992 – 1994)

In 1982 – 1984, India had strong links with USA, UK, Germany, Canada and Japan.

In 1992 – 1994, India had strong links with USA, Germany and Japan.

There is a restructuring of India's links during the ten – year interval between 1982 – 1984 and 1992 – 1994. While there was attenuation of links with UK and Canada, there was strengthening of links with some other countries, which were still below the threshold.

India's affinities towards its twenty significant partners may be visualized from Figure 4.

We have computed a graph – theoretic measure *'Eigenvector Centrality'* to assess the relative position of different countries in the global network of science. We have also computed the ' *Network Centralization Index*' to assess the degree of centralization of the entire network. Major trends are:

1. The network centralization index is very high for both networks, implying that the networks are dominated by a few countries, which occupy central positions in the network, while a large number of countries are at the periphery. However, the network centralization index has decreased over time (1982 – 1984: 91.5%; 1992 – 1994: 85.7%), which implies a reduction in the dominance of some 'central' countries.
2. None of the countries – nor even USA – has centrality close to 1, which implies that no single country dominates the network. It is rather a cartel of a few countries which dominate the network.
3. The centralities of scientifically large countries have decreased between 1982 – 1984 and 1992 – 1994. On the other hand, the centralities of Japan and Russia have increased considerably during this period, implying that these countries were playing a greater role in the international network of science in 1992 – 1994 than ten years earlier.
4. The centrality of India has slightly declined, but this is due to the decrease in its affinities towards certain central countries and increase in its affinities towards some peripheral countries.

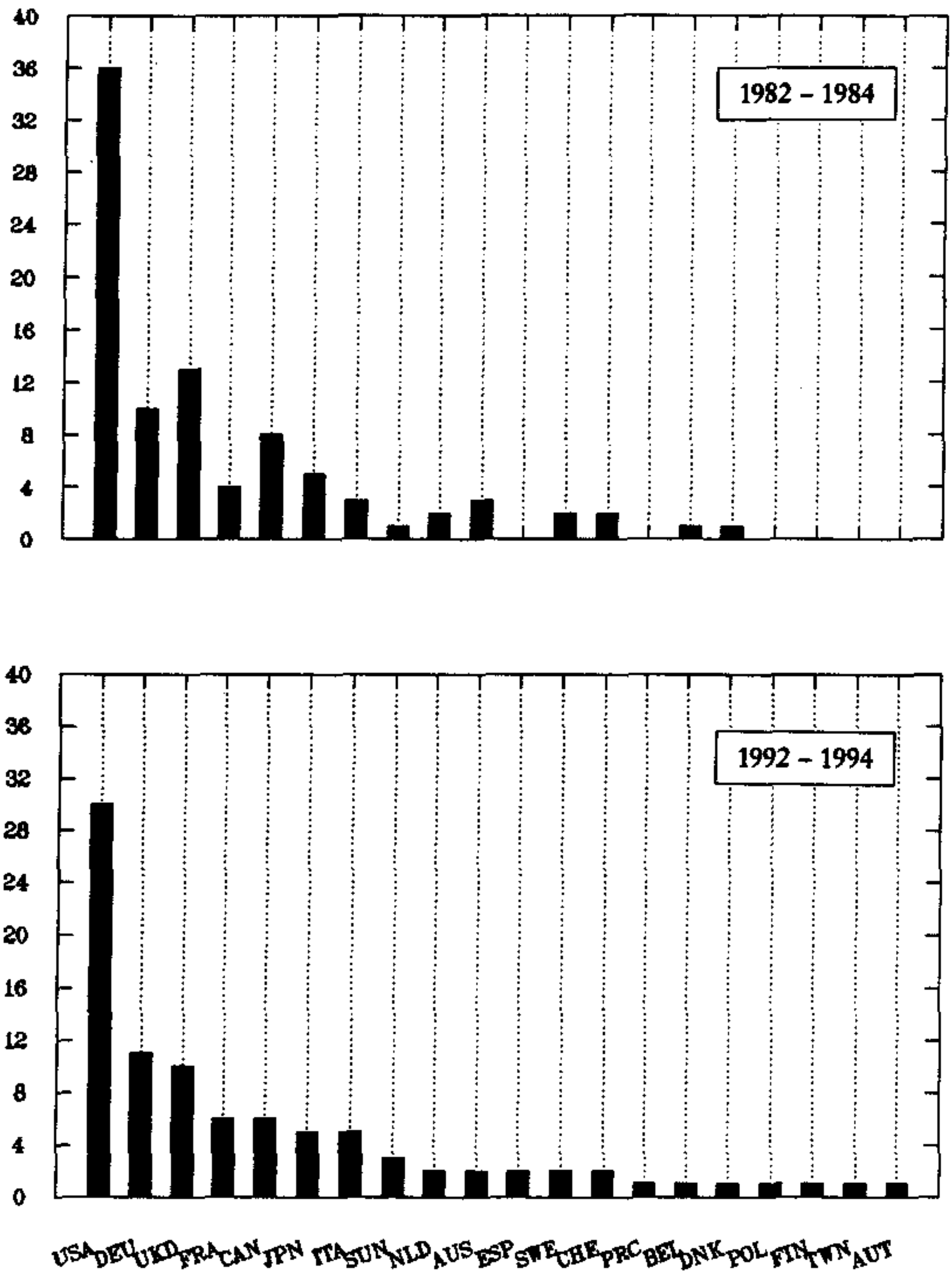


Fig. 4: India's affinities towards its major partners

5. The centrality of China has increased by a factor of 1.5 during this period. This increase is accompanied by restructuring of its linkages – decrease in its affinities towards USA, UK and France and increase in its affinities towards Germany, Japan and Italy.

3. Transnational Cooperation Links in Macrofields

India had published 52482 articles (*Articles*, *Reviews*, *Notes* and *Letters*) in the *SCI* – covered journals in five indexing years: 1990 – 1994. Of these, 6487 articles are internationally coauthored, indicating a total of 8503 cooperation links, spanning over 105 countries. This means that one out of eight articles is internationally coauthored, and one internationally coauthored article involves 1.31 cooperation links, indicating the extent of multilateral cooperation.

The distribution of cooperation links among India's partners is highly skewed. The top eleven countries – USA, UK, Germany, Canada, France, Japan, Italy, Russia, Australia, Switzerland and Netherlands account for about 79% of all cooperation links; the remaining 94 countries account for only 21% of all cooperation links. The variations in India's affinities towards its top eleven partner countries may be visualized from Figure 5.

India's important Asian partners are:

Country	*No. of Cooperation Links (COP)*
Japan	442
China	108
Bangladesh	60
Korea	41
Philippines	36
Taiwan	28
Thailand	24
Malaysia	22

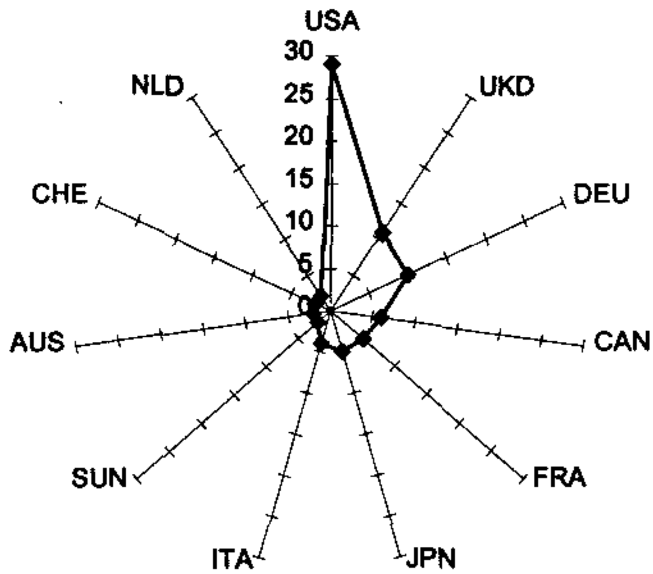


Fig. 5 : India's linkages in science (aggregated over all fields) (1990-1994)
(Affinity Index)

Inter - Field Differences in Cooperation Links

Mathematics is the most internationalized field. On the average, approximately every fourth article is internationally coauthored, followed by *Computer Science*; in this field, every fifth article is internationally coauthored. However, it is *Physics* that has the greatest attraction for international cooperation - 28.6 cooperation links per 100 articles. *Chemistry* is the least internationalized field. Only 7% articles are internationally coauthored. Moreover, cooperation in this field is bilateral. In *Earth & Atmospheric Sciences*, on the average, one out of six articles is internationally coauthored. Moreover this field has a tendency towards multilateral cooperation; on the average, there are 1.24 links per internationally coauthored article.

Transnational cooperation in *Clinical Medicine* and *Biomedical Research* is less frequent (below average for *Clinical Medicine* and slightly above average for *Biomedical Research*), but when it takes place, it tends to be multilateral.

Engineering & Technology has less than average level of transnational cooperation, which is by and large bilateral.

The eleven macrofields can be classified into four typology groups on the basis of cooperation links.

Typology of Transnational Cooperation

Frequency of Cooperation	*Nature of Cooperation*: *Multilateral*	*Nature of Cooperation*: *Bilateral*
Frequent	Type 1 PHY EAS	Type 2 MAT COM
Infrequent	Type 3 CLI BIM	Type 4 CHM BIO AGR ENT MTS

Inter - Country Differences in Cooperation

There are important differences among the countries in their choice of fields for cooperation with India. These variations can be visualized along two dimensions — inter - field differences in a given country and inter - country differences in a given field.

Inter - field differences in major countries may be visualized from Figure 6.

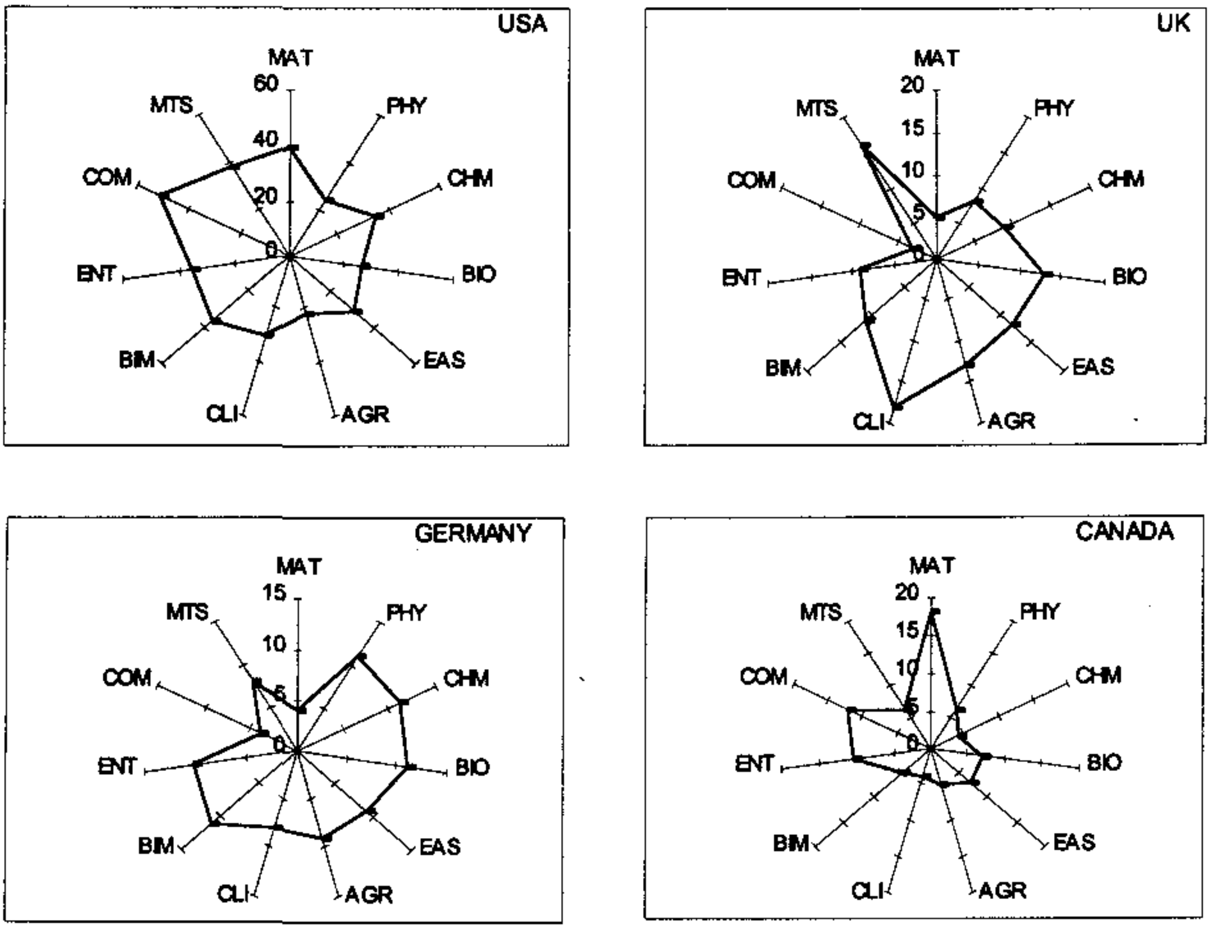


Fig. 6: India's affinities towards major cooperating countries in different fields of science (1990-1994)
(Affinity Index)

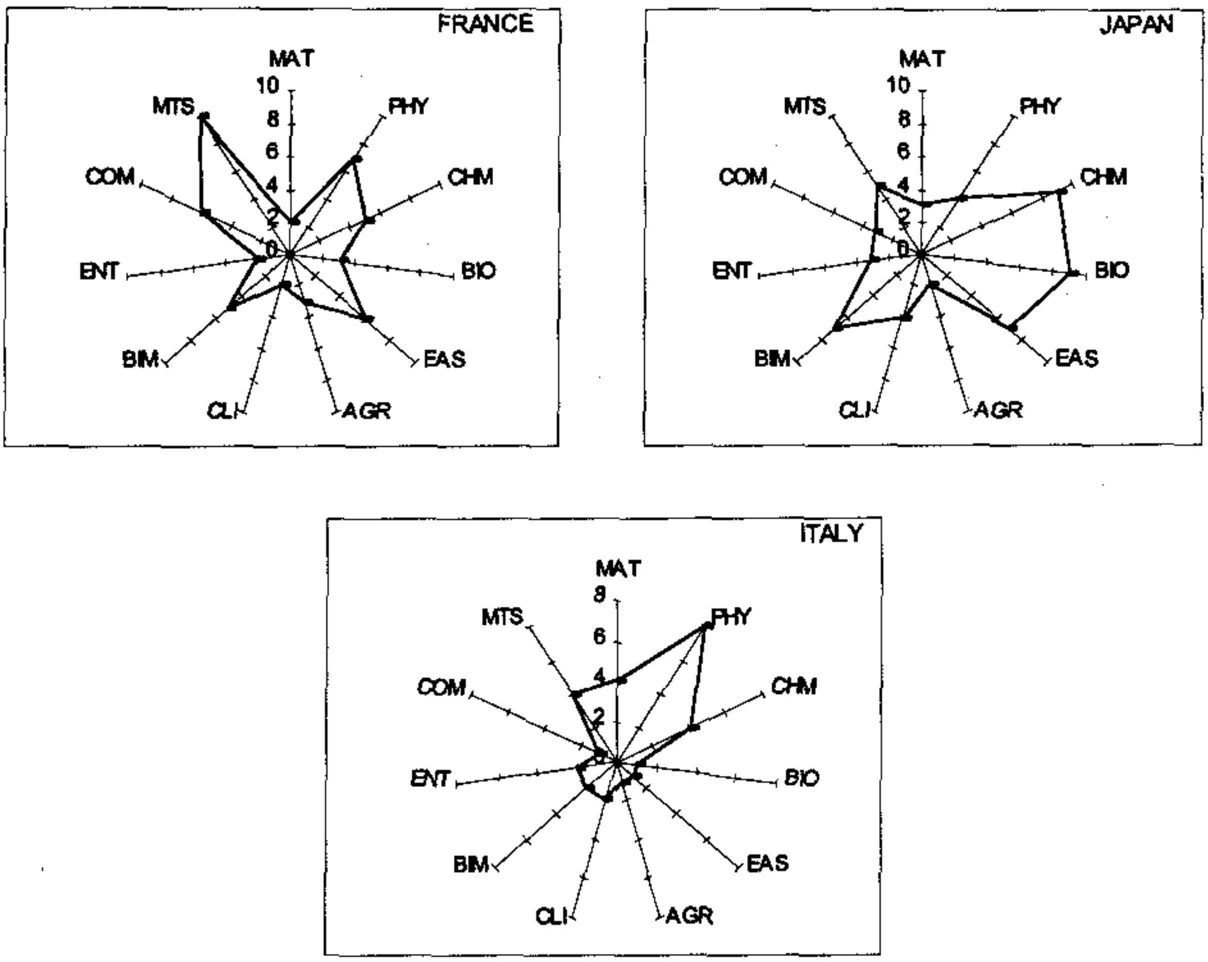


Fig. 6 (Contd.): India's affinities towards major cooperating countries in different fields of science (1990-1994) (Affinity Index)

USA *is consistently the most important partner country* for each field. The second and third positions are swapped between UK, Germany, Canada and France.

Fields	*Country*	
	Second rank	***Third rank***
Mathematics	CAN	NLD
Physics	DEU	UKD
Chemistry	DEU	UKD
Biology	UKD	DEU
Earth & Atmospheric Sciences	UKD	DEU
Food & Agriculture Research	UKD	DEU
Clinical Medicine	UKD	DEU
Biomedical Research	UKD	DEU
Engineering & Technology	DEU	CAN
Computer Science	CAN	FRA
Materials Science	UKD	FRA
All Fields	*UKD*	*DEU*

Structure of Transnational Cooperation

How are India's different partners placed relative to each other and eleven macrofields of science? This issue was examined by analyzing the structure of multivariate relationships between 35 significant countries (having at least 25 links) and eleven fields through Correspondence Analysis. A brief account of mapping techniques is given in Figure 7. The analysis showed that the first four factorial axes, summing up 80% of the total variance, provide the most parsimonious representation of the data. The remaining axes, indicating successively smaller amounts of variance, represent 'white noise' in the data. The results of Correspondence Analysis are summarized in the *Infographic Map* depicted in Figure 8.

Relationships with Super Powers of Science

The structure of relationships between three super powers of science (USA, UK, Japan) and eleven macrofields, as revealed by Correspondence Analysis, may be visualized from Figure 9.

Correspondence Analysis

Correspondence Analysis is a *pattern recognition* technique, whereby it is possible to compare the patterns of relationships between the rows and columns of a contingency table, for example the patterns of cooperation links of various countries in different fields or subfields (normalized profiles). The technique filters out noise and highlights the most legitimate correlations among the variables (i.e. countries and fields). These correlations can be best seen on biplots of factorial axes that describe ever - decreasing proportions of the total variance (i.e. information content) of the multidimensional system of relationship between the variables under study. The higher - order map, spanned by the first two factorial axes, reveals the strongest correlations among the variables. The lower - order maps reveal weaker, but equally meaningful correlations.

Correspondence Analysis generates factorial biplots and computes the eigen values, which indicate the variance in the multdimensional system explained by different factorial axes. It also computes absolute contributions (Ctr) and relative contributions ($Cos^2\phi$) of row and column elements of the data matrix, which help in the interpretation of the results of correspondence analysis.

We have devised an *Infographic Map*, in which the results of different factorial maps can be condensed to provide an overview or summary of the results of Correspondence Analysis.

Infographic Map

In the *Infographic Map*, the significant factorial axes are displayed together, whereas in Correspondence Analysis, the factorial axes are displayed two at a time, orthogonal to each other. Hence, in the *Infographic Map*, the factorial axes cannot be displayed as orthogonal to each other.

In the factorial map, all countries and fields are located at different points, and inter - point distances have certain meaning. In the *Infographic Map*, only those countries and fields are displayed, which are correlated to the significant factorial axes. Both countries and fields are located at the poles of the factorial axes and inter - point distances have no meaning!

Countries and fields located at a given pole of a factorial axis are associated. This means that the countries have stronger preference for cooperation in the fields located at the proximate pole. These countries are anticorrelated to the fields located at the opposite pole of the factorial axis and *vice versa*. However, the correlations and anticorrelations along the first axis are stronger than those on the second axis, which in turn are stronger than those on the third axis, and so on. This is due to the reason that the first factorial axis explains greater variance than the second axis, which in turn explains greater variance than the third axis, and so on.

Fig. 7: Mapping techniques

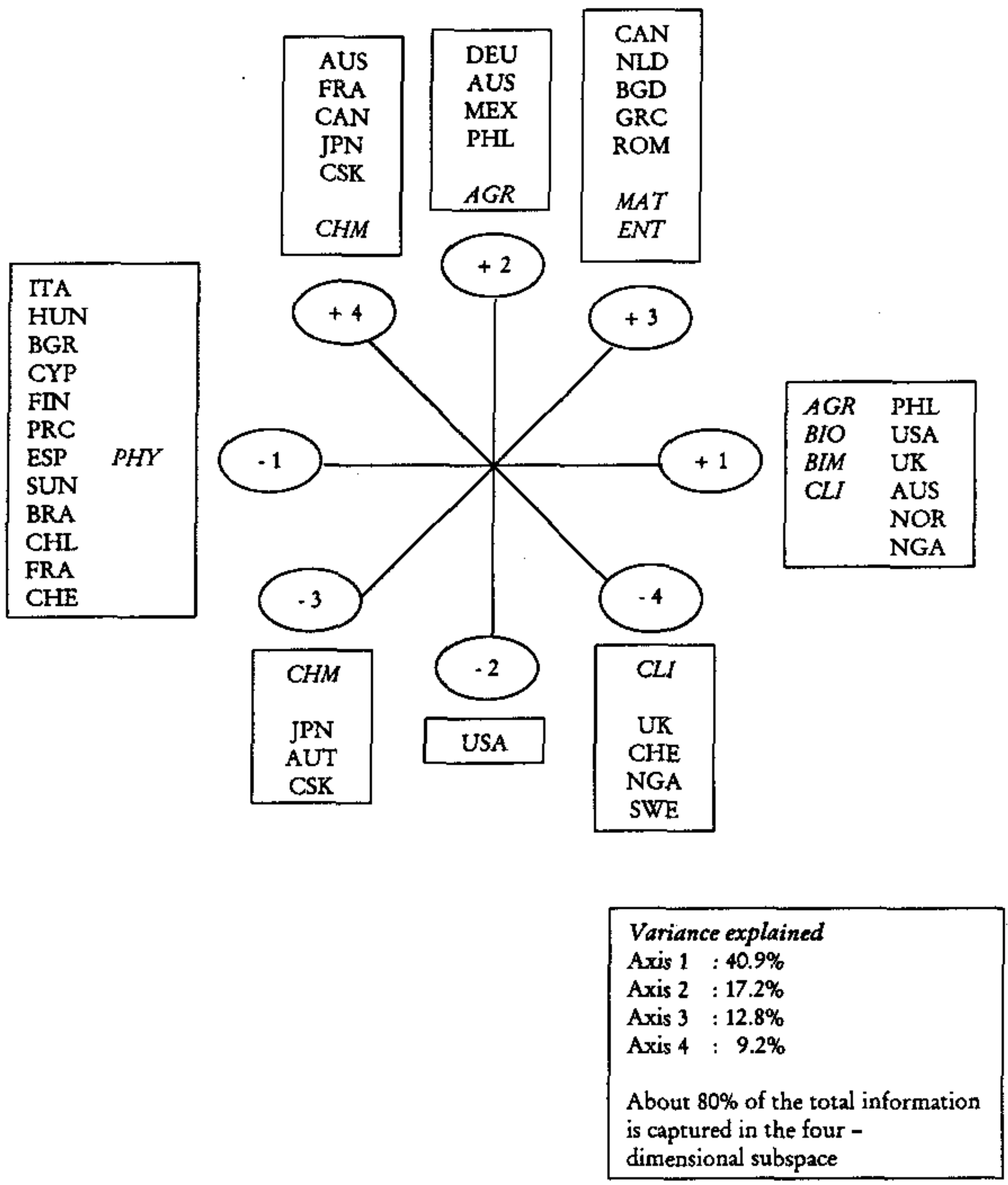


Fig. 8: Summary of correspondence analysis (macro fields)

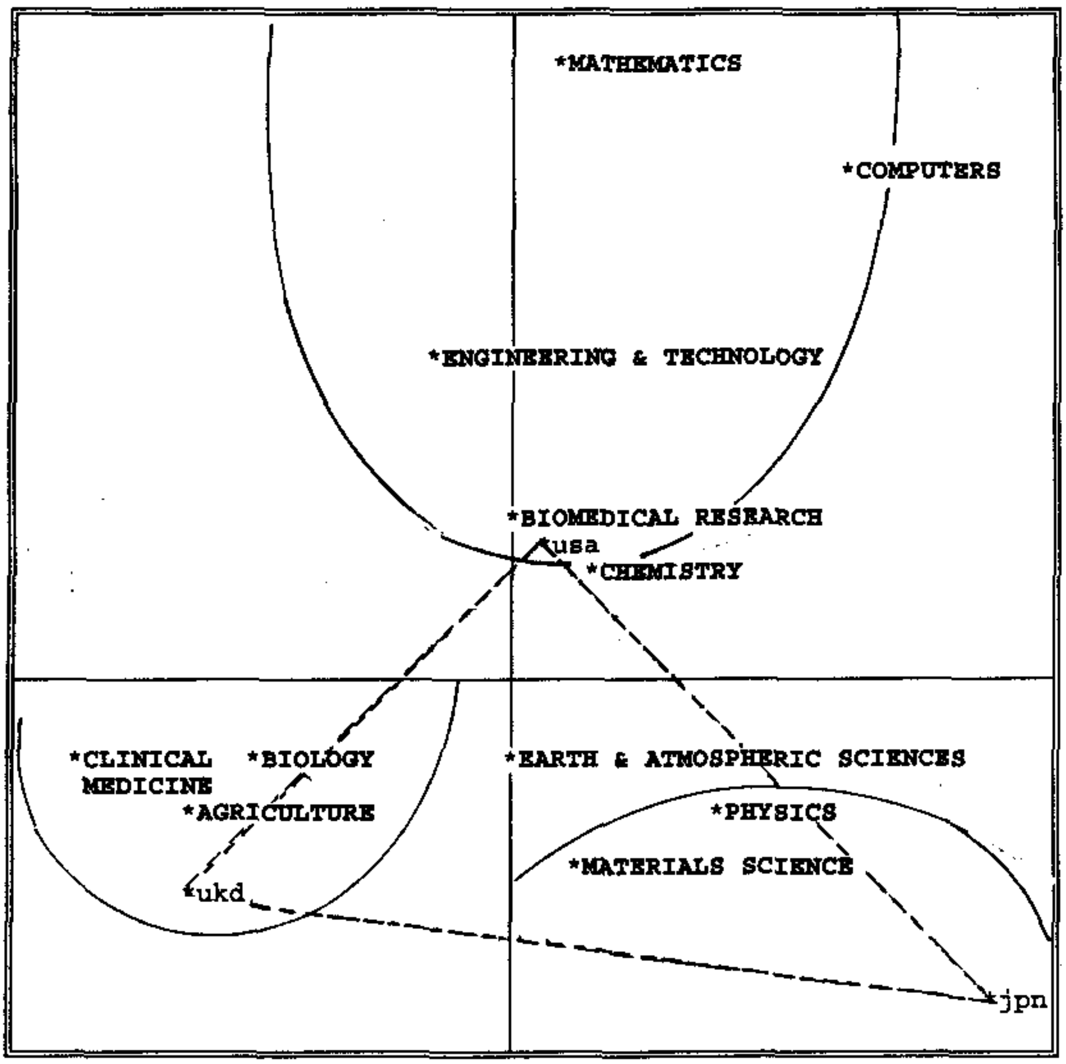


Fig. 9: Correspondence Analysis of transnational cooperation with super powers of Science

4. Transnational Links in Mathematics

India had published 923 articles in *Mathematics* in the *SCI* - covered journals during the 5 - year period: 1990 -1994. Of these 219 articles (33.7%) were internationally coauthored, indicating an aggregate of 246 cooperation links, spanning over 28 countries. On the average, there are 1.12 cooperation links per internationally coauthored article, which indicates the extent of multilaterality of cooperation.

The distribution of links is highly skewed. The top six countries (USA, Canada, Netherlands, UK, Germany and Italy) account for about 80% of all cooperation links.

Figure 10 depicts India's affinities towards its eleven significant partners (USA, CAN, NLD, UKD, DEU, ITA, JPN, AUS, BGD, FRA and KWT); each of these countries accounted for at least 2% of all transnational cooperation links in *Mathematics*.

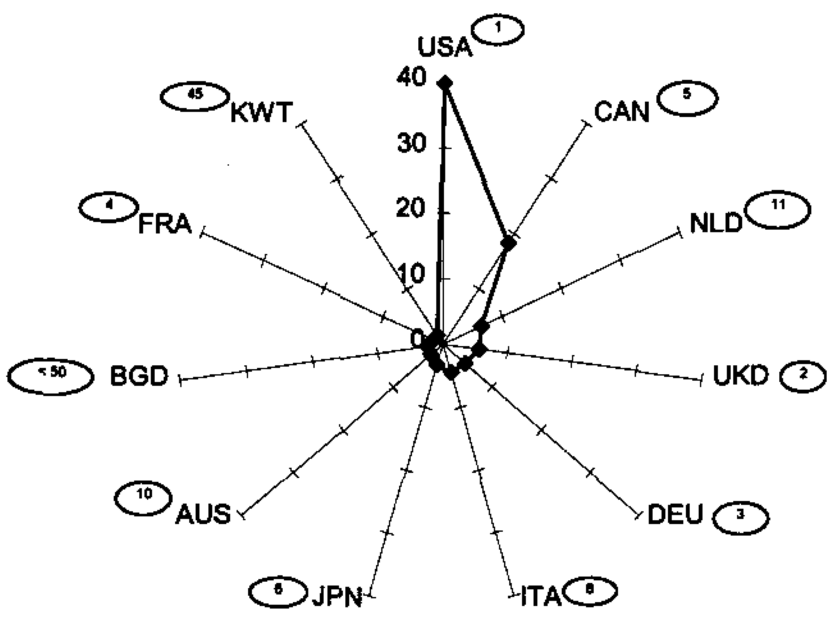


Fig. 10: India's Linkages in Mathematics (all subfields combined) (1990-1994)
(Affinity Index)

Note: Figures in ◯ indicate country's rank in Mathemtics

USA is consistently the most important partner country in all subfields, followed by Canada. The status of these eleven countries in different subfields may be visualized from Figure 11.

There are strong inter - field differences in attracting international cooperation. *Statistics & Probability* is the most internationalized subfield; 43% of articles in this area are internationally coauthored. In the other three areas, about one fifth of all articles are internationally coauthored. *Operations Research* has somewhat greater tendency to attract multicountry cooperation.

Structural analysis of cooperation links of these eleven countries in different subfields reveals the following trends:

1. USA and Canada have strong preference for cooperation in *Statistics & Probability* and *Operations Research.*
2. Netherlands, UK, Germany, Italy, Bangladesh, France and Kuwait have strong preference for cooperation in *General Mathematics.*
3. Japan has strong preference for cooperation in *Statistics & Probability.*
4. Australia has strong preference for cooperation in *Applied Mathematics.*

5. Transnational Links in Physics

India had published 11748 articles (*Articles, Reviews, Notes* and *Letters*) in the *SCI* - covered journals in *Physics* during 1990 - 1994. Of these, 2176 (19.55%) articles are internationally coauthored, indicating a total of 3360 cooperation links, spanning over 69 countries.

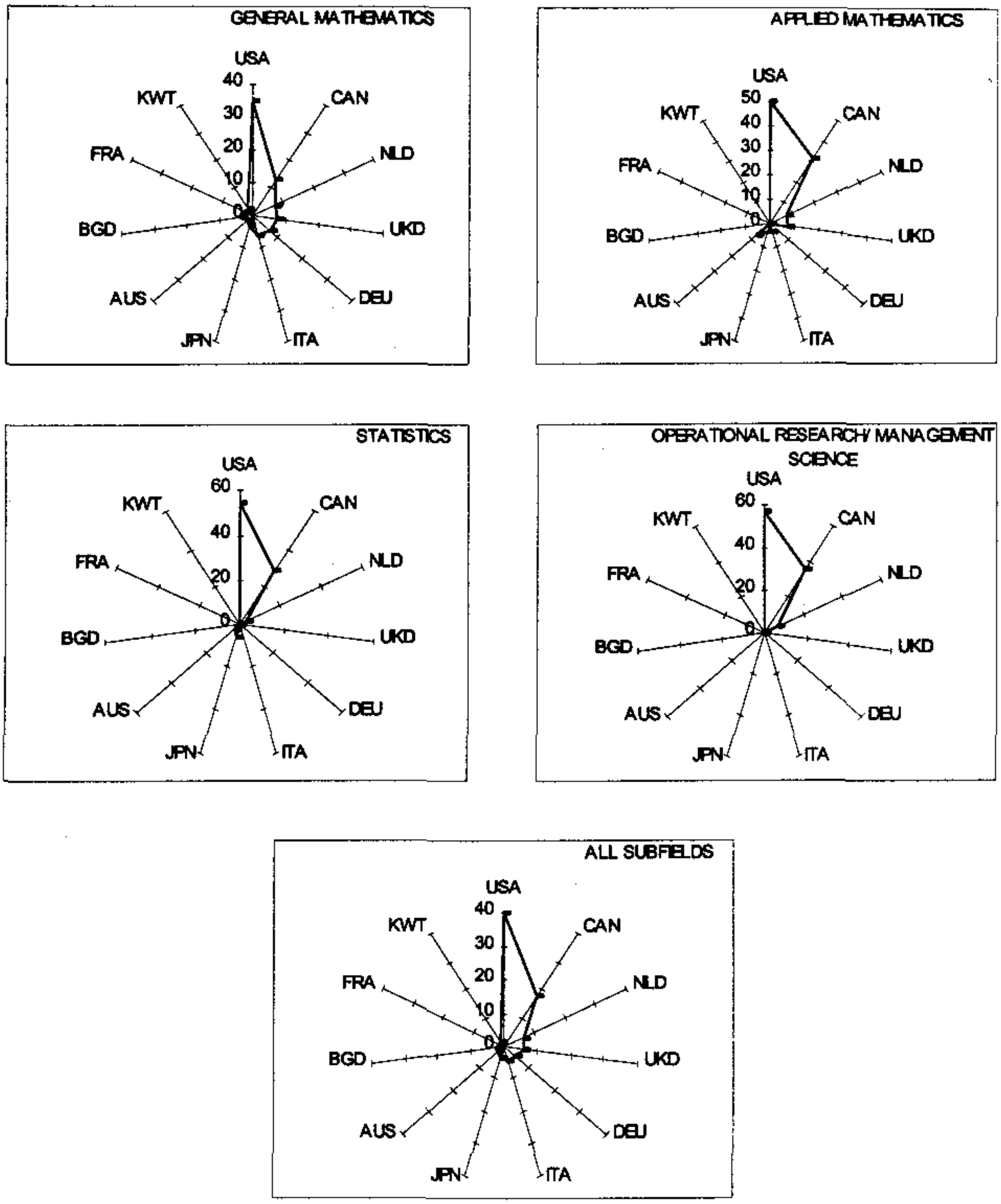


Fig. 11: India's linkages in different subfields of Mathematics (1990-1994)
(Affinity Index)

The distribution of links among the partner countries is highly skewed. The top ten countries account for about 77% of all cooperation links. USA alone accounts for about one fourth of all links. Germany ranks second with only 11.5% of all links. The variations in India's affinities towards its 14 major partners — USA, Germany, UK, Italy, France, Canada, Japan, Russia, Switzerland, Netherlands, Spain, China, Australia and Hungary may be visualized from Figure 12.

India's important Asian partners in this field are:

Country	*No. of Cooperation Links (COP)*
Japan	138
China	52
Korea	27
Bangladesh	13
Taiwan	13
Malaysia	11

Inter – Field Differences in Cooperation Links

There are strong inter – field differences in cooperation links. The proportion of internationally coauthored articles varies from 3.3% in *Acoustics* to 30.12% in *Nuclear & Particle Physics*. Transnational cooperation in the latter subfield is not only more frequent (about 85 links per 100 articles), but it is also relatively more multilateral. On the average, one internationally coauthored article involves cooperation with about three countries. *Astronomy & Astrophysics* has also a similar attraction for transnational cooperation, but to a lesser extent than *Nuclear & Particle Physics*. The incidence of transnational cooperation in *Crystallography* is high, but it is hardly multilateral.

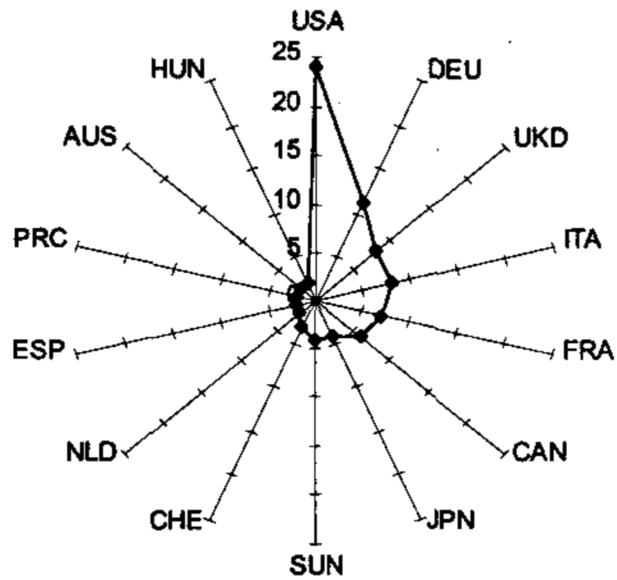


Fig. 12: India's Linkages in Physics (1990-1994)
(Affinity Index)

The propensity of different subfields for attracting international cooperation may be visualized from the following figure:

Typology of Transnational Cooperation

Frequency of Cooperation	*Nature of Cooperation*: *Multilateral* ($CEI>1.20$)	*Nature of Cooperation*: *Bilateral* ($CEI\leq1.20$)
Frequent ($COP>20.0$)	General Physics Astrophysics Fluids & Plasmas Nuclear Physics	Chemical Physics Crystallography Mathematical Physics Spectroscopy
Infrequent ($COP\leq20.0$)	Applied Physics	Acoustics Optics Solid State Physics

Inter - Country Differences in Cooperation

There are important differences among the countries in the choice of subfields for cooperation with India. These variations can be visualized along two dimensions — inter - field differences in a given country and inter - country differences in a given subfield.

The sunray plots given in Figure 13 indicate the variations in the preference given to different subfields by six major partner countries (USA, Germany, UK, Italy, France and Canada) in their cooperation with India.

The sunray plot for USA is approximately an equilateral polygon; its cooperation profile, therefore, does not exhibit much differentiation. The cooperation profiles of other countries are quite differentiated.

USA is consistently the most important partner country in all subfields, except *Mathematical Physics*. In this subfield, Canada is the most important partner. The second and third positions are swapped between France, Germany, Italy and Canada.

Subfield	*Countries*	
	Second rank	*Third rank*
General Physics	DEU	ITA
Applied Physics	DEU	FRA
Astronomy & Astrophysics	UK	DEU ≈ ITA
Chemical Physics	DEU	CAN
Crystallography	UK	JPN
Fluids & Plasmas	DEU	JPN
Mathematical Physics	USA	DEU
Nuclear & Particle Physics	DEU	ITA
Optics	UK	DEU
Solid State Physics	UK	FRA
Spectroscopy	ITA	JPN

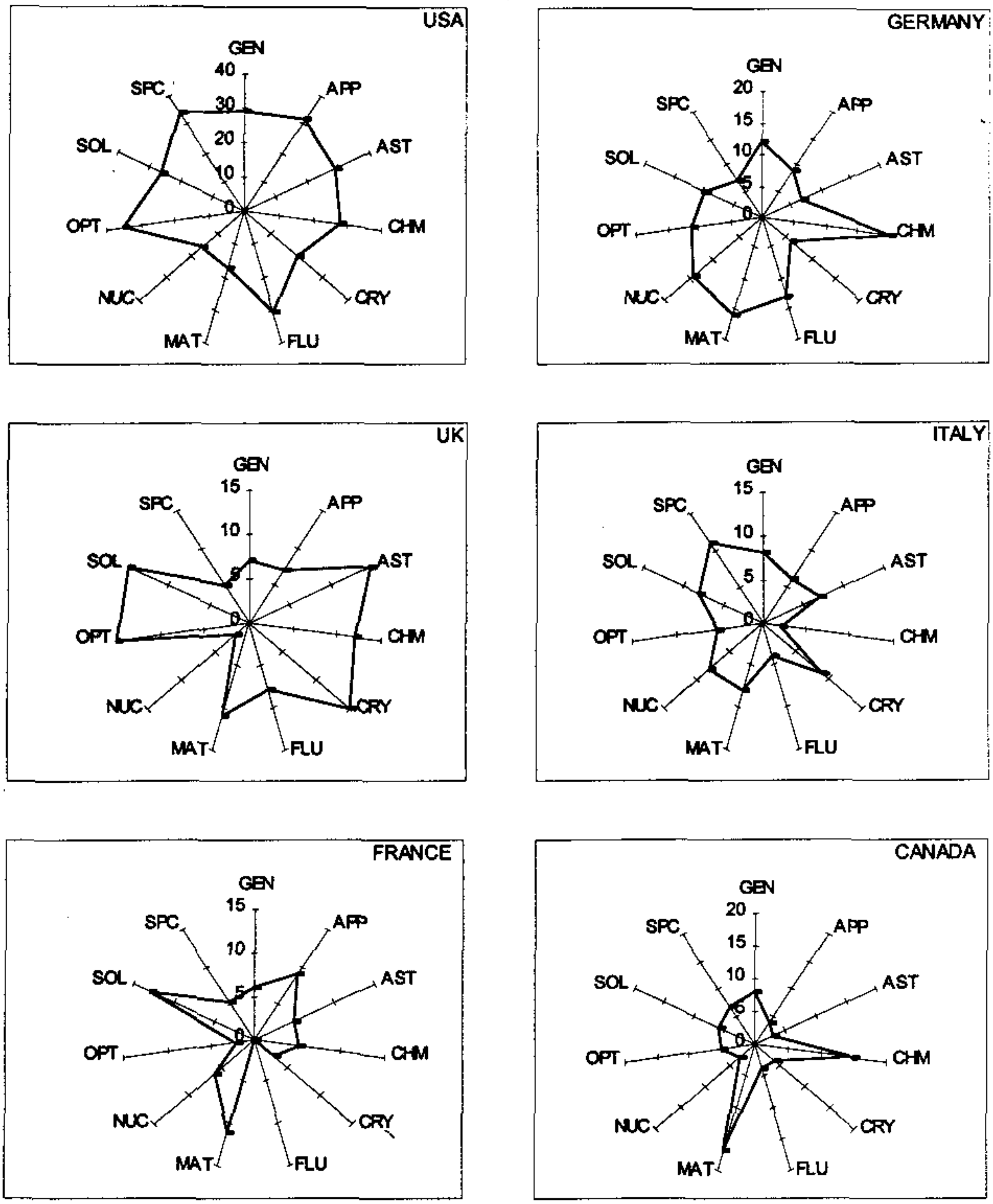


Fig. 13: India's affinities towards major cooperating countries in different subfields of Physics (1990-1994)
(Affinity Index)

Structure of Transnational Cooperation

The structure of transnational cooperation of 20 significant countries (having at least 25 cooperation links in eleven disciplinary areas of *Physics*) was analyzed through Correspondence Analysis. The first two factorial axes, summing up 73% of the total variance yield the most parsimonious representation of the data. Correspondence Analysis leads to the identification of clusters of countries and subfields preferred by them for cooperation with India. The first axis represents a polarity between Type 1 and Type 2 countries, whereas the second axis represents a polarity between Type 3 and Type 4 countries.

	Countries	*Preferred Fields*
Type 1	USA, UK, Japan	Solid State Physics
Type 2	Russia, Switzerland, Spain, China, Korea, Bulgaria, Cyprus, Hungary	Nuclear & Particle Physics
Type 3	Netherlands, Australia	Astronomy & Astrophysics, Crystallography
Type 4	Germany, Canada	Chemical Physics, Mathematical Physics

6. Transnational Links in Chemistry

During the five - year period: 1990 - 1994, Indian scientists had published 11,660 articles in *Chemistry* in the *SCI* - covered journals. Of these, only 7% articles were cosigned by authors from 44 countries. Chemistry is the least internationalized field, both in terms of proportions of internationally coauthored articles and the number of countries involved. Moreover the links are bilateral. Only twenty countries had more than five cooperation links with India.

The distribution of links among the cooperating countries is highly skewed. The top eight countries — USA, Germany, UK, Japan, France, Canada, Italy and Australia account for 86.5% of cooperation links in this field. The variations in India's affinities towards these countries may be visualized from Figure 14.

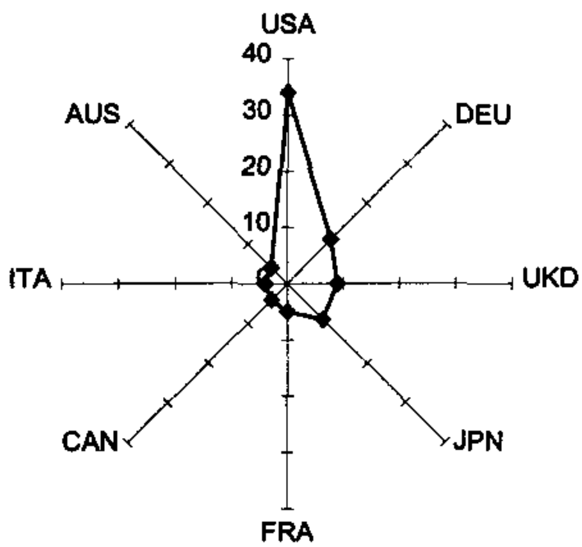


Fig. 14: India's linkages in Chemistry (1990-1994)
(Affinity Index)

Inter - Field Differences in Cooperation Links

Inter - field differences in cooperation are not very strong. *Transnational Cooperation Index* (*COP*) varies from 5.26 for *Organic Chemistry* to 13.01 for *Electrochemistry*.

Inter - Country Differences in Cooperation

Different fields do not receive the same importance in all the cooperating countries. Inter - field variations in five major countries — USA, Germany, UK, Japan and France may be visualized from Figure 15.

USA is consistently the most important partner country in all subfields, except *Electrochemistry*, where Canada is the most important partner. The second and third most important partners in different subfields are:

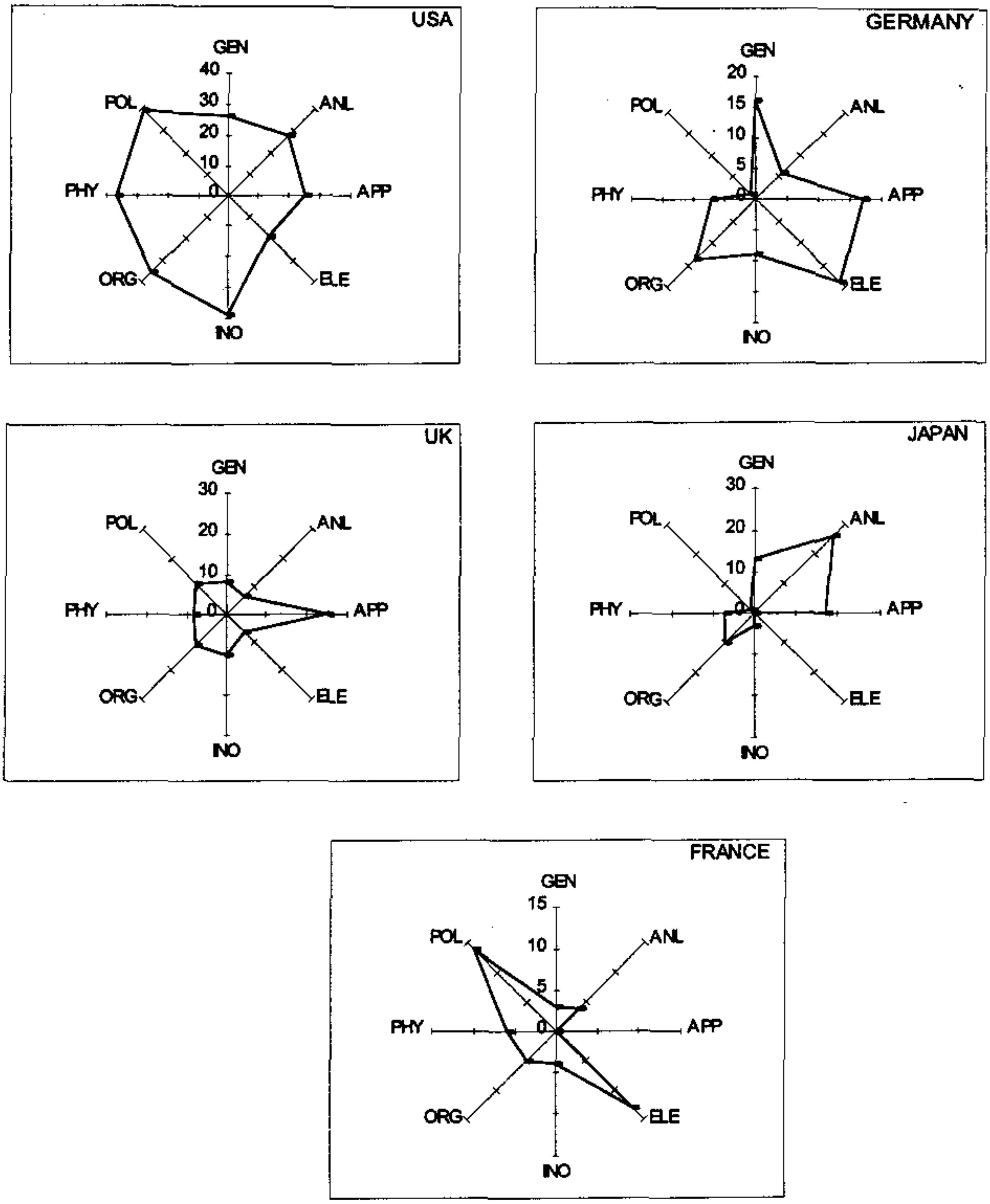


Fig. 15: India's affinities with major cooperating countries in different subfields of Chemistry (1990-1994) Affinity Index

Subfield	*Important Partners*	
	Second rank	*Third rank*
General Chemistry	DEU	JPN
Analytical Chemistry	JPN	ITA
Applied Chemistry	UK	JPN
Electrochemistry	USA	DEU
Inorganic Chemistry	UK	DEU
Organic Chemistry	DEU	UK
Physical Chemistry	UK	JPN
Polymers	FRA	UK

Structure of Transnational Cooperation

The correlations and specificities of fourteen significant partners (USA, Germany, UK, Japan, France, Canada, Italy, Australia, Russia, Denmark, Austria, Czechoslovakia, Spain and Switzerland) in eight subfields were analyzed through Correspondence Analysis. Five countries (Switzerland, Denmark, Spain, Australia and Czechoslovakia) were treated as passive variables. Passive variables do not influence the configuration of relationships. Correspondence Analysis revealed that the first three factorial axes, summing up 84.5% of the total variance, provide the most parsimonious representation of the multidimensional data. The results of Correspondence Analysis are summarized in Figure 16.

7. Transnational Links in Biology

India had published 2827 articles (*Articles*, *Reviews*, *Notes* and *Letters*) in the mainstream journals in the area of Biology covered by the *Science Citation Index* during 1990 – 1994. Of these, 405 articles (14.3%) are internationally coauthored, indicating 443 cooperation links, spanning over 51 countries. Cooperation links are by and large bilateral: 1.09 links per internationally coauthored article.

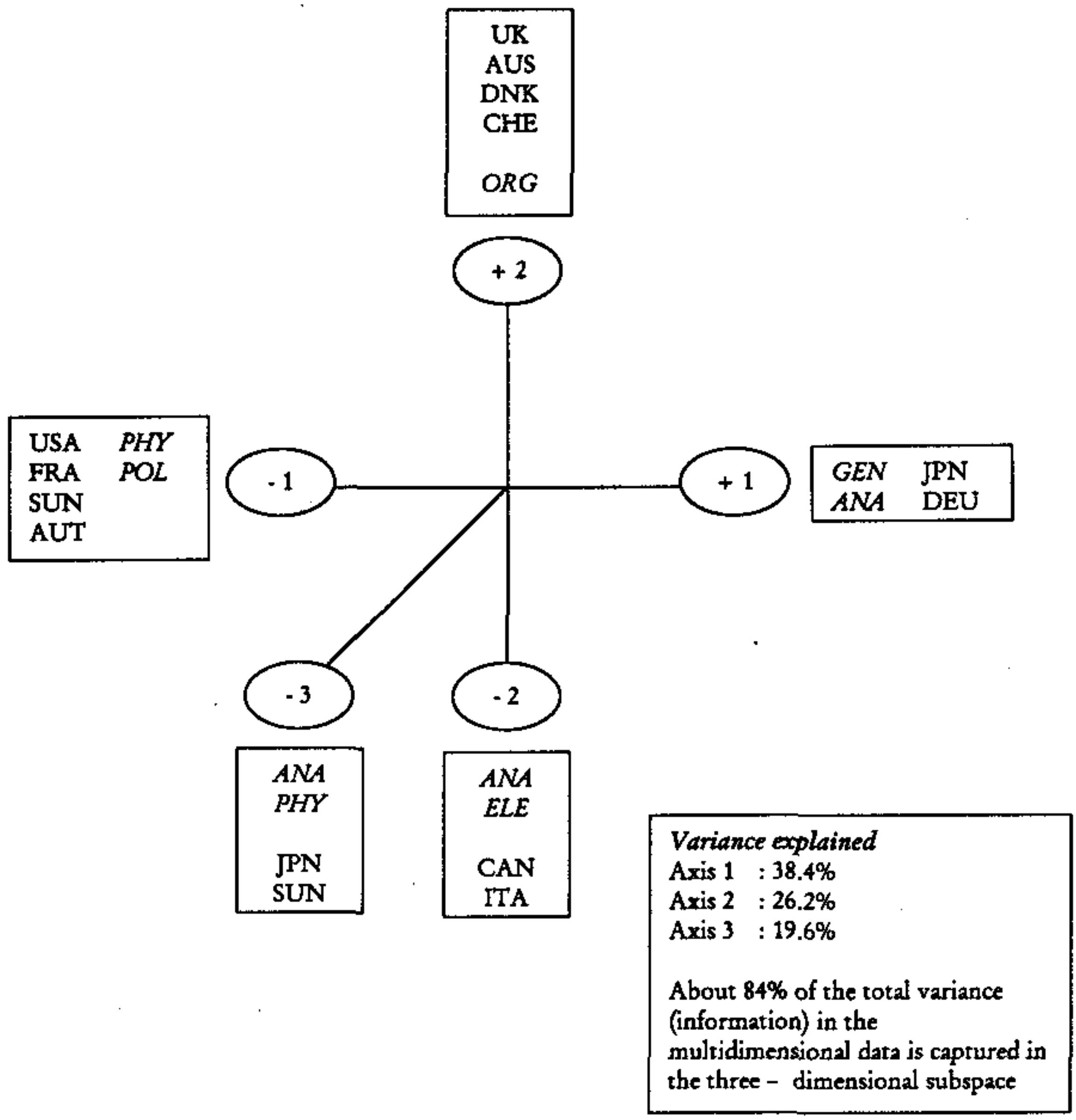


Fig. 16: Summary of correspondence analysis (Chemistry)

Using *SCI* classification[1], the field of Biology comprises eight subfields: *General Biology, Botany, Ecology, Entomology, Marine Biology & Hydrobiology, Miscellaneous Biology, General Zoology, Miscellaneous Zoology.* Of these, *Botany, Miscellaneous Biology, Zoology* and *Miscellaneous Zoology* attract more international cooperation than the other subfields.

India's affinities towards its major partner countries (USA, UK, DEU, JPN, CAN, AUS, FRA, SYR, BEL), which account for 80.5% of all cooperation links, may be visualized from Figure 17.

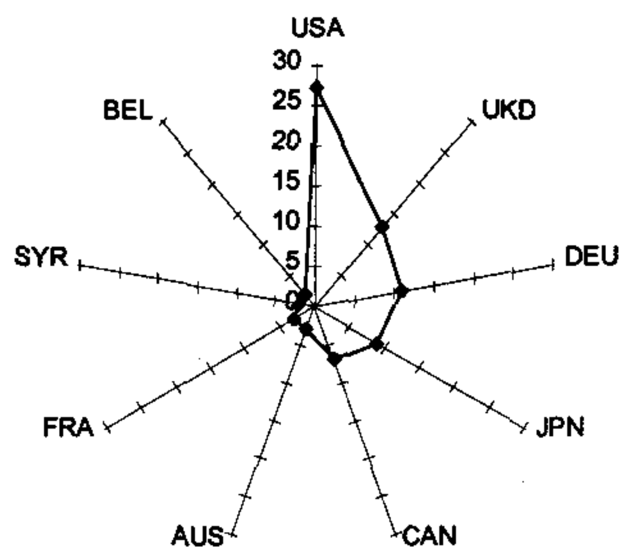


Fig. 17: India's linkages in Biology (1990-1994)
(Affinity Index)

Inter – field differences in India's affinity towards top five partner countries: USA, UK, Germany, Japan, Canada may be visualized from Figure 18.

[1] This classification is vague.

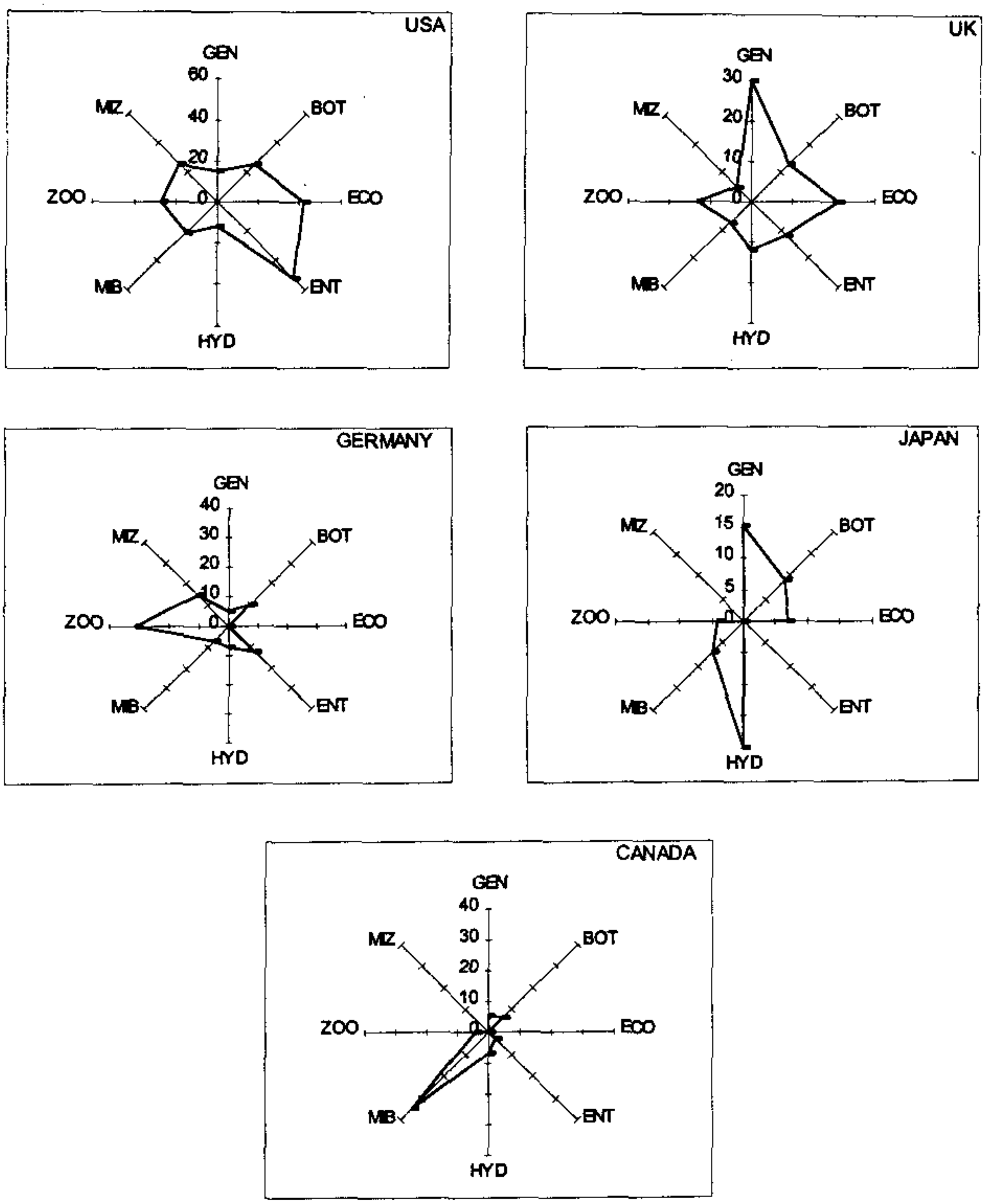


Fig. 18: India's affinities towards major cooperating countries in different subfields of Biology (1990-1994) (Affinity Index)

The most important partner countries in different subfields are:

Subfields	*Countries* *First*	*Second*
General Biology	UK	JPN ≈ USA
Botany	USA	UK
Ecology	USA	UK
Entomology	USA	UK
Hydrbiology	JPN	BEL
Miscellaneous Biology	CAN	USA
Zoology	DEU	USA
Miscellaneous Zoology	USA	DEU

Structural analysis of the multivariate relationships between nine major cooperating countries (USA, UK, Germany, Japan, Canada, Australia, France, Syria and Belgium) and eight subfields of Biology indicates the following pattern of relationships:

Country	*Subfields of preference for cooperation*
Japan, Belgium	Hydrobiology
USA, Germany	Entomology, Zoology Miscellaneous Zoology
Canada, Australia	Miscellaneous Biology

8. Transnational Links in Earth & Atmospheric Sciences

During the five - year period: 1990 - 1994, India had contributed 2198 articles in the mainstream literature in *Earth & Atmospheric Sciences* indexed in the *Science Citation Index*. Of these, 350 articles (15.5%) were internationally coauthored, indicating an aggregate of 436 cooperation links, spanning over 36 countries.

USA is the most important partner country, accounting for about 29.8% of India's all cooperation links. The top nine countries (USA, UK, Germany, Japan, Canada, France, Russia, Australia and Netherlands) account for about 80% of all links. Variations in India's affinities towards these countries may be visualized from Figure 19.

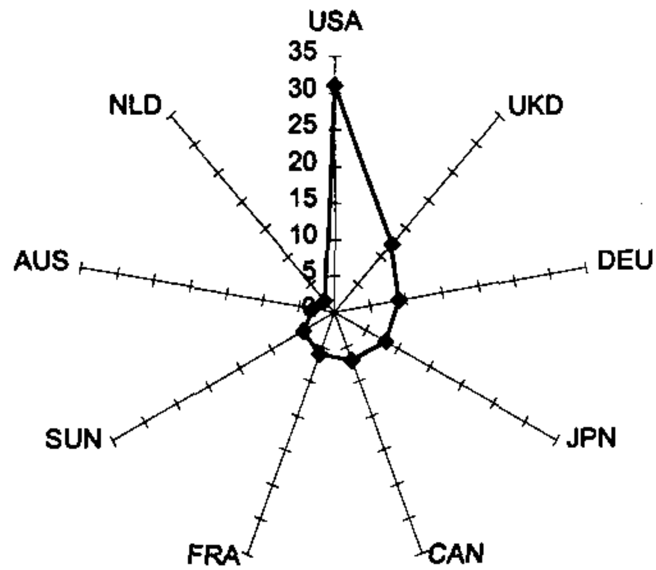


Fig. 19: India's linkages in Earth & Atmospheric Sciences (1990-1994)
(Affinity Index)

Obviously, the cooperating countries do not give the same importance to different subfields of *Earth & Atmospheric Sciences*. Inter - field variations in India's affinities towards top five countries (USA, UK, Germany, Japan and Canada) may be visualized from Figure 20, which indicates that the cooperation profiles of all these countries are quite differentiated.

Structure of Transnational Cooperation

The structure of India's multiple relations with its significant partner countries (USA, UK, Germany, Japan, Canada, France, Russia, Australia, Netherlands, Belgium, Sweden, Italy and Brazil) in different subfields of *Earth & Atmospheric Sciences* was analyzed through Correspondence Analysis.

The results of Correspondence Analysis are summarized in Figure 21.

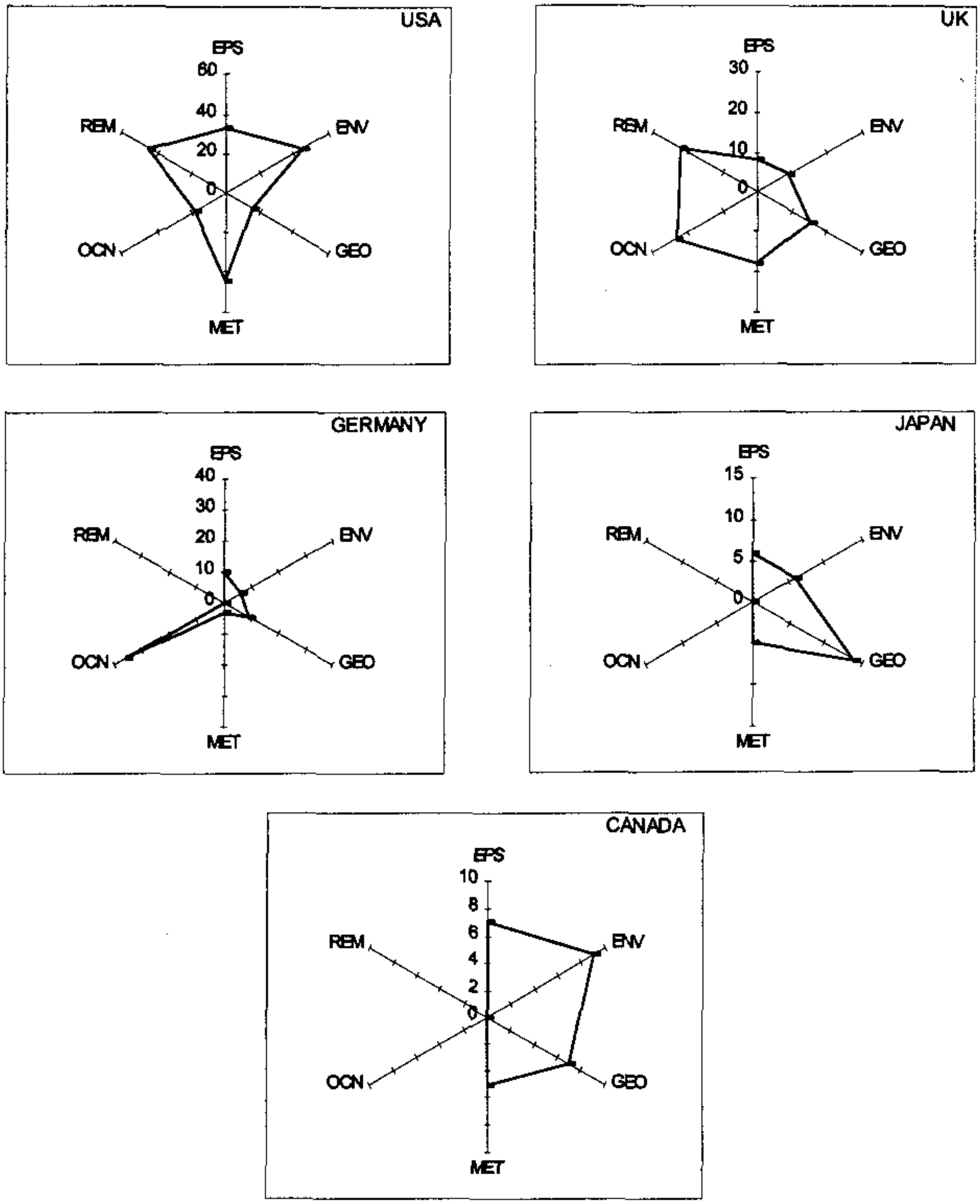
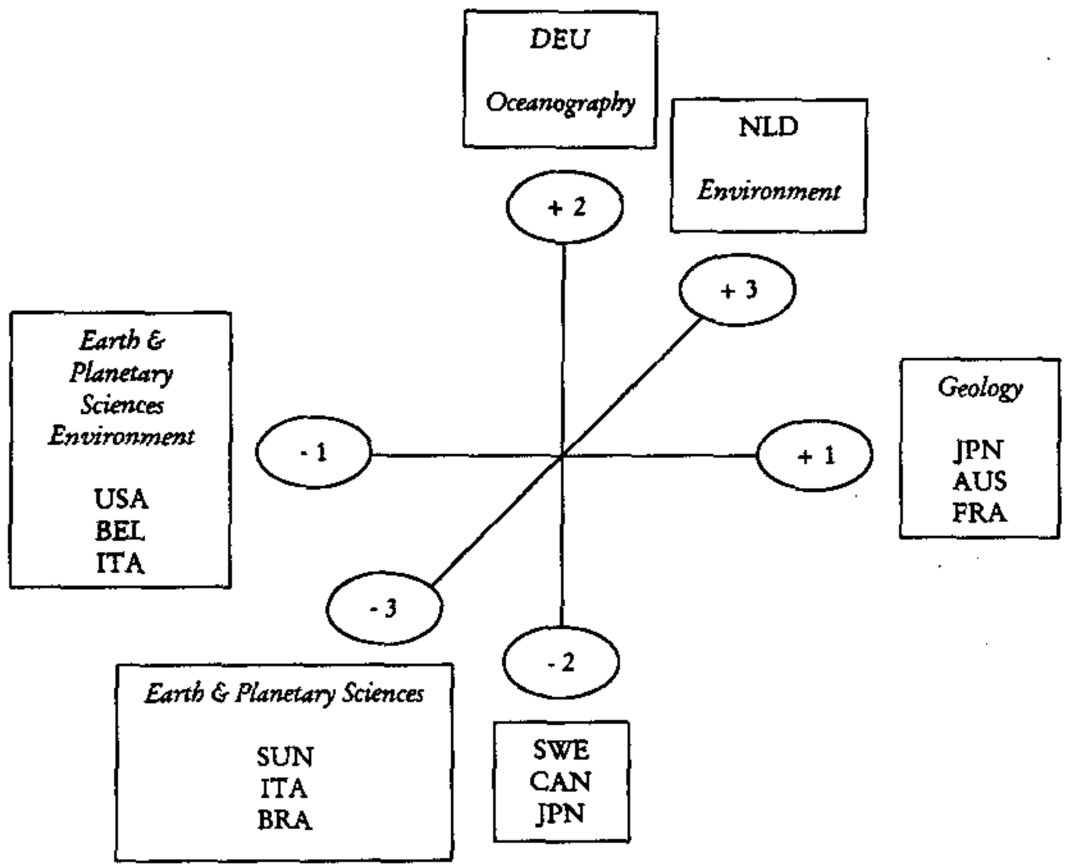


Fig. 20: India's affinities towards major cooperating countries in different subfields of Earth & Atmospheric Sciences (1990-1994)
(Affinity Index)



Variance explained
Axis 1 : 50.2%
Axis 2 : 23.7%
Axis 3 : 18.2%

More than 92% of the total variance (information) in the multidimensional data is captured in the three - dimensional subspace

Fig. 21: Summary of correspondence analysis (Earth & Atmospheric Sciences)

9. Transnational Links in Food & Agriculture Research

Indian scientists had published 1673 articles in the *SCI* - covered journals in the area of *Food & Agriculture Research* during five - years: 1990 - 1994. Of these, 219 (13.1%) articles are internationally coauthored, indicating an aggregate of 258 transnational cooperation links, spanning over 34 countries.

USA is the most important cooperating partner accounting for 22.5% of India's all transnational cooperation links. Among the top thirteen partners are six countries from Asia, Africa and West Asia (namely Niger, Philippines, Syria, Japan, Thailand and Nepal). The variations in India's affinities towards its thirteen significant partners (Number of links ≥ 5) may be visualized from Figure 22.

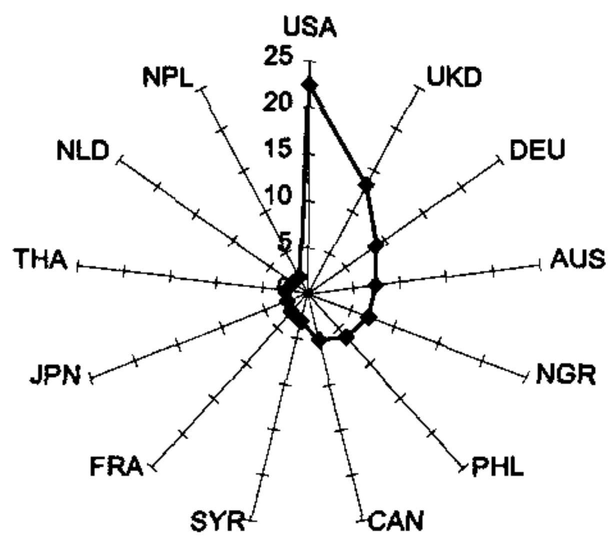


Fig. 22: India's linkages in Food & Agriculture Research (1990-1994)
(Affinity Index)

Inter - field differences in five major partner countries (USA, UK, Germany, Australia and Niger) may be visualized from Figure 23.

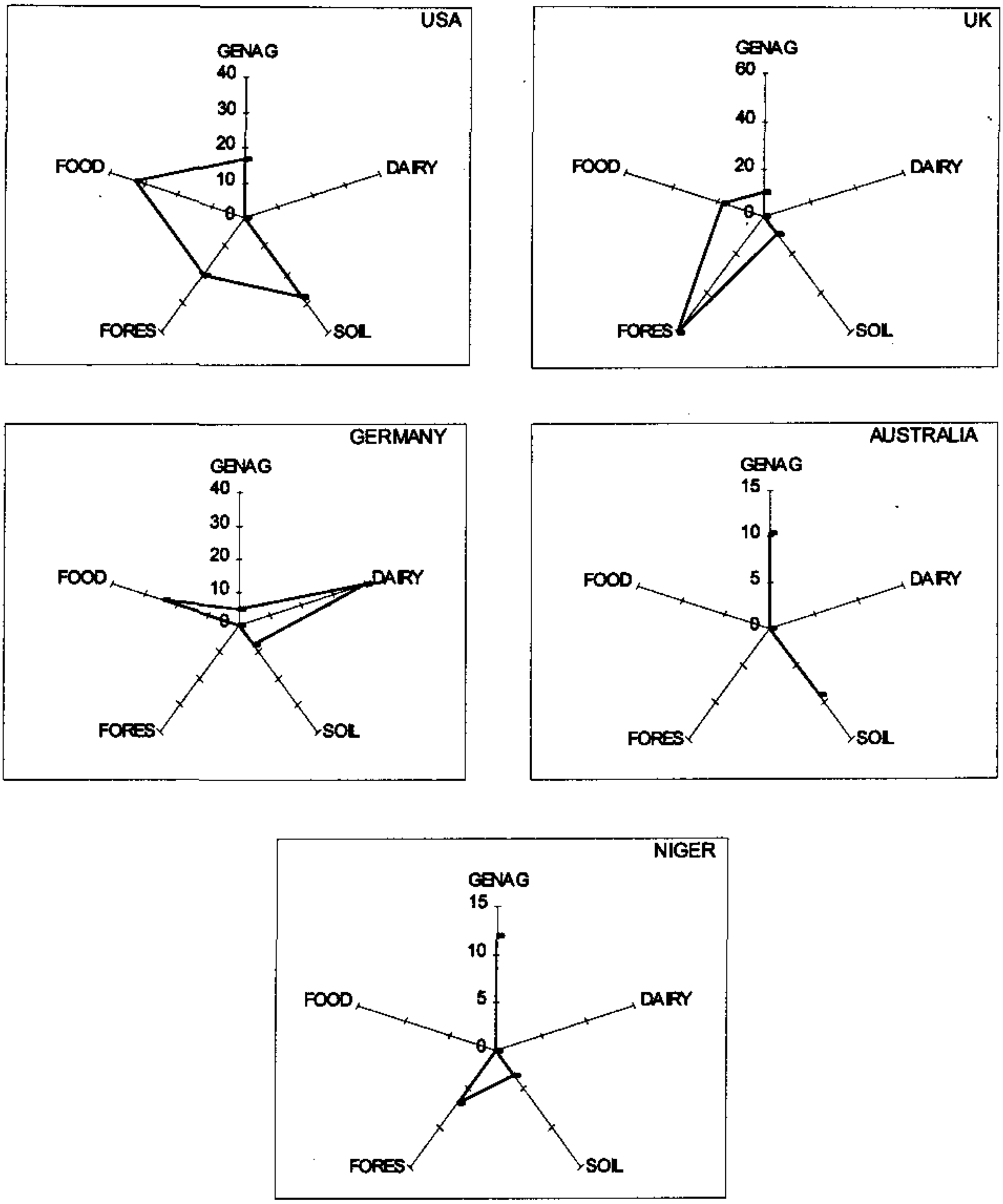


Fig. 23: India's affinities towards major cooperating countries in different subfields of Food & Agriculture Research (1990-1994)
(Affinity Index)

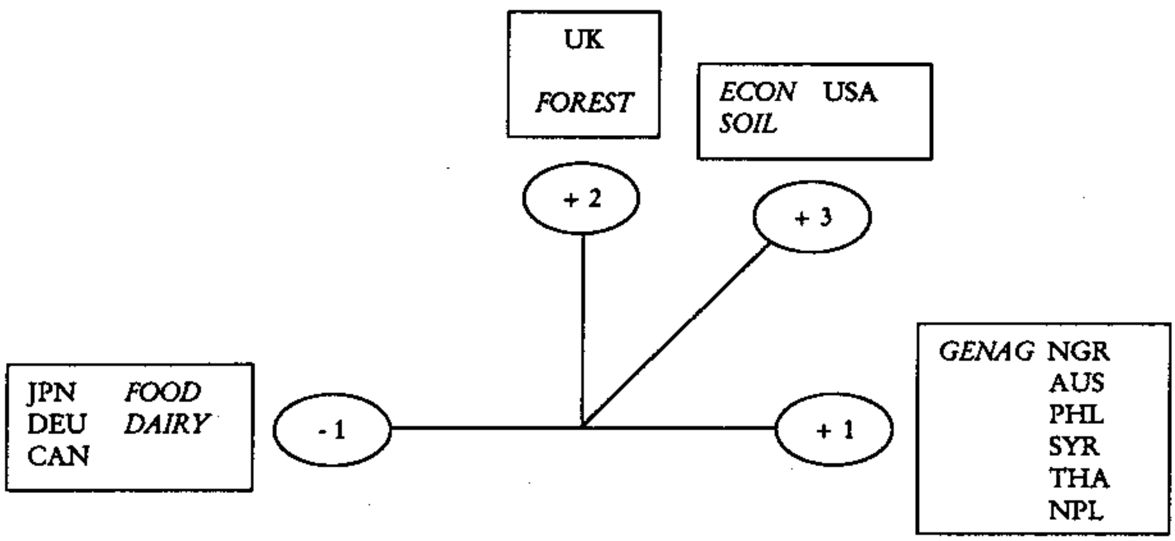
The following table indicates the subfields of highest and lowest affinities for five major cooperating countries (USA, UK, Germany, Australia and Niger).

Country	*Subfields of*	
	Highest affinity	*Lowest affinity*
USA	Food Science & Technology	Dairy & Animal Sciences
UK	Forestry	Dairy & Animal Sciences
Germany	Dairy & Animal Sciences	Forestry
Australia	General Agriculture	Dairy & Animal Sciences Food Science & Technology Forestry
Niger	General Agriculture	Dairy & Animal Sciences Food Science & Technology

Correspondence Analysis was performed to visualize the structure of multivariate relationships between India's significant partners and subfields of *Food and Agriculture Research*. Six countries (Syria, France, Japan, Thailand, Netherlands, Nepal), which had less than ten cooperation links with India, were treated as passive variables. The results of Correspondence Analysis are summarized in Figure 24.

Transnational Links in Clinical Medicine

India had published 7885 articles (*Articles, Reviews, Notes* and *Letters*) in the *SCI* - covered journals in five - years (1990 - 1994). Of these, 744 articles were internationally coauthored, indicating a total of 1005 cooperation links, spanning over 77 countries. The top 13 countries (USA, UK, Germany, Japan, Canada, Sweden, Italy, Switzerland, Australia, France, Netherlands, Austria and Bangladesh) accounted for about 81% of all cooperation links. The variations in India's affinities towards these countries may be visualized from Figure 25.



Variance explained
Axis 1 : 46.9%
Axis 2 : 30.5%
Axis 3 : 17.8%

More than 95% of the total variance (information) in the multidimensional data is captured in the three – dimensional subspace

Fig. 24: Summary of correspondence analysis (Food & Agriculture Research)

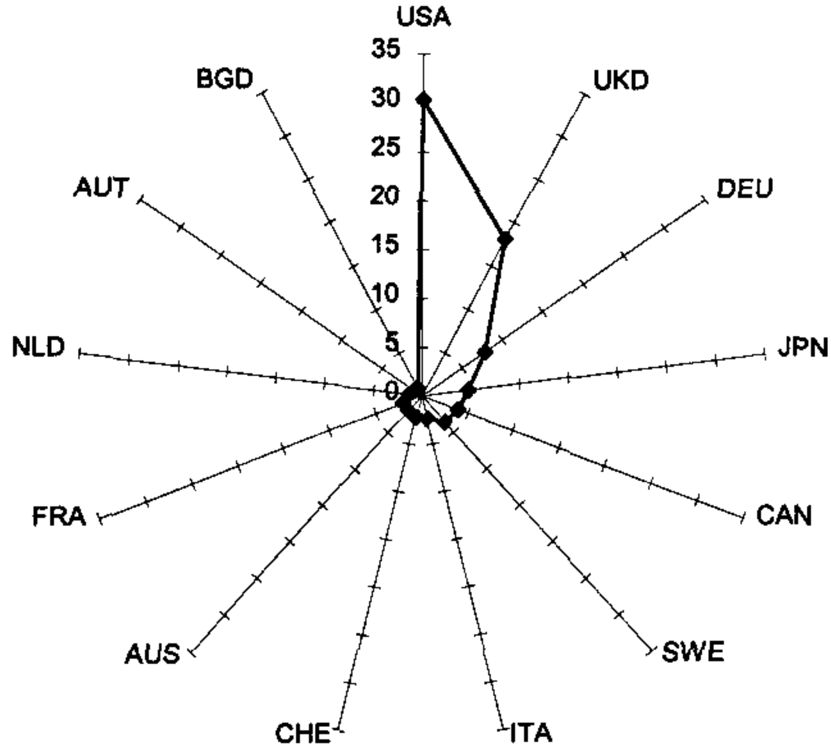


Fig. 25: India's linkages in Clinical Medicine (1990-1994)
(Affinity Index)

There are strong inter - field differences in their propensities to attract international cooperation. The proportion of internationally coauthored articles varies from a low of 3.32% in *Surgery* to 19.94% in *Endocrinology*. *Fertility* has the highest incidence of cooperation links - 38 links per 100 articles. The incidence of multilateral links is particularly high in the following areas: *Cardiovascular System*, *Fertility* and *Pharmacology* — on the average, cooperation links with more than two countries per internationally coauthored article.

The following table presents the ranking of subfields according to proportions of articles, internationally coauthored articles (*ICOA*) and cooperation links (*COP*).

Ranking of Subfields according to Proportions of Articles, ICOA's and COP's

	Ranking by proportions of		
Rank	*Articles*	*ICOA's*	*COP's*
1.	INM	INM	INM
2.	PHA	PHA	IMM
3.	ONC	IMM	PHA
4.	IMM	ONC	ONC
5.	DER	NEU	NEU
6.	RAD	FER	CAR
7.	NEU	END	FER
8.	SUR	DER	END
9.	CAR	VET	DER
10.	GAS	TROP/ RAD	VET

Endocrinology, *Fertility* and *Veterinary Medicine* are not very important subfields in terms of research output, but they are quite important in attracting international cooperation. *Fertility* ranks fifteenth in terms of publication output, but it ranks sixth in terms of internationally coauthored articles and seventh in terms of transnational links. This is possibly due to the role of international agencies in promoting research related to population control.

Inter – Field Variations in Cooperation Links

There are important differences among the countries in the choice of subfields for cooperation with India. These variations can be visualized along two dimensions: inter – field differences in a given country and inter – country differences in a given field.

The following table presents the list of two most important subfields for each of the thirteen major partner countries.

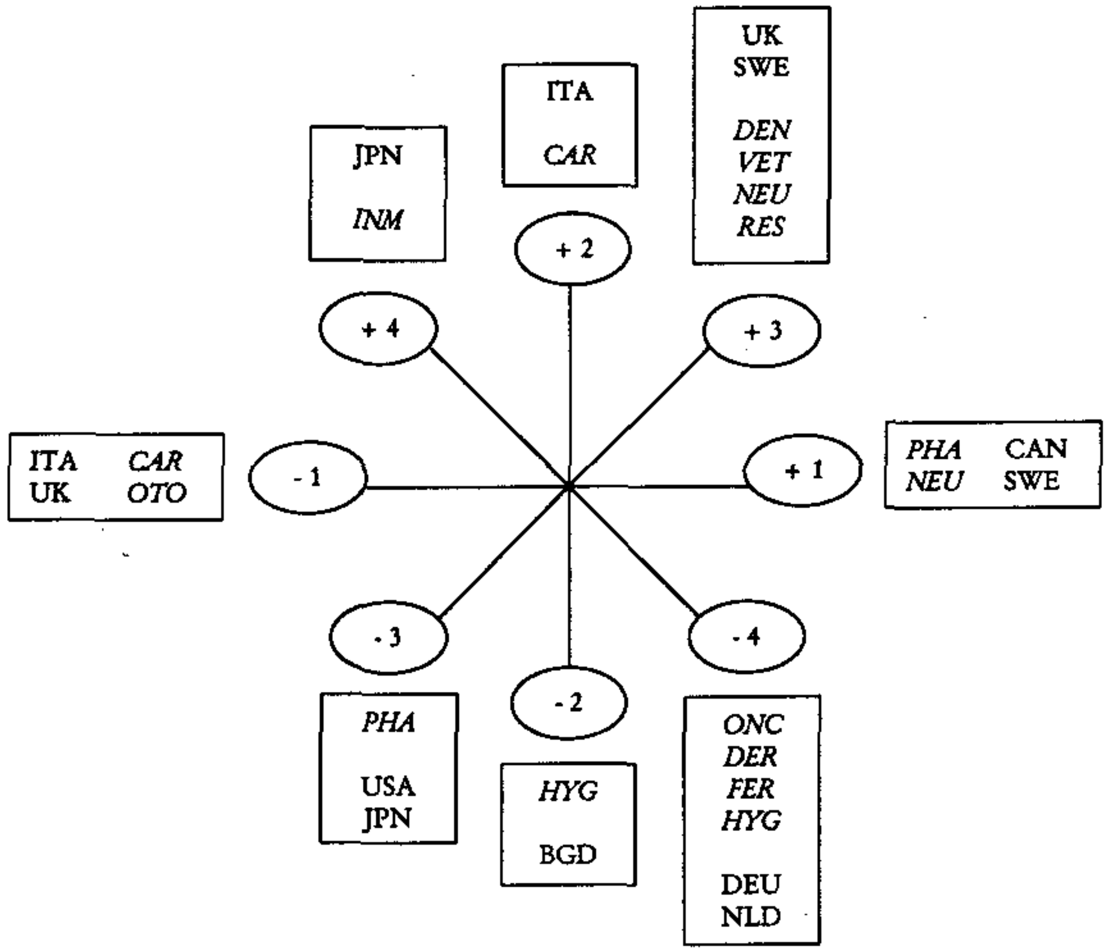
Country	*Subfields of Highest Affinities*	
	First rank	*Second rank*
USA	Ophthalmology	Gastroenterology
UK	Otorhinolaryngology	Pathology
Germany	Radiology & Nuclear Medicine	Dermatology
Japan	Pharmacology & Pharmacy	Immunology
Canada	Neurology & Neurosurgery	Respiratory System
Sweden	Pediatrics	Dentistry/ Urology
Italy	Cardiovascular System	Otorhinolaryngology
Switzerland	Hygiene & Public Health	Psychiatry
Australia	Urology	Pathology/ Otorhinolaryngology
France	Oncology	Dermatology/ Endocrinology
Netherlands	Dermatology	Gastroenterology
Austria	Urology	Fertility
Bangladesh	Pathology	Hygiene & Public Health

The following table indicates the three most important countries in each subfield.

Subfield	*Countries with Highest Affinities*		
	First rank	*Second rank*	*Third rank*
Internal Medicine	USA	UK	Japan
Cardiovascular System	Italy	UK	USA
Dermatology & Veneral Diseases	UK	Germany	USA
Endocrinology	USA	UK	Switzerland
Hygiene & Public Health	USA	UK	Switzerland
Immunology	USA	UK	Japan
Neurology	USA	Canada	Sweden
Oncology	USA	UK	Germany
Ophthalmology	USA	UK	-
Pharmacology	USA	Japan	Germany
Radiology & Nuclear Medicine	Germany	USA	UK
Urology	USA	Sweden	Austria
Veterinary Medicine	UK	USA	Germany

Correspondence Analysis was performed to examine the structure of multivariate relationship between India's thirteen major partners and 24 subfields of Clinical Medicine (*INM*, *CAR*, *DEN*, *DER*, *END*, *FER*, *GAS*, *HEM*, *HYG*, *IMM*, *NEU*, *OPT*, *OTO*, *PAT*, *PED*, *PHA*, *PSY*, *RAD*, *RES*, *SUR*, *TRO*, *URO*, and *VET*).

Eigen values issued by the Correspondence Analysis indicate wide variations in the amplitudes of cooperation profiles of these thirteen countries. The first four factorial axes, summing up 70% of the total variance provide the most parsimonious representation of the data. The remaining axes, indicating very small proportions of variance, represent 'white noise' in the multidimensional data. The results of Correspondence Analysis are summarized in Figure 26.



Variance explained
Axis 1 : 26.6%
Axis 2 : 18.4%
Axis 3 : 13.4%
Axis 4 : 11.7%

About 70% of the total variance (information) *in the multidimensional data is captured in* the four – dimensional subspace

Fig. 26: Summary of correspondence analysis (Clinical Medicine)

11. Transnational Links in Biomedical Research

Indian scientists had contributed 5010 articles (*Articles*, *Reviews*, *Notes* and *Letters*) in the mainstream journals in *Biomedical Research*, covered by the *Science Citation Index*. Of these, 666 articles were internationally coauthored, involving an aggregate of 831 cooperation links with 56 countries.

The distribution of cooperation links among the cooperating countries is highly skewed – the top five countries: USA, Germany, UK, Japan, France and Canada account for 88% of all cooperation links. The remaining 51 countries account for only 12% of all links.

Figure 27 indicates India's affinities towards its twelve partner countries, each accounting for at least 1% of all transnational links in this field.

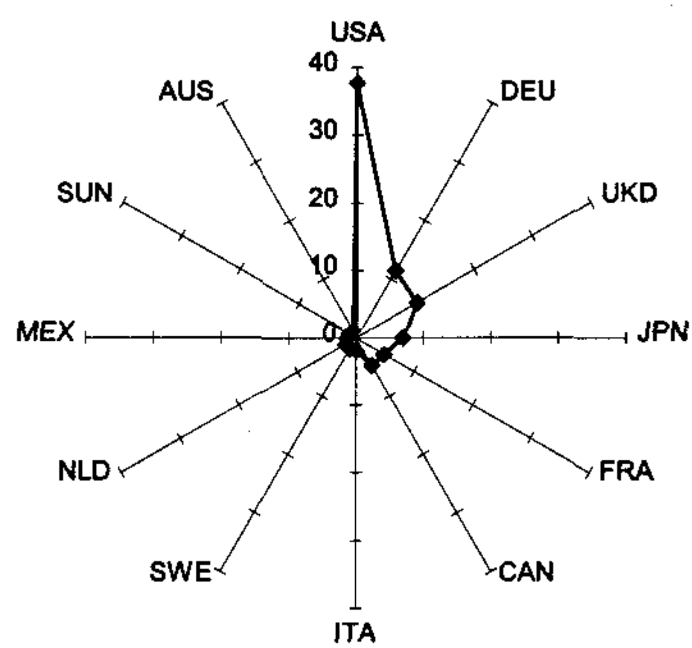


Fig. 27: India's linkages in Biomedical Research (1990-1994)
(Affinity Index)

There are considerable inter - field differences in India's propensity to attract international cooperation. The proportion of internationally coauthored articles varies from a low of 6.03% in *Biomedical Engineering* to a high of 33.33% in *Virology*. The latter subfield also tends to attract more multilateral cooperation.

There are important differences among the cooperating countries in the choice of subfields for cooperation with India. These variations can be visualized along two dimensions — inter - field differences in a given country and inter - country differences in a given field. The affinity profiles of five major countries may be visualized from Figure 28.

The first two important cooperating countries for each subfield are identified in the following table:

Subfield	*Country*	
	First rank	*Second rank*
General Biomedical Research	USA	DEU
Anatomy & Morphology	USA	DEU, UK, FRA
Biochemistry & Molecular Biology	USA	DEU
Biomedical Engineering	USA, DEU	FRA
Cell Biology	DEU	JPN
Embryology	USA, UK	JPN, CAN
Genetics & Heredity	USA	UK
Microbiology	USA	JPN
Nutrition & Dietetics	USA	CAN
Parasitology	UK	USA
Physiology	USA	CAN
Biophysics	USA	UK
Virology	USA	UK

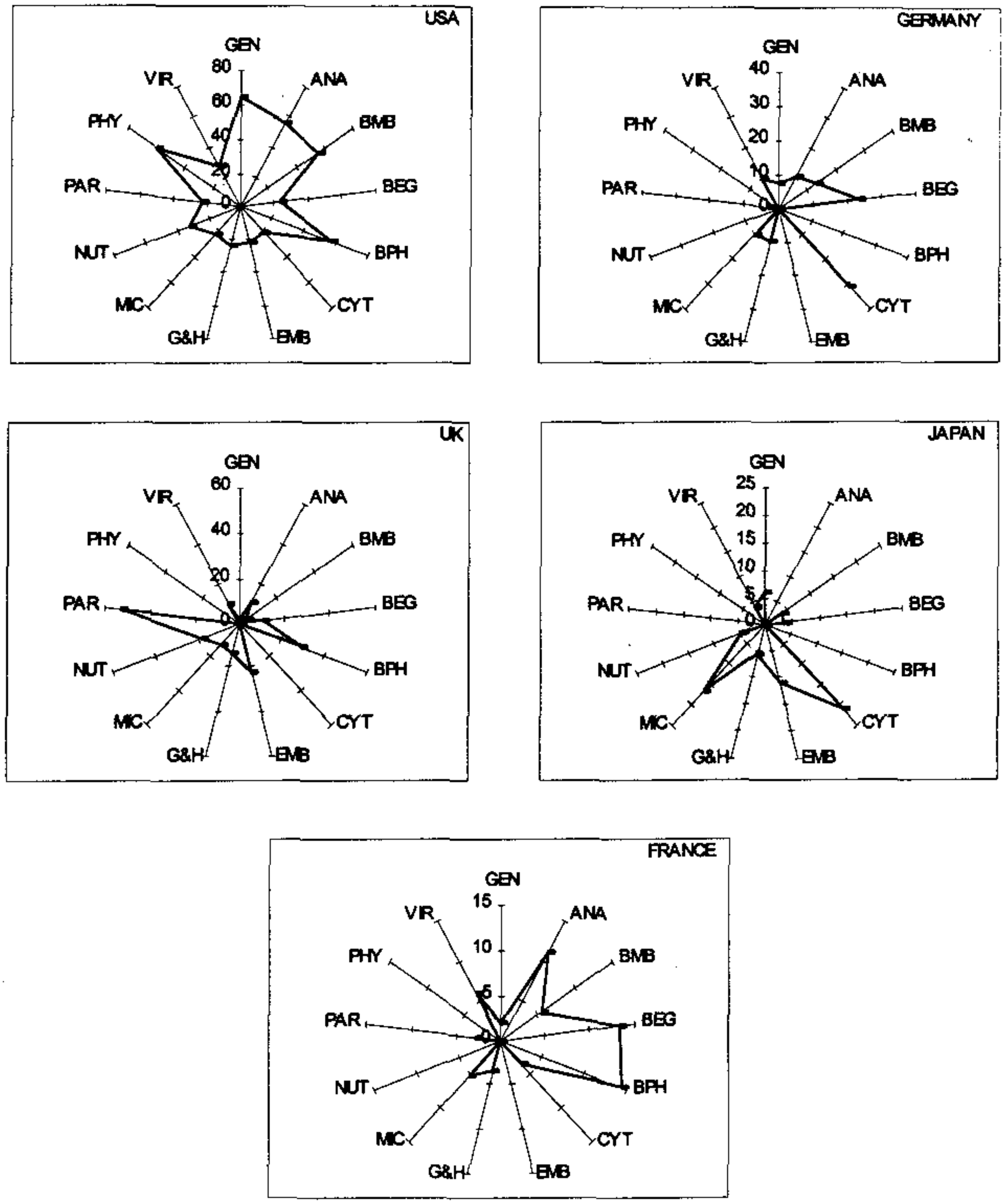


Fig. 28: India's affinities towards major cooperating countries in different subfields of Biomedical Research (1990-1994)
(Affinity Index)

Structure of Transnational Cooperation

The multivariate structure of cooperation links of twelve significant countries (USA, Germany, UK, Japan, Canada, Italy, Sweden, Netherlands, Mexico, Russia and Australia) in thirteen subfields of *Biomedical Research* was analyzed through Correspondence Analysis. Eigen values issued by the Correspondence Analysis indicated wide variations in the cooperation profiles of different countries.

The results of Correspondence Analysis are summarized in Figure 29.

12. Transnational Links in Engineering & Technology

India had published 4316 articles (*Articles, Reviews, Notes* and *Letters*) in the *SCI* - covered journals in *Engineering & Technology* during the five - year period: 1990 - 1994. Of these, 482 (i.e. 11% articles) were internationally coauthored, indicating 538 cooperation links, spanning over 44 countries. The top eleven countries (USA, Canada, Germany, UK, Japan, Switzerland, Bangladesh, France, Italy, Mexico and Australia) accounted for about 80% of all cooperation links. Figure 30 depicts India's affinities towards these countries.

Inter - Field Differences in Transnational Cooperation

There are strong inter - field differences in India's propensity to attract international cooperation.

Civil Engineering is the most internationalized subfield. About one fourth of all articles in this subfield are internationally coauthored. *Aerospace Engineering, Metals & Metallurgy* and *Telecommunication* have above average values of *Internationalization Index* (*INI*). *Electrical & Electronics Engineering* and *Mechanical Engineering* have about average values of *INI*. The values of *COI* also reveal a similar trend. *Nuclear Technology* has less than average level of internationalization, but involves relatively more frequent multilateral cooperation than the other subfields of *Engineering & Technology*.

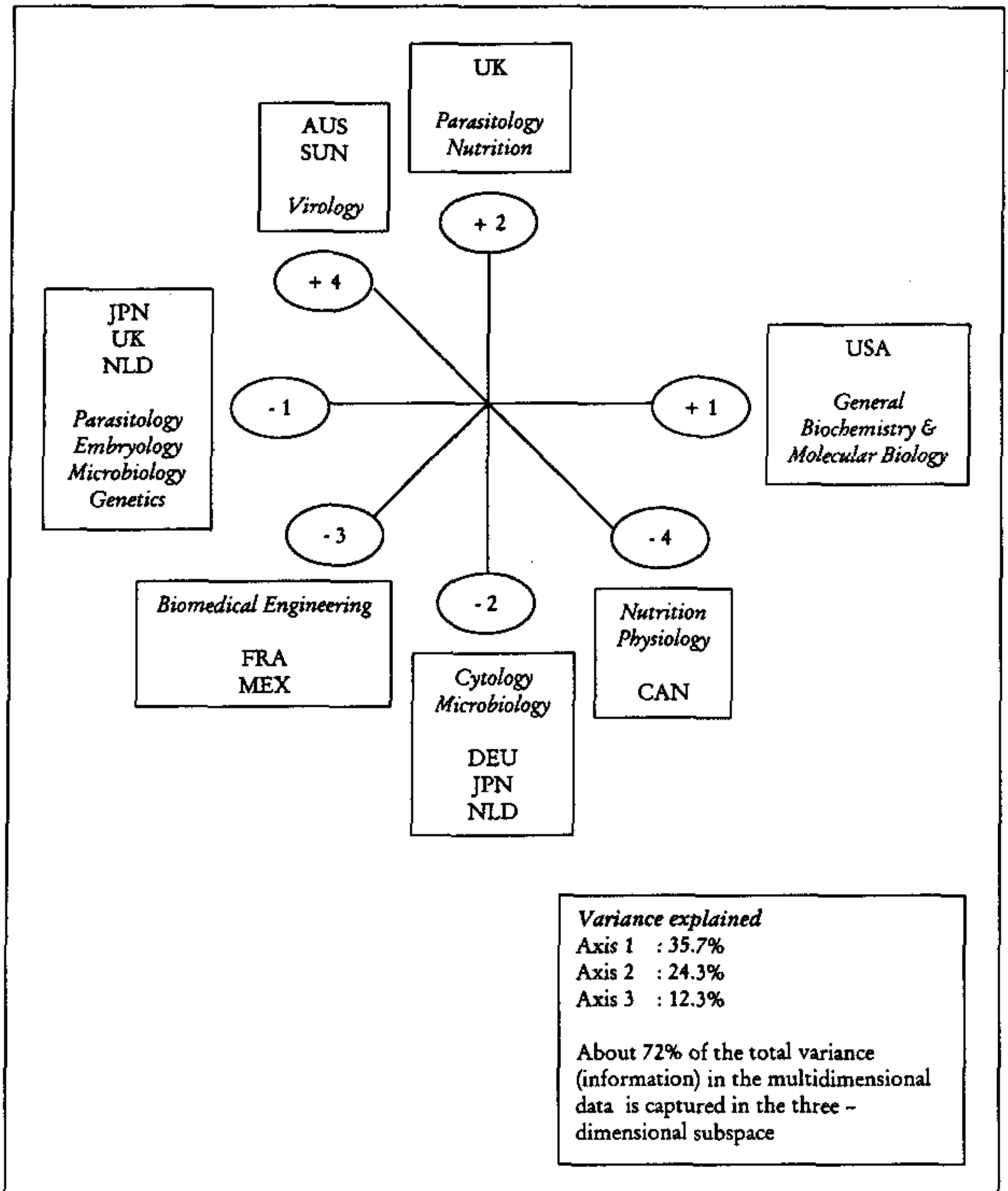


Fig. 29: Summary of correspondence analysis (Biomedical Research)

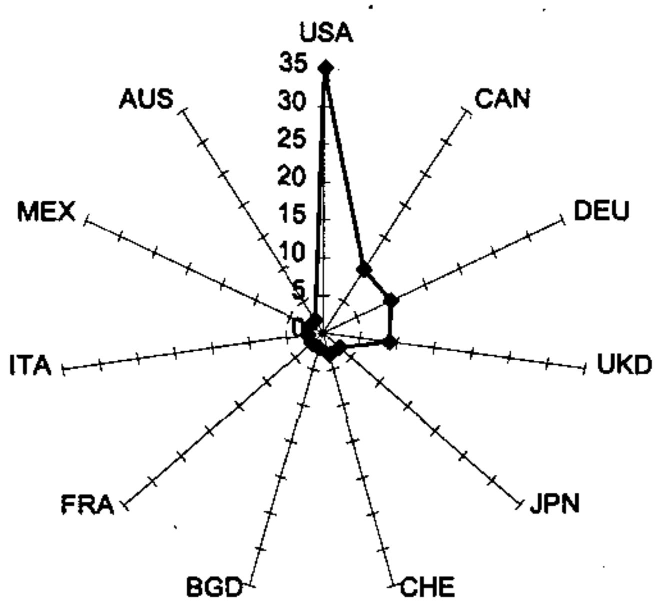


Fig. 30: India's linkages in Engineering and Technology (1990-1994)
(Affinity Index)

Inter - Country Differences in Transnational Cooperation

Obviously, all the subfields do not receive the same importance by India's partner countries in their cooperation with India. Inter – field differences in the affinity profiles of four major cooperating countries (USA, Canada, Germany and UK) may be visualized from Figure 31.

USA is consistently the most important partner of India in all subfields, except *General Engineering* and *Nuclear Engineering*. The prominence of different countries in the affinity profiles of different subfields may be visualized from the following table.

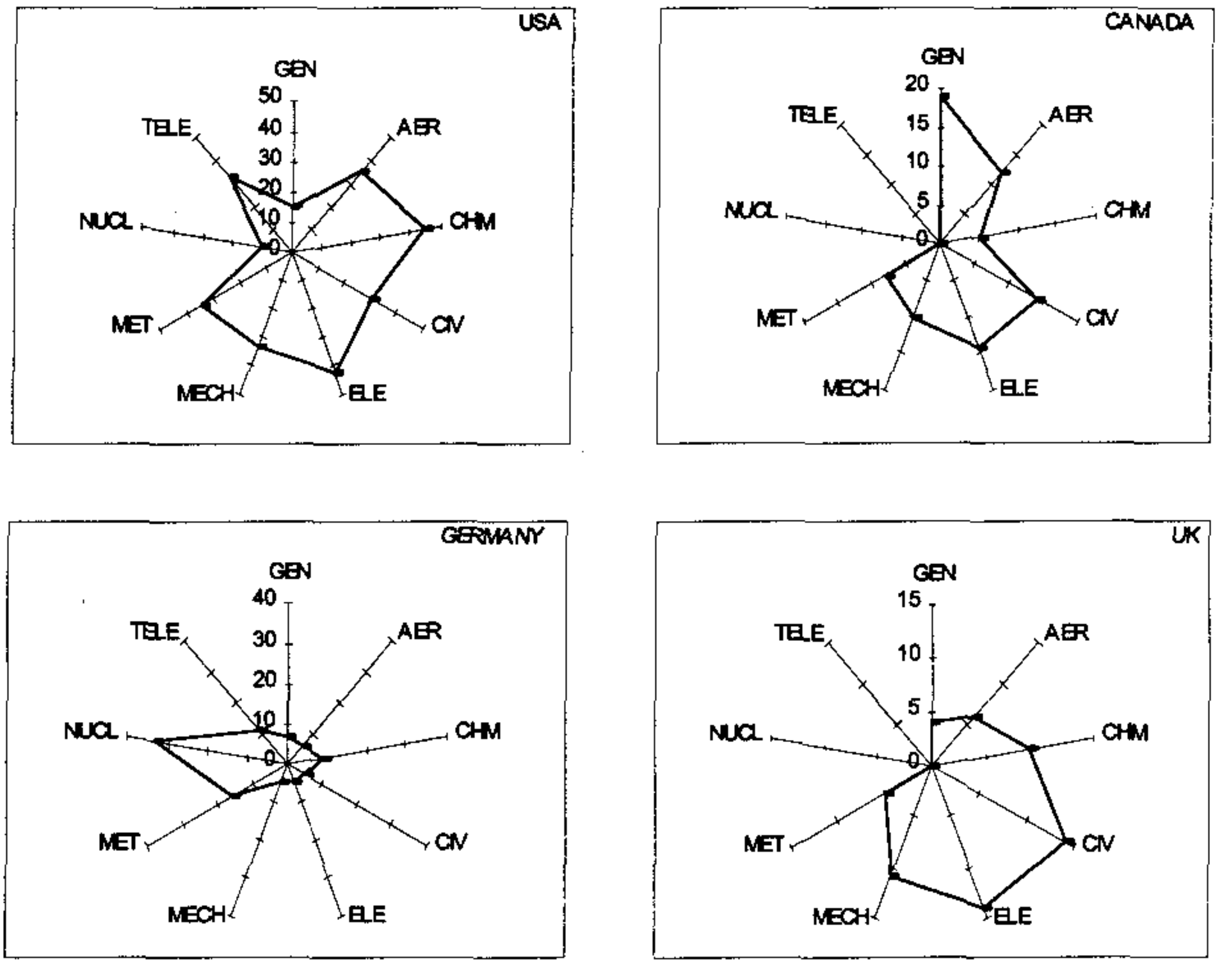


Fig. 31: India's affinities towards major cooperating countries in different subfields of Engineering & Technology (1990-1994)
(Affinity Index)

Subfield	*Country*	
	First rank	*Second rank*
General Engineering	CAN	USA
Aerospace	USA	CAN
Chemical Engineering	USA	DEU, UK
Civil Engineering	USA	UK
Electrical Engineering	USA	UK ≈ CAN
Mechanical Engineering	USA	UK
Metals & Metallurgy	USA	DEU
Nuclear Engineering	DEU	CHE
Telecommunication	USA	JPN

Structure of Transnational Cooperation

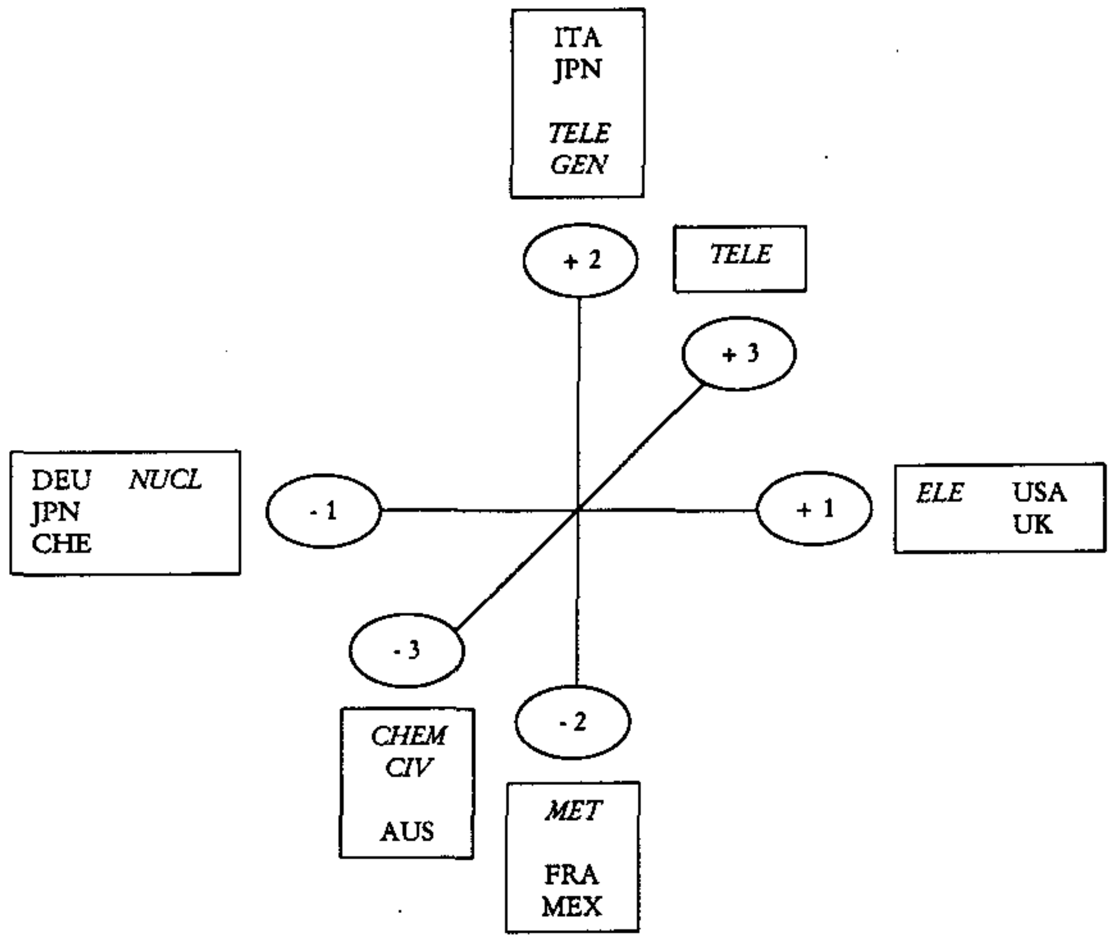
The structure of multivariate relationships between India's eleven major partners with nine subfields of Engineering & Technology (*General Engineering, Aerospace, Chemical Engineering, Civil Engineering, Electrical Engineering, Mechanical Engineering, Metals & Metallurgy, Nuclear Engineering, Telecommunication*) was analyzed through Correspondence Analysis.

Eigen values issued by the Correspondence Analysis indicate wide variations in the amplitudes of cooperation profiles of different countries.

The results of Correspondence Analysis are summarized in Figure 32.

13. Transnational Links in Materials Science

India had contributed 1950 articles (*Articles, Reviews, Notes* and *Letters*) in the mainstream literature in eight different subfields of *Materials Science*. Of these 192 articles (9.85%) were internationally coauthored, indicating a total of 207 cooperation links, spanning over 23 countries.



Variance explained
Axis 1 : 40.3%
Axis 2 : 27.9%
Axis 3 : 12.2%

More than 80% of the total variance (information) in the multidimensional data is captured in the three – dimensional subspace

Fig. 32: Summary of correspondence analysis (Engineering & Technology)

The distribution of cooperation links among the countries is highly skewed. USA alone accounts for about 38% of all cooperation links in this field; UK, which ranks second, is far behind, accounting for about 16% of all links. Only eight countries had more than five cooperation links.

Figure 33 depicts India's affinities towards its six major partners in *Materials Science* (all subfields combined). This figure also represents India's affinities towards its major partners, separately for two subfields (*General Materials Science* and *Ceramics*). Affinity indices for other subfields were not computed, since there were only a few links in those subfields.

The structure of India's cooperation links with its six major partners (USA, UK, France, Germany, Canada and Japan) in eight subfields of *Materials Science* was analyzed through Correspondence Analysis. *As a result of Correspondence Analysis, the set of six countries* can be classified into four typology categories:

Typology Group	*Countries*	*Subfields of Prominence*
Type 1	UK	Coatings & Films Biomaterials
Type 2	Japan	Ceramics
Type 3	Germany	Composites Characterization Paper & Pulp
Type 4	USA, Canada, France	Average Profile

Transnational Links in Computer Science

During the five - year period: 1990 - 1994, India had published 410 articles in *Computer Science* journals, covered in the *Science Citation Index*. Of these, 84 articles (20.5%) were internationally coauthored, indicating 105 cooperation links, spanning over 19 countries. The distribution of cooperation links is highly skewed. USA occupies the most important position in India's transnational cooperation in this field and accounts for about 47% of all transnational links. Canada and Switzerland occupy the second position, each accounting for 11.4% of all cooperation links.

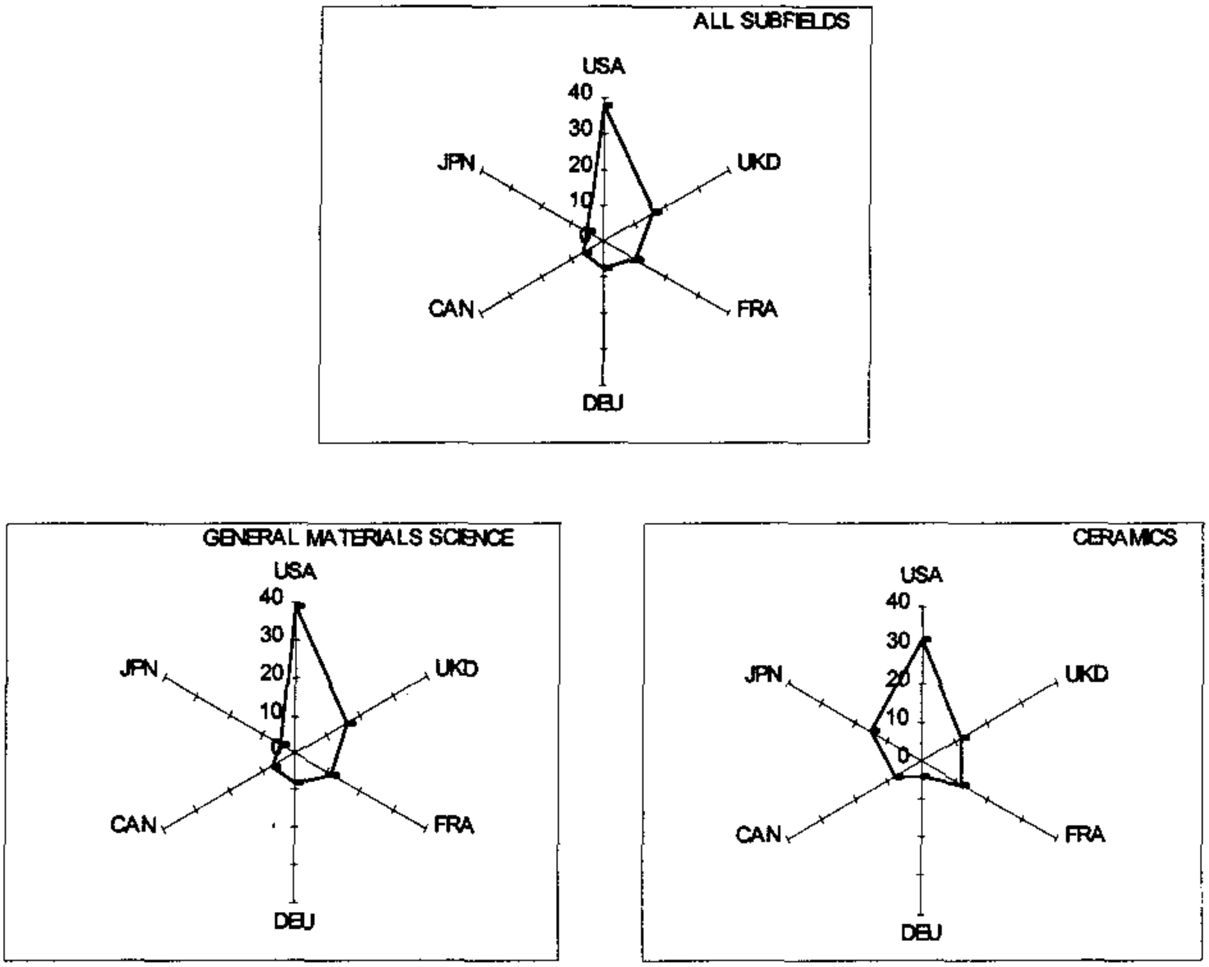


Fig. 33: India's linkages in different subfields of Materials Science (1990-1994)
(Affinity Index)

India's affinities towards its significant partners (USA, CAN, CHE, FRA, DEU, DNK, JPN, NLD and UKD) may be visualized from Figure 34.

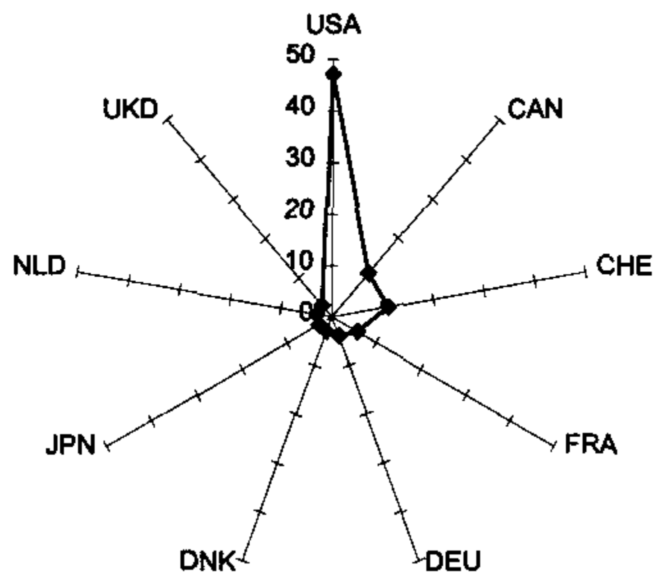


Fig. 34: India's linkages in Computer Science (1990-1994)
(Affinity Index)

Figure 35 indicates inter - field differences in India's affinities towards its major partners (USA, Canada, Switzerland and France).

Correspondence Analysis was performed to analyze the multidimensional structure of relationships between India's four major partners and nine subfields of Computer Science (*Artificial Intelligence*, *Cybernetics*, *Computer Hardware*, *Information Systems*, *Computer Applications*, *Computer Software*, *Robotics*, *Computer Theory* and *Miscellaneous*).

Eigen values issued from Correspondence Analysis indicate large variations in the amplitudes of cooperation profiles of these countries. The results of Correspondence Analysis are summarized in Figure 36.

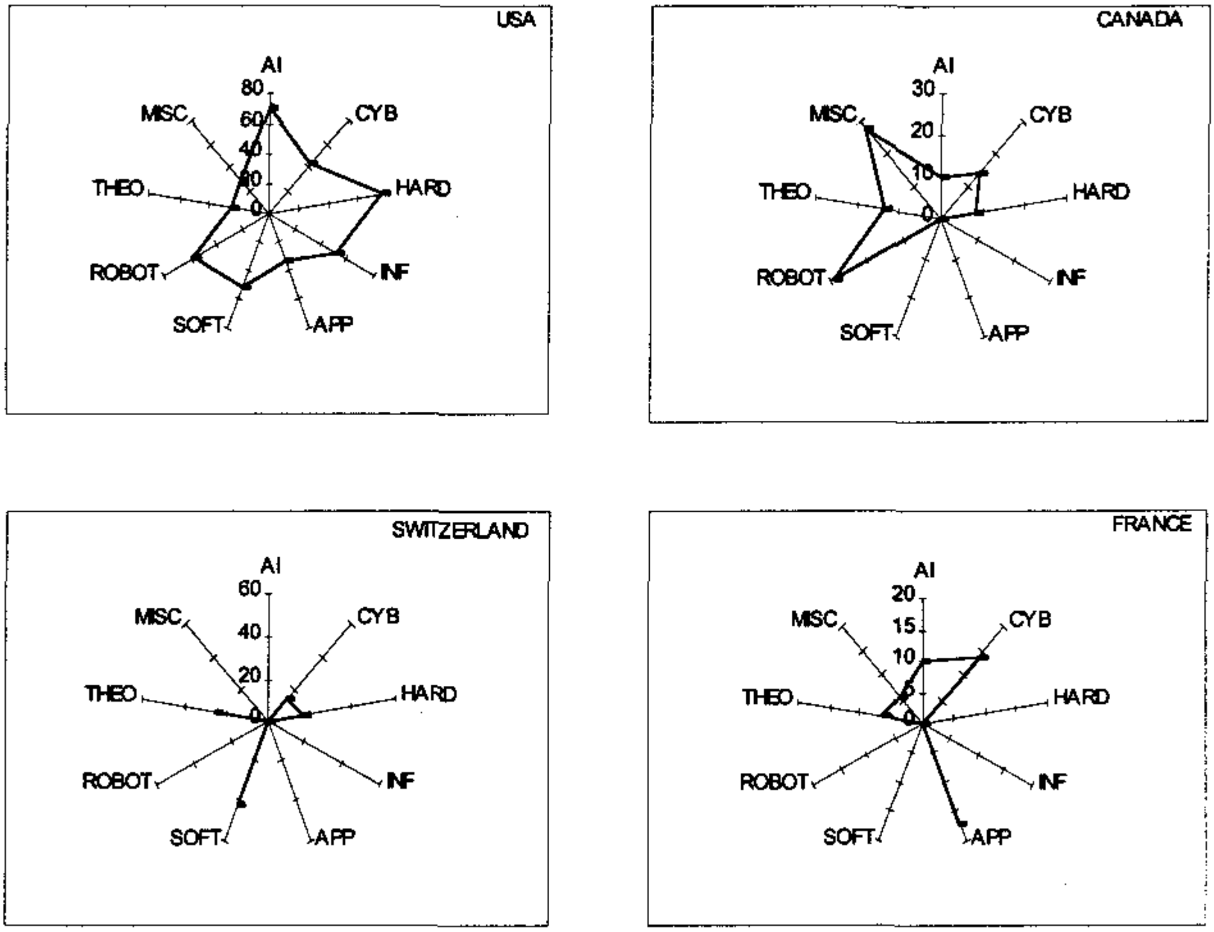
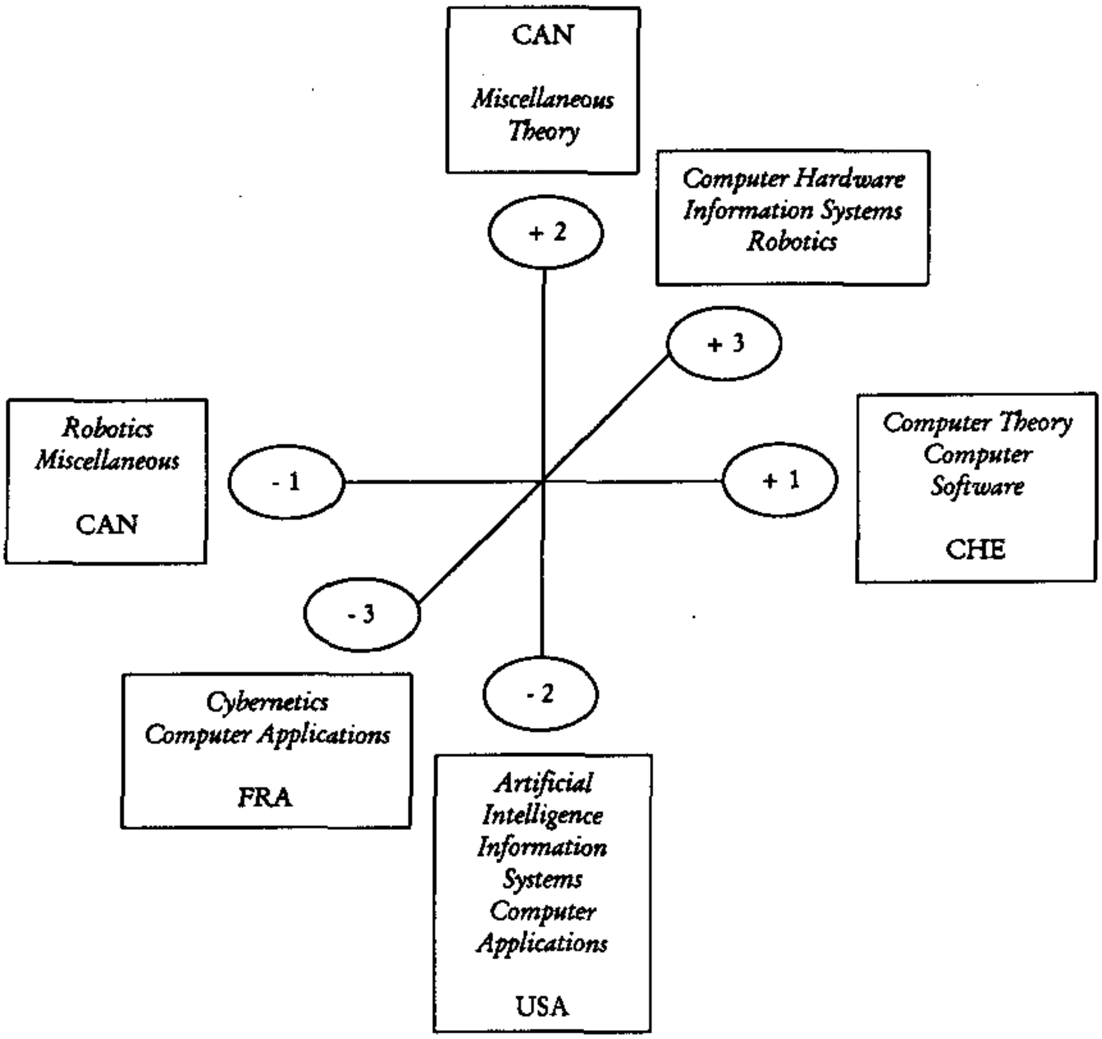


Fig. 35: India's affinities towards major cooperating countries in different subfields of Computer Science (1990 -1994)
(Affinity Index)



Variance explained
Axis 1 : 49.2%
Axis 2 : 29.8%
Axis 3 : 21.1%

All the variance (information) in the multidimensional data is captured in the three – dimensional subspace

Fig. 36: Summary of correspondence analysis (Computer Science)

1 Introduction

Scientific Collaboration

Collaborative research is an important feature of the contemporary organization of scientific inquiry. Statistical data indicate that the percentage of research produced by teamwork, though highly variable across research fields, has been growing monotonically over the past five or six decades (Clarke, 1964; de Solla Price, 1963). Collaboration takes place not only in the immediate work environment of researchers, but also extends beyond institutional and national boundaries.

Collaborative articles are considered as more important than those involving no collaboration. A recent study by Narin and Whitlow (1990) indicates that articles cosigned by authors from two or more countries had received more citations than articles cosigned by authors from two or more institutions in the same country, which in turn received more citations than articles cosigned by authors from the same institutions. These results imply that internationally coauthored articles represent the more significant segment of the world science. According to Arunachalam *et al.* (1994), internationally coauthored articles are published in more prestigious journals. Thus, multicountry articles represent a more important segment of the world science, meriting special attention by both researchers and decision - makers.

Now – a – days, the majority of publications have multiple authorships, *Mathematics* being an exception, where single authorship is more prevalent. Multiple authorship ranges from some 85% in *Chemistry*, *Clinical Medicine* and *Biomedicine* to 70% in *Engineering & Technology* and *Earth & Space Sciences* and to a low of less than 40% in *Mathematics*[1]. The main growth in multiple authorship is almost entirely due to a large increase in the number of publications with four or more authors. This trend, which is observed in almost all fields, reflects the increasing complexity of research problems (NSF, 1990). What are the reasons for this phenomenon?

The most frequently advanced explanation is the '*Specialization*' hypothesis. According to this hypothesis, scientific vision is becoming more specialized and consequently more narrow, which is unable to cope up with the growing complexity of scientific problems that cannot be solved within the domains of narrow specializations. Hence, the imperative of inter – dependence and complementary knowledge and skills of groups of researchers for the advancement of scientific knowledge. This hypothesis has, however, partial validity, since it fails to explain large inter – field differences in the incidence of collaboration. The extent of collaboration is strongly conditioned by the inherent characteristics of research fields.

Another explanation is the so called '*Advantage*' hypothesis, which implies that collaborative relationship bestows certain advantages to the researcher in the accumulation and advancement of scientific knowledge. It provides a mechanism for gaining and sustaining access to recognition in the scientific community. Further, it facilitates not only access to information, support and facilities, but also increases productivity and visibility. Visibility gives an aspiring researcher access to the more important savants of the time. This increases his knowledge of the latest research, which in turn affects the relevance of

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[1]. In Mathematics, the number of authors per article is lower than that in other fields.

his work. Figure 1.1 illustrates the pattern of collaboration of the aspiring researcher with a member of the elite.

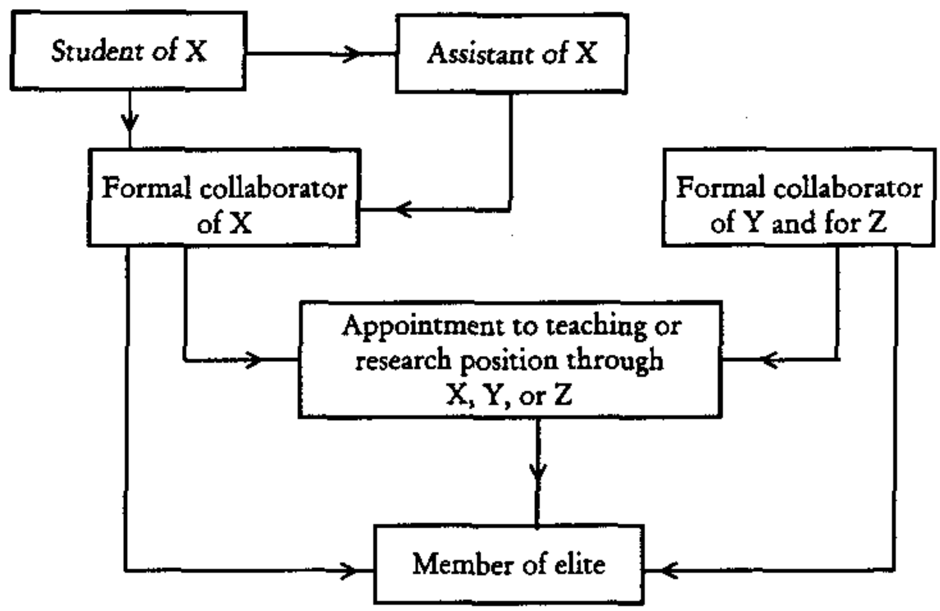

Fig. 1.1: The pattern for collaboration of the aspiring scientists with a member of the elite

Another explanation for the phenomenal growth of collaboration is the '*Complexity*' hypothesis. Scientific and technical problems of today are so complex that they cannot be solved within the frameworks of single disciplines, nor by single individuals, groups, institutions or sometimes even countries. Another facet of '*Complexity*' hypothesis is the ever – growing sophistication and complexity of research technology.

International cooperation is most extensive in 'big science' than in 'little science'. The highest levels of collaboration are observed in fields such as high - energy physics, astronomy, oceanography and space exploration. In these fields, research is organized around unique instruments and facilities, which require teams of experts from several fields. The lowest levels of collaboration are observed in fields which are traditionally viewed as 'little science', although such fields increasingly require sophisticated equipment and facilities.

Beaver and Rosen (1978) have listed the following reasons for scientific collaboration:

Motives of collaboration: a summary		
Access	:	to special equipment and facilities to special skills to unique materials (e.g. chemical compounds) to visibility recognition
Efficiency in	:	use of time use of labour
Others	:	to gain experience to train researchers to sponsor a protegee to increase productivity to multiply proficiencies (thereby increasing access to sources of support, visibility, recognition) to avoid competition (thereby forestalling loss of priority, i.e., recognition) to surmount intellectual isolation need for additional confirmation or evaluation of a problem need for stimulation or cross - fertilization spatial propinquity accident (serendipity)

Source: D. de B. Beaver, R. Rosen (1978)

Types of Collaboration

Collaborative relations among researchers can be classified into the following four categories:

(i.) *Intra - departmental collaboration* — collaboration between researchers within the same department.

(ii.) *Inter - departmental, intra - institutional collaboration* — collaboration between researchers in different departments within the same university or institution.

(iii.) *Inter - institutional, intra - national collaboration* — collaboration between researchers in different institutions in the same country.

(iv.) *Transnational collaboration* — collaboration between researchers in different countries.

The present study focusses on the last category of collaboration, *viz.* transnational collaboration.

Transnational Collaboration

Transnational cooperation in science is becoming more frequent and more extensive and is playing a significant role in the production of scientific knowledge. A study of the scientific community in Europe indicates that international cooperation is one of the powerful determinants of success in science; on the practical side, collaboration with foreign scientists can bring access to funds, otherwise unavailable (Franklin, 1988).

There are a variety of kinds and modes of cooperation between researchers and institutions of different countries. These include international meetings of experts, exchange of scientists and students, sharing of information as well as collaborative research 'projects'. Many of the collaborative 'projects' occur outside the formal inter - governmental agreements or programs. Spontaneous cooperation initiated by researchers is still the major impulse of transnational linkages in science (OECD, 1988). Such informal cooperation is often not recorded in the funding agencies, research councils or academies. Hence, international cooperation can be traced only by the end - results of each collaborative work, which most often takes the form of coauthored articles published in scientific journals.

Articles cosigned by authors from different countries are thus a signature of international cooperation. They are an authoritative indicator of international cooperation and provide more detailed information on the dynamics of the mainstream science than other available indicators (Leclerc, *et al*, 1992). They provide information on the trends and the degree of scientific collaboration of a country in comparison with other countries.

The growth of international scientific cooperation is accompanied by the increase in the number of participating laboratories (or institutions) and of coauthorships between several countries. The growth in the number of cosignees reflects the progress of research coalitions, often activated under the auspices of large international programs (Leclerc, *et al*, 1992).

An indicator of the magnitude of international collaboration is the percentage of all published research papers, which are cosigned by authors from two or more countries. The data indicate a general pattern of continuous growth in scientific collaboration at the world level.

Table 1.1 presents the data on the percentage of internationally coauthored publications in eight macrofields: *Mathematics*, *Earth & Space Science*, *Physics*, *Biomedicine Research*, *Biology*, *Engineering & Technology*, *Chemistry* and *Clinical Medicine* (ranked by the degree of international collaboration).

Table 1.1
Internationally Coauthored Publications as a Percentage of Total World Publications

	1973	1980	1986	1990*
Mathematics	5.5	9.0	13.4	16.5
Earth & Space Science	5.4	9.7	12.4	14.0
Physics	4.4	7.8	10.5	12.0
Biomedicine	3.5	5.7	8.3	9.5
Biology	3.0	4.6	6.5	8.0
Engineering & Technology	2.0	3.9	6.8	8.0
Chemistry	2.4	4.3	6.1	7.5
Clinical Medicine	2.5	3.8	5.7	7.0
Mean	3.7	6.1	8.7	10.3

* OECD estimate.
Source: Science & Engineering Indicators (1987 and 1989), US National Science Board.

Scientific cooperation at the world level is expected to accelerate, probably at a faster rate than in the past on account of the following reasons:

- Political and economic changes in central and eastern Europe are expected to foster greater international cooperation.

- Relatedly, the shift from military to civil research in several countries is likely *to increase opportunities for scientific collaboration.*

- Greater cooperation is also likely to result from concerns with environmental problems and climatic changes that require collaboration at regional and global levels.

- Cooperation is now easier and less expensive than in the past, because of modern telecommunication facilities, which permit researchers to 'collaborate at a distance'.

Objectives of the Study

The main purpose of this study is to map out the pattern of transnational linkages of Indian science during the five year period: 1990 - 1994. For this purpose, a number of bibliometric indicators are constructed and used:

(i.) To observe the magnitude and pattern of transnational linkages of Indian science in different fields and subfields.

(ii.) To identify major partners (i.e. countries) having collaborative links with India and assess the pattern of bidirectional affinity between India and its major partners.

(iii.) To examine the magnitude and pattern of India's transnational linkages *vis - a - vis* those of some other countries.

(iv.) To assess India's status in the international network of science and its relationship with different regions of the world.

Implications for Science Policy

Internationalization of research has altered the state of equilibrium, which became established within domestic borders. It has overturned the traditional modes of exchange of communication among scientists. As a result, international scientific cooperation has become one of the major and recurrent themes of national science policy. Domestic scientific activity has to look beyond national boundaries and take into account the external factors outside its immediate influence. The effectiveness of the domestic framework is no longer dissociable from the external elements which condition its development (Salomon, 1964).

It is expected that the data and analyses presented in the study would provide useful insights into the pattern of India's external relations in science and its strengths and weaknesses.

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2 Methodology

Measurement of Collaboration

In this study, scientific collaboration is measured by coauthorships, which signify a formal acknowledgment of joint research. Here, the principal assumption is that the writing of coauthored articles is a manifestation of a fairly active linkage between researchers, closer and more active than the exchange of materials and information or sharing of research facilities. However, it is important to note that bibliometric measures under - estimate the level of mutual collaboration. As pointed out by Luukkonen *et al.* (1992), all collaborative efforts do not necessarily end up in coauthorships. Further, it is quite possible that researchers who had collaborated extensively may still write separately authored articles; particularly in the case of large teams, self - contained units in different countries (or institutions) may each publish their own parts of the research project.

International coauthorship is defined in terms of articles cosigned by authors from different countries. These coauthorships are used to identify relationships by means of *institutional affiliation of the authors and not by means of their nationalities.* An important, but controversial, issue in coauthorship analysis is how to assign credit of a coauthored article to a unit (*country or institution*). *Since the objective of the study is not* coauthorships *per se*, but the international relationships which they pattern, we have adopted the 'whole count' method in preference to 'fractional counting'. Here, we assume that a contact between countries is always a fixed single unit, which does not vary with the number of countries involved in a coauthored article. A contact is a link that always has the same value between any two countries, irrespective of the number of participants. For example, if an article has authors from three countries (A,B,C), three coauthorship linkages would occur: A $\leftrightarrow$ B, B $\leftrightarrow$ C, A $\leftrightarrow$ C. If the number of authors from a given country exceeds one, the collaboration with that country is registered only once. In other words, a link cannot be valued as one - third in one collaboration and one - fourth in another at macro - level analysis. Whatever the number of scientists, institutions or countries involved in a coauthorship, one link is always established between each pair of participating countries.

In the analysis of international collaboration, it is useful to distinguish between internationally coauthored articles (*ICOA*) and international cooperations (*COP*). If an article is cosigned by authors from three countries, say India, USA and Japan, it counts for one *ICOA*, but it counts for two *COP*'s (of India), one with USA and the other with Japan.

Choice of Database

Despite certain limitations, which are amply discussed in the literature, *Science Citation Index (SCI)* is by far the most important database for scientometrics research (Carpenter & Narin, 1981). This is due to the following reasons:

(i.) The *SCI* contains complementary publication and citation data which allows the development of publication - and citation - based indicators.

(ii.) The *SCI* is comprehensive. It covers the entire spectrum of scientific fields.

(iii.) The *SCI* includes every article in its covered journals, thus obviating indexer bias in the selection of articles.

(iv.) Using a single source avoids the problem of overlap, since many of the abstracting and indexing services cover overlapping sets of journals, necessitating massive screening to avoid double counting in analysis based on a combination of different abstracting services.

(v.) The *SCI* is recognized for timeliness. Other abstracting services are *sometimes years behind for a specific subject area or a specific country.*

(vi.) The *SCI* is the only database which includes the corporate addresses of all the authors of an article, whereas other databases give the corporate address of only the first author.

On account of these reasons, the *SCI* is the most appropriate database for the study of scientific collaboration. It should, however, be recognized that the *SCI* is not completely balanced and representative of all of the world's science. It is extremely selective in the choice of journals, which represent the mainstream science (Frame & Carpenter, 1979). Currently, it includes the central core of about 4500 scientific journals.

The Data

Two sets of data were taken from the CD - ROM version of *Science Citation Index (SCI).* The first set comprises publications signed by an author (either as principal author or a coauthor) based in India. This set is used for mapping the linkages of Indian science within and outside the country. The second set, comprising dyadic linkages among different countries, is used for evaluating India's status in the international network of science. Other researchers (e.g. Okubo *et al.*, 1992) have used the 'fixed journal method' (i.e. the constant set of journals) for examining the patterns of transnational linkages in science. However, this method prevents the tracking of transnational linkages in rapidly developing fields such as *Superconductivity*, *Computers*, *AIDS*, etc. Instead, we have used the 'dynamic' set of journals to capture the pattern of linkages in rapidly developing areas.

Data on Linkages of Indian Science

The first set comprising articles signed or cosigned by Indian authors listed in the *SCI* data - base was downloaded from the CD - ROM's for five indexing years: 1990 - 1994. The downloaded data comprises more than 54,000 records of publications. Each record comprises the following elements:

- Names of all authors.
- Source: Title of the journal, volume and year of publication, page numbers.
- Title of the publication.
- Number of references cited.
- Type of publication: Article, research note, review, etc.
- Addresses of all authors in the following format: Name of the institution or university; name of the department; name of the city, name of the country.

The downloaded data is not amenable to retrieval or statistical analysis unless it is transformed into a database.

Initially, we used the UNESCO software *CDS - ISIS* for transformation of the downloaded data into a useable database. This software was particularly chosen in view of its flexible format and interface with a statistical software *IDAMS* (Internationally Developed Data Analysis and Management Software Package) developed by UNESCO. But due to certain technical limitations of the software and logistic reasons, we had to abandon the idea of using *CDS - ISIS*. Instead, we used the commercially available software *FOXPRO, which has interface with the well - known statistical software SPSS* (Statistical Package for Social Sciences). *FOXPRO* has also a limitation. It has a fixed format, which means that one has to define as many variables as the number of addresses in the record which has the largest number of addresses. Some of the records had more than 100 coauthors and therefor more than 100 addresses (in one case, there were 300 addresses).

The transformation of 54,000 records into *FOXPRO* format would roughly require diskspace of more than 400 MB. This problem was overcome by partitioning of the downloaded data into two files: one in which the number of addresses did not exceed 10. The second file had only 128 records. It was processed as follows: Different countries and different institutions were identified and coded manually prior to computerization.

Both the data files were further processed to filter out documents which do not indicate research output. *ISI* classifies the documents into twelve categories:

1. Article	7. Letter
2. Biographical Item	8. Meeting Abstract
3. Book Review	9. Note
4. Correction	10. Reprint
5. Discussion	11. Review
6. Editorial	12. Software Review

Obviously, some of these categories do not represent research output and their inclusion in the datafiles will distort the mapping of Indian science. Computer Horizons Inc. (*CHI*) database (which is derived from the *ISI* database) includes articles, notes and reviews.

Articles are the basic means of communicating new scientific knowledge. *CHI* includes notes, because shorter publications in many important journals are classified as 'notes' and these are an important part of the scientific literature. It can be argued that a review does not generally constitute an original piece of research, but rather a synthesis of work done by others. It is not so much an indication of research output as of scholarship. The counter argument is that scholarship is a form of research. Moreover, review authors are generally regarded as authorities in their field. Hence a review article does provide information on the relative standing of different countries.

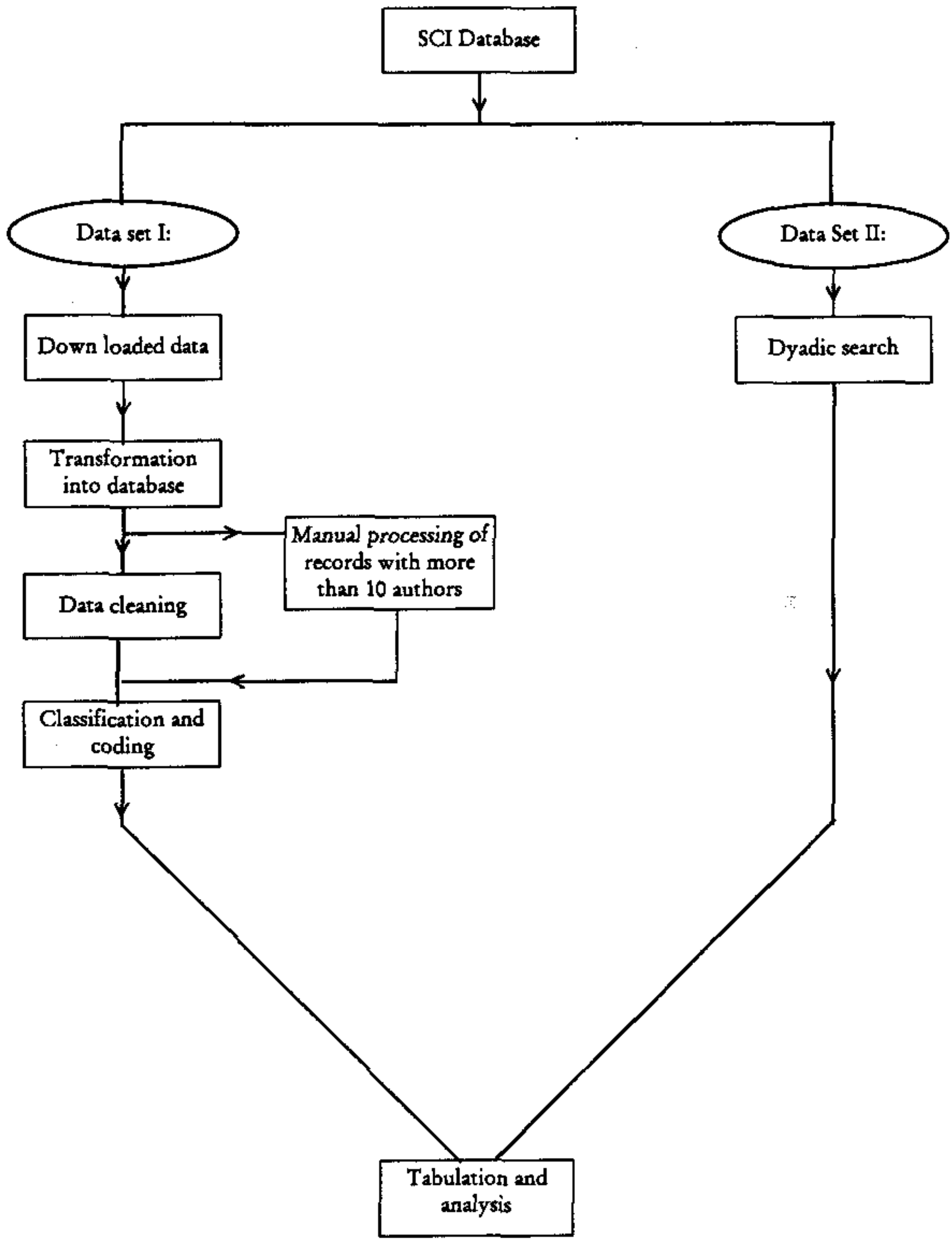

Fig. 2.1: Schematic representation of data collection procedure and analysis

'Meeting abstracts' account for 18 - 20% of the *SCI* covered documents. These are not included in *CHI* for the following reasons:

(i.) To avoid double counting. Many scientific results initially presented at meetings are subsequently published as journal articles.

(ii.) Review procedure for such contributions are less rigorous than for articles.

CHI also does not include editorials and letters as they do not normally report substantive research contributions.

The Hungarian database (*ISSRU*) which is also derived from *ISI* data, includes articles, notes, reviews and letters. *ISSRU* contends that although all the anecdotic arguments on the 'originality', 'basicity', 'fundamentality', 'importance' or 'scholariness' of one or another type of journal articles contain a certain grain of reliability, it is advisable to use a more homogeneous and universal criterion for inclusion or exclusion of certain types of documents. One such criterion is 'Citation Impact'. As such, it seems desirable, when constructing indicators of national scientific output, to include in the count all publication types which are cited at an appreciable level. The citation rate of letters is comparable to or in some cases even higher than that of articles. Further, in most of the commonwealth countries, including India, the production of letters amounts to a considerable part of the total scientific output. In the case of India, letters constitute about 4% of all publications.

We have followed *ISSRU*'s procedure and included articles, notes, reviews and letters in the construction of datafiles for mapping of cooperation links of Indian science.

Data cleaning

The names of institutions listed in the *SCI* database are not standardized. The large variety of names referring to the same research institution encountered in the address lists were unified semi – automatically.

Classification of articles

Classification of articles into fields or subfields is a neuralgic point of scientometrics research (Schubert & Braun, 1985). Classification of more than 50,000 articles is obviously an uphill task that would require several analysts with familiarity in different disciplines. Hence, we have adopted the procedure developed and tested by Computer Horizons Inc. (*CHI*). According to this procedure, the journals are classified into subfields, subfields into fields, and each article is classified into the field and subfield of the journal in which it is published. This methodology is based on the assumption that science journals are the fundamental units of assessment. Although exceptions are there, science journals, as a rule, encompass definite research areas (frequently a single 'paradigm') and also a standard of quality guaranteed by the editorial gatekeeping process. Therefore, it seems justified to assign a set of publications to subject fields on the basis of the field classification of journals.

The starting point of our classification schema is the *SCI* journal classification system. *SCI* classifies the journals into subfields, using a combination of techniques — journal - to - journal citation patterns, keyword analysis and user feedback (Katz & Hicks, 1995). A major limitation is that about 20% of all journals are classified into more than one subfield. Further, 62 journals are classified as 'Multidisciplinary' as they include articles from diverse fields. Journals like *Nature, Science, Current Science, Journal of Scientific and Industrial Research* belong to this category. However, this does not mean that these journals cover only multidisciplinary research. It only means that their field is not identified.

There is, however, no standard classification of subfield categories into macrofield categories. This is primarily due to the intersections of subfield categories. Therefore any attempt to develop a standard classification system is bound to be somewhat arbitrary. Theoretically, one can agglomerate subfield categories into macrofield categories through cluster analysis or factor analysis. Remi Barre (1991) has classified 107 research fields in the *PASCAL* database into 13 macrofields, using cluster analysis.

A few examples of agglomeration of subfield categories into macrofields categories are mentioned below:

1. Institute of Scientific Information (*ISI*)

1.	Physics	10.	Clinical Medicine
2.	Chemistry	11.	Neurosciences
3.	Materials Science	12.	Pharmacology
4.	Engineering	13.	Biology & Biochemistry
5.	Computer Science	14.	Agricultural Sciences
6.	Mathematics	15.	Geosciences
7.	Astrophysics & Astronomy	16.	Ecology & Environment
8.	Immunology	17.	Plant & Animal Sciences
9.	Molecular Biology & Genetics		

2. R. BARRE (1991) (Observatory of Science and Technology)

1.	Fundamental Physics	8.	Earth Sciences
2.	Fundamental Life Sciences	9.	Space & Environmental Sciences
3.	Applied Physics & Chemistry, Electronics	10.	Renewable Resources Sciences
4.	Applied Chemistry, Materials Science & Technology	11.	Agriculture & Food Science & Technology
5.	Electronics	12.	Medical and Health Sciences & Technology
6.	Computer Science & Technology	13.	Medical Sciences & Engineering
7.	Mechanical & Chemical Engineering		

3. BRAUN, GLANZEL and GRUPP (1995)

1. Mathematics
2. Life Sciences
3. Electrical Engineering
4. Nuclear Sciences
5. Mechanical, Civil & Other Engineering
6. Inorganic Chemistry & Chemical Engineering
7. Analytical Chemistry
8. Physical Chemistry
9. Organic Chemistry
10. Applied Physics
11. Solid State Physics
12. Geosciences
13. Other Physics
14. Ecology
15. Food Science & Agriculture
16. Biotechnology
17. Microbiology
18. General Biology
19. Pharmacology & Pharmacy
20. Public Health
21. Pathology
22. Neurosciences
23. Reproduction Medicine & Geriatrics
24. General Medicine
25. Internal Medicine
26. Research Medicine
27. Immunology

4. Computer Horizon, Inc. (*CHI*)

1. Biology
2. Biomedical Research
3. Chemistry
4. Clinical Medicine
5. Earth & Space Science
6. Engineering & Technology
7. Mathematics
8. Physics
9. Psychology
10. Multidisciplinary

5. **National Institute of Science, Technology and Development Studies (*NISTADS*)**

We have classified the subfields into the following macrofields:

1. Mathematics (MAT)
2. Physics (PHY)
3. Chemistry (CHM)
4. Biology (BIO)
5. Earth & Atmospheric Sciences (EAS)
6. Food & Agriculture Research (AGR)
7. Clinical Medicine (CLI)
8. Biomedical Research (BIM)
9. Engineering and Technology (ENT)
10. Computer Science (COM)
11. Materials Sciences (MTS)
12. Multidisciplinary (MUL)

Data on dyadic linkages

The second set of data comprises inter - country linkages among the top 45 countries, which were identified on the basis of their publication output. These countries account for more than 95% of the world output of articles included in the *Science Citation Index*. The data yield a matrix of inter - country collaboration, where the number of coauthorships between each country pair is plotted.

Analyses

A number of indicators have been constructed from coauthorship data, which are used to analyze the following aspects of transnational linkages of Indian science:

(i.) India's status and role in the international network of science, *vis - a - vis* other countries.

(ii.) The level of India's participation in international collaboration in different fields or subfields of science.

(iii.) Identification of major partner countries in different fields and subfields of science.

(iv.) Multivariate structure of India's relationships with its major partners in different research fields.

The analyses are carried out at two different levels: (i) macrofields and (ii) subfields. Analysis at the level of macrofields provides an overview of the topology of collaboration, whereas that at the level of subfields provides its fine - grained structure. Univariate and multivariate statistical techniques are used for description and analysis of the data. Main trends are depicted by means of infographics and algorithmic mapping.

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3 Global Network of Science

This chapter seeks to examine India's status in the global network of science and the changes that have occurred therein during the ten - year interval between 1982 - 1984 and 1992 - 1994. Its main concerns are —

1. What is the volume and pattern of international cooperation in science and how have they changed over time?
2. Which are the most important partners of India and some other countries?
3. What is the structure of the global network of science and how has it changed over time?
4. Which are the countries that are more active in international cooperation i.e. occupy a central position in the network and which are the countries that occupy a peripheral position in the network? How have their positions changed over time?

The Data

The data on publication output and coauthorship links of 45 major countries were taken by means of dyadic searches from the CD - ROM version of *Science Citation Index* (*SCI*) for two time - spans: indexing years 1982 - 1984 and 1992 - 1994. The data for 1982 - 1984 covers 46 countries - West and East Germany separately, whereas the data for 1992 -

1994 includes unified Germany. The three - year time - span was chosen to smoothen any year - to - year fluctuation in the data. The countries were identified on the basis of their publication output above the threshold of 1500 publications in five years (1989 - 1993). This threshold was necessary to keep the data analysis within manageable limits and to filter out noise in the data. These countries account for more than 95% of the world *output registered in the SCI database (Braun, Glanzel and Grupp, 1995). Hence, for all* intents and purposes, the network of coauthorship links between these countries can be considered as the global network of science. The names of these countries and their ISO triliteral codes are given below —

Argentina (ARG)
Australia (AUS)
Austria (AUT)
Belgium (BEL)
Brazil (BRA)
Bulgaria (BGR)
Canada (CAN)
Chile (CHL)
China (PRC)
Czechoslovakia (CSK)
Denmark (DNK)
Egypt (EGY)
Finland (FIN)
France (FRA)
Germany
  East Germany (GDR)
  West Germany (FRG)
  After unification (DEU)
Greece (GRC)
Hongkong (HKG)
Hungary (HUN)
India (IND)
Ireland (IRL)
Israel (ISR)
Italy (ITA)
Japan (JPN)
Korea (South) (KOR)
Mexico (MEX)
Netherlands (NLD)
New Zealand (NZL)
Nigeria (NGA)
Norway (NOR)
Poland (POL)
Portugal (POR)
Romania (ROM)
Russia (incl. CIS countries) (SUN)
Saudi Arabia (SAU)
Singapore (SGP)
South Africa (ZAF)
Spain (ESP)
Sweden (SWE)
Switzerland (CHE)
Taiwan (TWN)
Turkey (TUR)
United Kingdom (UKD)
USA (USA)
Venezuela (VEN)
Yugoslavia (YUG)

In all tables and figures, the countries are identified by their ISO codes.

Concepts and Indicators

The cooperative efforts (*COP*) made by a given set of countries can be measured by counting the links created through coauthored articles. Using the counts of cooperation links, we have constructed three indicators for assessing and comparing the cooperative efforts (*COP*) made by different countries:

(i.) Participation Index (*PAI*)

(ii.) Cooperation Index (*COI*)

(iii.) Affinity Index (*AFI*)

Participation Index (*PAI*)

Participation Index (*PAI*) shows the degree of participation of a country in the *international scientific community. PAI is computed as follows:*

$$PAI = \frac{\text{Total } COP\text{'s of a country}}{\text{Total } COP\text{'s of the world}} \times 100$$

Here, the world means the set of 45 countries.

Cooperation Index (*COI*)

This index measures the incidence of cooperation links in a given field compared to publication output in that field.

$$COI = \frac{\text{Number of cooperation links}}{\text{Number of all articles}} \times 100$$

Affinity Index

Affinity Index (*AFI*) is a measure of the amount of scientific cooperation between a given country A and another country B compared to the total cooperation of the given country with the entire world (WRD). *AFI* is therefore the number of *COP*'s between A and B divided by the total *COP*'s A has with the rest of the world. It indicates the scientific affinity of A toward B (A→B).

$$AFI\,(A\rightarrow B) = \frac{COP\,(A\leftrightarrow B)}{COP\,(A\leftrightarrow WRD)} \times 100$$

Similarly, affinity of B towards A (B→A) is computed as follows:

$$AFI\,(B\rightarrow A) = \frac{COP\,(B\leftrightarrow A)}{COP\,(B\leftrightarrow WRD)} \times 100$$

Affinity index is used to find how B situates in A's international activity with the world. It also reciprocally finds how A situates in B's international activity with the world.

The index *PAI* measures the status of a country in the international network of science, but it does not indicate the extent of its effort in developing cooperation links, since the index *PAI* does not take into account the scientific size of the country. A small country with a large proportion of internationally coauthored articles would rate low on *PAI*. Hence, we have constructed the index *COI* in which the confounding effect of size is eliminated.

The Participation Index (*PAI*) and Cooperation Index (*COI*) are useful for crossnational and cross – temporal comparisons, while the third indicator (*AFI*) is useful for measuring the level of bilateral cooperation between countries.

General Overview of the Data

Table 3.1 presents the aggregated data on publication output and transnational links of these countries for the two time – spans. These countries are listed according to their ranks determined by their publication output in 1992 – 1994.

Table 3.1
Publication Output and Transnational Links of Major Countries

Country	*1982 – 1984*		*1992 – 1994*		*Country*	*1982 – 1984*		*1992 – 1994*	
	PUB	*COP*	*PUB*	*COP*		*PUB*	*COP*	*PUB*	*COP*
USA	628788	50396	751702	125272	BRA	6469	1656	12370	6749
UKD	131154	23838	182188	57021	NOR	8482	2180	10438	6426
JPN	99643	6926	156023	24750	ZAF	8554	1134	9022	2645
FRG	98974	18145	*	*	KOR	1203	409	8771	3293
GDR	41198	2326	136853	54814	NZL	7348	1147	8636	2999
FRA	76370	14547	107753	44007	HUN	8437	1879	7796	5437
CAN	67713	12372	90838	30294	GRC	3406	1008	7326	5323
SUN	78087	2928	81839	17016	CSK	11240	2040	6565	3213
ITA	38247	8128	65220	29814	ARG	5026	677	6499	2613
NLD	27960	6627	45161	21250	MEX	3023	1062	6364	2951
AUS	33359	5033	43892	12565	EGY	3776	853	4747	1504
ESP	11862	2474	39277	15710	TUR	1125	371	4635	1339
SWE	26561	6944	34060	18082	IRL	3365	820	4572	2873
IND	34783	2438	33457	5702	BGR	3267	703	4495	2208
CHE	23512	7693	31339	22051	HKG	1289	321	4024	1991
PRC	8103	1814	23943	8729	POR	1132	484	3626	3376
ISR	17864	4764	22105	11295	CHL	3469	699	3526	1999
BEL	15326	4122	20360	13298	YUG	3832	984	3429	1611
DNK	13792	4194	18115	11928	SGP	746	151	3100	997
POL	11936	2867	16249	10046	SAU	1269	374	2589	647
FIN	10115	2139	14227	7651	ROM	1956	308	2307	1249
TWN	1889	570	13242	2869	NGA	2628	407	1867	605
AUT	9299	2302	13091	7876	VEN	902	528	1831	921

PUB: Total Number of Publications
COP: Total Number of Cooperation Links

It can be easily seen that USA occupies a dominant position in the production of scientific knowledge as well as its linkages with other countries. It accounts for —

1982 – 1984	1992 – 1994
39.3 % of all publications	36.3% of all publications
23.6% of all links	*20.4% of all links*

USA is also the most important partner of almost all the countries in both time – spans.

Growth of International Cooperation

A characteristic feature of the world science is that the volume of international cooperation has increased faster than publication output. Taking all the countries together, the number of publications increased from 1,598,479 to 2,069,460 during the interval of ten years, indicating average annual growth rate of 2.6%, whereas the number of links increased from 213,782 to 615,422, indicating average annual growth rate of 11.1%. These results imply that international cooperation is playing a far greater role in the generation of scientific knowledge today than in the past.

All the countries do not have the same growth rates. Generally, (scientifically) small countries are growing faster than large countries, both in publication output and transnational links. The variations in the growth rates in publication output and transnational links of certain selected countries may be observed from the data presented in Table 3.2.

Table 3.2
Growth Rates in Publication Output and Links of Selected Countries

Country	*Publications*	*Links*
IND	-0.4%	8.9%
PRC	11.4%	17.0%
JPN	4.6%	13.6%
CAN	3.0%	9.4%
FRA	3.5%	11.7%
AUS	2.8%	9.6%
ESP	12.7%	17.6%
KOR	22.0%	23.2%
TWN	21.5%	17.5%
SGP	15.4%	20.8%
USA	1.8%	9.5%
UKD	3.3%	9.1%
World	**2.6%**	**11.1%**

During the ten - year interval between 1982 - 1984 and 1992 - 1994, India had average negative growth rate (- 0.4%) in publication output and less than (world) average growth rate in international links. Its Asian neighbours, China, South Korea, Taiwan and had very high growth rates in publication output as well as in international links – far above the world average. A similar trend is replicated in the case of Spain. Its scientific activity is characterized by a high growth rate in publication output and transnational links. These trends could be attributed to the growth in scientific activity of these countries, but could also be attributed to the drawing of these countries' scientists to the international journals covered in *SCI*.

Crossnational Comparison of Cooperation Links

Table 3.3 presents the data on Participation Index (*PAI*) and Cooperation Index (*COI*) of these countries for the two time – spans.

Table 3.3
Cooperation Links of Major Countries

Country	*1982 – 1984*			*1992 – 1994*		
	PAI	*COI*	*COD*	*PAI*	*COI*	*COD*
USA	23.57	8.01	0.60	20.37	16.67	0.56
UKD	11.15	18.18	1.36	9.27	31.30	1.05
JPN	3.24	6.95	0.52	4.02	15.86	0.53
FRG	8.49	18.33	1.37	8.91	40.05	1.35
GDR	1.09	5.65	0.42	*	*	*
FRA	6.80	19.05	1.42	7.16	40.84	1.37
CAN	5.79	18.27	1.37	4.92	33.35	1.12
SUN	1.37	3.75	0.28	2.77	20.79	0.70
ITA	3.80	21.25	1.59	4.85	45.71	1.54
NLD	3.10	23.7	1.77	3.46	47.05	1.58
AUS	2.35	15.09	1.13	2.04	28.63	0.96
ESP	1.16	20.86	1.56	2.55	40.00	1.35
SWE	3.25	26.14	1.95	2.94	53.09	1.79
IND	1.14	7.01	0.52	0.93	17.04	0.57
CHE	3.60	32.72	2.45	3.59	70.36	2.37
PRC	0.85	22.39	1.67	1.42	36.46	1.23
ISR	2.23	26.67	1.99	1.84	51.10	1.72
BEL	1.93	26.90	2.01	2.16	65.31	2.20
DNK	1.96	30.41	2.27	1.94	65.85	2.22
POL	1.34	24.02	1.80	1.63	61.83	2.08
FIN	1.00	21.15	1.58	1.24	53.78	1.81
TWN	0.27	30.17	2.26	4.67	21.67	0.73

(Contd.)

Table 3.3 (Contd.)
Cooperation Links of Major Countries

Country	*1982 – 1984*			*1992 – 1994*		
	PAI	*COI*	*COD*	*PAI*	*COI*	*COD*
AUT	1.08	24.76	1.85	1.28	60.16	2.02
BRA	0.77	25.60	1.91	1.10	54.56	1.84
NOR	1.02	25.70	1.92	1.05	61.56	2.07
ZAF	0.53	13.26	0.99	0.43	29.32	0.99
KOR	0.19	34.00	2.54	0.54	37.54	1.26
NZL	0.54	15.61	1.17	0.49	34.73	1.17
HUN	0.88	22.27	1.67	0.88	69.74	2.35
GRC	0.47	29.59	2.21	0.87	72.66	2.44
CSK	0.95	18.15	1.36	0.52	48.94	1.65
ARG	0.32	13.47	1.01	0.43	40.21	1.35
MEX	0.50	35.13	2.63	0.48	46.37	1.56
EGY	0.40	22.59	1.69	0.25	31.68	1.07
TUR	0.17	32.98	2.47	0.22	28.89	0.97
IRL	0.38	24.37	1.82	0.47	62.84	2.11
BGR	0.33	21.52	1.61	0.36	49.12	1.65
HKG	0.15	24.9	1.86	0.32	49.48	1.66
POR	0.23	42.76	3.20	0.55	93.11	3.13
CHL	0.33	20.15	1.51	0.33	56.69	1.91
YUG	0.46	25.68	1.92	0.26	46.98	1.58
SGP	0.07	20.24	1.51	0.16	32.16	1.08
SAU	0.17	29.47	2.20	0.11	24.99	0.84
ROM	0.14	15.75	1.18	0.20	54.14	1.82
NGA	0.19	15.49	1.16	0.10	32.40	1.09
VEN	0.25	58.54	4.38	0.15	50.30	1.69

PAI: Participation Index
COI: Cooperation Index
COD: Cooperation Density

The index *COI* has an important limitation; it does not indicate whether a country has more or less cooperation, as there is no yardstick to judge its value. Also, it is not possible to compare the extent of international cooperation of a country at different intervals from the values of *COI*, which are confounded by the momentum of international cooperation itself. For example, in the case of China, the value of *COI* increased from 29.4% to 36.4% between the two time – spans. Can we say that China's international cooperation has inclined over time? As we shall see later, it has actually declined. Hence, we have computed another index - *Cooperation Density* (*COD*), which compares the cooperation index of a country with that of the entire world. This index is computed as follows:

$$COD = \frac{COI \text{ of Country A}}{COI \text{ of the World}}$$

If $COD > 1$, it means that the country has above average level of transnational links - more than expected on the basis of its scientific activity (i.e. publication output). If $COD < 1$, it means that the country has below average level of transnational links. The values of *COD* are also given in Table 3.3.

It can be easily seen from the table that scientifically large countries rank high on Participation Index (*PAI*), but they rank low on Cooperation Index (*COI*). The correlation coefficient between these two indices is negative.

USA has the highest rank on *PAI*, but its rank is quite low on *COI*. The values of *COD* are much less than 1 in both the time - spans.

It can be easily seen from the table that India has less than average cooperation density, which is about the same in both the time - spans. This means that India's international cooperative activity has essentially remained the same, inspite of a large quantitative increase in the number of cooperation links, when we take into account the momentum of international cooperation of the entire world. By the same token, the international cooperation activity of China has slackened. The growth of its international cooperation is less than commensurate with the growth in its publication output. International cooperation has not kept pace with the scientific activity of China.

Analysis of Mutual Ties

Another dimension of international collaboration is the pattern of mutual ties i.e. who cooperates with whom and how much. A simple indicator of these relationships is Affinity Index (*AFI*). Figure 3.1 shows the absolute number of India's cooperation with its twenty major partners:

> USA, Germany, UK, Canada, France, Japan, Italy, Russia (including CIS countries), Australia, Netherlands, Switzerland, Spain, Sweden, China, Belgium, Hungary, Brazil, Bulgaria, Denmark and Korea.

Figure 3.2 shows India's affinities with these countries. It can be easily seen that there has been some restructuring of India's affinities with these countries over the ten - year interval between 1982 - 1984 and 1992 - 1994. The affinities with its two top most partners: USA and UK have declined. UK was the second most important partner of India is 1982 - 1984, but UK swapped its position with Germany in 1992 - 1994.

India's affinities with France, Canada and Australia have decreased, but those with Russia, Italy, Spain, China, Finland, Taiwan and Austria have increased during this period.

Figures 3.3 - 3.12 provide a double viewing of affinities of ten countries - India, USA, Germany, UK, France, Japan, Canada, Russia, China, Korea - with their respective ten major partners. These figures are self - explanatory and any elaboration would be redundant.

Networks of International Cooperation

The networks of cooperation links among the countries can be depicted in the form of 'Sociomatrix' for the two time - spans.

$$\text{Sociomatrix } C = |C_{ij}|$$

where C_{ij} indicates the number of cooperation links between country i and country j. Obviously $C_{ii} = 0$. Since these links are bidirectional, the sociomatrix is symmetric.

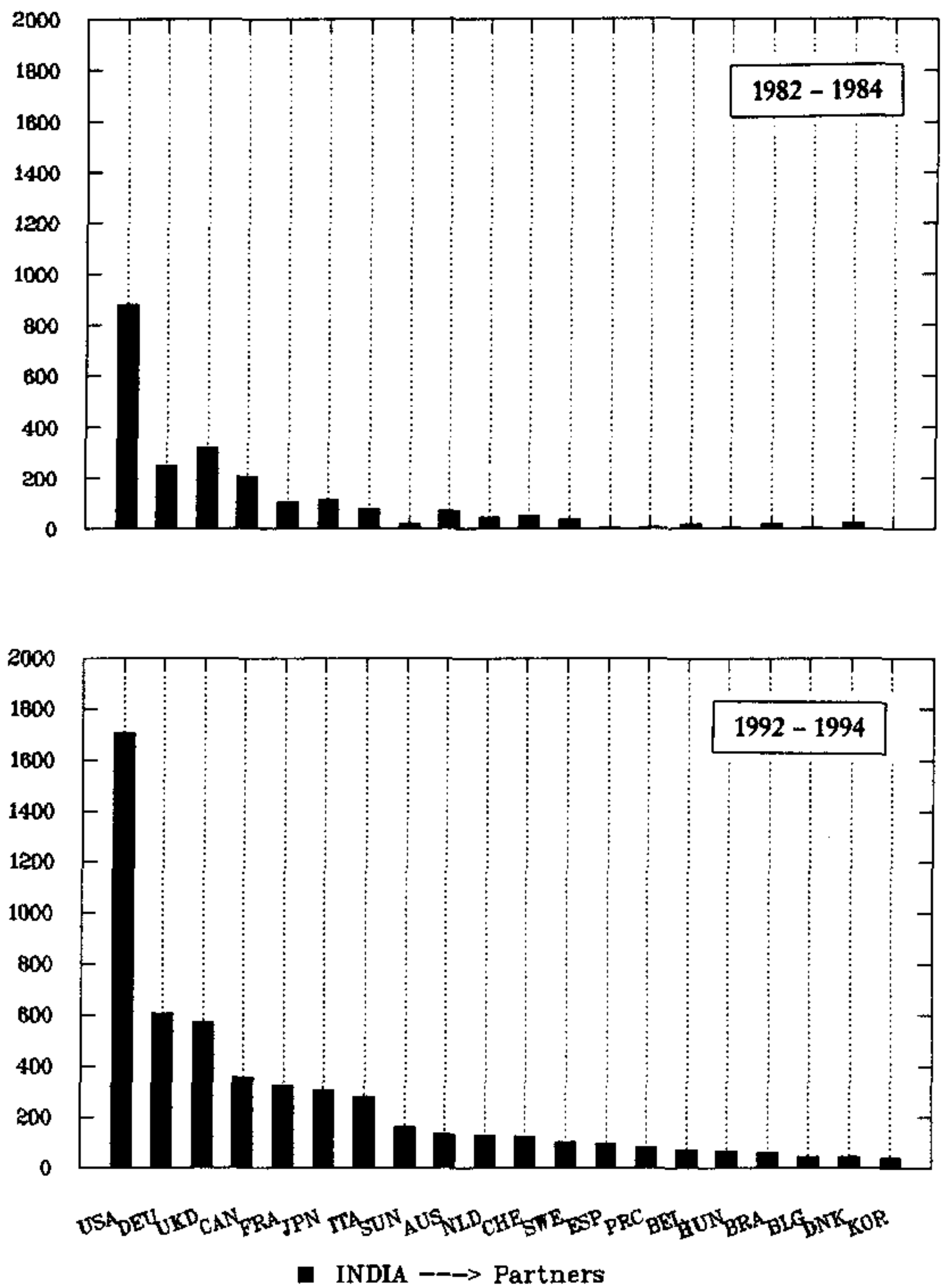


Fig. 3.1: Linkages between India & its first 20 partners

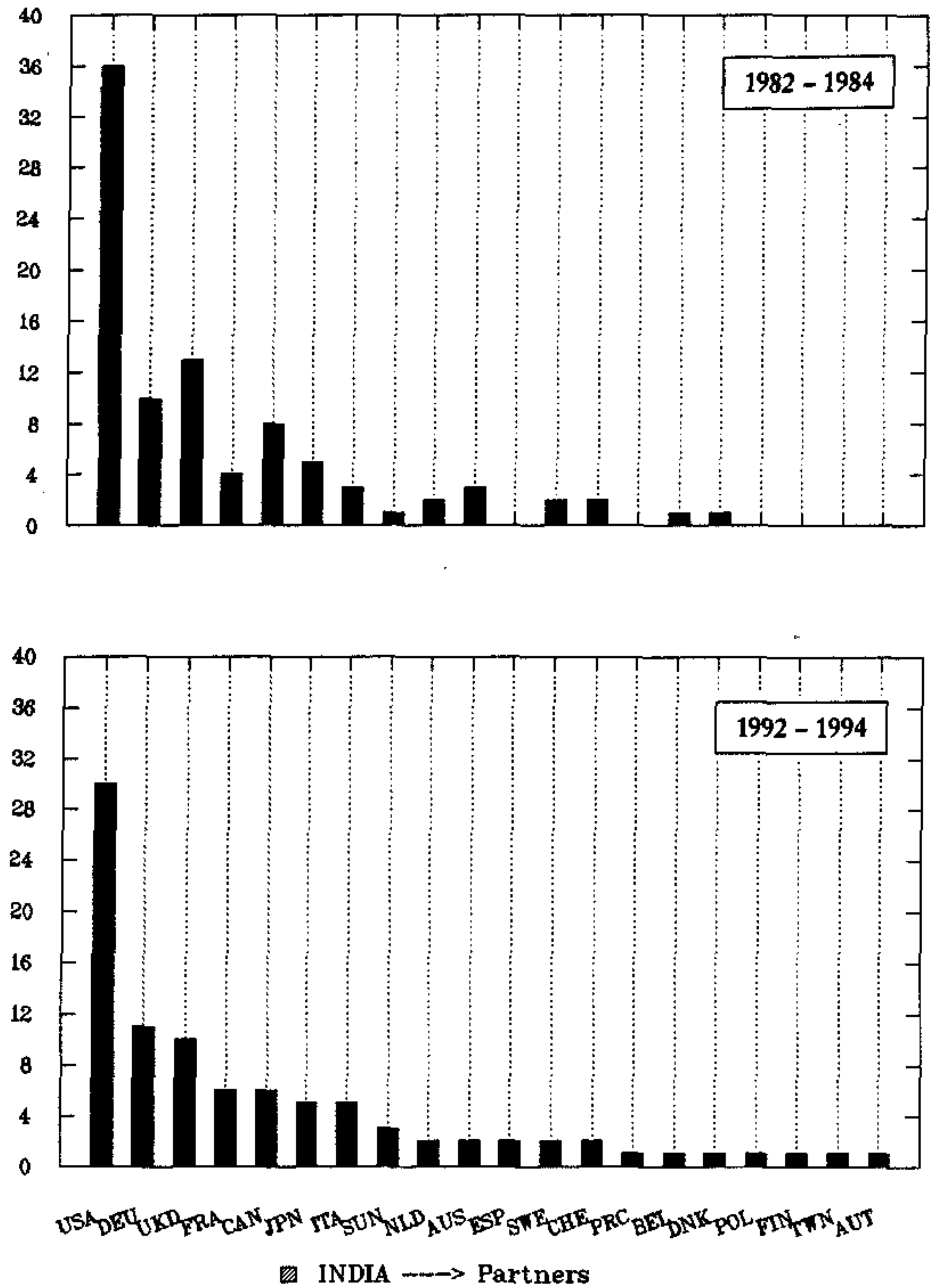


Fig. 3.2: Affinities between India & its first 20 partners

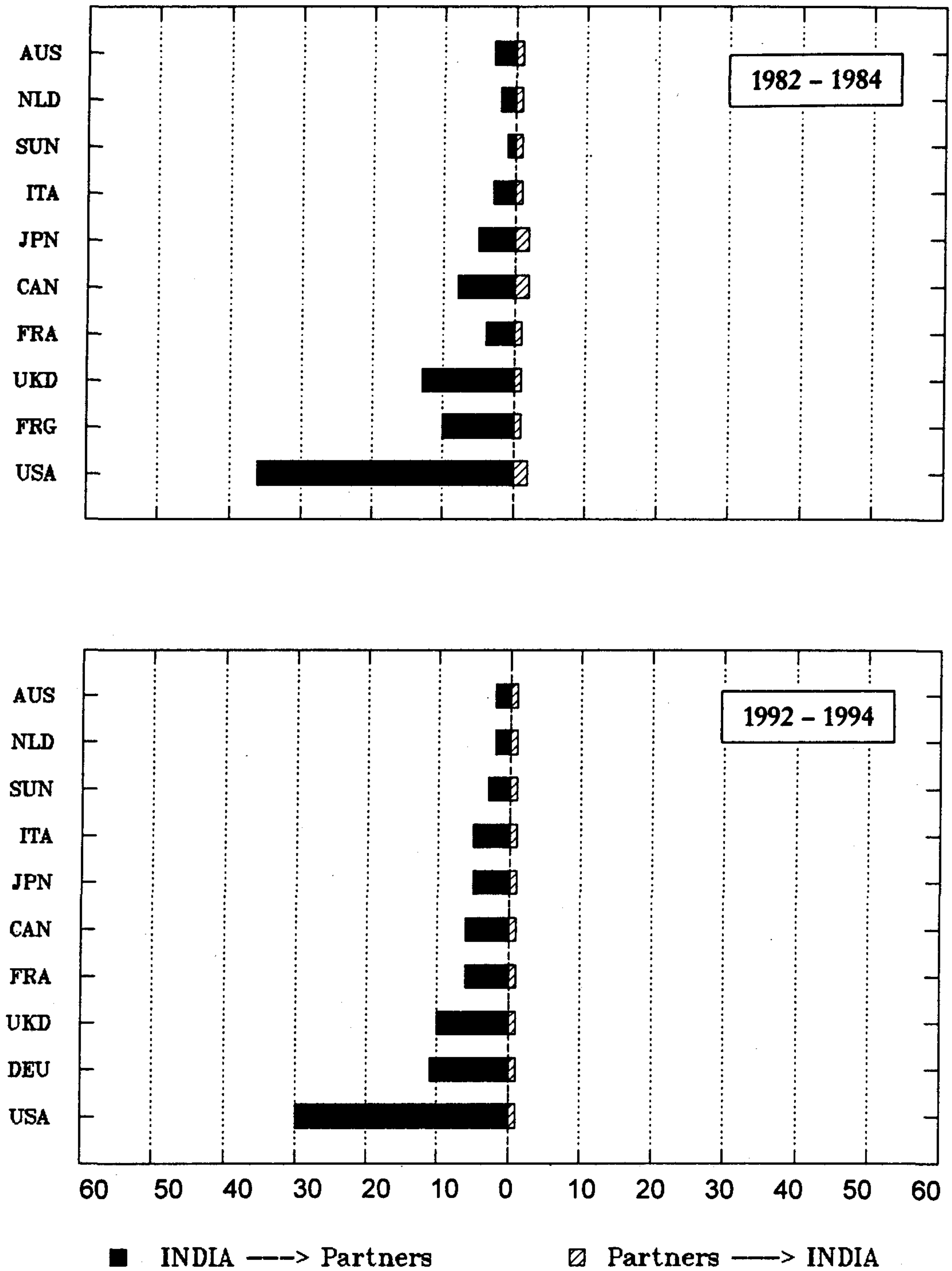


Fig. 3.3: Affinities between India & its first 10 partners

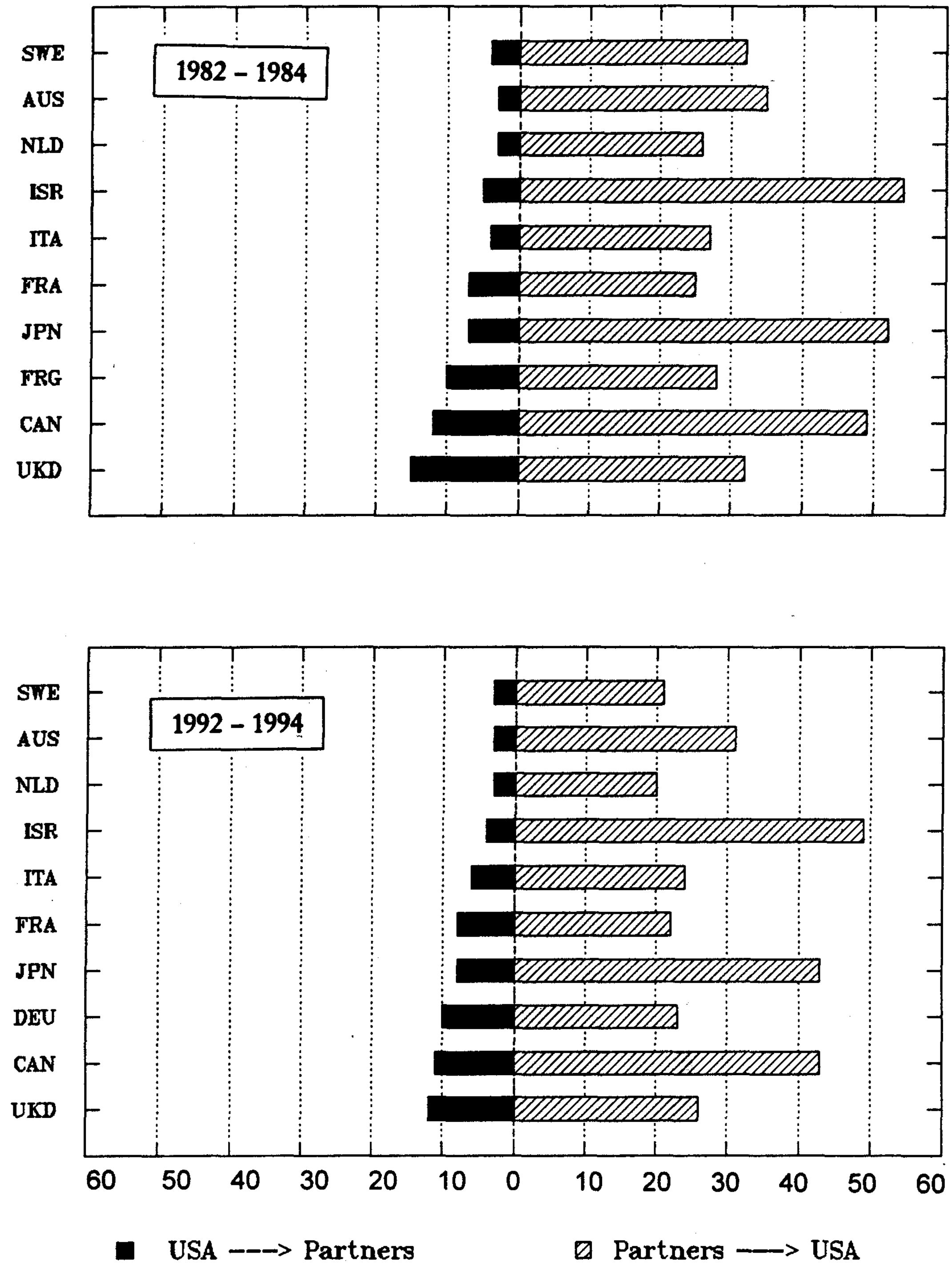


Fig. 3.4: Affinities between USA & its first 10 partners

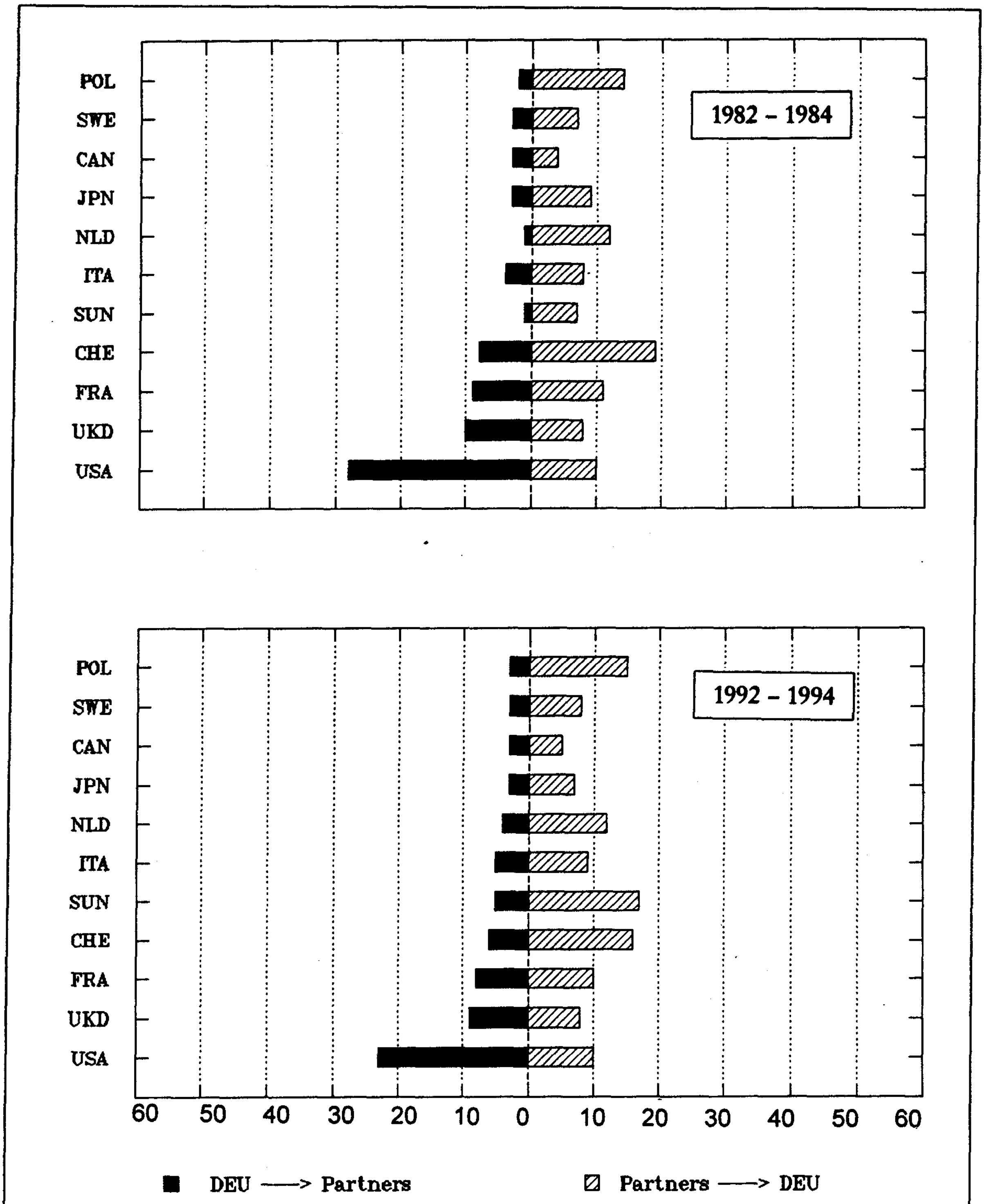


Fig. 3.5: Affinities between Germany & its first 10 partners

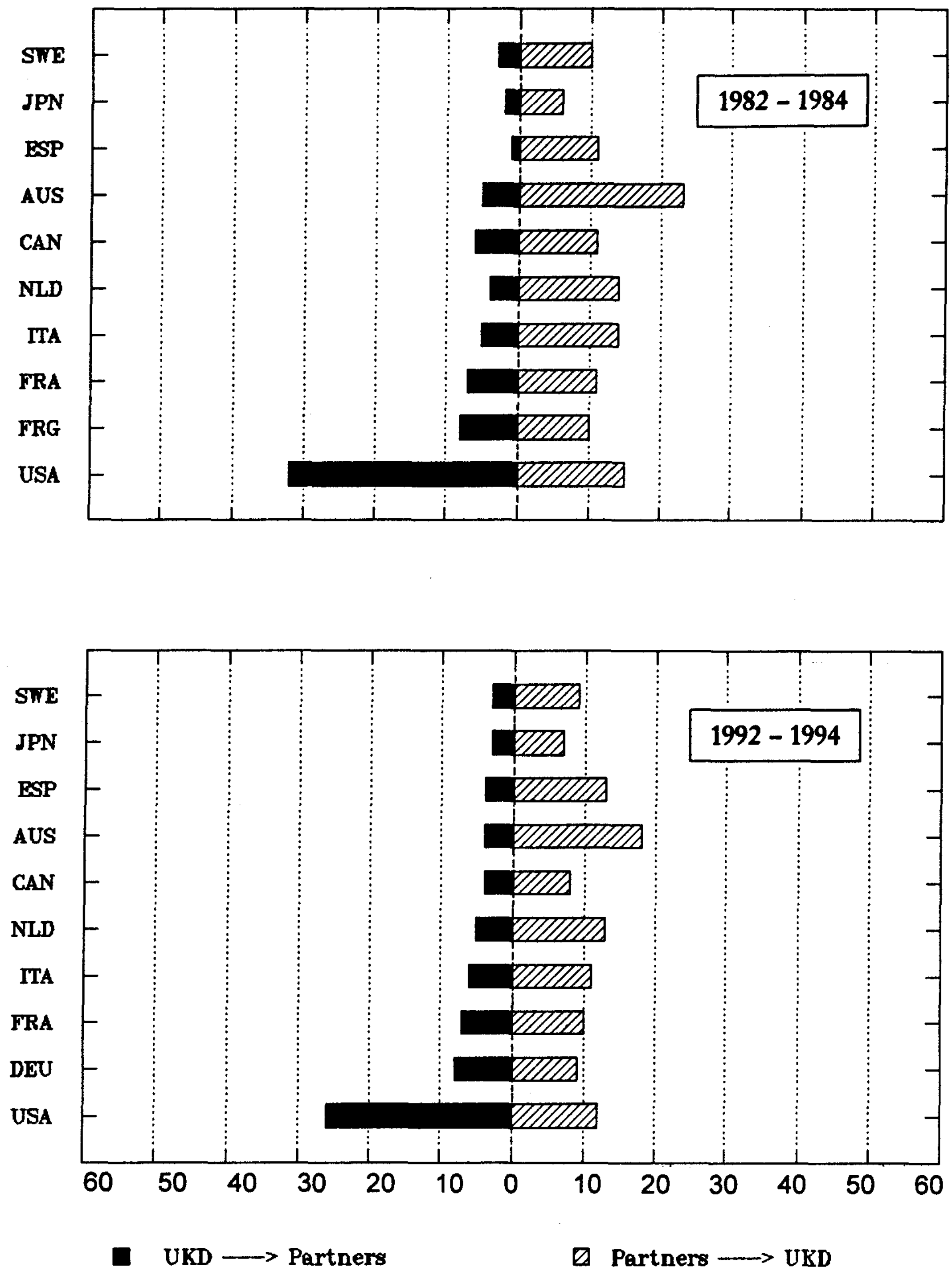


Fig. 3.6: Affinities between UK & its first 10 partners

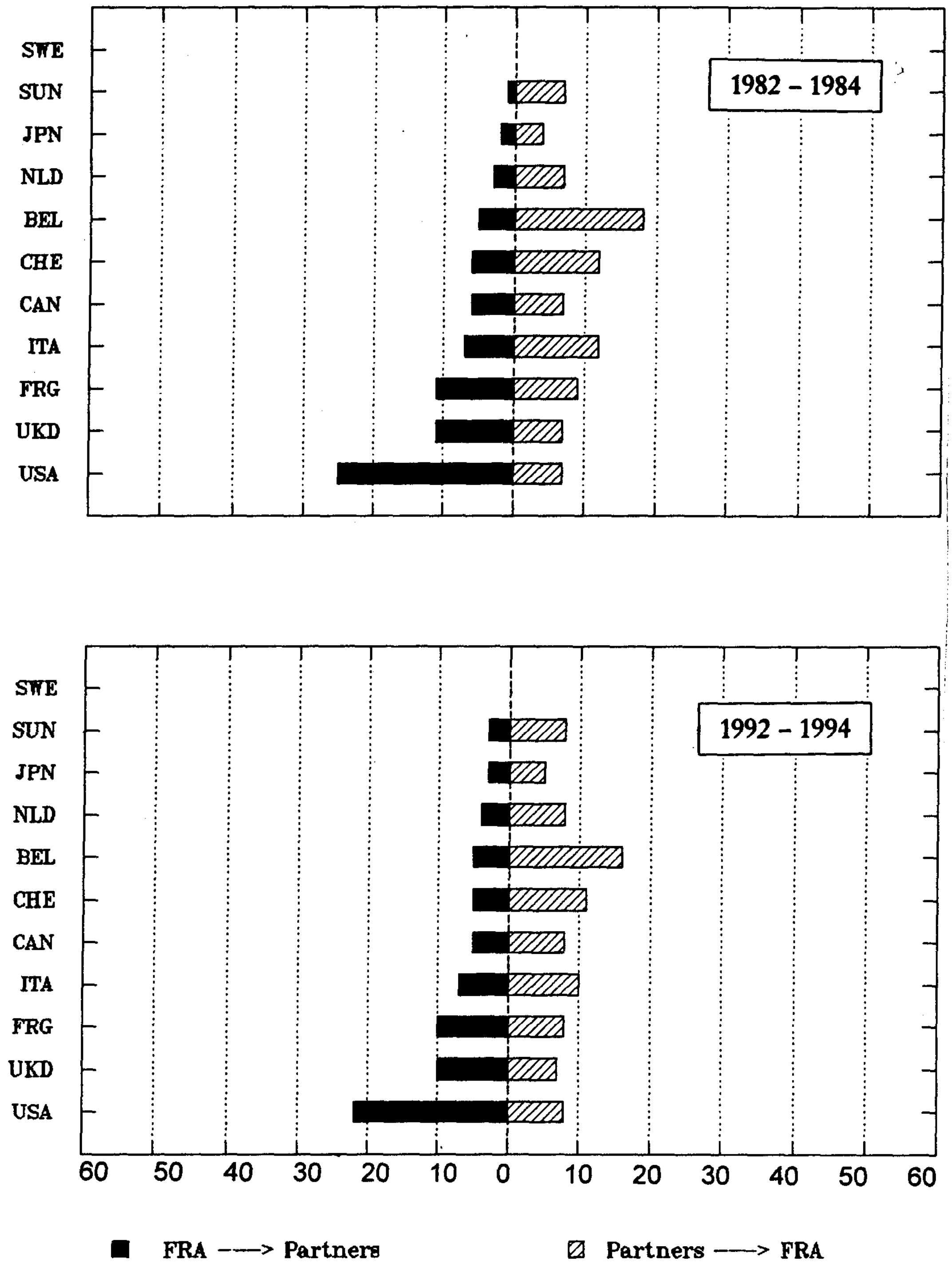


Fig. 3.7: Affinities between France & its first 10 partners

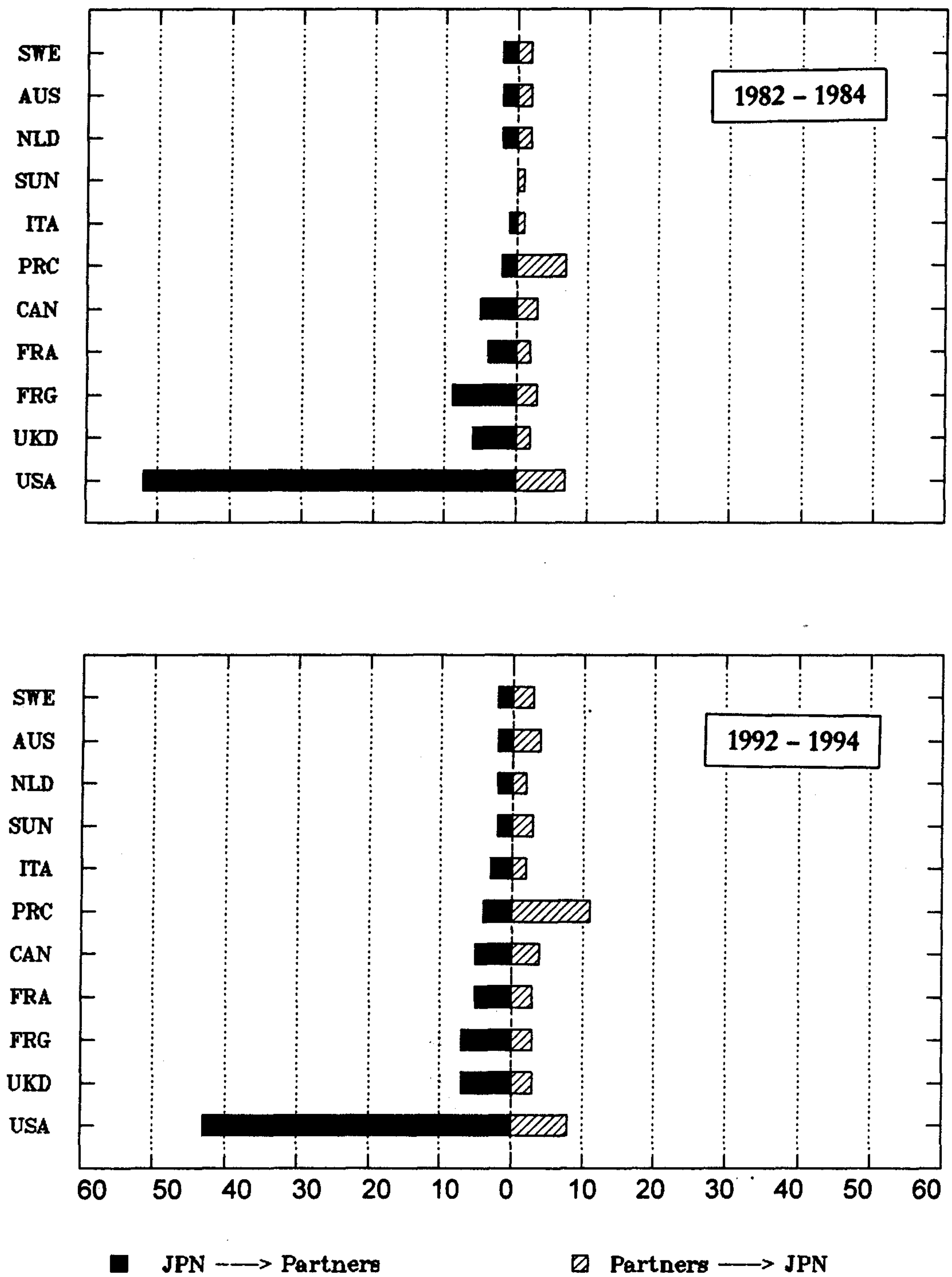


Fig. 3.8: Affinities between Japan & its first 10 partners

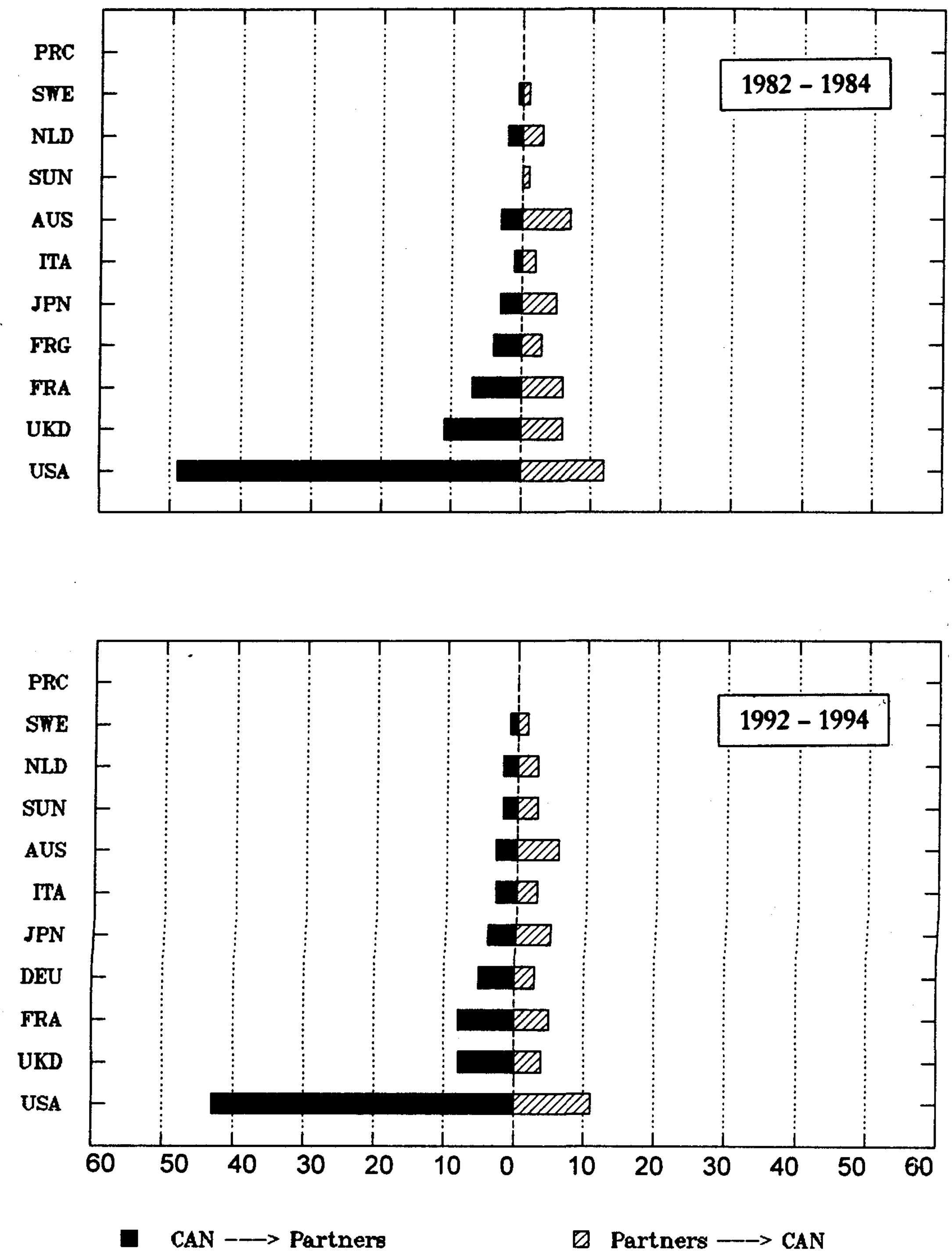


Fig. 3.9: Affinities between Canada & its first 10 partners

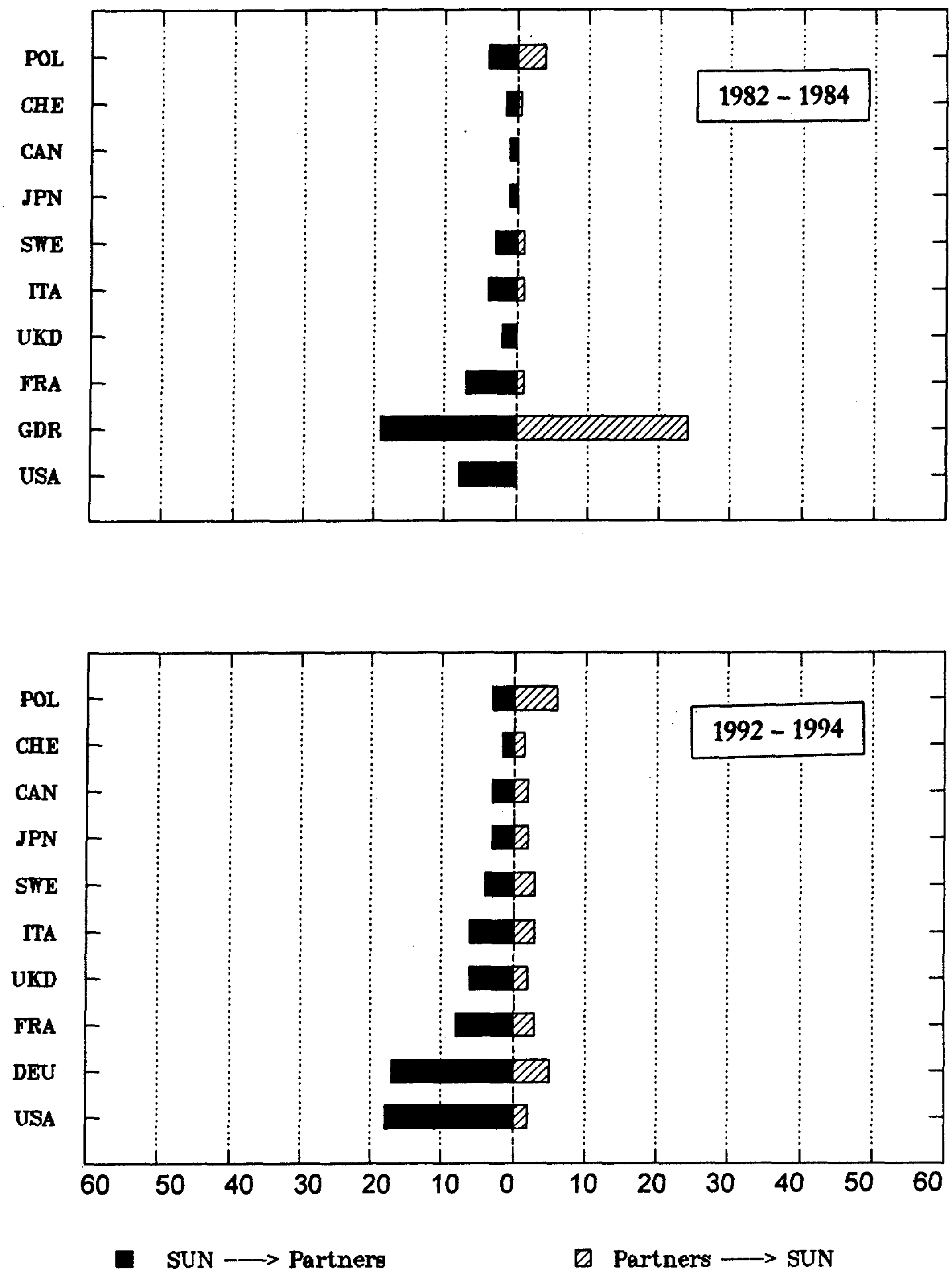


Fig. 3.10: Affinities between Russia & its first 10 partners

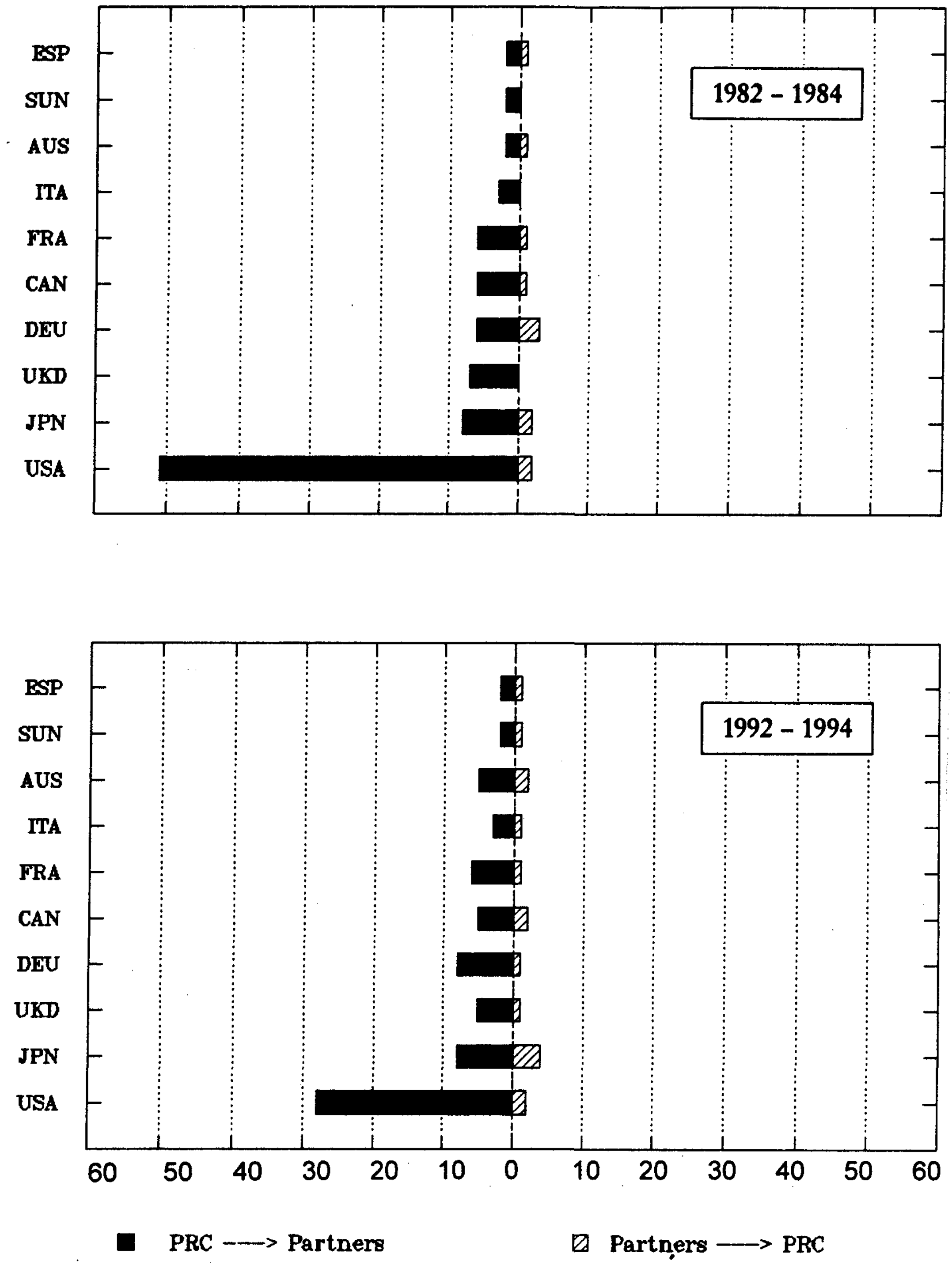


Fig. 3.11: Affinities between China & its first 10 partners

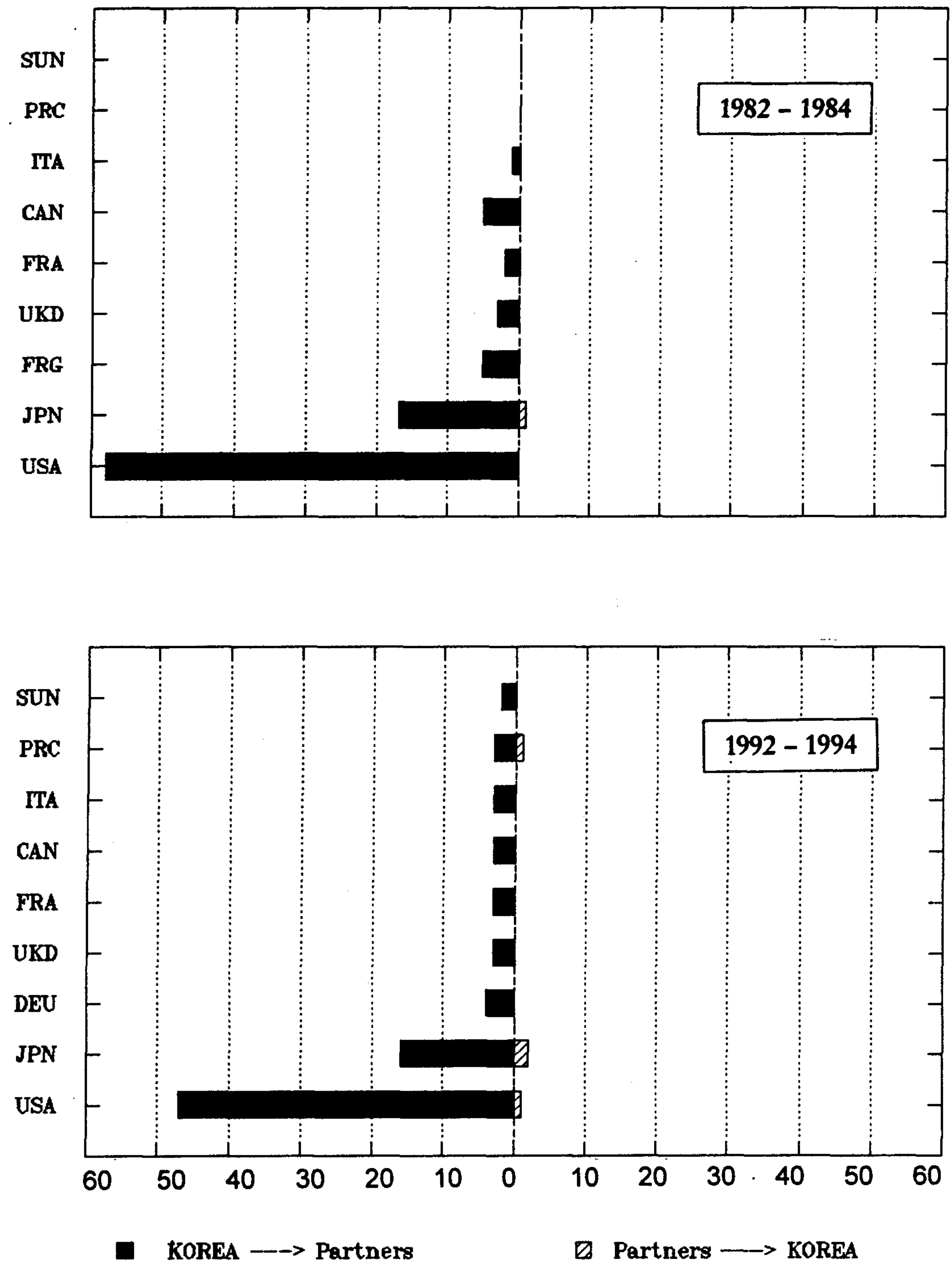


Fig. 3.12: Affinities between Korea & its first 10 partners

For the 1982 - 1984 data, a total of 213,782 links are observed, which for 2070 cells, give a mean country - country links of 103.3 for the three - year period. This we term the overall *density* of the network. For the 1992 - 1994 data, the overall density is 310.8. This means that the density of mutual links has increased by a factor of three over the ten - year interval. Further the number of empty cells (excluding the diagonal) has decreased from 18% to 4%. This means that scientific cooperation between countries has not only become more intensive, but has also become more extensive.

It is observed that some of the matrix cells are either empty or have very small values, whereas some other cells have large values, implying that there are wide variations in mutual ties. The development of cooperation between any two countries is influenced by geographical proximity, historical or political factors, culture and tradition. It is also influenced by the dynamics of supply and demand.

Certain countries have strong links with many countries; their network of cooperation is quite extensive. In other words, they occupy a central position in the international network of science. On the other hand, there are certain countries which have links with only a few countries and thus occupy a peripheral position in the network. We use the graph theoretic measure of centrality to quantify the position of different countries in the network. If a country has connections with many other countries in the network, its centrality would be high. If a country has connections with only a few countries, its centrality would be low.

In this study, we have used the Bonacich eigenvector centrality measure (Bonacich, 1987) to indicate the position of a country in the network. In this formulation, a link with a country occupying a central position counts more than a link with a country occupying a peripheral position. Thus, the centrality of a country is determined by the centralities of the countries to which it is connected. Bonacich eigenvector centrality index ranges from 0 to 1. We have also computed the *Network Centralization Index*, which measures the centralization of the entire network. Larger this index, more likely that a single country (or only a few countries) is quite central and the remaining countries are much less central. The less central countries may be viewed as residing in the periphery of a centralized system. The software *UCINET* IV (Borgatti, Everett and Freeman, 1992) was used to compute the eigenvector centralities of different countries and the network centralization index.

Table 3.4 presents the data on the centralities of different countries for the two time - spans. In the table, the countries are ranked by their publication output in 1992 - 1994.

Table 3.4
Eigenvector Centrality of Different Countries

Country	*Eigenvector Centrality*		*Country*	*Eigenvector Centrality*	
	1982 - 1984	*1992 - 1994*		*1982 - 1984*	*1992 - 1994*
USA	0.620	0.593	BRA	0.037	0.050
UKD	0.427	0.374	NOR	0.038	0.039
JPN	0.175	0.215	ZAF	0.026	0.019
FRG	0.322	0.347	KOR	0.011	0.030
GDR	0.022	*	NZL	0.024	0.023
FRA	0.259	0.289	HUN	0.026	0.038
CAN	0.304	0.267	GRC	0.022	0.034
SUN	0.024	0.110	CSK	0.023	0.019
ITA	0.157	0.208	ARG	0.013	0.018
NLD	0.127	0.145	MEX	0.028	0.025
AUS	0.114	0.102	EGY	0.019	0.012
ESP	0.055	0.106	TUR	0.009	0.011
SWE	0.132	0.112	IRL	0.018	0.018
IND	0.055	0.045	BGR	0.006	0.012
CHE	0.134	0.154	HKG	0.007	0.014
PRC	0.046	0.065	POR	0.010	0.019
ISR	0.126	0.109	CHL	0.015	0.014
BEL	0.072	0.085	YUG	0.016	0.011
DNK	0.075	0.078	SGP	0.003	0.007
POL	0.046	0.065	SAU	0.009	0.005
FIN	0.036	0.047	ROM	0.004	0.008
TWN	0.014	0.029	NGA	0.010	0.005
AUT	0.040	0.051	VEN	0.013	0.008
Network centralization index					
	91.49%	85.66%			

The main features of the networks are summarized below:

1. The network centralization index is very high for both networks, implying that the networks are dominated by a few countries which occupy central positions in the network, while a large number of countries are at the periphery. However, the network centralization index has decreased over time (1982 - 1984: 91.5%; 1992 - 1994: 85.7%), which implies a reduction in the dominance of some 'central' countries.

2. None of the countries - nor even USA - has centrality close to 1, which implies that no single country dominates the network. It is rather a cartel of a few countries which dominate the network.

3. USA has the highest centrality, but this has decreased over time, which implies that centralities of some other countries have increased. In other words, certain less central countries are now participating more in the international network than ten years earlier.

4. Scientifically large countries have higher centralities than scientifically small countries, indicating their dominance in the network. A notable exception is Russia, which, despite its scientific size, had very low centrality (0.024) in 1982 - 1984 - even less than Poland. However, the centrality of Russia has considerably increased over the ten - year period.

5. The centralities of scientifically large countries have decreased between 1982 - 1984 and 1992 - 1994. On the other hand, the centralities of Japan and Russia have increased considerably during this period, implying that these countries were playing a greater role in the international network of science in 1992 - 1994 than ten years earlier.

6. The centrality of India has slightly declined, but this is due to the decrease in its affinities with certain central countries and increase in its affinities with some peripheral countries.

7. The centrality of China has increased by a factor of 1.5 during this period. This increase is accompanied by a restructuring of its linkages - decrease in its

affinities with USA, UK and France and increase in its affinities with Germany, Japan and Italy.

The entries in the sociomatrices can be viewed in terms of both the overall levels of cooperation and patterns of cooperation. The overall level of cooperation is largely a function of the size of the country while the pattern is not. The pattern of cooperation must be viewed without any confounding effects due to size. Since we are concerned primarily with the structure of these matrices, we have computed *Jaccard indices* for controlling the effects of size. *Jaccard Index* is computed by the following formula:

$$J(ij) = \frac{Cij}{Cio + Coj - Cij}$$

where

Cij = Number of links between any two countries i and j

Cio = Total number of links of country i.

Coj = Total number of links of country j.

The matrices of *Jaccard indices* represent purely the structural features of the data purged of distortions due to skewed marginal distributions. Entries in these matrices indicate the strength of linkages between pairs of countries. However, these matrices do not convey much information as it is not easy to discern the pattern of linkages from a large data matrix. Since, visual representations are useful in getting a sense of the data, we have transformed these matrices into graphs. The graphs were developed by subjecting the matrices of *Jaccard indices* to Multidimensional Scaling (MDS). The multidimensional scaling algorithm locates countries in a low - dimensional metricized space such that the countries are located close together if they have a large number of ties with the same other partners. In other words, countries which are 'structurally similar' are placed close together. The countries which are structurally dissimilar are located far apart from each other. It should, however, be noted that the distance between any two points does not necessarily indicate the strength of relationships.

Krack Plot 3.0 (Krackhardt, Blythe & McGrawth, 1995) was used to aesthetically improve the maps yielded by the MDS algorithm. The maps were re - oriented and rotated such that the resulting configuration approximated the location of the countries as in a geographical map (with as few exceptions as possible). Then the country points were adjusted for clarity, first manually and then through simulated annealing.

The networks are presented in Figures 3.13 and 3.17 respectively, wherein the arcs between the nodes representing the countries indicate the strength of cooperation links above a certain threshold (*Jaccard Index* > .01). Thus, the arcs between the nodes indicate strong links between the countries.

Since a large number of countries are situated around the origin, it is not possible to clearly represent the network of relationships among these countries. The subgraphs presented in Figure 3.14 and 3.18 provide a zoomed view of the network of relationships among these countries. *Krack Plot* 3.0 was used to generate the zoomed maps.

These figures depict how different countries are embedded in the international network of science. The networks for the two time - spans can be compared to detect visually the changes that have occurred in the structure of the network over the period of ten years. It should, however, be remembered that these networks depict the links between countries above a certain threshold (*Jaccord Index* > .01). Links below the threshold are omitted.

Network for 1982 - 1984

The network for 1982 - 1984 is depicted in Figure 3.13, which shows that the central region of the network which is occupied by the countries of Europe and North America is densely packed. Inter - point distances among the countries are small, which implies that these countries are structurally similar in their patterns of cooperation with other countries. Figure 3.14 gives an exploded view of the central region of the map, which shows the connections among the countries in the region rather more clearly.

The Nordic countries (Sweden, Norway, Finland and Denmark) are situated on the top of the region. These countries are not only connected among themselves, but they also have partners in the East - European and West - European countries.

South American countries — Argentina, Brazil, Chile, Mexico and Venezuela, which are situated on the left side of the map, constitute a subgraph. These countries are interconnected, but not completely. There are missing links between Argentina and Mexico, between Venezuela and Chile and between Mexico and Chile. These countries have very few links outside the subgraph. Only Brazil and Mexico have partners outside the subgraph.

East - European countries, which are situated on the right side of the map, constitute another subgraph. Figure 3.15 gives an exploded view of the East - European subgraph and its neighbors in the map. It can be easily seen that these countries are well connected among themselves, but they do not have many partners outside the subgraph.

We shall now focus our attention on three countries — India, China and Spain — as we shall see later that there are important changes in patterns of their linkages. Moreover, these countries are of comparable scientific size. Figure 3.16, provides a zoom of India's linkages, which shows that India is connected to USA, UK, Germany, Canada and Japan, but not to other super - powers of science, viz. USSR and France.

China is connected to only two countries — USA and Japan.

Spain is connected to USA, UK, Canada, Italy, Belgium and Chile.

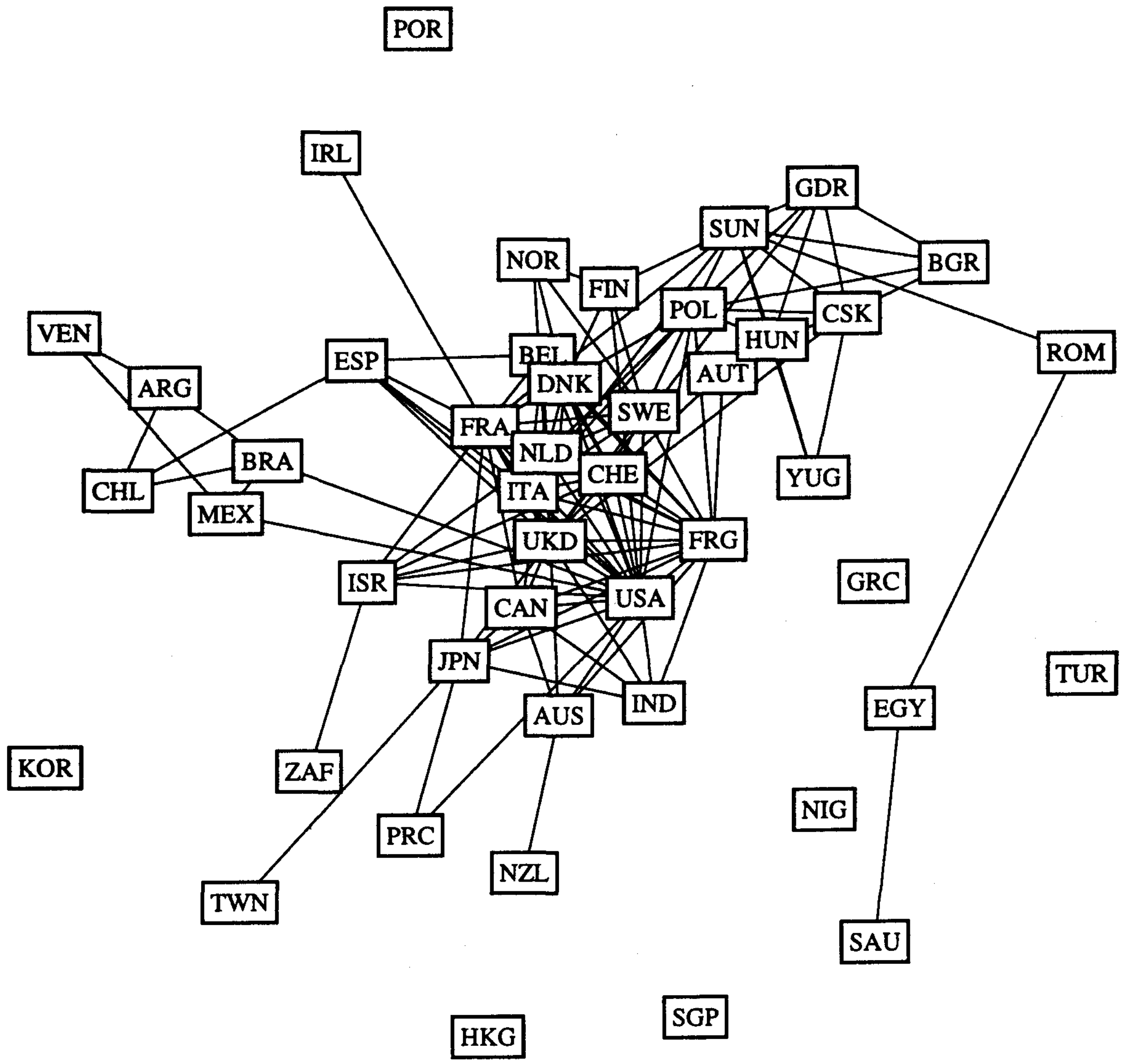


Fig. 3.13: Global network of science for 1982 – 1984

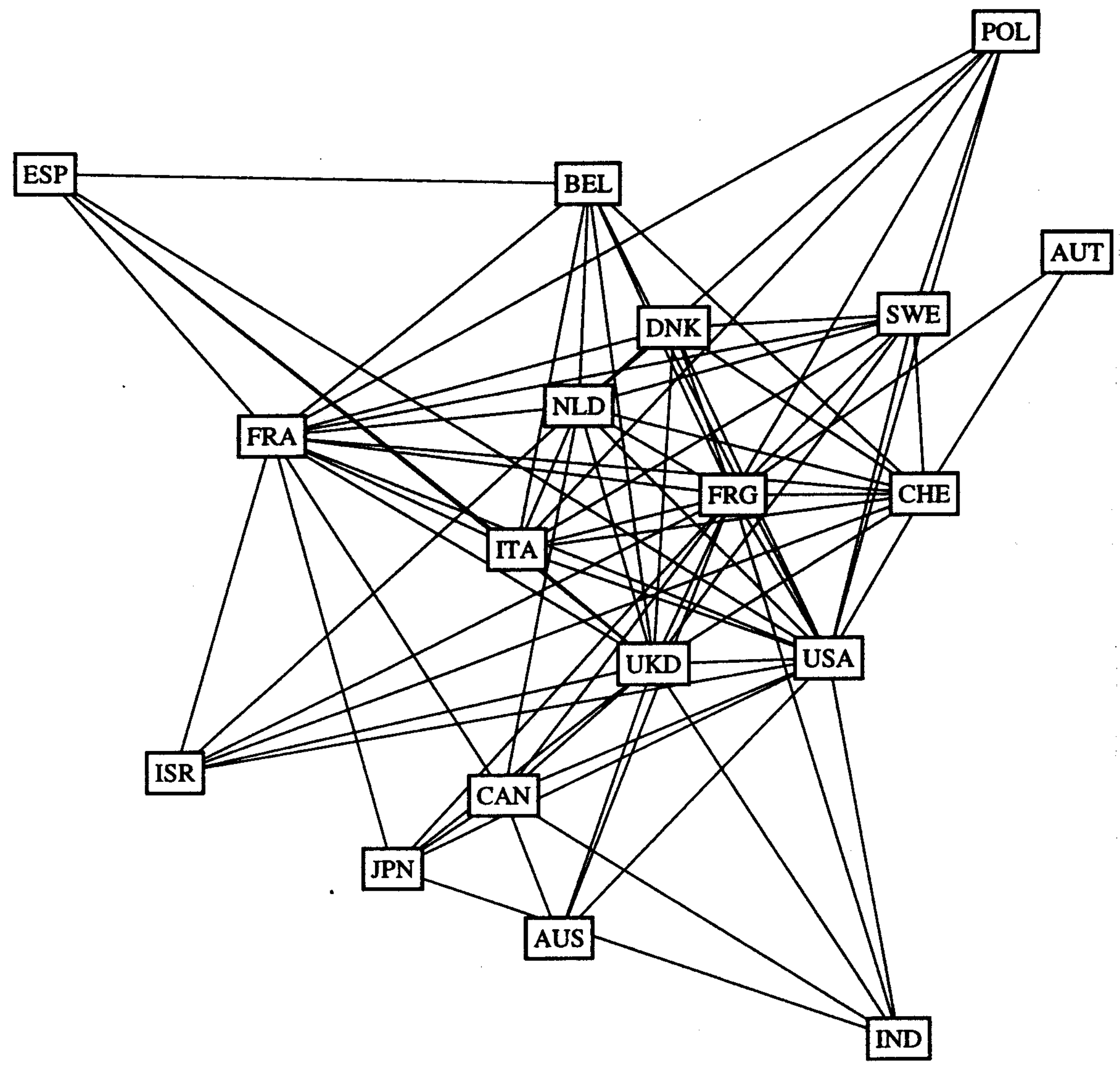


Fig. 3.14: Exploded view of the central region of the network (1982 - 1984)

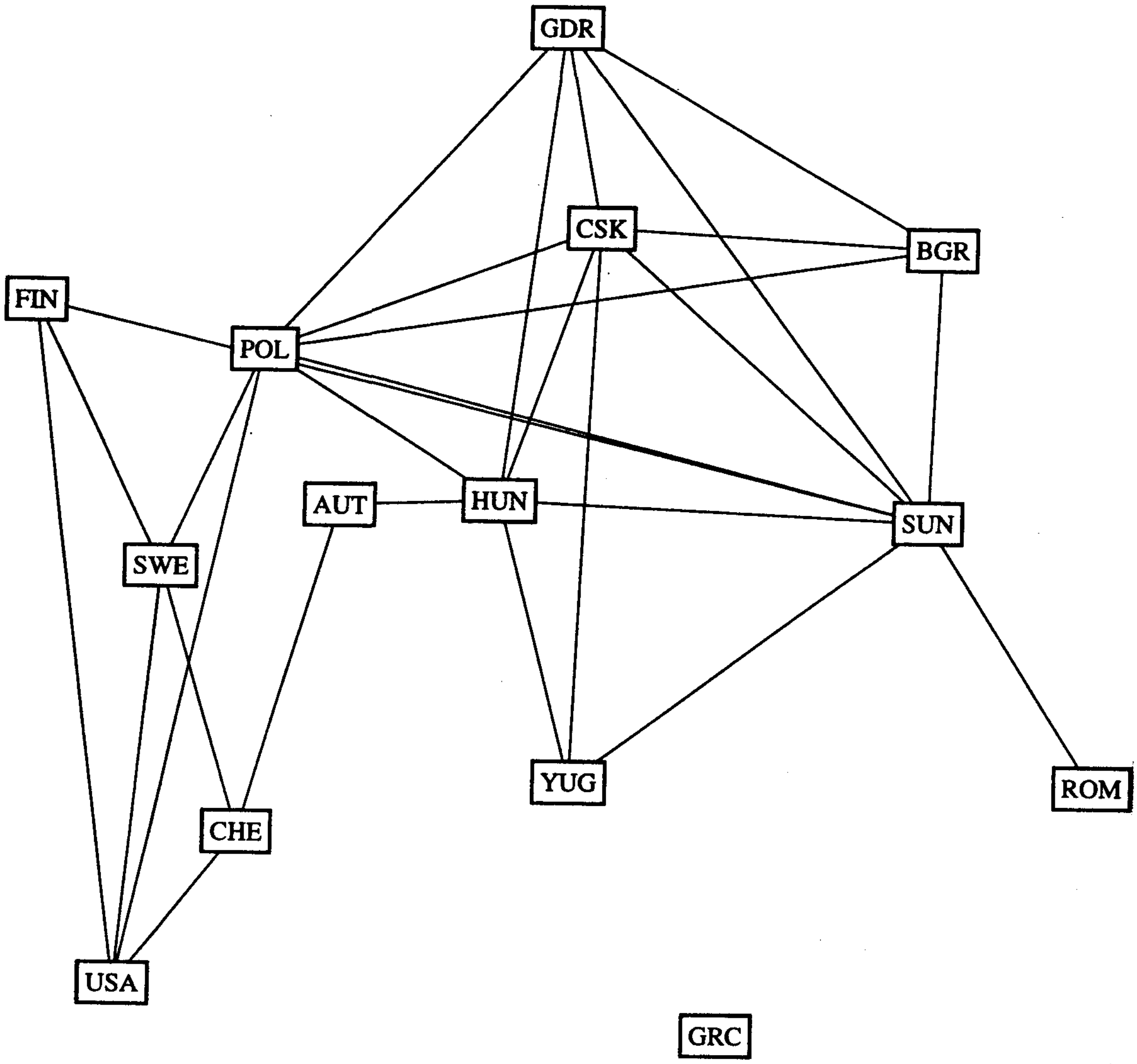


Fig. 3.15: Exploded view of the East European subgraph (1982-1984)

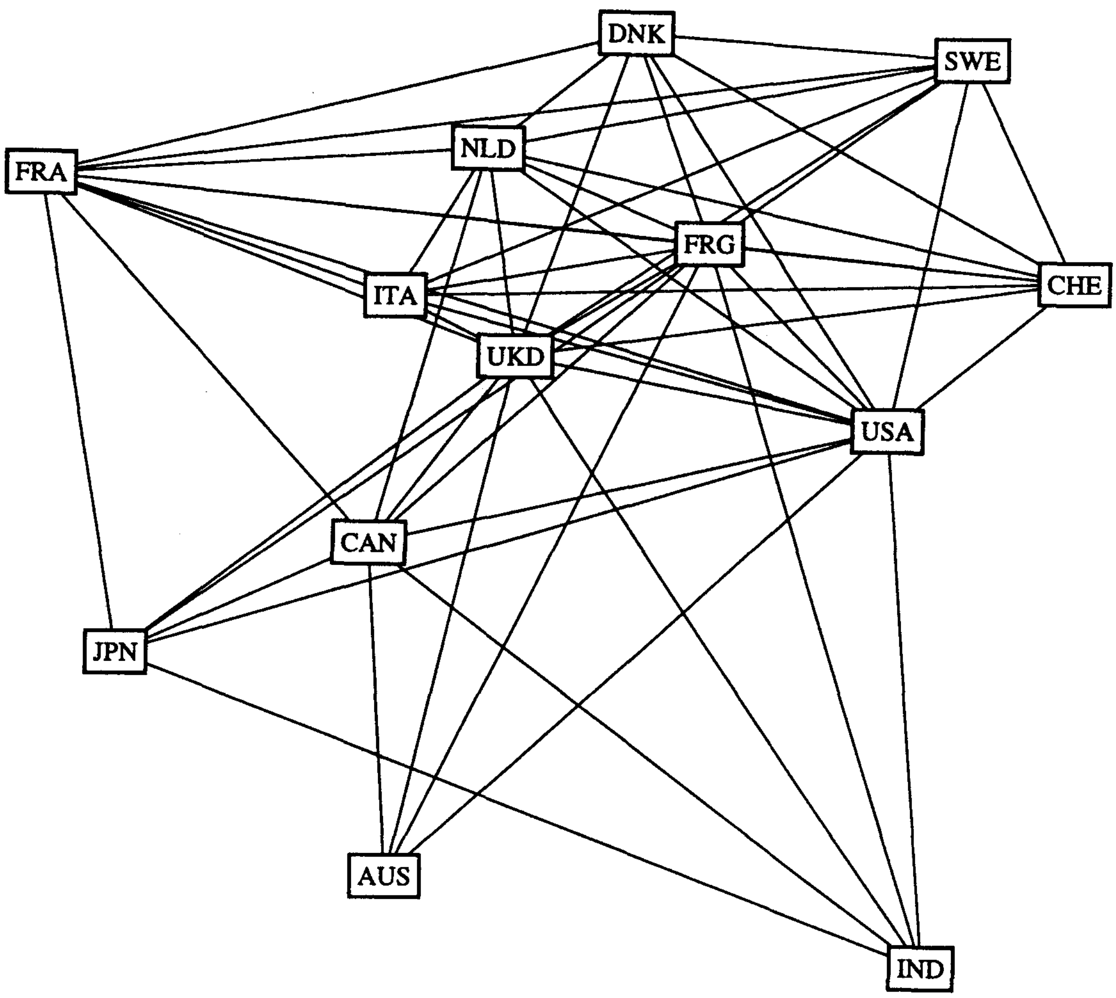


Fig. 3.16: Exploded view of India's linkages in 1982 - 1984

Network for 1992 - 1994

The macro level features of the network for 1992 - 1994 (Figure 3.17) are essentially the same as those of the network for 1982 - 1984. There is a dense region at the center of the map, which is occupied by the countries of West Europe and North America. The Nordic countries are situated on the top of this region. There are also subgraphs of South American and East European countries. The subgraph of East European countries is not well demarcated. There are, however, important differences between the two networks at the micro level, which are briefly discussed below.

Figure 3.18 provided an exploded view of the central region of the map, which shows more clearly the connections among the countries in the region.

East - European countries are now located on the left side of the map, but this is not important as the orientation of the axes in multidimensional scaling is arbitrary. What is important is the inter - point distances between the countries, which indicate structural similarities of the countries. Larger the distance, more dissimilar are the countries. This subgraph has a large diameter. It occupies a large area in the map, since the inter - point distances have increased. This means that the patterns of cooperation of these countries within and outside the subgraph have changed. Figure 3.19 provides an exploded view of the subgraph of the East - European countries, *vis - a - vis* their neighbors in the map

While Romania and Yugoslavia have become isolates, Russia, Poland and Hungary have found many new partners outside the subgraph.

Russia is now connected to eighteen countries - USA, UK, Japan, Germany, France, Canada, Italy, Netherlands, Australia, Sweden, Switzerland, Belgium, Denmark, Poland, Finland, Hungary, Czechoslovakia and Bulgaria. In 1982 - 1984, it had only three partners outside the East - European subgraph, but in 1992 - 1994, it had fifteen partners outside the subgraph.

Poland had five partners inside and six partners outside the subgraph in 1982 - 1984; it has now thirteen partners outside and only one partner inside the subgraph.

Bulgaria, Czechoslovakia, Hungary and Poland are all connected to USSR, but there are no significant ties among themselves. It appears that the East European countries are trying to get away from the East - European subgraph and are forging alliances with the Western countries. Another interesting observation is the absence of links between the East - European countries and China in both the time - spans.

Figure 3.20 gives an exploded view of India and its neighbors in the network. Attenuation of links with UK and Canada (< threshold) are the characteristic features of India's position in 1992 - 1994 in the international network of science. These two countries are missing in the network for 1992 - 1994. India's significant partners in 1992 - 1994 are USA, Germany and Japan.

Spain has widely expanded its international cooperation. In 1982 - 1984, it had only six partners (USA, UK, Canada, Italy, Belgium and Chile). In 1992 - 1994, it had fifteen partners — USA, UK, Germany, France, Russia, Italy, Netherlands, Sweden, Switzerland, Belgium, Denmark, Poland, Argentina, Mexico and Portugal.

China had only two partners in 1982 - 1984 (viz. USA and UK), but it has found five new partners besides maintaining strong links with USA and UK: Japan, Australia, Canada, Germany and Italy.

Yugoslavia, Romania, Venezuela, Nigeria, Turkey, Singapore and South Africa are isolates.

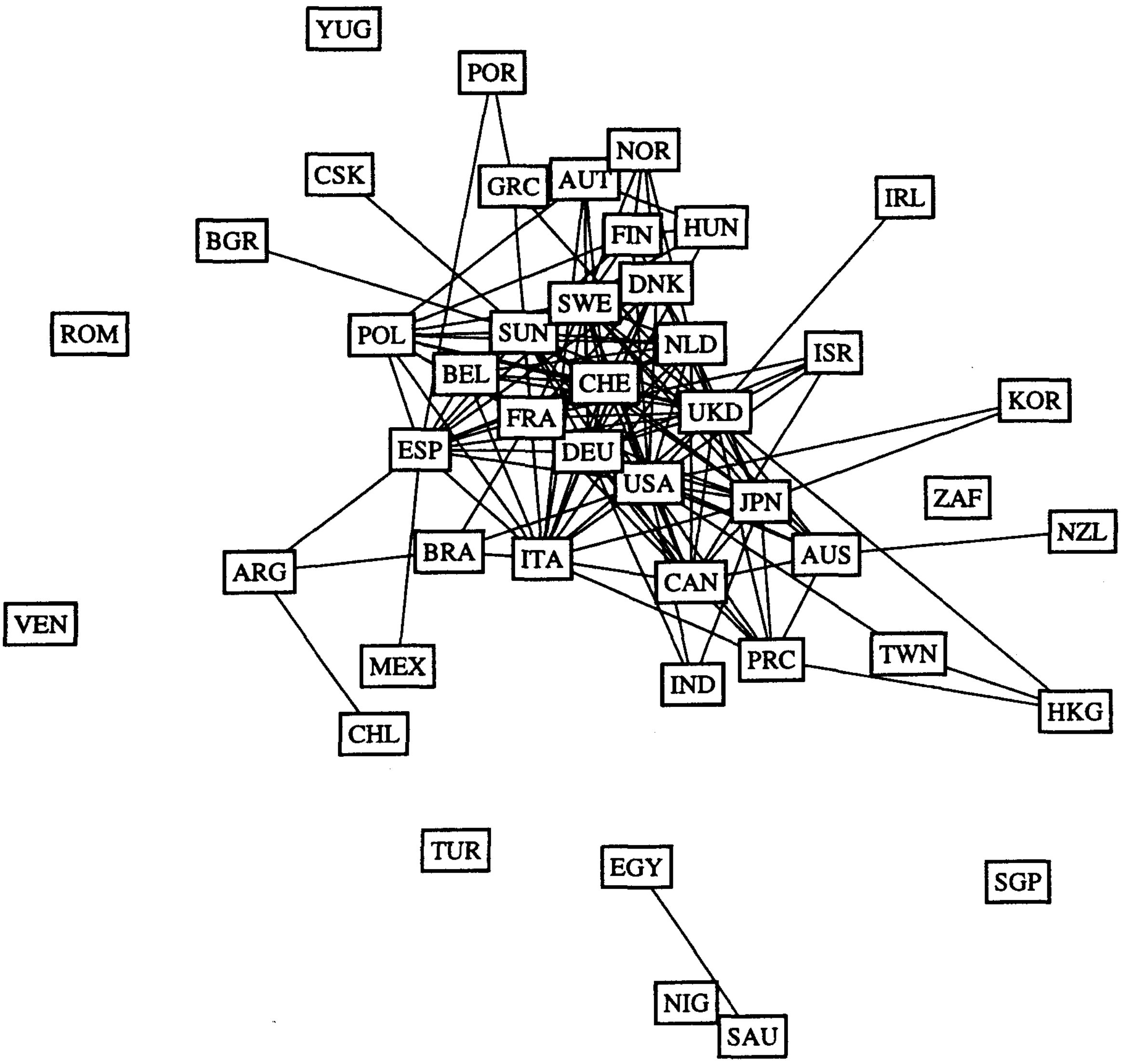


Fig. 3.17: Global network of science for 1992 - 1994

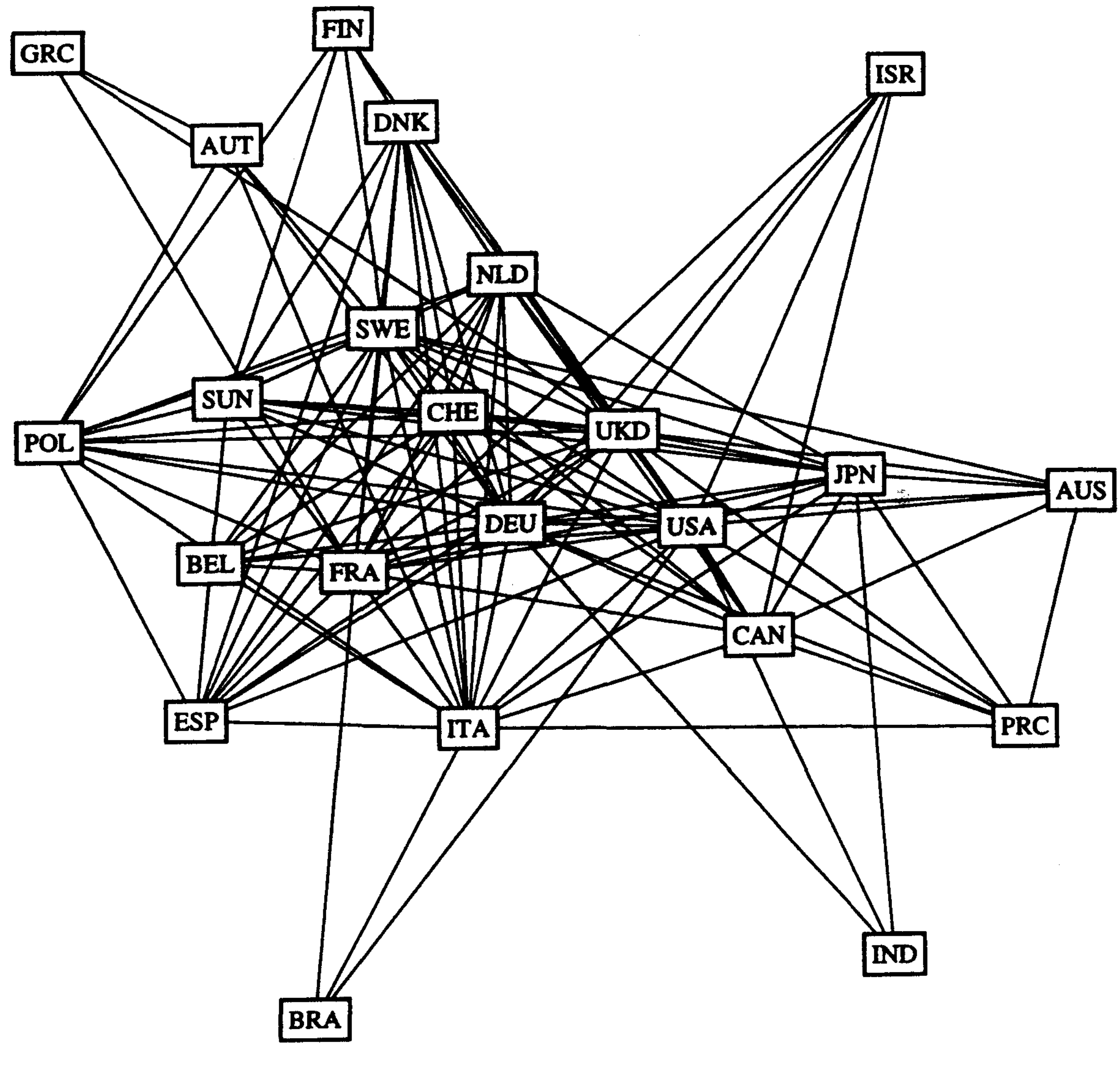


Fig. 3.18: Exploded view of the central region of the network (1992 - 1994)

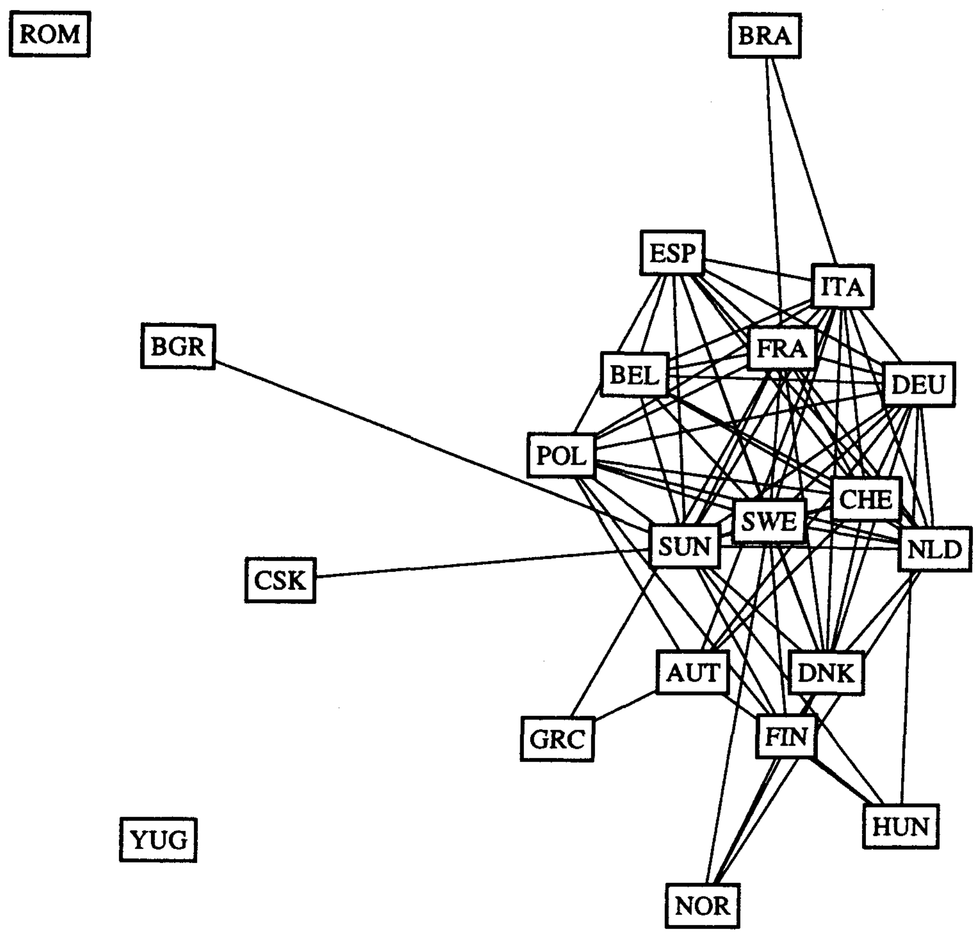


Fig. 3.19: Exploded view of the East - European subgraph (1992 - 1994)

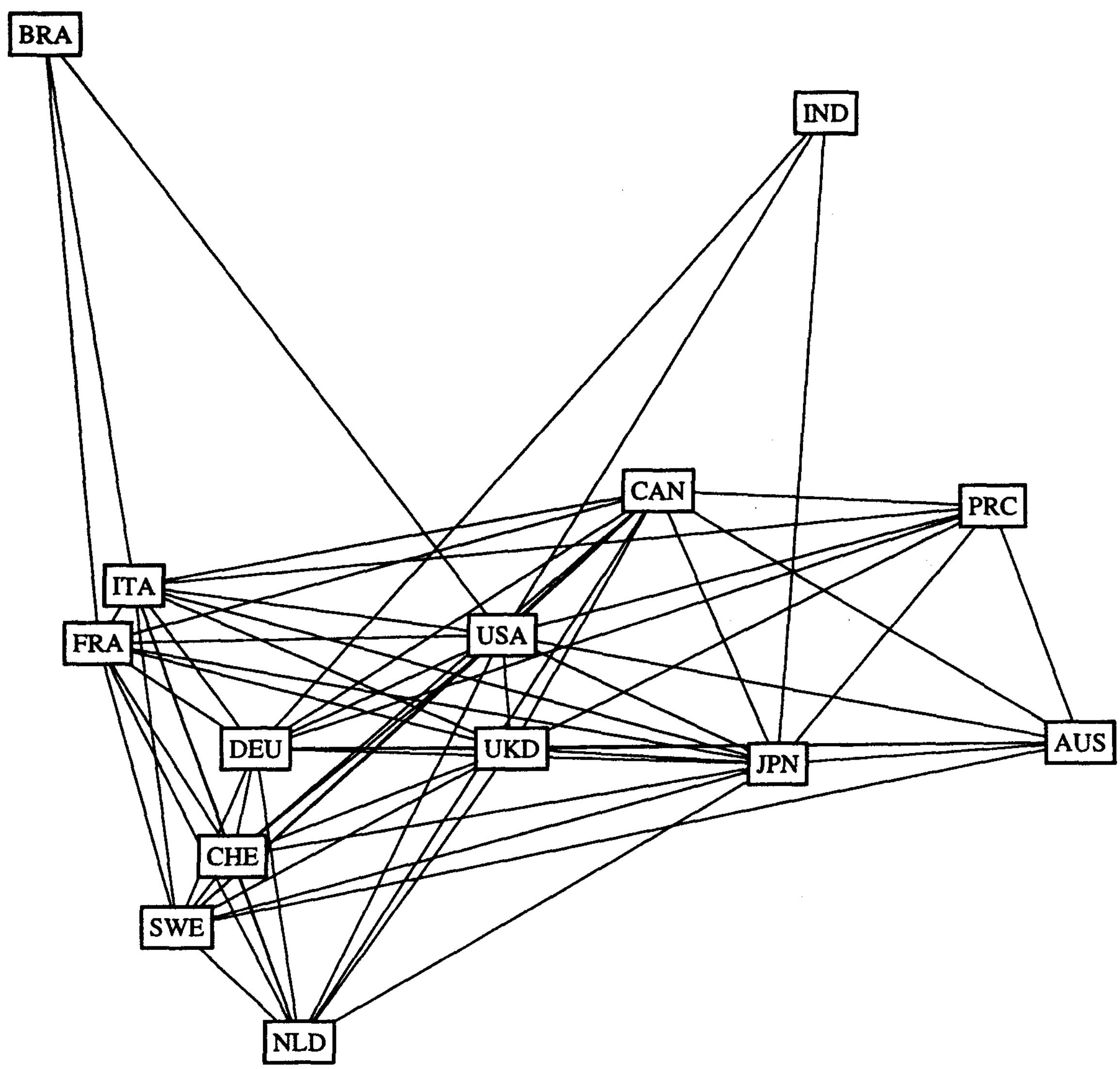


Fig. 3.20: Exploded view of India's linkages in 1992 - 1994

Structured Changes in the Pattern of Cooperation

The networks presented in Figures 3.13 and 3.17 are quite revealing as they provide a synoptic view of country - by - country relationships. But these networks are quite large and difficult to comprehend. The network for 1982 - 1984 involves 46 nodes and 255 arcs, whereas that for 1992 - 1994 involves 45 nodes and 292 arcs. It is therefore essential to find a parsimonious representation of the total configuration by clustering the countries into subgroups (blocks) and then depict the relationships among the subgroups. In social network analysis, subgroups are identified on the basis of graph - theoretic measures, e.g. structural equivalence or internal cohesion. Burt (1978) has pointed out that subgroups based on structured equivalence should be preferred to those based on cohesion. A number of algorithms are proposed in the literature for finding structurally equivalent subgroups or blocks. However, in the present study, we have classified the countries into seven blocks according to their geographic location. The resulting configuration of relationship between the blocks may be termed as a 'pseudo - block model'.

β_1 (North America)	: USA, CAN
β_2 (West Europe)	: DEU, FRA, ITA, NLD, ESP, SWE, CHE, BEL DNK, FIN, AUT, NOR, GRC, TUR, IRL, POR
β_3 (East Europe)	: SUN, POL, HUN, CSK, BGR, YUG, ROM
β_4 (Asia)	: JPN, IND, PRC, TWN, KOR, HKG, SGP
β_5 (South America)	: BRA, ARG, MEX, CHL, VEN
β_6 (West Asia and Africa)	: ISR, ZAF, EGY, SAU, NGA
β_7 (Australia and New Zealand)	: AUS, NZL

The pseudo block models were constructed as follows. The matrices of *Jaccard Indices* were dichotomized by recoding the values of *Jaccard Index*:

1 if *Jaccard Index* $\geq$ .01

0 otherwise

The resulting matrices having entries 1 or 0 are called *adjacency matrices.*

The rows and columns of the adjacency matrices were permuted such that the countries belonging to the same block are adjacent in the permuted matrix. The densities of links between and within the blocks were computed by summing up the cell values in the permuted matrices and dividing the sum by the number of possible cells. Tables 3.5 and 3.7 present block densities for the two time - spans.

The 'density matrices' were transformed into image matrices by dichotomizing the density matrices with mean density as cut - off values. The image matrices are presented in Tables 3.6 and 3.8. These matrices indicate the presence or absence of links between and within the blocks.

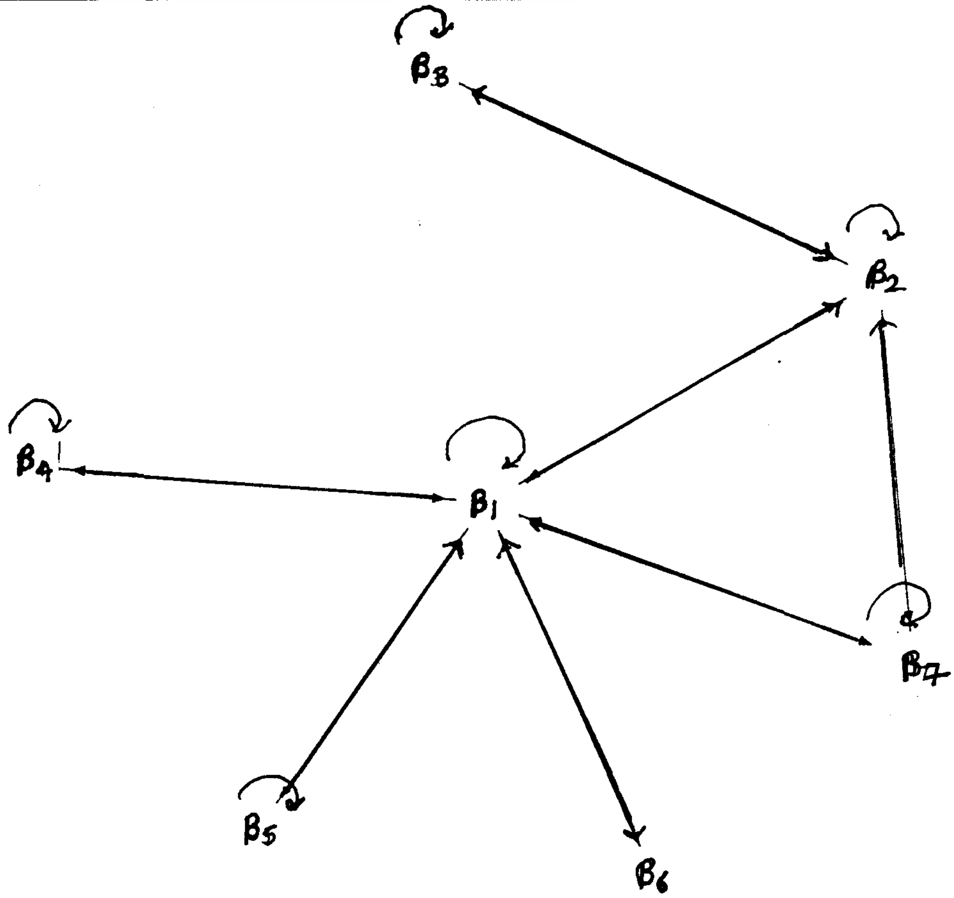
Figures 3.21 and 3.22 depict the networks of relationship between the blocks for the two time - spans.

<u>1982 - 1984</u>

It can be easily seen from Figure 3.21 that β_1 (North America) is connected to all other blocks, except β_3 (East Europe). Blocks β_2 (West Europe) and β_7 (Australia and New Zealand) are strongly connected. Blocks β_4 (Asia), β_5 (South America) and β_6 (West Asia and Africa) are satellites of β_1 (North America). These blocks are not connected to any other block. There are no strong links within block β_6 (West Asia and Africa). All the other blocks have strong internal connections.

<u>1992 - 1994</u>

Block β_1 (North America) has strong connections with all the other blocks except β_6 (West Asia and Africa). Block β_2 (West Europe) has strong connections with blocks β_3 (East Europe) and β_4 (Asia). Ten years earlier there were no strong relationships between East Europe and West Europe and between Asia and West Europe. There is no strong connection between β_3 (East Europe) and β_4 (Asia). Block β_6 (West Asia and Africa) is an isolate, but it has strong internal connections. β_5 (South America) and β_7 (Australia and New Zealand) continue to have links with only one block (North America).



β_1 (North America) : USA, CAN

β_2 (West Europe) : DEU, FRA, ITA, NLD, ESP, SWE, CHE, BEL DNK, FIN, AUT, NOR, GRC, TUR, IRL, POR

β_3 (East Europe) : SUN, POL, HUN, CSK, BGR, YUG, ROM

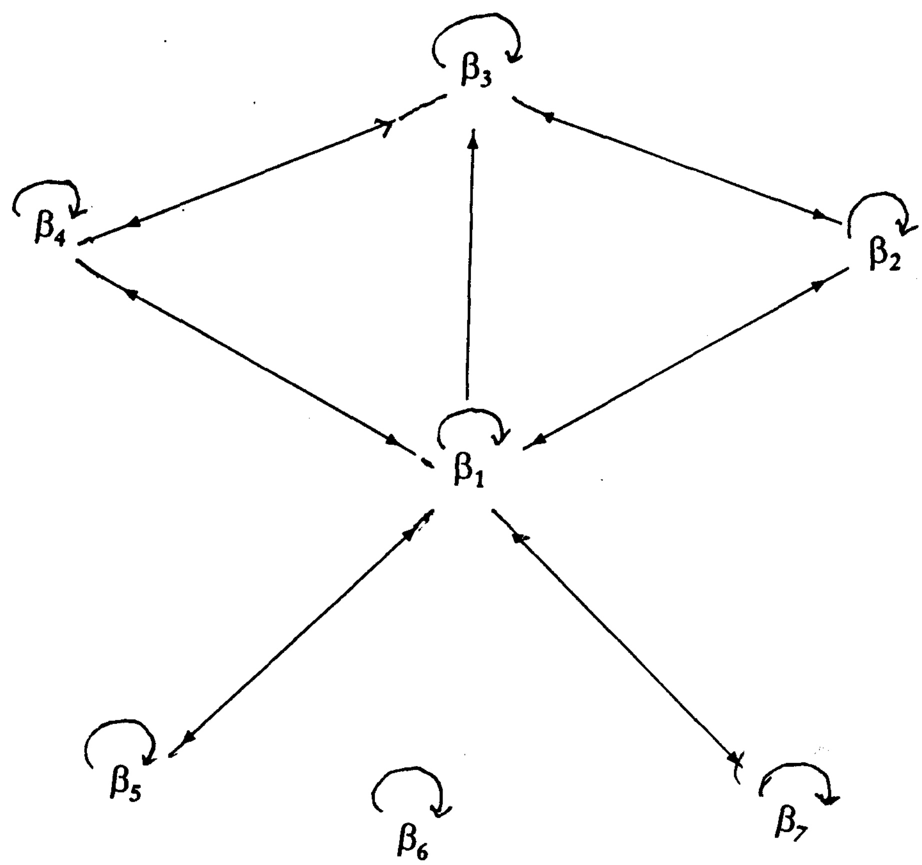
β_4 (Asia) : JPN, IND, PRC, TWN, KOR, HKG, SGP

β_5 (South America) : BRA, ARG, MEX, CHL, VEN

β_6 (West Asia and Africa) : ISR, ZAF, EGY, SAU, NGA

β_7 (Australia and Newzealand) : AUS, NZL

Fig. 3.21: Pseudo - block model of the network for 1982 - 1984



β_1 (North America)	: USA, CAN
β_2 (West Europe)	: DEU, FRA, ITA, NLD, ESP, SWE, CHE, BEL DNK, FIN, AUT, NOR, GRC, TUR, IRL, POR
β_3 (East Europe)	: SUN, POL, HUN, CSK, BGR, YUG, ROM
β_4 (Asia)	: JPN, IND, PRC, TWN, KOR, HKG, SGP
β_5 (South America)	: BRA, ARG, MEX, CHL, VEN
β_6 (West Asia and Africa)	: ISR, ZAF, EGY, SAU, NGA
β_7 (Australia and Newzealand)	: AUS, NZL

Fig. 3.22: Pseudo - block model of the network for 1992 - 1994

Table 3.5
Density of links between blocks 1982 - 1984

	β_1	β_2	β_3	β_4	β_5	β_6	β_7
β_1	1.000	0.705	0.187	0.500	0.500	0.400	1.000
β_2	0.705	0.566	0.294	0.117	0.070	0.152	0.264
β_3	0.187	0.294	0.821	0.000	0.000	0.025	0.000
β_4	0.500	0.117	0.000	0.285	0.028	0.028	0.214
β_5	0.500	0.070	0.000	0.028	0.900	0.000	0.000
β_6	0.400	0.152	0.025	0.028	0.000	0.200	0.100
β_7	0.000	0.264	0.000	0.214	0.000	0.100	1.000

Legend:

β_1 North America	: USA, CAN
β_2 West Europe	: UKD, FRG, FRA, ITA, NLD, ESP, SWE, CHE, BEL DNK, FIN, AUT, NOR, GRC, TUR, IRL, POR
β_3 East Europe	: GDR, SUN, POL, HUN, CSK, BGR, YUG, ROM
β_4 Asia	: JPN, IND, PRC, TWN, KOR, HKG, SGP
β_5 South America	: BRA, ARG, MEX, CHL, VEN
β_6 West Asia &Africa	: ISR, ZAF, EGY, SAU, NGA
β_7 Australia & New Zealand	: AUS, NZL

Table 3.6
Image matrix for 1982-1984 (Using mean cutoff: 0.25)

	β_1	β_2	β_3	β_4	β_5	β_6	β_7
β_1	1	1	0	1	1	1	1
β_2	1	1	1	0	0	0	1
β_3	0	0	1	0	0	0	0
β_4	1	0	0	1	0	0	0
β_5	1	0	0	0	1	0	0
β_6	1	0	0	0	0	0	0
β_7	1	1	0	0	0	0	1

Table 3.7
Density of links between blocks 1992 - 1994

	β_1	β_2	β_3	β_4	β_5	β_6	β_7
β_1	1.000	0.735	0.357	0.571	0.300	0.200	1.000
β_2	0.735	0.753	0.344	0.201	0.141	0.094	0.264
β_3	0.357	0.344	0.476	0.102	0.028	0.028	0.000
β_4	0.571	0.201	0.102	0.476	0.028	0.028	0.285
β_5	0.300	0.141	0.028	0.028	0.800	0.000	0.000
β_6	0.200	0.094	0.028	0.028	0.000	0.300	0.200
β_7	1.000	0.264	0.000	0.285	0.000	0.200	1.000

Legend:

β_1	North America	: USA, CAN
β_2	West Europe	: UKD, DEU, FRA, ITA, NLD, ESP, SWE, CHE, BEL DNK, FIN, AUT, NOR, GRC, TUR, IRL, POR
β_3	East Europe	: SUN, POL, HUN, CSK, BGR, YUG, ROM
β_4	Asia	: JPN, IND, PRC, TWN, KOR, HKG, SGP
β_5	South America	: BRA, ARG, MEX, CHL, VEN
β_6	West Asia &Africa	: ISR, ZAF, EGY, SAU, NGA
β_7	Australia & New Zealand	: AUS, NZL

Table 3.8
Image matrix for 1992 - 1994 (Using mean cutoffs: 0.29)

	β_1	β_2	β_3	β_4	β_5	β_6	β_7
β_1	1	1	1	1	1	0	1
β_2	1	1	1	1	0	0	0
β_3	1	1	1	0	0	0	0
β_4	1	0	0	1	0	0	0
β_5	1	0	0	0	1	0	0
β_6	0	0	0	0	0	1	0
β_7	1	0	0	0	0	0	1

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4 Transnational Links in Science Fields

This chapter seeks to examine the patterns of research output and transnational linkages of Indian science during five (indexing) years: 1990 – 1994 in eleven macrofields:

1. Mathematics (*MAT*)
2. Physics (*PHY*)
3. Chemistry (*CHM*)
4. Biology (*BIO*)
5. Earth & Atmospheric Sciences (*EAS*)
6. Food & Agriculture Research (*AGR*)
7. Clinical Medicine (*CLI*)
8. Biomedical Research (*BIM*)
9. Engineering and Technology (*ENT*)
10. Computer Science (*COM*)
11. Materials Science (*MTS*)

During this period, India had published 52,482 articles (*Articles, Reviews, Notes* and *Letters*) in the mainstream scientific journals covered by the *Science Citation Index*. Of these, 6,487 articles (12.4%) were cosigned by authors from 105 countries, indicating a total of 8,503 links. Many of these countries (36) had less than five links with India; these countries may be designated as '*transients*'.

Table 4.1 presents the data on cooperation links of '*non-transient*' countries aggregated over all fields of science (including unspecified area: *Multidisciplinary*).

In this table, the countries are ranked by the number of cooperation links with India. It can be easily seen that the distribution of links is highly skewed. The top ten countries - USA, UK, Germany, Canada, France, Japan, Italy, Russia (including CIS countries), Australia and Switzerland account for 77.5% of all cooperation links of the Indian science.

Table 4.1
Cooperation Links in Science

Country	*No. of Links*	*%*	*Country*	*No. of Links*	*%*	*Country*	*No. of Links*	*%*
USA	2504	29.45	CSK	37	0.44	IRL	13	0.15
UKD	893	10.50	MEX	36	0.42	LBY	13	0.15
DEU	860	10.11	PHL	36	0.42	PAK	13	0.15
CAN	505	5.94	FIN	34	0.4	YUG	16	0.19
FRA	434	5.10	ISR	33	0.39	IRN	11	0.13
JPN	442	5.20	EGY	30	0.35	NPL	11	0.13
ITA	377	4.43	GRC	28	0.33	ARG	10	0.12
SUN	206	2.42	TWN	28	0.33	KWT	10	0.12
AUS	189	2.22	NOR	27	0.32	TUR	8	0.09
CHE	181	2.13	NGA	27	0.32	ARE	7	0.08
NLD	167	1.96	CHL	26	0.31	COL	7	0.08
SWE	123	1.45	ROM	25	0.29	IRQ	7	0.08
ESP	118	1.39	CYP	25	0.29	OMN	7	0.08
PRC	108	1.27	THA	24	0.28	BHR	6	0.07
BEL	96	1.13	ZAF	24	0.28	ETH	6	0.07
HUN	87	1.02	MYS	22	0.26	JOR	6	0.07
BRA	75	0.88	SYR	21	0.25	TUN	6	0.07
BGD	60	0.71	NER	20	0.24	ZMP	6	0.07
DNK	52	0.61	NZL	19	0.22	ZWB	6	0.07
AUT	47	0.55	SGP	19	0.22	BRN	5	0.06
BGR	47	0.55	SAU	18	0.21	IDN	5	0.06
POL	46	0.54	KEN	17	0.2	LKA	5	0.06
KOR	41	0.48	HKG	16	0.19	MWI	5	0.06

The distribution of articles, internationally coauthored articles (*ICOA*) and cooperation links in different fields may be visualized from Figure 4.1. It can be easily seen that the proportions of articles, *ICOA's* and cooperation links in different fields do not match with each other, which implies that all the fields do not have the same propensity for attracting transnational cooperation.

If the proportion of *ICOA's* is greater than that of articles in a given field, it means that the particular field is more internationalized than expected on the basis of its publication output, and *vice versa*. *Mathematics*, *Physics*, *Biology*, *Earth & Atmospheric Sciences* and *Biomedical Research* are more internationalized, whereas *Chemistry*, *Materials Science* and *Clinical Medicine* are less internationalized.

If the proportion of links is greater than that of *ICOA's* in a field, it indicates greater incidence of multicountry cooperation in that particular field compared to the average for all fields. The proportion of links is greater than that of *ICOA's* only in *Physics*, which means that the incidence of multicountry articles is higher in this field.

Indicators of Transnational Cooperation

It is obvious that we cannot assess inter-field or inter-country differences in transnational cooperation on the basis of counts of internationally coauthored articles or those of cooperation links, since they are confounded by the size of the countries and the size of the subject fields. Hence, we have constructed the following 'relational' indicators for inter-field and inter-country comparisons: *Internationalization Index* (INI), *Cooperation Index* (COI), *Cooperation Extensiveness Index* (CEI) and *Affinity Index* (AFI). These indicators are defined in Figure 4.2.

Inter-field Differences in Transnational Cooperation

Table 4.2 presents the data on the output of articles, internationally coauthored articles and cooperation links in different fields. The values of associated indicators of transnational cooperation, viz. *INI*, *COI* and *CEI* are also given in the table.

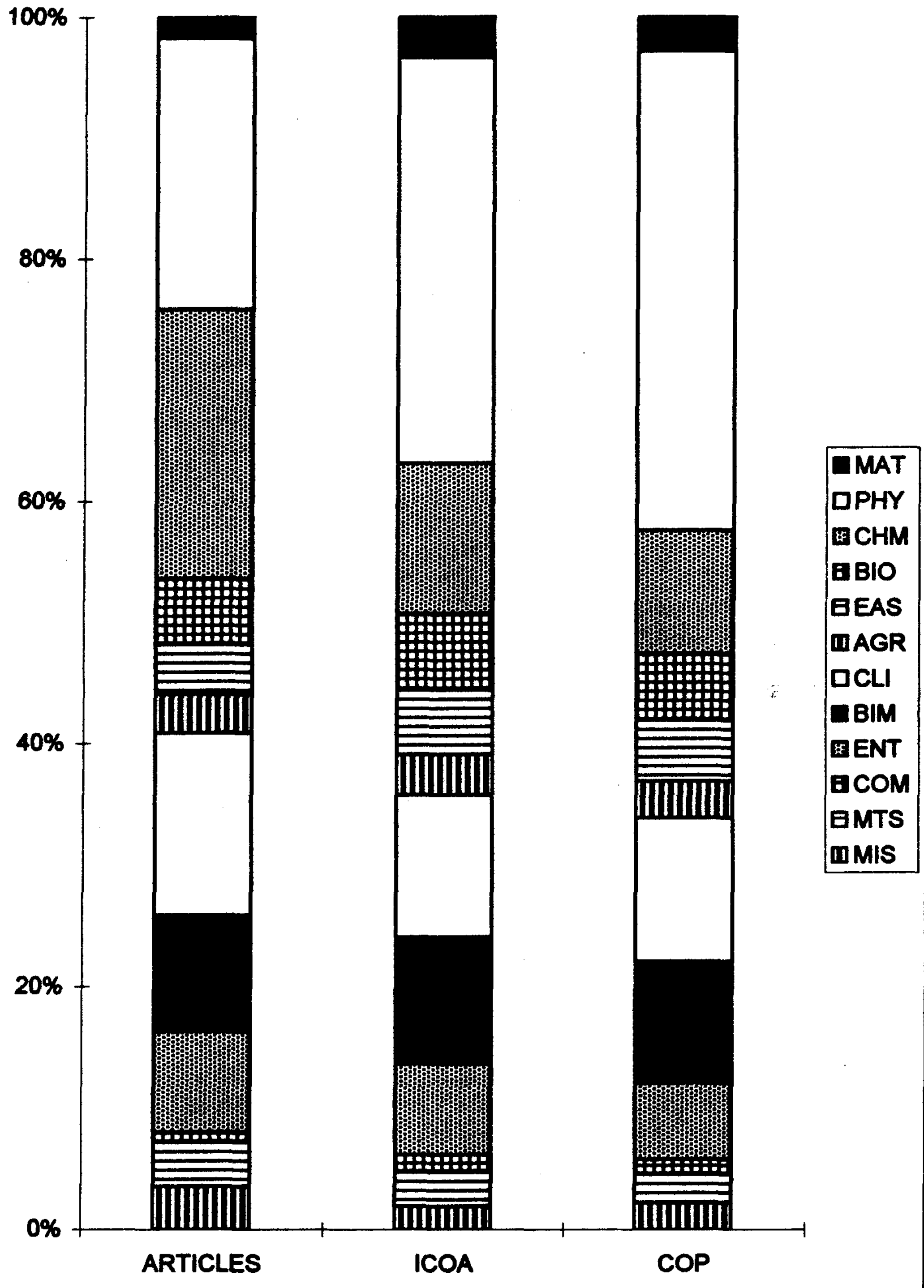


Fig. 4.1: Distribution of articles, internationally coauthored articles (ICOA) and cooperation links (COP) in different fields of Science

Internationalization Index (*INI*)

This index measures the output of internationally coauthored articles in a given field or country compared to that of all articles (*ICOA* + non *ICOA*) in that given field (or country).

$$INI = \frac{\text{Number of internationally coauthored articles}}{\text{Number of all articles}} \times 100$$

Cooperation Index (*COI*)

This index measures the incidence of cooperation links in a given field compared to the publication output in that field.

$$COI = \frac{\text{Number of cooperation links}}{\text{Number of all articles}} \times 100$$

Cooperation Extensiveness Index (*CEI*)

This index measures the incidence of cooperation links in a field compared to the output of internationally coauthored articles in that field.

$$CEI = \frac{\text{Number of cooperation links}}{\text{Number of internationally coauthored articles}} \times 100$$

If the value of *CEI* is close to 1, it means that all the internationally coauthored articles are based on bilateral cooperation. If the value of $CEI > 1$, it means greater incidence of multilateral cooperation.

Affinity Index (*AFI*)

Affinity Index (*AFI*) is a measure of the amount of collaboration between a given country *A* and another country *B* compared to the total collaboration of the given country *A* with the entire world (*WRD*) in a given field of science during a given period of time. *AFI* is therefore the number of links between *A* and *B* divided by the total links *A* has with the rest of the world (*WRD*) in a given field and during a given period of time. It indicates the scientific affinity of *A* toward *B* ($A \rightarrow B$).

$$AFI\,(\mathrm{A} \rightarrow \mathrm{B}) = \frac{COP\,(\mathrm{A} \leftrightarrow \mathrm{B})}{OP\,(\mathrm{A} \leftrightarrow \mathrm{WRD})} \times 100$$

Affinity index can be used to find how *B* situates in *A*'s international activity with the world and *vice versa*.

Fig. 4.2: Indicators of transnational cooperation

The values of *INI* indicate that *Mathematics* is the most internationalized field, followed by *Computer Science* and *Physics* in that order. About one fourth of all articles in *Mathematics* are internationally coauthored, whereas about one fifth of all articles in *Physics* and *Computer Science* are internationally coauthored. *Chemistry* is the least internationalized field, with only 7% of articles involving international cooperation.

Table 4.2
Publication Output and Cooperation Links in Scientific Fields (1990-1994)

Fields	*No. of Articles*	*ICOA*	*No. of Links*	*Internationalization Index INI %*	*Cooperation Index COI %*	*Cooperation Extensiveness Index CEI*
MAT	923	219	246	23.7	26.7	1.12
PHY	11746	2176	3360	18.5	28.6	1.54
CHM	11660	802	865	6.9	7.4	1.08
BIO	2827	405	463	14.3	16.4	1.14
EAS	2201	350	434	15.9	19.7	1.24
AGR	1673	219	258	13.1	15.4	1.18
CLI	7909	761	1006	9.6	12.7	1.32
BIM	5010	674	848	13.5	16.9	1.26
ENT	4319	484	534	11.2	12.4	1.10
COM	410	84	97	20.5	23.7	1.15
MTS	1950	192	208	9.8	10.7	1.08
MUL	1854	121	184	6.4	-	-
Total	52482	6487	8503	12.36	16.20	1.31

Physics ranks first on *COI*, but it ranks third on *INI*. It has lower incidence of internationally coauthored articles than *Mathematics* and *Computer Science*, but it has greater incidence of cooperation links than any other field. The value of *COI* (28.6) is far greater than that of *INI* (18.5), implying greater incidence of multilateral cooperation. This is also confirmed from the value of *CEI* (1.54) which is far in excess of 1. Thus, transnational cooperation in *Physics* is not only more frequent, but it is also more multilateral.

Mathematics has the highest value of *INI* (23.7), which is closely challenged by *Computer Science* (20.5), but the values of *COI* in these fields are only slightly greater than those of *INI*, implying little incidence of multilateral cooperation in these fields. This result is also confirmed from the values of *CEI*, which are close to 1 (*Mathematics*: 1.12; *Computer Science*: 1.15).

Chemistry has the lowest value of *INI* (6.9) which is quite close to that of *COI* (7.4), implying that transnational cooperation in *Chemistry* is not only infrequent compared to other fields, but it is also bilateral. This is also confirmed from the value of *CEI* (1.08), which is quite close to 1.

Clinical Medicine and *Biomedical Research* present an entirely different picture. The values of *INI* and *COI* are quite low, implying lower incidence of internationally coauthored articles and cooperation links, but the values of *COI* are much greater than those of *INI*, which implies greater incidence of multicountry articles in these two fields; the values of *CEI* are also much greater than 1. In other words, transnational cooperation in *Clinical Medicine* and *Biomedical Research* is less frequent (below average for *Clinical Medicine* and slightly above average for *Biomedical Research*), but when it takes place, it tends to be multilateral.

Engineering & Technology and *Materials Science* have lower incidence of internationally coauthored articles and cooperation links. The values of *INI* and *COI* are below average (of all fields). The values of *COI* are quite close to those of *INI*. Moreover, the values of *CEI* are quite close to 1.

	INI	*COI*	*CEI*
Engineering and Technology	11.2	12.4	1.10
Materials Science	9.8	10.7	1.08
Average (of all fields)	12.4	16.2	1.31

These results imply that transnational cooperation in *Engineering & Technology* and *Materials Science* is not only infrequent, it is also bilateral.

We can summarize the foregoing results by constructing a typology of transnational cooperation as follows:

Typology of Transnational Cooperation

		Nature of Cooperation	
		Multilateral	*Bilateral*
Frequency of Cooperation	Frequent	$\boxed{\text{Type 1}}$ PHY EAS	$\boxed{\text{Type 2}}$ MAT COM
	Infrequent	$\boxed{\text{Type 3}}$ CLI BIM	$\boxed{\text{Type 4}}$ CHM BIO AGR ENT MTS

Inter - Country Differences in Transnational Cooperation

The propensity for cooperation between any two countries depends on historical tradition, socio - cultural and political factors, levels of scientific potential and differences in international activity of the cooperating countries. Hence, a large skewness is observed in the distribution of India's links with its partner countries.

Inter - country differences in India's cooperation with various countries were assessed from the values of *Affinity Index*. Figure 4.3 represents India's affinities towards its eleven major partners aggregated over all fields of science (including undefined area: *Multidisciplinary*). Countries that account for at least 2% of all transnational links of India are designated as major partners. USA occupies the most important position in India's international cooperation; the same is also true for almost all other countries in the world. About 30% of India's international cooperation is conducted with USA. This country is also the most important partner of India in each of the eleven fields. UK and Germany each account for more than 10% of India's transnational links. Japan does not have commensurate prominence in India's international cooperation, inspite of its high status in the world of science (Japan occupies the third rank in the world in scientific output). The same is also true for Russia.

Figure 4.4 indicates India's affinities in eleven fields separately towards each of its seven major partners: USA, UK, Germany, Canada, France, Japan and Italy. It can be easily seen from the figure that affinities towards these countries covary with fields.

The profile of India's affinity towards USA does not exhibit much differentiation. All the fields are quite prominent in India's cooperation with USA, but *Computer Science* receives relatively greater importance than any other field, followed by *Mathematics* and *Materials Science*. *Agriculture* receives less importance than any other field.

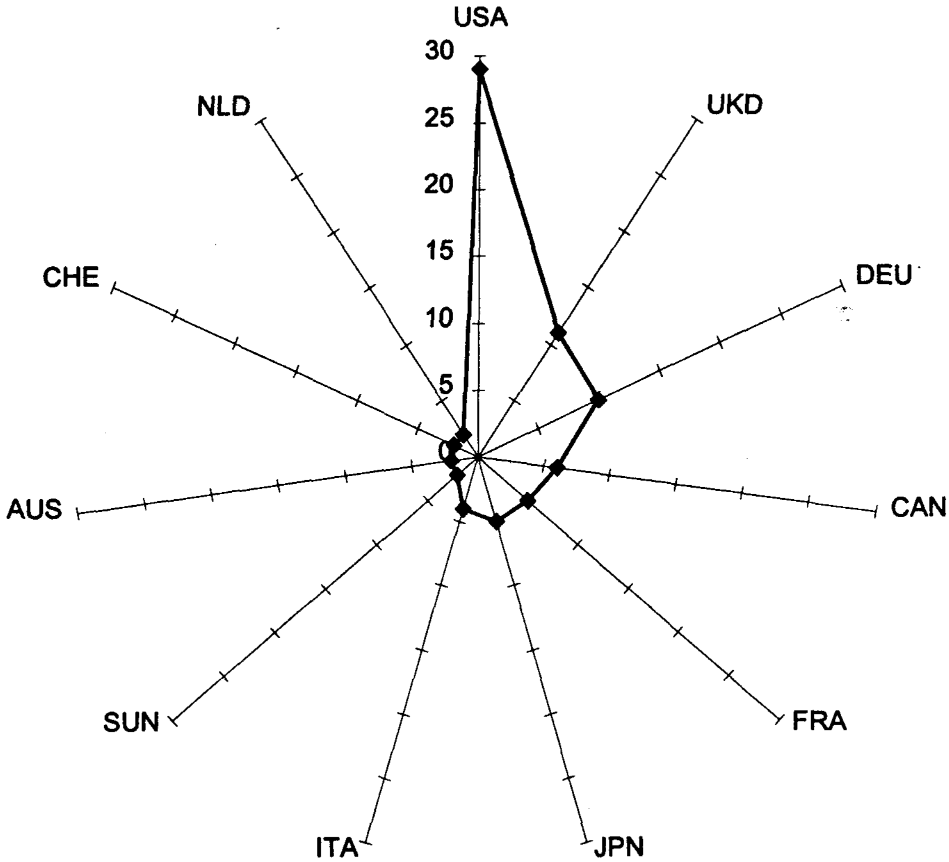


Fig. 4.3 : India's linkages in science (aggregated over all fields) (1990-1994)
(Affinity Index)

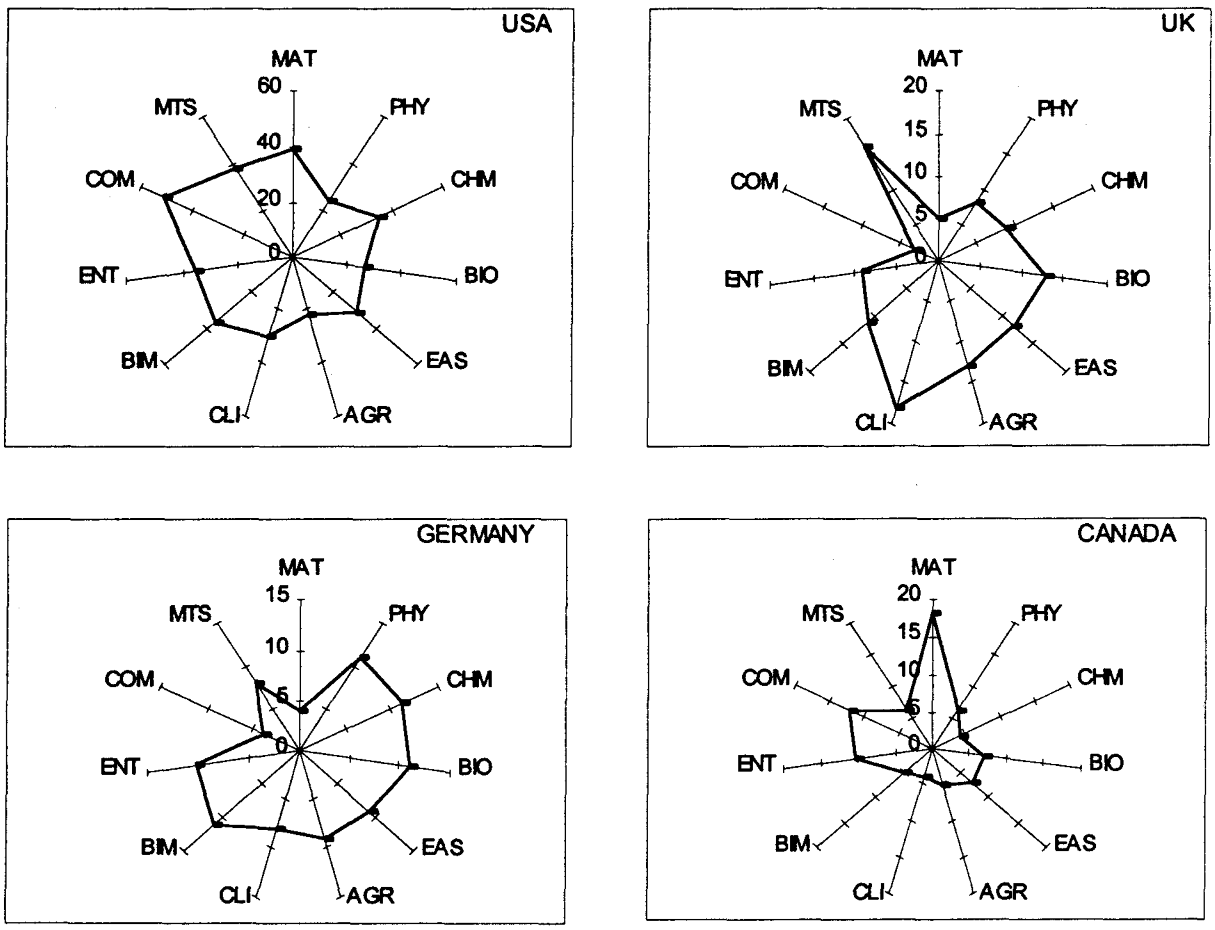


Fig. 4.4: India's affinities towards major cooperating countries in different fields of Science (1990-1994)
(Affinity Index)

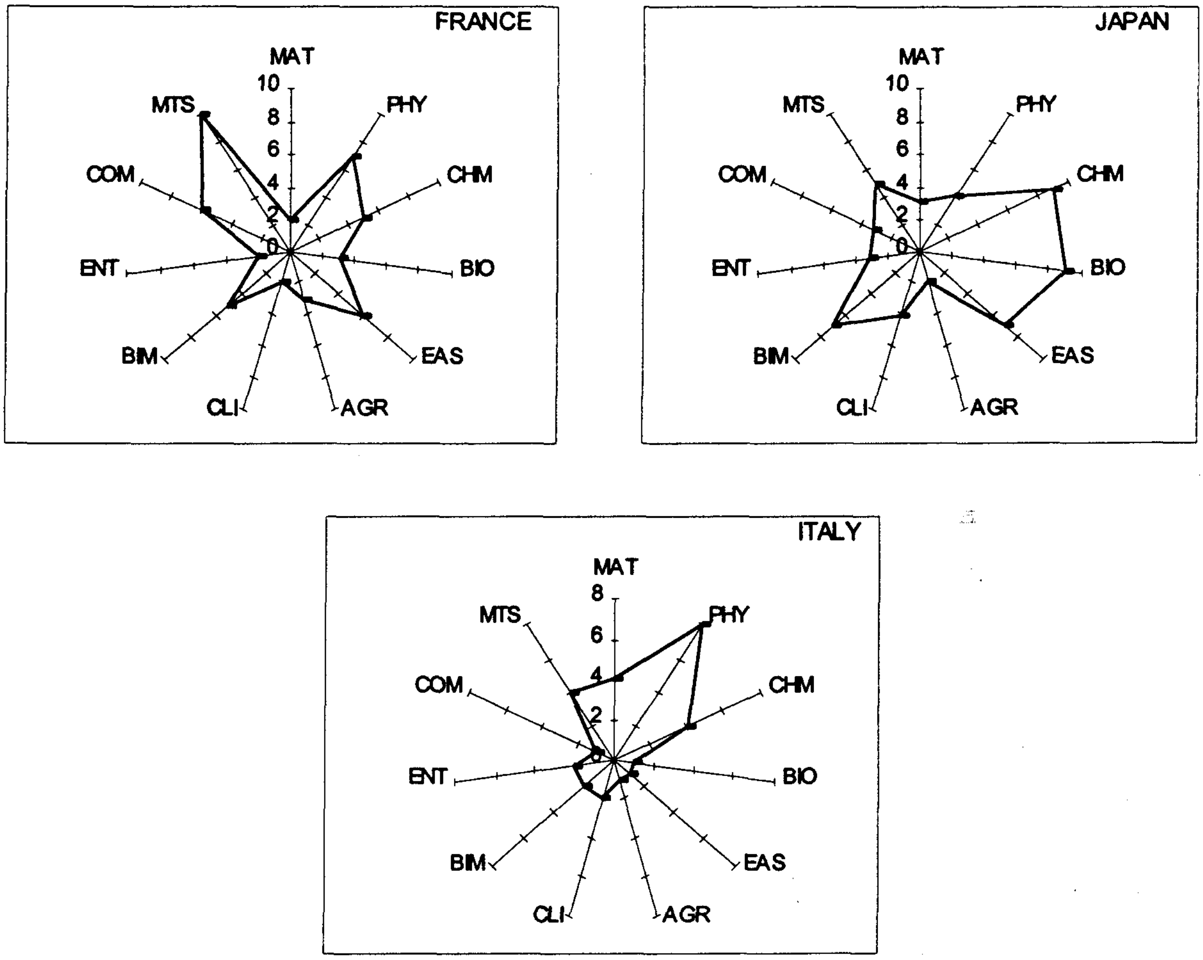


Fig. 4.4 (Contd.): India's affinities towards major cooperating countries in different fields of Science (1990-1994) (Affinity Index)

The profile of India's affinity towards UK does not show much differentiation. Except for *Computer Science*, *Mathematics* and *Engineering & Technology*, all the fields are quite prominent in India's cooperation with UK. *Clinical Medicine* is the most important field for bilateral cooperation between India and UK, whereas *Computer Science* is the least important field.

Cooperation with Japan gives the highest importance to *Chemistry*, followed by *Biology*. The least important fields are *Computer Science* and *Agriculture*.

The foci of cooperation between India and Canada are *Mathematics* and *Computer Science*. *Clinical Medicine* receives the lowest importance.

Cooperation with France gives the highest importance to *Materials Science*, followed by *Physics*. *Clinical Medicine*, *Mathematics* and *Engineering & Technology* receive the lowest importance.

Equally high prominence to several fields (viz. *Physics*, *Chemistry*, *Biology*, *Biomedical Research* and *Engineering & Technology*) is a characteristic feature of India's cooperation with Germany. *Computer Science* does not receive much importance.

Figure 4.5 indicates India's affinities with its major partners (*AFI* $\geq$2) separately for each field. This figure is self-explanatory and any elaboration would be redundant.

The first two most important partners of India in different fields are listed below:

Mathematics	USA, CAN
Physics	USA, DEU
Chemistry	USA, DEU $\approx$ UK $\approx$ Japan
Biology	USA, DEU
Earth and Atmospheric Sciences	USA, UK
Food & Agriculture Research	USA, UK
Clinical Medicine	USA, UK
Biomedical Research	USA, UK $\approx$ DEU
Engineering & Technology	USA, DEU $\approx$ CAN $\approx$ UK
Computer Science	USA, CAN
Materials Science	USA, UK

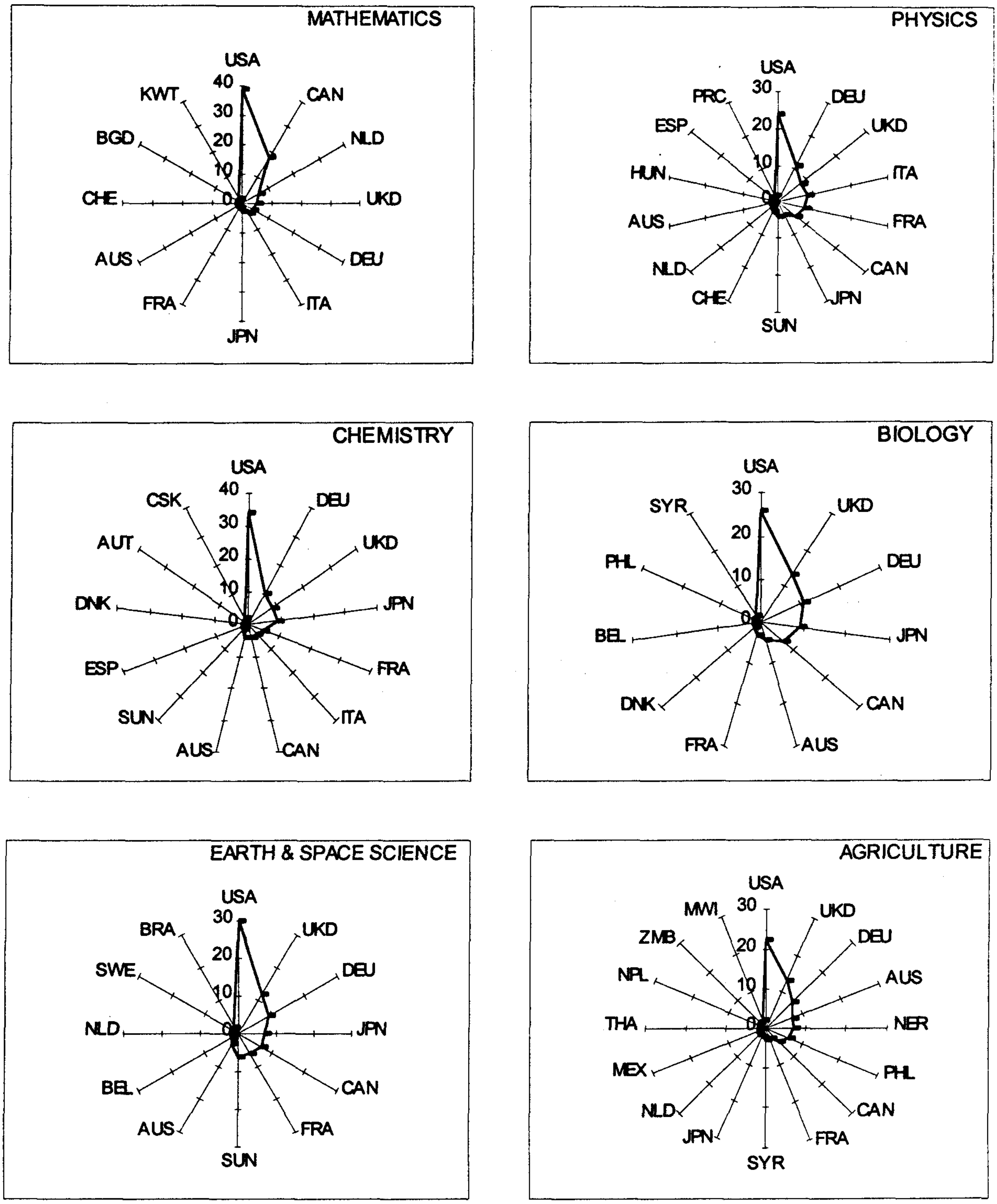


Fig. 4.5: India's linkages in different fields of Science (1990-1994)
Affinity Index

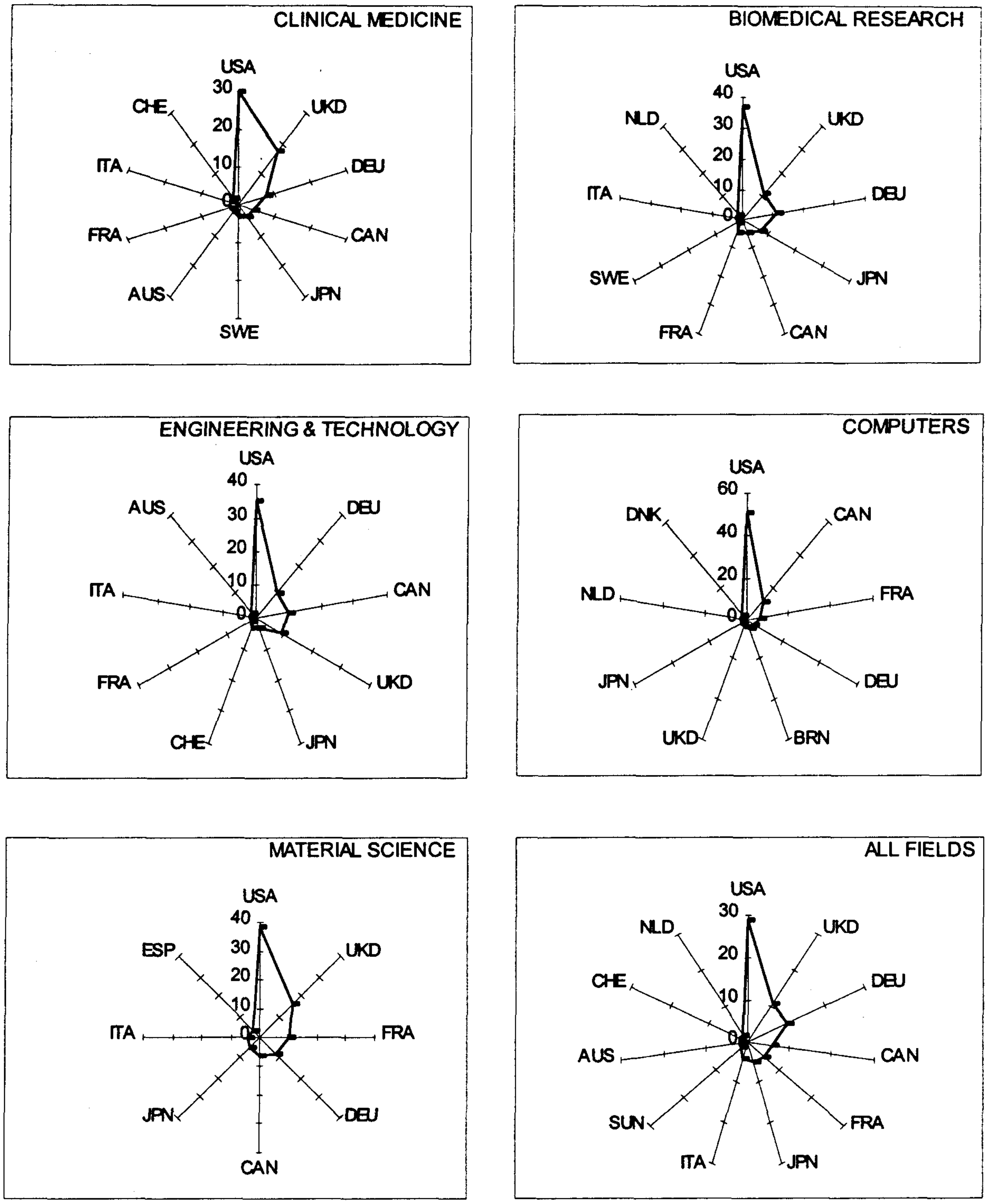


Fig. 4.5 (Contd.): India's linkages in different fields of Science (1990-1994)
Affinity Index

Structure of Transnational Cooperation

The foregoing country - by - country and field - by - field comparisons of transnational cooperation links of Indian science are very enlightening, but very time consuming. Moreover, they provide only unidimensional views of the data, which is essentially multidimensional. They cannot reveal the structure of the multivariate relations that exist between India's major partners and different scientific fields. Hence, we have used Correspondence Analysis (*CA*) which transduces the rectangular matrix of correlations between countries and fields into geometric measurements. Correspondence Analysis shows how India's significant partners are placed relative to each other and different research areas of science.

Thirty five countries, which had at least 25 links with India aggregated over all fields (including *Multidisciplinary*) were identified as major partners of Indian science. The lower bound of 25 links was fixed to filter out noise from the data and to keep the analysis and geometrical representation of the data within manageable limits. This threshold also seems to be reasonable for statistical validity of the results.

The data matrix of 35 countries (rows) and 11 fields (columns) presented in Table 4.3 was analyzed through Correspondence Analysis, using the computer program *CORAN* (Lebart, Morineau and Warwick, 1984). As a result of Correspondence Analysis, each field in the high-dimensional space is projected into the low - dimensional subspace of 35 countries, whereas each country is projected into the conjugate subspace of eleven scientific fields.

The program computes the coordinates of row and column points and represents them in two-dimensional factorial maps. It also computes the following statistics for interpretation of the results of Correspondence Analysis.

Table 4.3
Distribution of Cooperation Links in Eleven Fields

Country	*MAT*	*PHY*	*CHM*	*BIO*	*EAS*	*AGR*	*CLI*	*BIM*	*ENT*	*COM*	*MTS*
USA	97	822	290	120	132	58	305	313	188	49	78
UKD	12	268	81	62	52	34	185	93	49	3	33
DEU	11	385	93	49	39	23	79	94	52	4	16
CAN	45	187	36	32	29	13	40	39	52	12	13
JPN	8	138	77	42	32	6	44	56	18	3	10
FRA	4	224	47	15	26	7	21	40	13	6	20
ITA	11	253	36	4	6	2	24	16	13	1	9
SUN	2	130	20	1	24	0	5	10	3	0	2
AUS	5	52	34	17	15	19	21	9	11	0	1
CHE	5	108	12	0	2	3	23	8	15	0	0
NLD	15	83	6	5	10	5	14	15	8	3	1
SWE	0	40	9	3	8	2	35	16	7	1	0
ESP	1	79	13	1	1	0	9	4	1	0	7
PRC	1	76	2	4	3	1	9	4	4	0	2
BEL	3	39	9	10	9	0	8	7	3	1	1
HUN	2	52	9	4	4	0	4	4	5	1	1
BRA	2	46	1	2	7	0	6	5	5	0	0
BGD	6	13	6	2	1	2	10	7	13	0	0
DNK	0	11	14	7	1	0	9	2	3	3	0
AUT	1	11	14	2	1	0	10	6	2	0	0
BGR	0	40	2	1	0	0	1	2	1	0	0
POL	2	17	7	5	0	1	7	4	2	1	0
CSK	0	14	13	0	2	1	2	2	0	0	3
MEX	1	13	1	2	0	4	3	11	1	0	0
PHL	0	0	0	8	2	16	3	7	0	0	0
FIN	1	22	3	0	2	0	2	3	0	0	0
ISR	1	11	3	1	1	1	3	8	3	0	1
EGY	0	4	2	1	4	0	6	2	6	0	0
GRC	1	10	2	1	0	1	3	3	3	1	1
TWN	0	13	1	1	1	0	3	5	3	1	0
NOR	0	3	1	3	4	1	6	5	4	0	0
NGA	0	4	3	0	0	3	9	3	1	1	0
CHL	0	19	0	1	0	0	2	2	0	1	0
ROM	0	18	0	0	0	0	0	0	7	0	0
CYP	0	25	0	0	0	0	0	0	0	0	0

i. Eigen values of different factorial axes.

ii. Absolute contributions of the row and column points to the composition of each factorial axis.

iii. Relative contribution ($Cos^2\phi$) of each factorial axis to the representation of row and column points in the direction of the factorial axis.

The program also computes the distances (χ^2 - metrics) of rows and columns from the center of gravity (barycenter) of the multidimensional system in the full space. The row (or column) points which are near the barycenter have profiles which approximate the average profile of all the row (or column) points - i.e. '*typical*' profile of the multidimensional system. The points far away from the barycenter have 'specific' or '*atypical*' profiles.

Typicality of Fields

Figure 4.6 indicates the χ^2 - distances of different fields from the barycenter. None of the fields is located at the barycenter or even close to it, implying that none of the fields corresponds to the average profile (i.e. the average proportion of links of all the thirty five countries). This means that the proportions of links among the countries vary with the field. *Physics* is situated nearest to the barycenter, with *Biomedical Research* as a close challenger. This implies that India's links in these fields are relatively more widespread and evenly distributed among the countries. *Agriculture* has the most atypical behaviour, followed by *Computer Science* and *Mathematics*. India's links in these fields are not widespread and are very unevenly distributed.

Typicality of Countries

It can be easily seen from Figure 4.6 that Germany and USA are situated close to the barycenter, indicating an average proportion of eleven fields in these two countries. Thereafter, France, UK and Japan are situated nearest to the barycenter. These countries

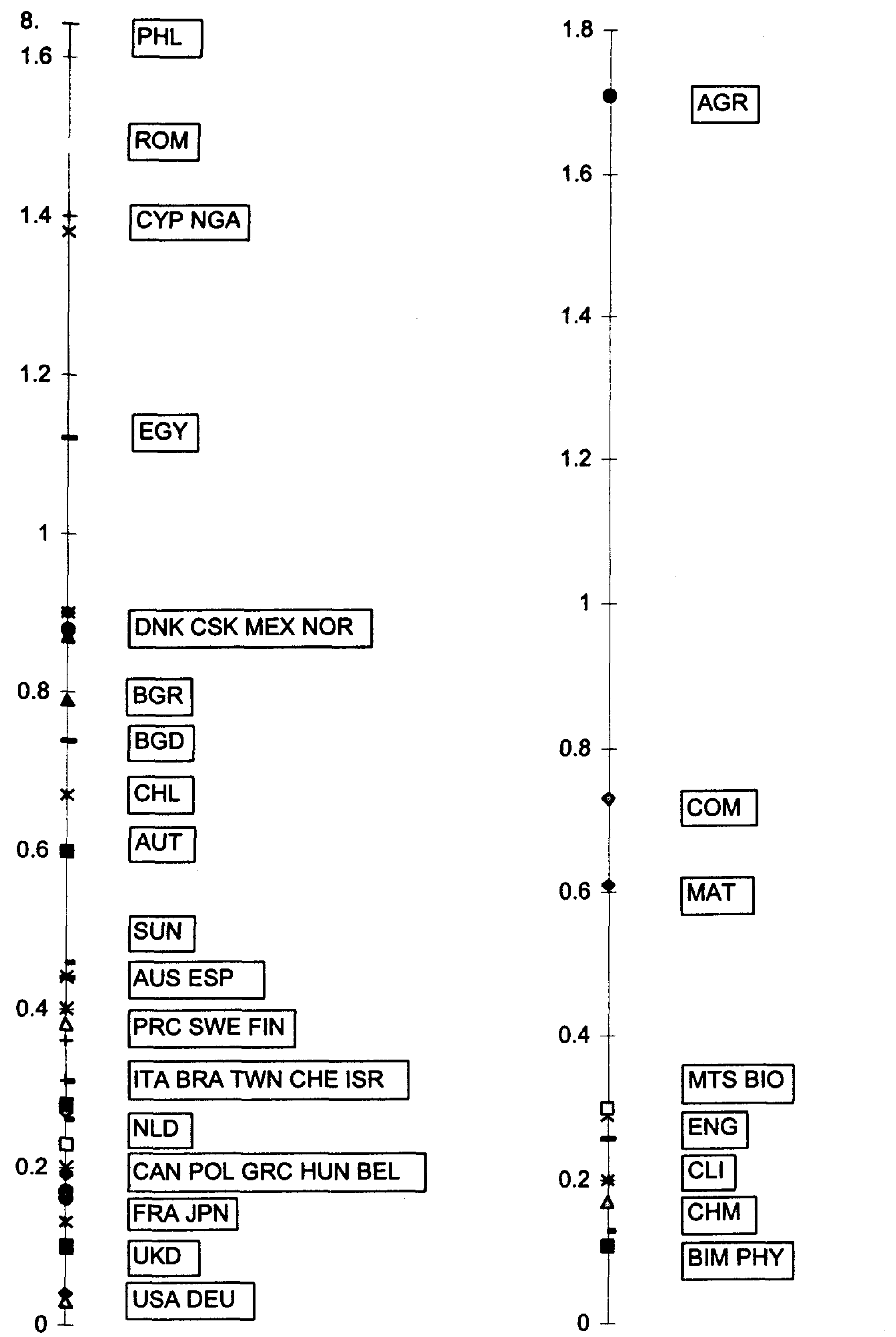


Fig. 4.6: Chi square distance from the barycenter

collaborate more evenly in the eleven scientific fields than do the rest of the countries (excluding Germany and USA).

Quite often, countries with a large amount of scientific articles tend to be located nearest to the barycenter. Scientifically small countries are situated far away from the barycenter. Philippines has the most atypical profile of collaboration with India. Almost all its links with India are confined to one field, viz. *Agriculture*. Other countries far way from the barycenter are: *Romania*, *Cyprus*, *Nigeria* and *Egypt*. These scientifically small countries distribute their cooperations with India quite unevenly among the fields. This phenomenon is rather natural, as large countries represent most often the large volume of cooperation with India; they form the principal core of the data matrix. However, some countries such as Russia, Italy, Netherlands, despite their large amounts of scientific activity, are situated at large distances from the barycenter, indicating specificities in their cooperation with India.

Results of Correspondence Analysis

Eigen values obtained from the Correspondence Analysis of the data indicate that the total variance ($\Sigma\lambda i = 0.223553$) is sufficiently large, which implies considerable deviations (from the average) in the amplitudes of profiles of cooperation with these countries. The first four factorial axes, accounting for 80.1% of the total variance in the multidimensional system, yield the most parsimonious representation of the data. The remaining axes, accounting for successively smaller amounts of variance, represent information of an idiosyncratic nature, which does not have much bearing on the structure of the multidimensional data. The first two axes, accounting for 58.1% of the total variance represent the main features of the multidimensional data. The third and the fourth axes, respectively accounting for 12.8% and 9.2% of the variance, provide complementary data for further analysis. The numerical results of Correspondence Analysis are presented in Tables 4.4. and 4.5.

Table 4.4
Contributions of explicative points to the composition of the first four factorial axes (Absolute contribution, permill)

Cloud	*Explicative points with positive coordinates*	*Explicative points with negative coordinates*
	Axis 1 (λ_1 = .091374, τ_1 = 40.87%)	
Fields	Biology (90) Agriculture (203) Clinical Medicine (113)	Physics (485)
Countries	USA (50) UKD (81) AUS (39) PHL (161)	FRA (40) ITA (150) SUN (83) CHE (34) ESP (52) PRC (44) BGR (44)
	Axis 2 (λ_2= .038393, τ_2 = 17.17%)	
Fields	Agriculture (611)	–
Countries	PHL (552) AUS (75) MEX (29)	USA (104))
	Axis 3 (λ_3 = .028622, τ_3 =12.80%)	
Fields	Mathematics (419) Engineering & Technology (193)	Chemistry (204)
Countries	CAN (330) NLD (98) BGD (72) ROM (31)	JPN (92) UKD (85) CSK (51) AUT (40) DNK (29)
	Axis 4 (λ_4 = .020643, τ_4 =9.23%)	
Fields	Chemistry (265)	Clinical Medicine (490)
Countries	CAN (38) JPN (120) FRA (43) AUS (35) CSK (54)	UKD (209) CHE (83) SWE (170) NGA (45)

Table 4.5
Contributions of the explained points to the eccentricities of the first four factorial axes (Relative contribution - permill)

Cloud	*Explained points with positive coordinates*	*Explained points with negative coordinates*
	Axis 1 (λ_1 = .091374, τ_1 = 40.87%)	
Fields	Biology (535) Agriculture (419) Clinical Medicine (404) Biomedicine (433)	Physics (930)
Countries	USA (411) UKD (460) AUS (358) PHL (398) NOR (480) NGA (394)	ITA (887) FRA (514) SUN (538) CHE (497) ESP (702) PRC (724) HUN (848) BGR (815) FIN (761) CHL (531) ROM (270) CYP (825)
	Axis 2 (λ_2= .038393, τ_2 = 17.17%)	
Fields	Agriculture (530)	—
Countries	DEU (256) AUS (287) MEX (284) PHL (572)	USA (362)
	Axis 3 (λ_3 = .028622, τ_3 = 12.80%)	
Fields	Mathematics (664), Engineering & Technology (347)	Chemistry (338)
Countries	CAN (770) NLD (575) BGD (372) GRC (308)	JPN (336) AUT (324) CSK (346)
	Axis 4 (λ_4 = .020643, τ_4 = 9.23%)	
Fields	Chemistry (316)	Clinical Medicine (397)
Countries	JPN (311) CSK (261)	SWE (614) UKD (267) CHE (274), NGA (226)

Figures 4.7 and 4.8 represent the two - dimensional map constituted by ϕ_1 and ϕ_2 axes separately for fields and countries. The representation of fields and countries in different graphics was done to avoid cluttering of the points in the same graphic. However, these two graphics are superimposable.

Factor ϕ_1 : The first factorial axis, accounting for 40.9% of the total variance, constitutes the most important element of the multivariate structure of relationships between countries and scientific fields.

On the cloud of fields, this factor is characterized by the polarity between *Agriculture*, *Biology*, *Clinical Medicine* and *Biomedical Research* on the one hand and *Physics* on the other. All these fields are quite well represented on this axis. *Physics* is projected on this axis with negative coordinate, whereas *Agriculture*, *Biology*, *Clinical Medicine* and *Biomedical Research* are projected on this axis with positive coordinates. Thus, the first factorial axis may be deemed as *Biosciences* versus *Physics* axis. This implies that countries which emphasize *Physics* in their collaboration with India tend to de - emphasize *Biosciences* and *vice - versa.*

The countries projected on this axis can be classified into two clusters, depending upon whether they are projected with positive or negative coordinates.

Cluster I: UK, USA, Philippines, Nigeria, Australia, Norway.

Cluster II: Italy, Hungary, Bulgaria, Cyprus, Finland, China, Spain, Russia, Brazil, Chile, France, Switzerland, Romania.

All these countries are best represented on this axis than any of the first four axes.

Cluster I countries, which are projected on this axis with positive coordinates, are correlated to *Biosciences* and anticorrelated to *Physics*. Philippines is the most eccentric point in the map. It is situated around the pole of *Agriculture*, indicating strong preference to this field in its cooperation with India. Nigeria and Australia, which are situated far away from the origin, are also more prominent in *Agriculture* in their cooperation with India. USA, UK and Nigeria are relatively more prominent in *Clinical Medicine / Biomedical Research* in their links with India.

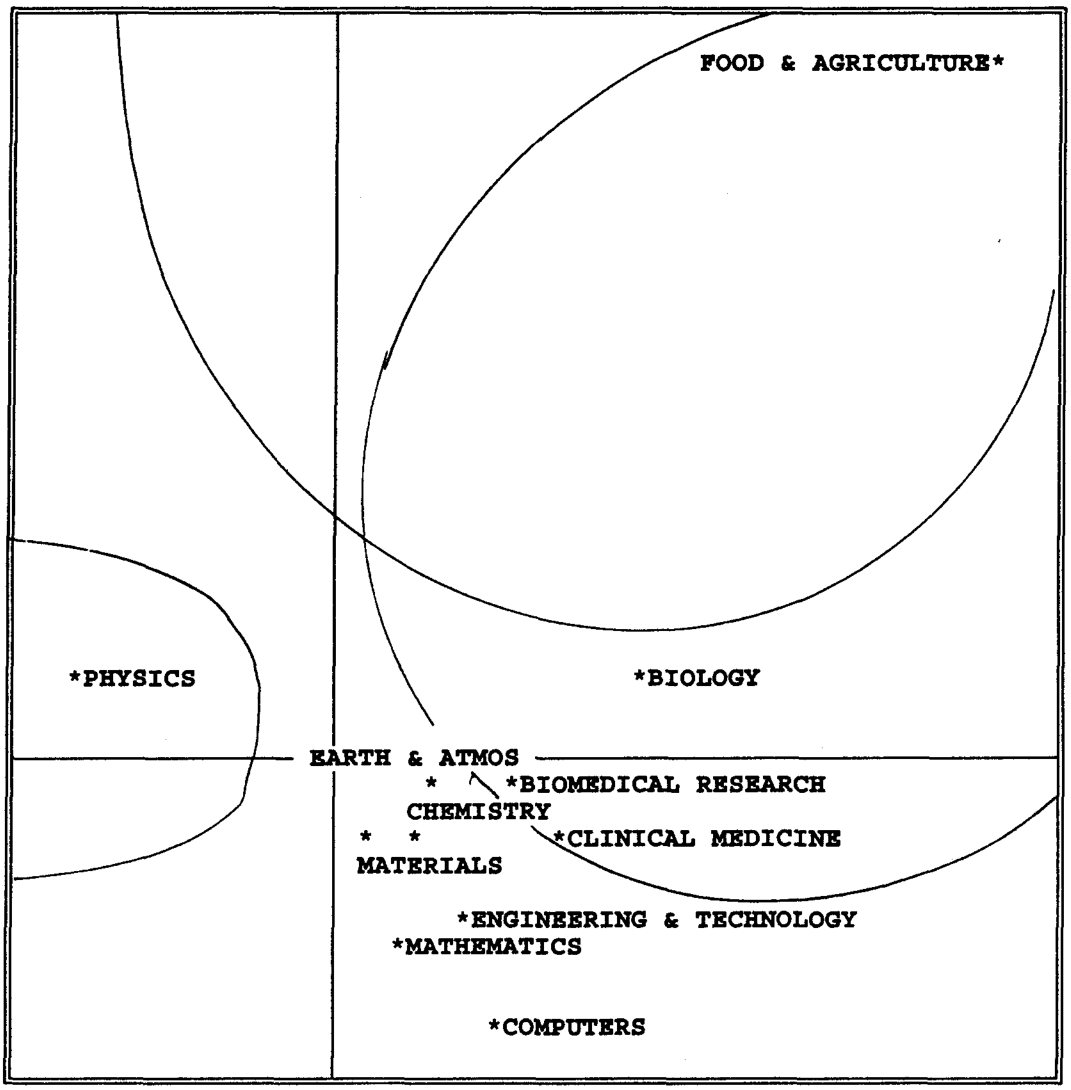


Fig. 4.7: Correspondence Analysis of transnational cooperation in Science fields (Field Points)

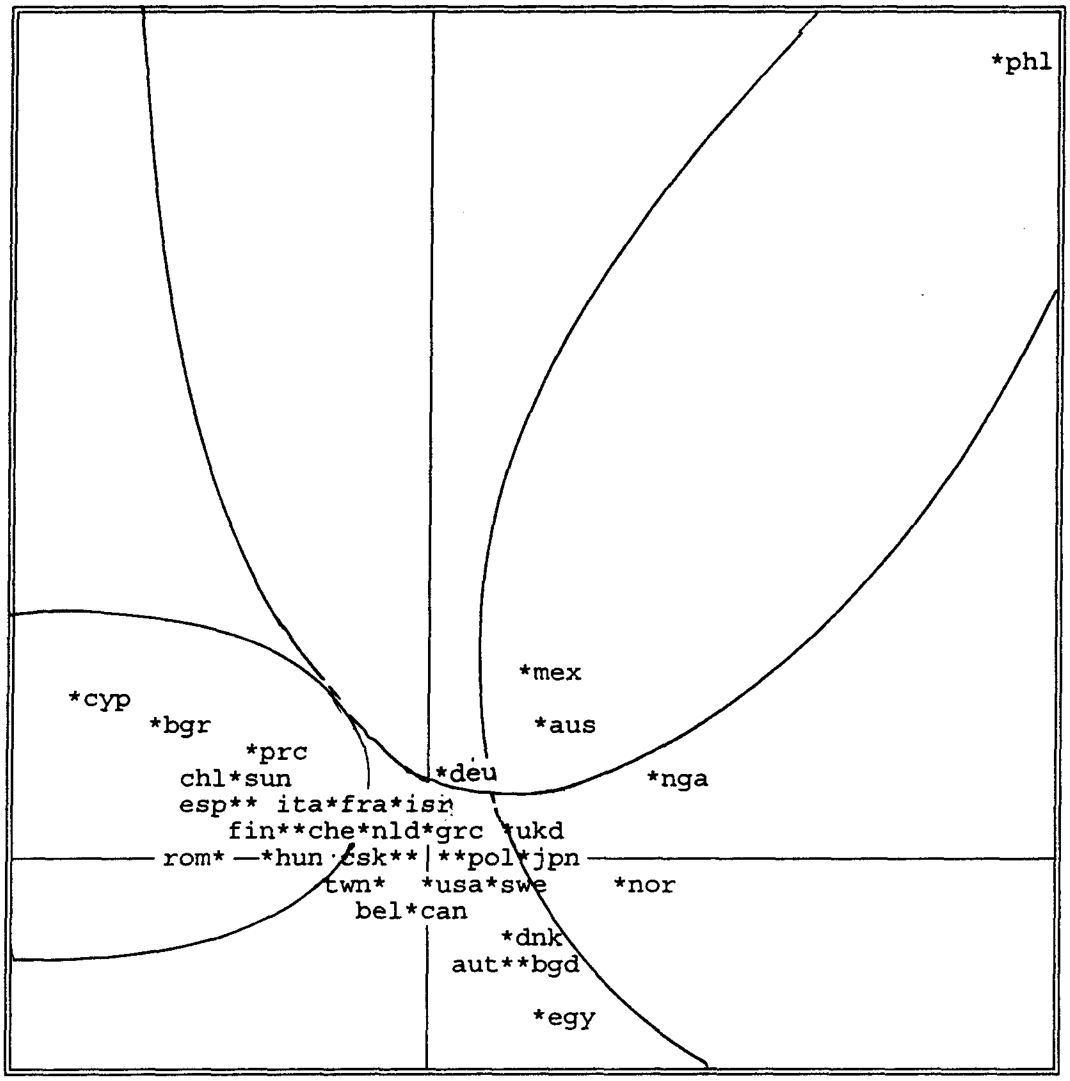


Fig. 4.8: Correspondence Analysis of transnational cooperation in Science fields (Country Points)

Cluster II countries are projected with negative coordinates on this axis. These countries are correlated to *Physics* and anticorrelated to *Biological Sciences*.

Factor ϕ_2: The second factorial axis, accounting for 17.2% of the total variance, constitutes the second most important element of the multidimensional data.

On the cloud of fields, this factor does not represent a polarity. This factor is dominated by *Agriculture* which is projected on this axis with positive coordinate.

On the country cloud, this axis represents the polarity between Philippines, Australia, Mexico and Germany on the one hand and USA on the other.

USA, which is projected on this axis with negative coordinate, is anticorrelated to *Agriculture*.

Philippines, Australia, Mexico and Germany, which are projected on this axis with positive coordinates, are correlated to *Agriculture.*

Factor ϕ_3: The third factorial axis accounts for 12.8% of the total variance. Figure 4.9(a) represents the main relationship between fields and countries in the form of a vertical scale (one – dimensional representation).

On the cloud of fields, this factor is characterized by the opposition between *Mathematics* and *Engineering & Technology* on the one hand and *Chemistry* on the other. These fields are better represented on this axis than on any other axis.

Mathematics and *Engineering & Technology* are projected on this axis with positive coordinates, whereas *Chemistry* is projected on this axis with negative coordinate.

The countries correlated to this factorial axis can be classified into two clusters, depending on whether they are projected on this axis with positive or negative coordinates.

Cluster I: Canada, Netherlands, Bangladesh, Greece and Romania.

These countries are best represented on this axis. These countries are projected on this axis with positive coordinates; they are therefore correlated to *Mathematics* and *Engineering & Technology*, depending upon their proximities to the poles of these fields. These countries are anticorrelated to *Chemistry*.

Cluster II: Czechoslovakia and Japan.

These countries are better represented on this axis than on any other axis. These countries are projected on this axis with negative coordinates and are therefore correlated to *Chemistry*, and anticorrelated to *Mathematics* and *Engineering & Technology*.

Factor ϕ_4 : The fourth factorial axis accounts for 9.2% of the total variance. Figure 4.9(b) represents the main relationships between fields and countries in the form of a vertical scale (one – dimensional representation).

On the cloud of fields, this axis represents the polarity between *Chemistry* and *Clinical Medicine. Chemistry* is projected on this axis with positive coordinate, whereas *Clinical Medicine* is projected on this axis with negative coordinate.

The countries correlated to this axis can be classified into two clusters according to the signs of coordinates of their projection.

Cluster I: Australia, France, Canada, Japan and Czechoslovakia.

Cluster II: Sweden, UK, Switzerland and Nigeria.

Cluster I countries are projected on this axis with positive coordinates and are therefore correlated to *Chemistry* and anticorrelated to *Clinical Medicine. Cluster* II countries, on the other hand, are correlated to *Clinical Medicine* and anticorrelated to *Chemistry*.

The complex structure of relationships of 35 countries with eleven scientific fields (in which they cooperate with India) as revealed by the Correspondence Analysis of the data matrix is summarized in the *Infographic Map* (Figure 4.10). Some keys for interpreting the *Infographic Map* are given in Figure 7 (page: 15).

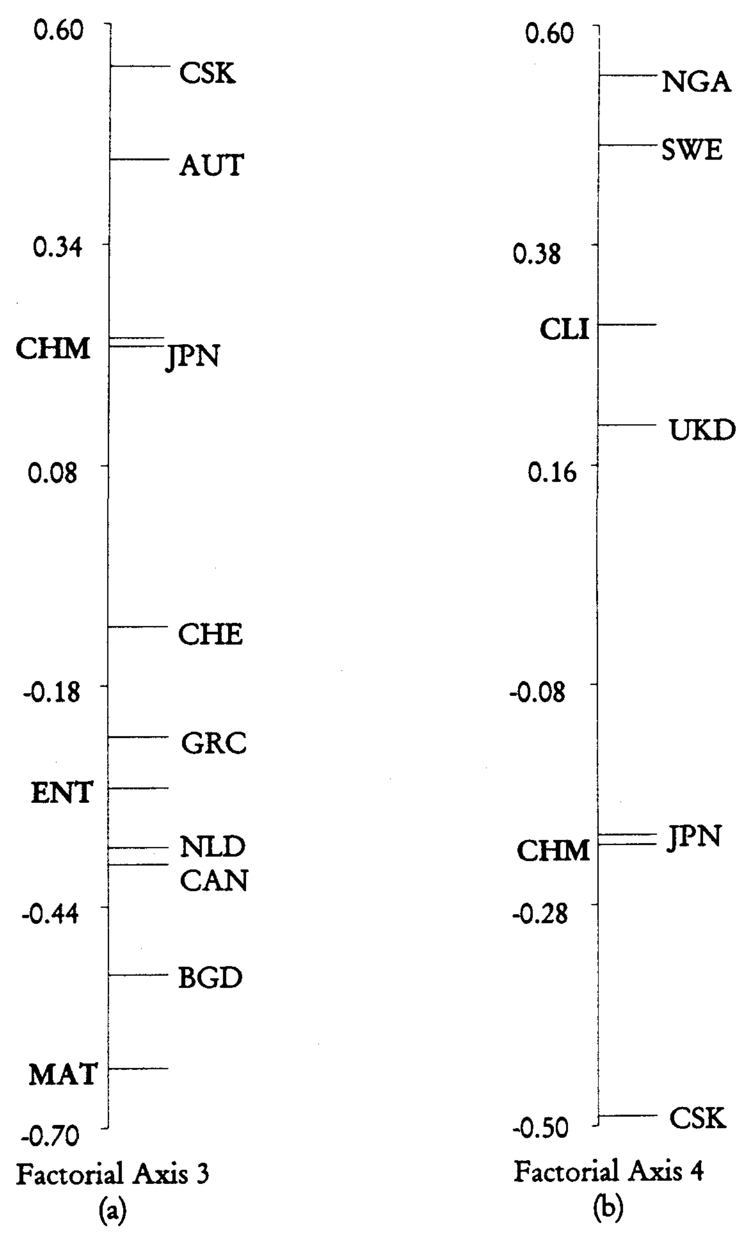
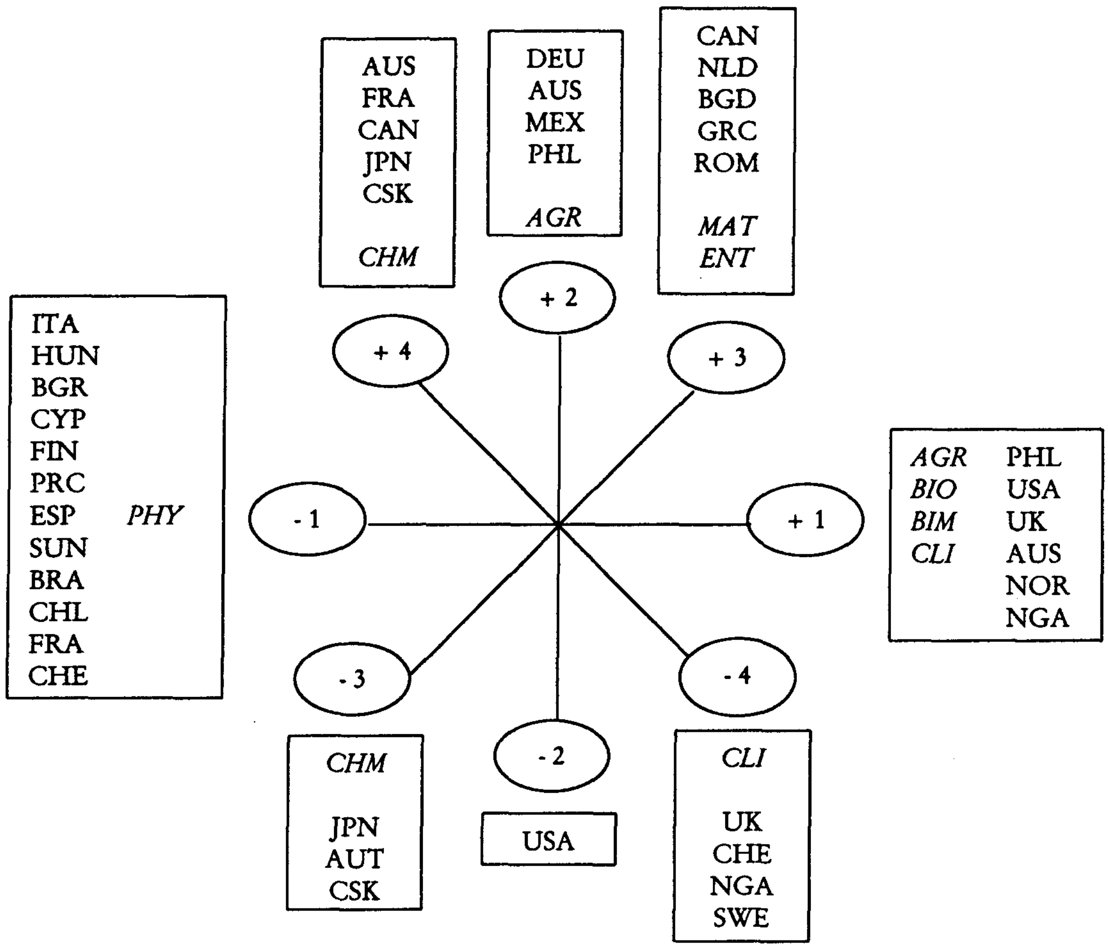


Fig. 4.9 Correspondence analysis of cooperation links in science fields



Variance explained
Axis 1 : 40.9%
Axis 2 : 17.2%
Axis 3 : 12.8%
Axis 4 : 9.2%

About 80% of the total information is captured in the four - dimensional subspace

Fig. 4.10: Summary of correspondence analysis

Subpopulation Analyses

Correspondence Analysis of the matrix of correlations between India's 35 significant partner countries and eleven scientific fields has provided an overview of the global structure of relationships. We would now focus on a limited set of closely related countries or fields to reveal the fine - grained structures of relationships in the multidimensional data. Simplified Correspondence Analysis maps, representing 100% of the variance, can be created by selecting three rows or columns as reference variables.

Structure of Cooperation in Biosciences

Figure 4.8 indicates that a number of countries are situated in the right - hand quadrants in a dense cloud around the ϕ_1 axis and publish in three related fields, viz. *Biology*, *Clinical Medicine* and *Biomedical Research* in a way which is relatively homogeneous compared to the average (of 35 countries). However, certain preferences can be highlighted through Correspondence Analysis of the submatrix: 35 countries × three fields (*Biology*, *Clinical Medicine* and *Biomedical Research*). *Agriculture* is not included in the subset analysis, since its profile is quite different from those of *Biology*, *Clinical Medicine* and *Biomedical Research*. It may be recalled that *Agriculture* is the most eccentric point in the two - dimensional factorial map (Figure 4.7).

Figure 4.11 presents the two - dimensional factorial map spanned by ϕ_1 and ϕ_2 axes.

The first factorial axis (ϕ_1), indicating 58.9% of the variance, is characterized by the polarity between *Clinical Medicine* (AC=50.5%; RC=0.916) and *Biology* (AC=40.2%; RC=0.586). *Clinical Medicine* is projected with positive coordinate, whereas *Biology* is projected with negative coordinate.

UK, Italy, Switzerland, Spain, Brazil, Bangladesh, Austria, Egypt, Nigeria and Sweden are projected on this axis with positive coordinates. These countries, therefore, indicate relatively stronger preference for cooperation in *Clinical Medicine*. On the other hand, Germany, Canada, France, Japan, Hungary, Philippines and Bulgaria are projected on this axis with negative coordinates. These countries indicate relatively stronger preference for cooperation in *Biology* than in *Clinical Medicine*.

The second factorial axis, indicating 41.1% of the variance, mirrors the polarity between *Biology* (*AC*=40.7%; *RC*=0.414) and *Biomedical Research* (*AC*=52.7%; *RC*=0.798). *Biomedical Research* is projected on this axis with positive coordinate, whereas *Biology* is projected with negative coordinate.

USA, Japan, Russia, Netherlands, Czechoslovakia, Mexico, Finland, Israel, Greece and Taiwan are projected on this axis with positive coordinates. These countries therefore indicate relatively stronger preference for cooperation in *Biomedical Research*. On the other hand, UK, Australia, China, Belgium, Denmark, Poland and Norway, which are projected on this axis with negative coordinates, indicate relatively stronger preference for cooperation in *Biology*.

Structure of Cooperation in Engineering & Technology, Materials and Computer Sciences

Figure 4.12 presents the two - dimensional factorial map indicating the structure of correlations between India's significant partner countries and fields of *Engineering & Technology*, *Materials* and *Computer Science*.

The first factorial axis, accounting for 65.5% of the total variance, is characterized by the polarity between *Engineering & Technology* (*AC*=29.1%; *RC*=0.874) and *Materials Science* (*AC*=70.9%; *RC*=0.974). The second factorial axis, indicating 34.5% of the total variance, does not have a polarity. It is characterized by *Computer Science* (*AC*=88.4%; *RC*=1.000).

Engineering & Technology is projected on the first axis with positive coordinate whereas *Materials Science* is projected with negative coordinate.

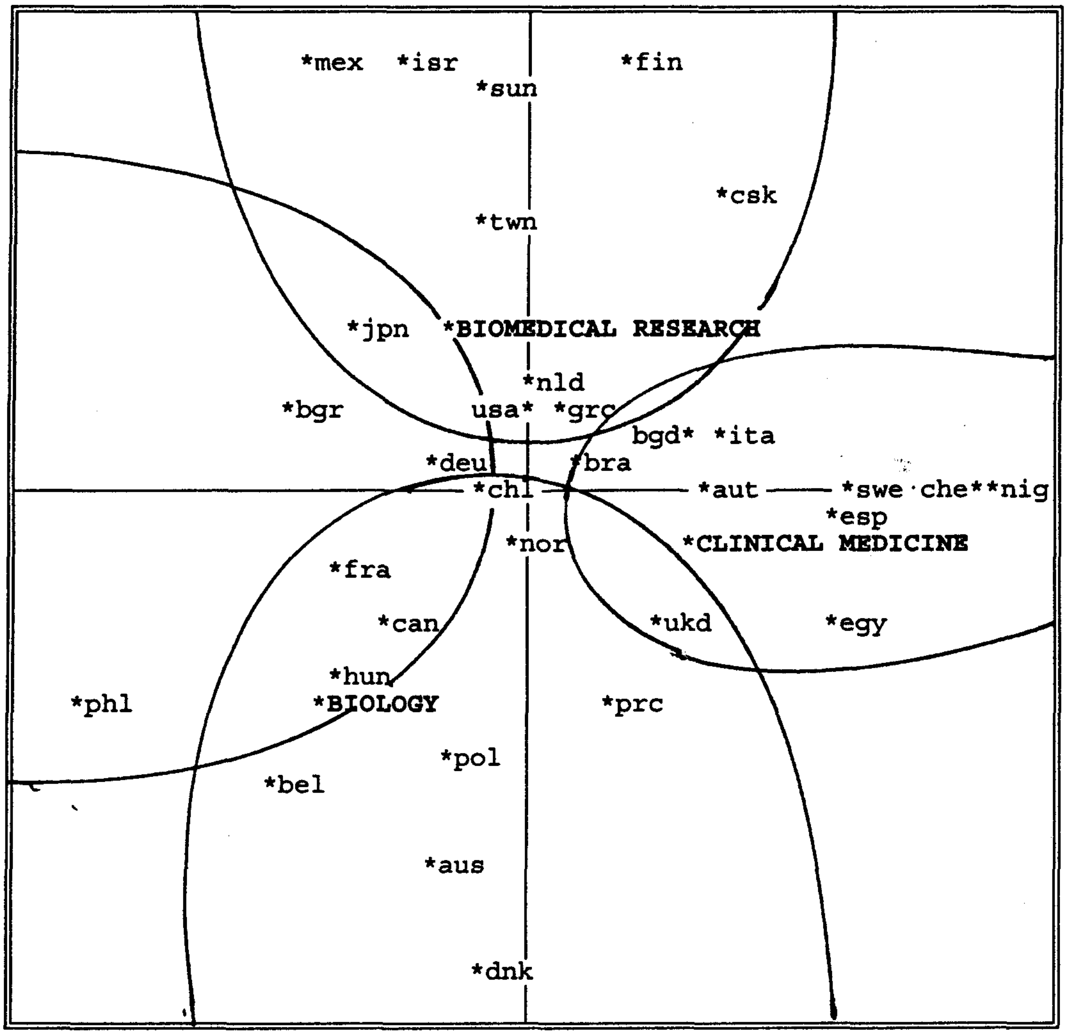


Fig. 4.11: Correspondence Analysis of transnational cooperation in Bioscience fields

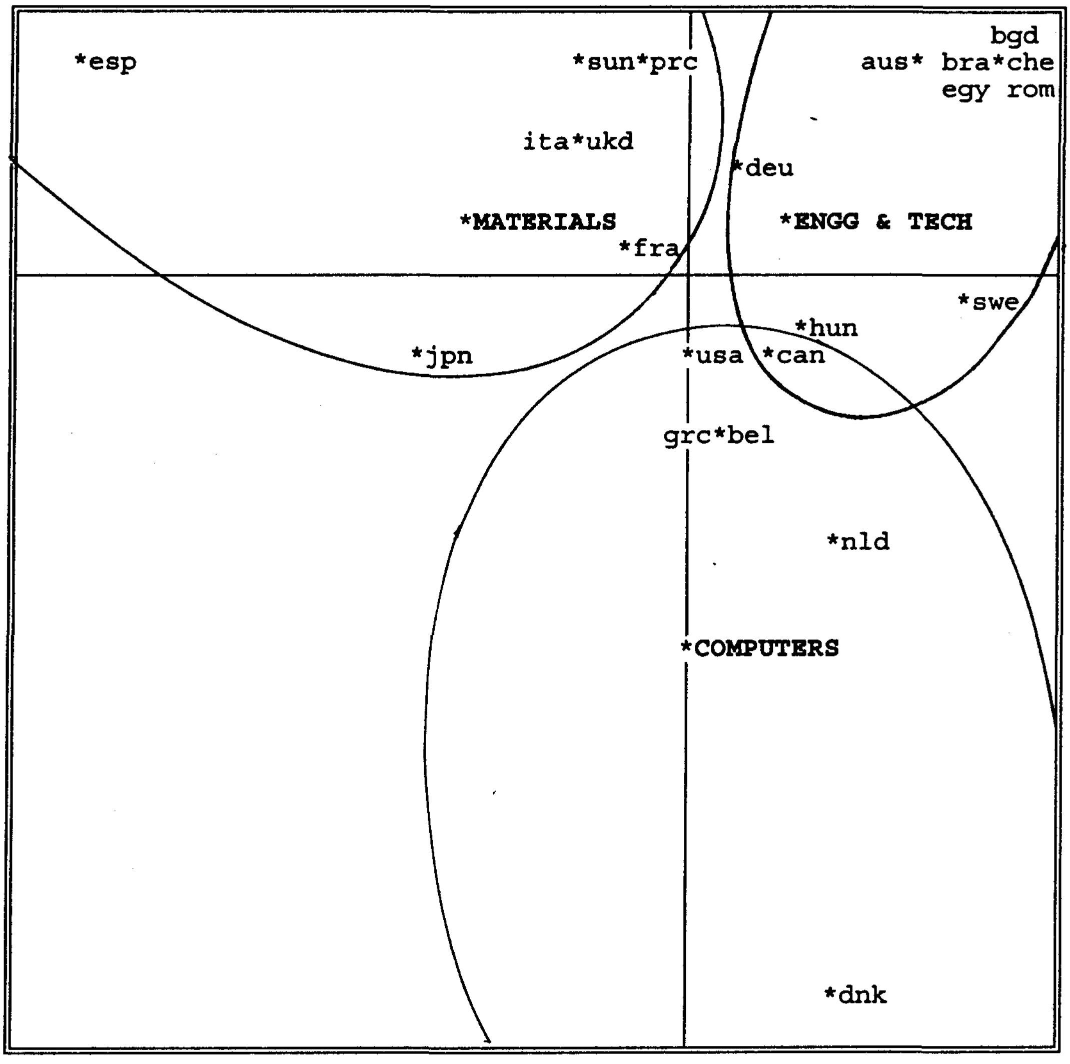


Fig. 4.12: Correspondence Analysis of transnational cooperation in three fields (Engineering & Technology, Materials and Computer Science)

Canada, Hungary, Brazil, Bangladesh, Egypt, Switzerland, Germany and Romania are projected on this axis with positive coordinates. These countries indicate relatively stronger preference for *Engineering & Technology* in their cooperation with India. UK, France, Japan, Italy and Spain, which are projected on this axis with negative coordinates, indicate relatively stronger preference for *Materials Science* in their cooperation with India.

Computer Science is projected on the second factorial axis with negative coordinate. Also, USA, Canada, Netherlands, Belgium, Denmark and Greece are projected on this axis with negative coordinates. These countries indicate relatively stronger preference for *Computer Science* in their cooperation with India.

Structure of Cooperation in Cutting Edge Areas

Biochemistry & Molecular Biology, *Immunology* and *Neurosciences* are some of the cutting edge areas of scientific research today. How are India's partner countries situated in these three disciplines?

Fourteen countries (USA, UK, Germany, Japan, Canada, Sweden, Italy, Switzerland, Australia, France, Russia, Austria and Poland) had at least five links with India in these three disciplinary areas combined together. The structure of correlations between the fourteen countries and three disciplinary areas was explored through Correspondence Analysis. The results are presented in Figure 4.13.

The first factorial axis, indicating 53.35% of the total variance, does not represent a polarity. *Neurosciences* (AC=83.0%; RC=0.977) is projected on this axis with negative coordinate. Austria, Sweden and Canada, which are projected in the left - hand quadrants, are correlated to *Neurosciences*. These countries indicate relatively stronger preference for cooperation with India in this area.

The second factorial axis, indicating 46.65% of the total variance, is characterized by the polarity between *Immunology* (AC=64.4%, RC=0.830) and *Biochemistry & Molecular Biology* (AC=33.4%; RC=0.841). *Immunology* is projected on this axis with positive coordinate, whereas *Biochemistry* & *Molecular Biology* is projected with negative coordinate. Australia, Japan, Switzerland and UK are projected in the upper right - hand quadrant. These countries are correlated to *Immunology* and thus give greater importance to this area in their cooperation with India.

France, Germany, Italy, Russia and USA, which are situated in the lower right - hand quadrant, are correlated to *Biochemistry & Molecular Biology*. These countries indicate relatively stronger preference to *Biochemistry & Molecular Biology* in their cooperation with India.

Structure of Cooperation with Super Powers of Science

The structure of correlations between three super - powers of science, USA, UK and Japan and eleven fields in which they cooperate with India can be visualized from the two - dimensional factorial map (Figure 4.14) issued by the Correspondence Analysis.

The first factorial axis is characterized by the opposition between Japan (*AC*=51.9%; *RC*=0.717) and UK (*AC*=46.9%; *RC*=0.738).

Japan, which is situated in lower right - hand quadrant, indicates stronger preference for cooperation in *Physics* and *Materials Science*, whereas UK, situated in the lower left - hand quadrant, indicates stronger preference for *Clinical Medicine*, *Biology* and *Agriculture*.

The second factorial axis represents the polarity between USA (*AC*=33.4%; *RC*=0.940) on the one hand and UK (*AC*=29.8%; *RC*=0.262) and Japan (*AC*=36.8%; *RC*=0.283) on the other. USA is situated in the upper right - hand quadrant. Its distance from the barycenter is less than that of either UK or Japan. Thus, USA has a more homogeneous profile than the other two super powers. However, it shows somewhat greater inclination for cooperation with India in *Mathematics*, *Computer Science*, *Engineering & Technology* and *Biomedical Research*.

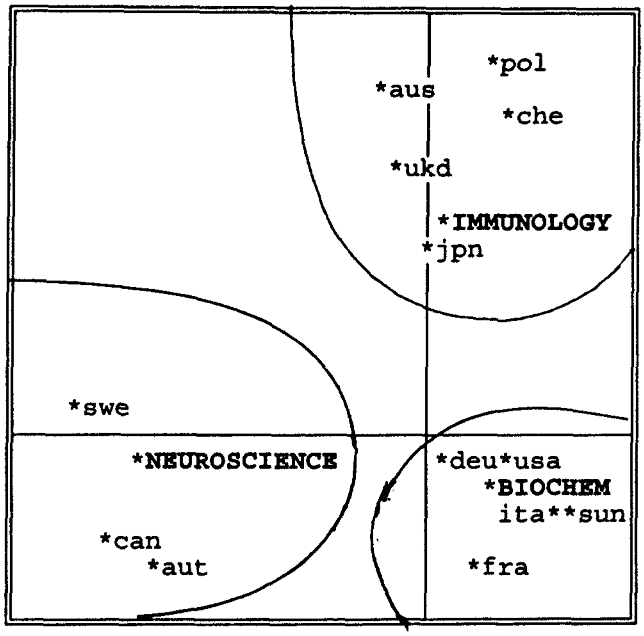


Fig. 4.13: Correspondence Analysis of transnational cooperation in cutting edge areas of Science

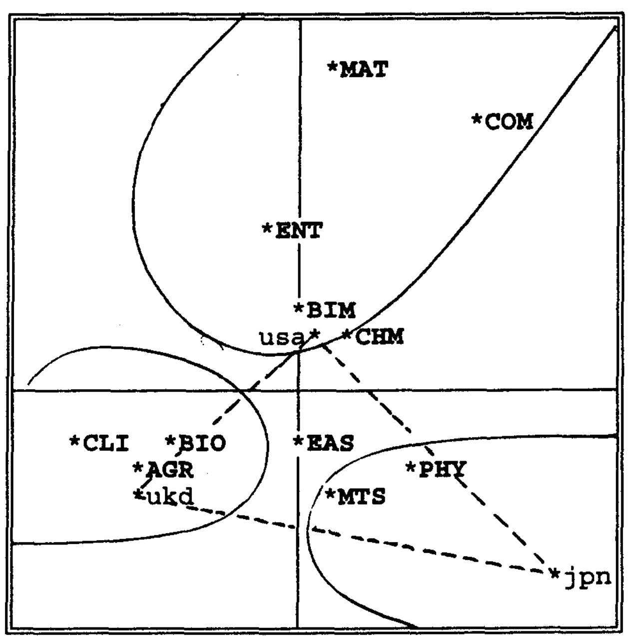


Fig. 4.14: Correspondence Analysis of transnational cooperation with super powers of Science

5 Transnational Links in Mathematics

This chapter analyzes the patterns of India's research output and transnational links in different subfields of *Mathematics* during 1990 – 1994.

1. General Mathematics (*GEN*)
2. Applied Mathematics (*APP*)
3. Interdisciplinary Mathematics (*IND*)
4. Probability and Statistics (*STAT*)
5. Operations Research & Management Science (*OR/MS*)

General Overview of the Data

During these five years, India had published 923 articles in Mathematics in the mainstream journals covered by the *Science Citation Index*. Of these, 219 articles were cosigned by authors from 28 countries, accounting for 246 transnational links.

Table 5.1 presents the data on India's cooperation links with 28 countries in different subfields of *Mathematics*. In this table, the countries are ranked by the number of links aggregated over all subfields.

Table 5.1
Cooperation Links in *Mathematics*

Country	*GEN*	*APP*	*IND*	*STAT*	*OR/MS*	*Total*
USA	57	14	0	19	8	98
CAN	21	7	2	10	5	45
NLD	12	2	0	1	1	16
UKD	12	2	0	0	0	14
DEU	11	0	0	0	0	11
ITA	10	1	0	0	0	11
JPN	5	0	1	2	0	8
AUS	3	2	0	1	0	6
BGD	6	0	0	0	0	6
FRA	4	0	0	0	0	4
KWT	4	0	0	0	0	4
BEL	3	0	0	0	0	3
BRA	1	0	0	1	0	2
HUN	2	0	0	0	0	2
POL	2	0	0	0	0	2
SUN	2	0	0	0	0	2
AUT	0	0	0	1	0	1
ESP	1	0	0	0	0	1
FIN	1	0	0	0	0	1
GRC	1	0	0	0	0	1
IRN	1	0	0	0	0	1
ISR	1	0	0	0	0	1
KOR	0	0	0	1	0	1
MEX	1	0	0	0	0	1
NZL	0	0	0	1	0	1
OMN	0	0	0	1	0	1
PRC	1	0	0	0	0	1
YUG	1	0	0	0	0	1
Total	163	28	3	35	14	246

It can be easily seen that the distribution of links is highly skewed; the top five countries - USA, Canada, Netherlands, UK and Germany account for 80% of all cooperation links in *Mathematics.*

Figure 5.1 indicates the distribution of articles, internationally coauthored articles (*ICOA*) and transnational cooperation links (*COP*) in different subfields. It can be easily seen that the proportions of articles, *ICOA*'s and cooperation links do not always match with each other. This implies that all the subfields do not have the same propensity or opportunity for developing transnational cooperation. For instance, *Probability & Statistics* accounts for only 8.2% of all articles in *Mathematics*, but this area accounts for 15.1% of all *ICOA*'s and 15.4% of all transnational links in *Mathematics*. On the other hand, *Applied Mathematics* accounts for 13.3% of all articles, 11.4% of all *ICOA*'s and 11.4% of all transnational links in *Mathematics.*

Inter - Field Differences in Transnational Cooperation

Table 5.2 presents the data on the output of articles, internationally coauthored articles and transnational links and associated indicators (*INI, COI, CEI*) for different subfields of Mathematics.

Probability & Statistics is the most internationalized subfield. About 43% of all articles in this subfield are internationally coauthored. This is followed by *General Mathematics* - about 24% of all articles in this subfield are internationally coauthored. *Operations Research & Management Science* has the highest value of *CEI* (1.27) which implies that the incidence of multilateral cooperation is higher in this subfield than in any other subfield of *Mathematics.*

Since there were only three transnational links in *Interdisciplinary Mathematics*, indices of cooperation, viz. *INI*, *COI* and *CEI* were not computed for this subfield. For further analysis this subfield was merged with *Applied Mathematics.*

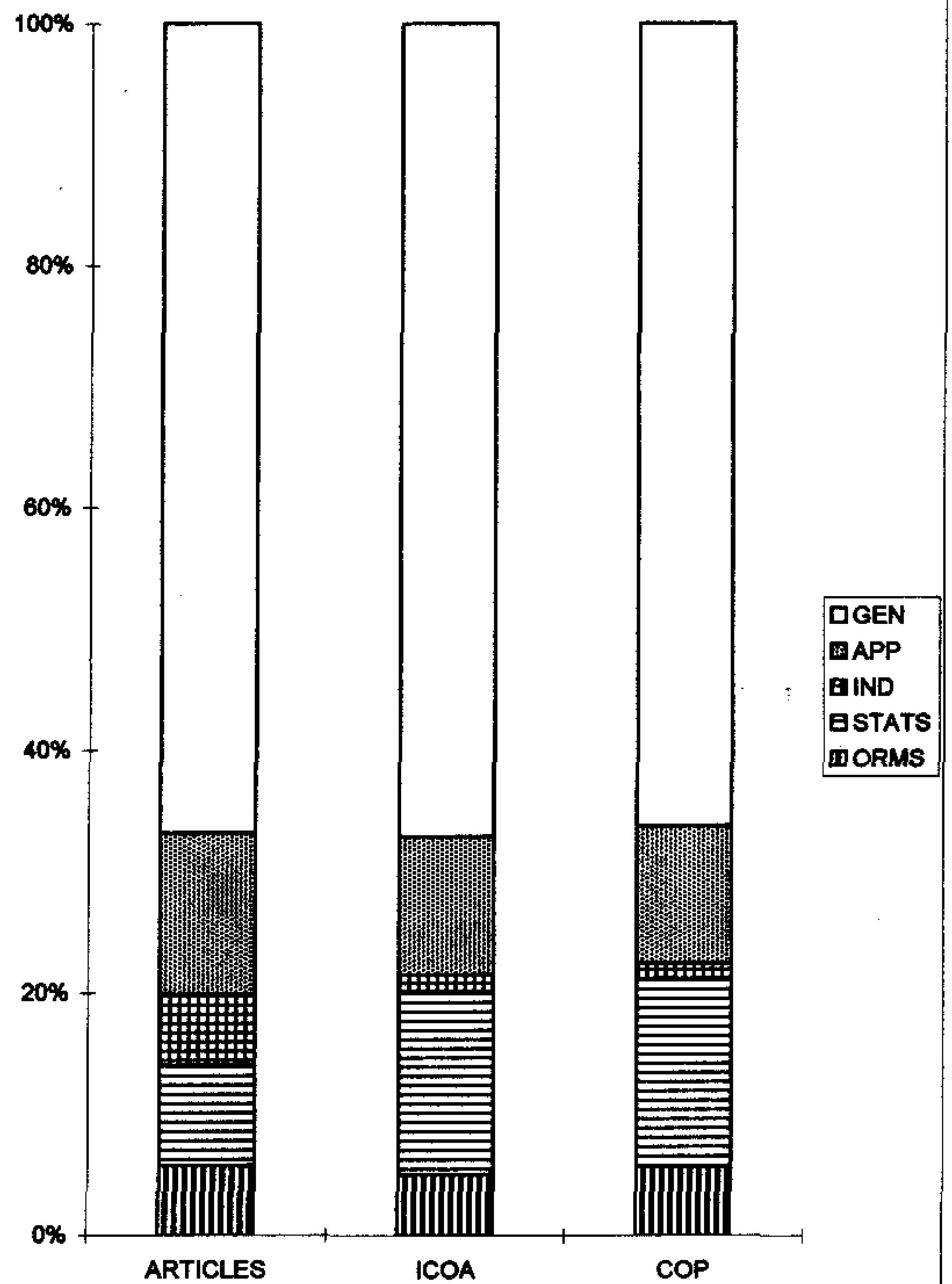


Fig. 5.1: Distribution of articles, internationally coauthored artilces (ICOA) and cooperation links (COP) in different subfields of Mathematics

Table 5.2
Publication Output and Cooperation Links in *Mathematics* subfields(1990-1994)

Subfields	*No. of Articles*	*ICOA*	*No. of Links*	*Internationalization Index INI %*	*Cooperation Index COI %*	*Cooperation Extensiveness Index CEI*
GEN	617	147	163	23.80	26.4	1.10
APP	123	25	28	20.30	22.8	1.12
IND	54	3	3	-	-	-
STAT	76	33	38	43.40	50.0	1.15
OR/MS	53	11	14	20.75	26.4	1.27

Inter - Country Differences in Transnational Cooperation

Inter - country differences in transnational cooperation were assessed by computing the Affinity Index (*AFI*). Figure 5.2 depicts India's affinities towards eleven major partners aggregated over all subfields of *Mathematics:* USA, Canada, Netherlands, UK, Germany, Italy, Japan, Australia, Bangladesh, France and Kuwait.

USA occupies the most important position in India's transnational cooperation in *Mathematics*. About 40% of all internationally coauthored articles involve cooperation with USA. Canada occupies the second rank - about 18% of all internationally coauthored articles involve cooperation with this country.

UK occupies the second rank in the world in the output of articles in *Mathematics*, but India does not have much affinity (*AFI* ≈ 5%) towards this country. The same is also true for Germany, which ranks third in the world.

Figure 5.3 depicts India's affinities in four subfields - *General Mathematics, Applied Mathematics, Probability & Statistics* and *Operations Research & Management Science* separately towards each of its three major partners (USA, Canada, Netherlands).

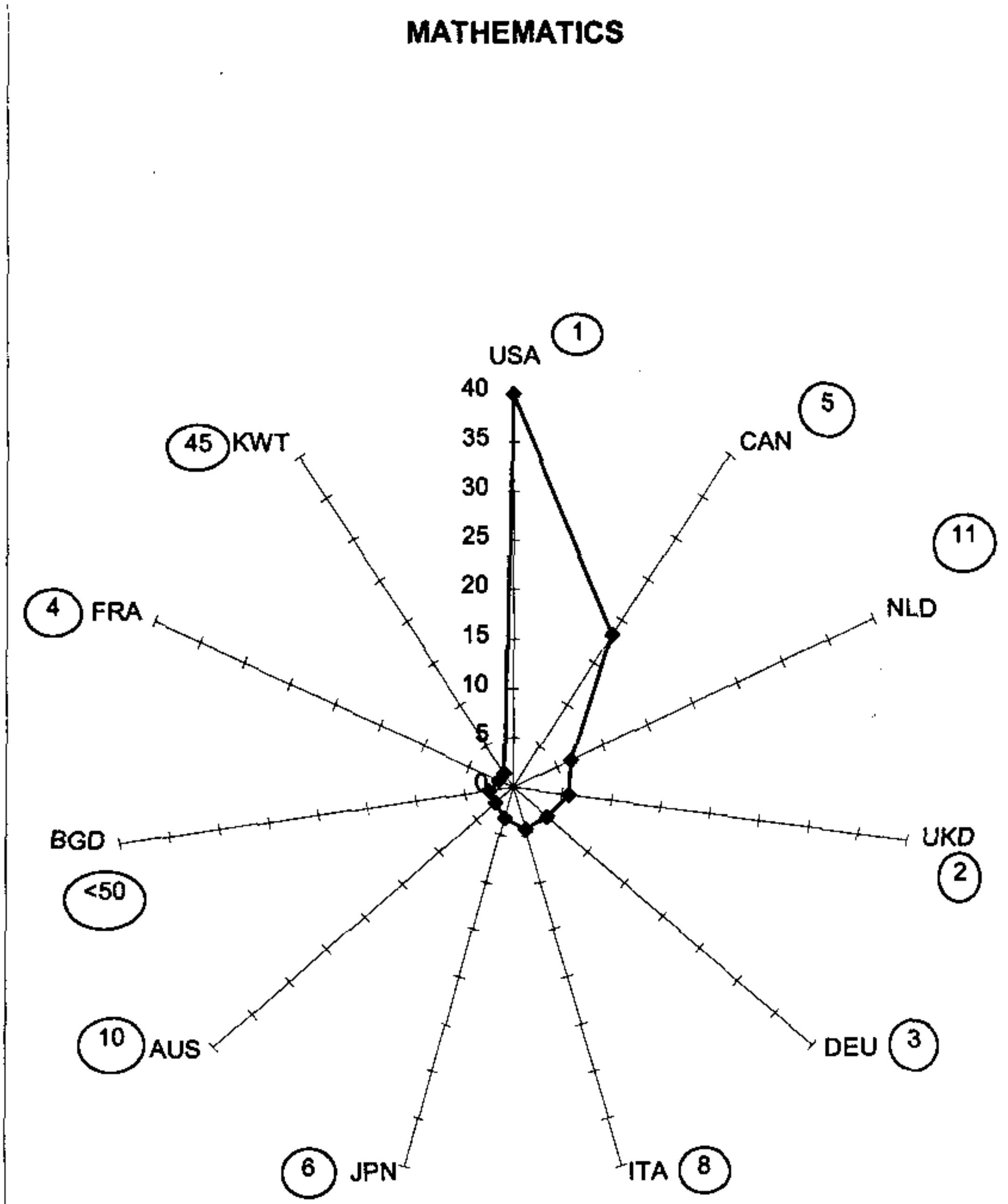


Fig. 5.2: India's Linkages in Mathematics (all subfields combined) (1990-1994) (Affinity Index)

Note: Figures in ○ indicate country's rank in Mathemtics

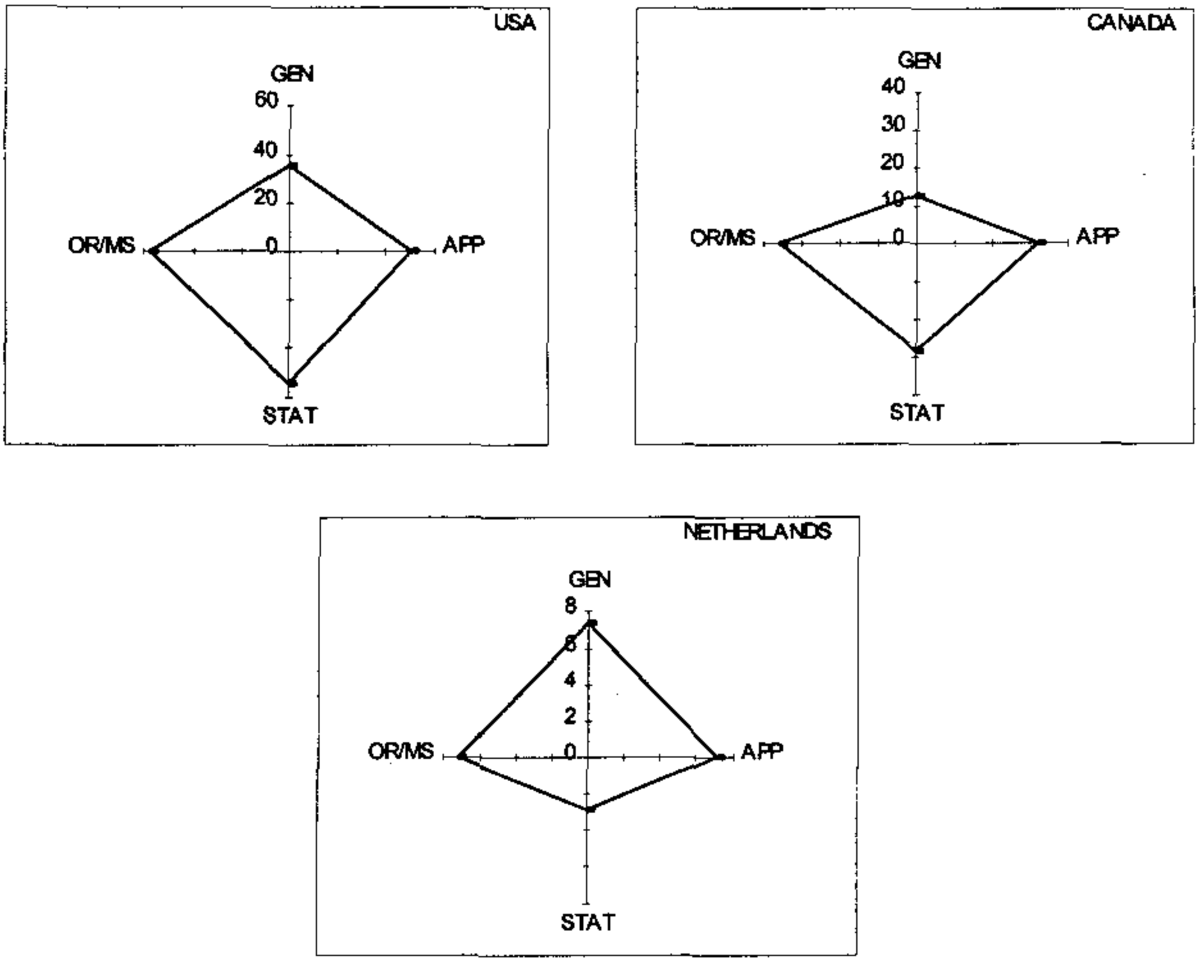


Fig. 5.3: India's affinities towards major cooperating countries in different subfields of Mathematics (1990-1994)
(Affinity Index)

India has maximum affinity towards USA in *Operations Research & Management Science* (*AFI* = 57%), followed by *Probability & Statistics* (*AFI* = 54%), *Applied Mathematics* (*AFI* =50%) and *General Mathematics* (*AFI* = 35%). India has maximum affinity towards Canada in *Operations Research & Management Science* (*AFI* = 36%), followed by *Applied Mathematics* (*AFI* = 32%), *Probability & Statistics* (*AFI* = 29%). India's affinity towards Netherlands is characterized by equal emphasis on *General Mathematics*, *Applied Mathematics* and *Operations Research & Management Science*.

Figure 5.4 depicts India's affinities towards its eleven major partners separately for each subfield. This figure is self - explanatory and any elaboration would be redundant.

These country - by - country and field - by - field comparisons are enlightening, but time consuming. They do not provide a global view of the specificities and correlations of these eleven countries with four subfields of *Mathematics*.

Figure 5.5 presents a global view of India's affinities with these countries in different subfields of *Mathematics*.

Structure of Transnational Cooperation

The specificities and correlations of eleven countries with four subfields of Mathematics were analyzed through Correspondence Analysis, using the computer program SimCA (Greenacre, 1986). As a result of Correspondence Analysis, each subfield in the high - dimensional space is projected into the low - dimensional space of eleven countries, and each country is projected into the conjugate space of four subfields of *Mathematics*. Correspondence Analysis shows how India's significant partners are placed relative to each other and different research areas of *Mathematics*. The results of Correspondence Analysis are summarized in Tables 5.3 and 5.4.

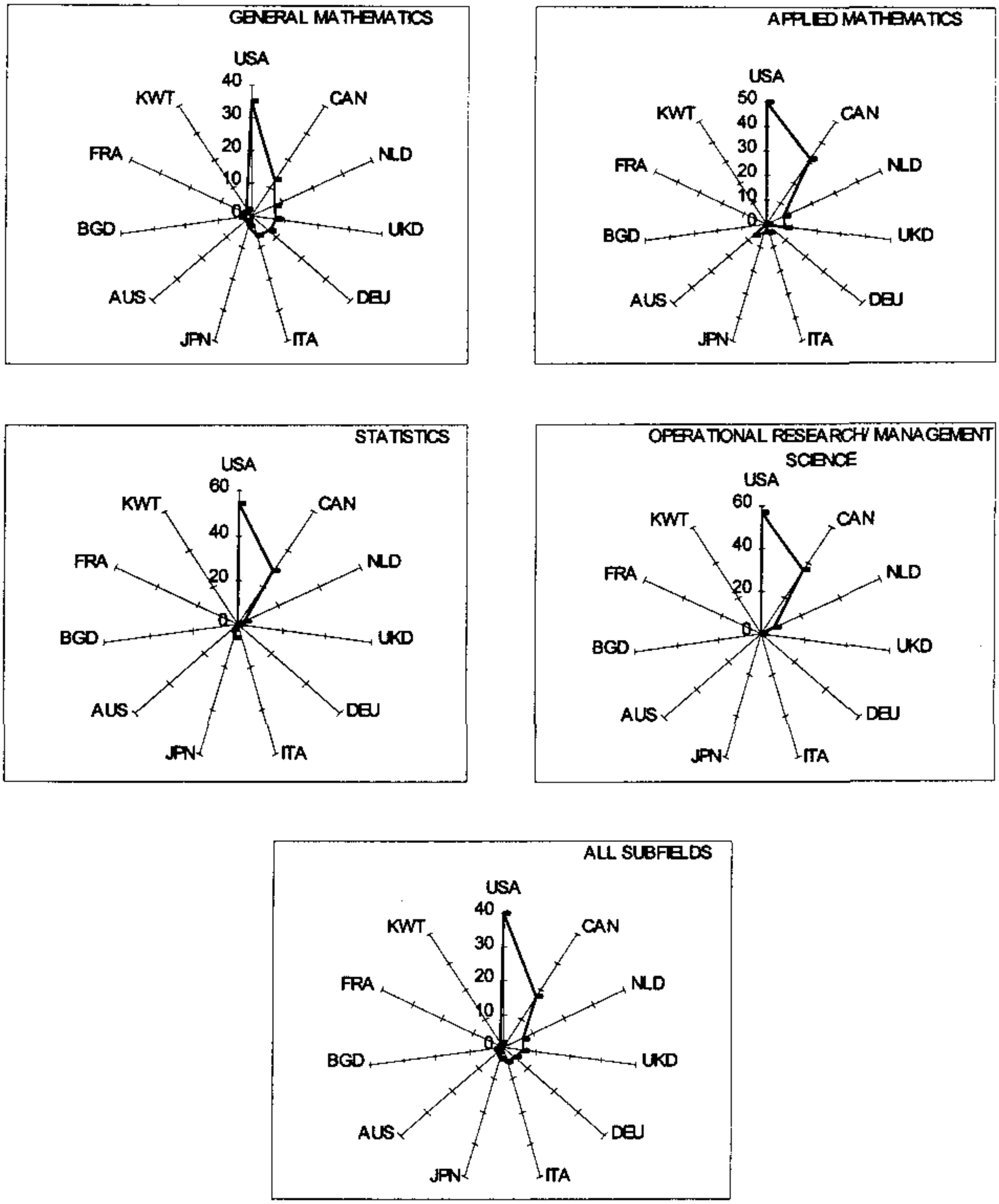


Fig. 5.4: India's linkages in different subfields of Mathematics (1990-1994)
(Affinity Index)

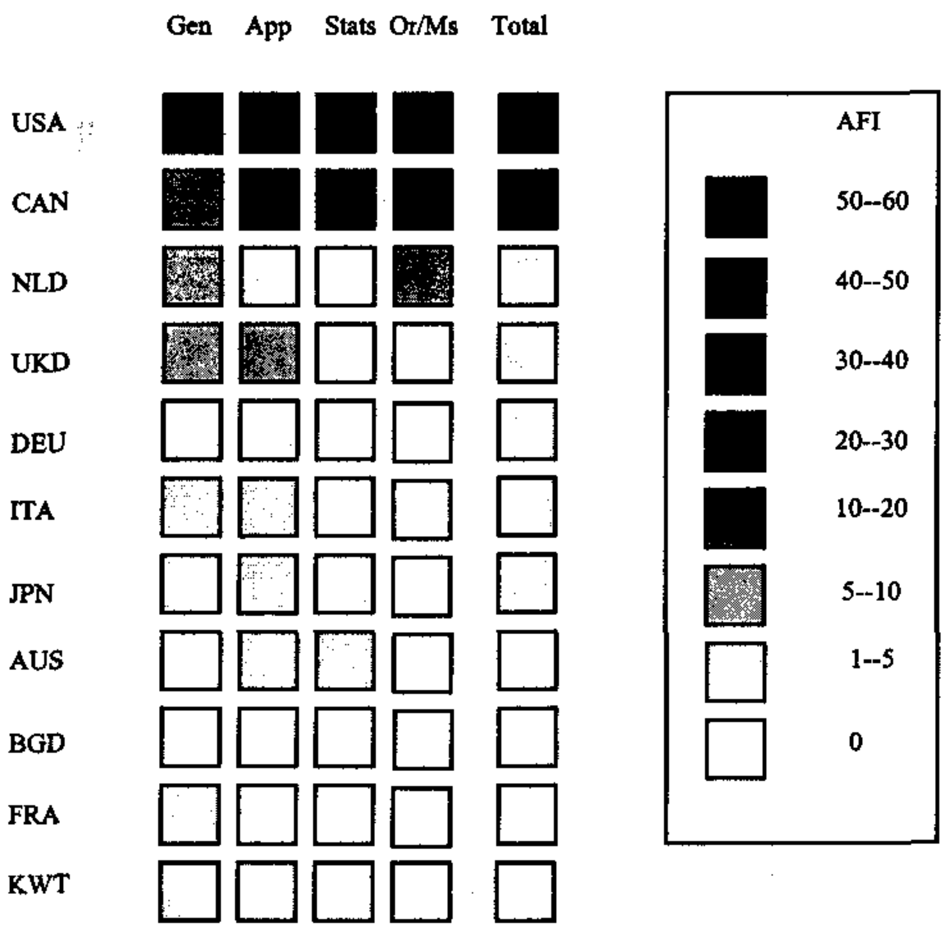


Fig. 5.5: An overview of India's linkages in different subfields of Mathematics

Table 5.3
Contributions of explicative points to the composition of the first two factorial axes (Absolute contribution, permill)

Cloud	*Explicative points with positive coordinates*	*Explicative points with negative coordinates*
	Axis 1 (λ_1 = 0.136927, τ_1 = 79.4%)	
Subfields	General Mathematics (333)	Statistics (431) Operational Research (148)
Countries	UK (112) Germany (185) Italy (119) Bangladesh (101)	Canada (239)
	Axis 2 (λ_2 = 0.025709, τ_2 = 14.9%)	
Subfields	Statistics (278)	Applied Mathematics (702)
Countries	Japan (485)	Australia (253)

Table 5.4
Contributions of the explained points to the eccentricities of the first two factorial axes (Relative contribution permill)

Cloud	*Explained points with positive coordinates*	*Explained points with negative coordinates*
	Axis 1 (λ_1 = 0.136927, τ_1 = 79.4%)	
Subfields	General Mathematics (991)	Statistics (875) Operational Research (723)
Countries	*Netherlands (720)* UK (833) Germany (952) Italy (980) Bangladesh (952) France (952) Kuwait (952)	*USA (971)* Canada (984)
	Axis 2 (λ_2 = 0.025709, τ_2 = 14.9%)	
Subfields	—	Applied Mathematics (583)
Countries	Japan (736)	Australia (547)

Eigen values computed by the program indicate that the first two factorial axes, account for 94.3% of the total variance. Figure 5.6 represents the two - dimensional factorial map constituted by ϕ_1 and ϕ_2 axes.

Factor ϕ_1: The first factorial axis accounting for 79.4% of the total variance constitutes the most important element of the multidimensional data.

On the cloud of research fields, this axis represents the opposition between *General Mathematics* on the one hand and *Operations Research* and *Statistics* on the other. *General Mathematics* is projected on this axis with positive coordinates, whereas *Statistics* and *Operations Research* are projected with negative coordinates.

On the cloud of countries, this axis represents the opposition between Netherlands, UK, Germany, Italy, Bangladesh, France and Kuwait on the one hand and USA and Canada on the other.

Netherlands, UK, Germany, Italy, Bangladesh, France and Kuwait are projected on this axis with positive coordinates. These countries cooperate with India mainly in *General Mathematics*.

USA and Canada are projected on this axes with negative coordinates and are therefore correlated to *Statistics* and *Operations Research*. Both these countries have above average representation of these subfields in their cooperation profiles. Canada gives relatively greater emphasis to these subfields than USA.

Factor ϕ_2: This factorial axis accounts for 14.9% of the total variance in the multidimensional data.

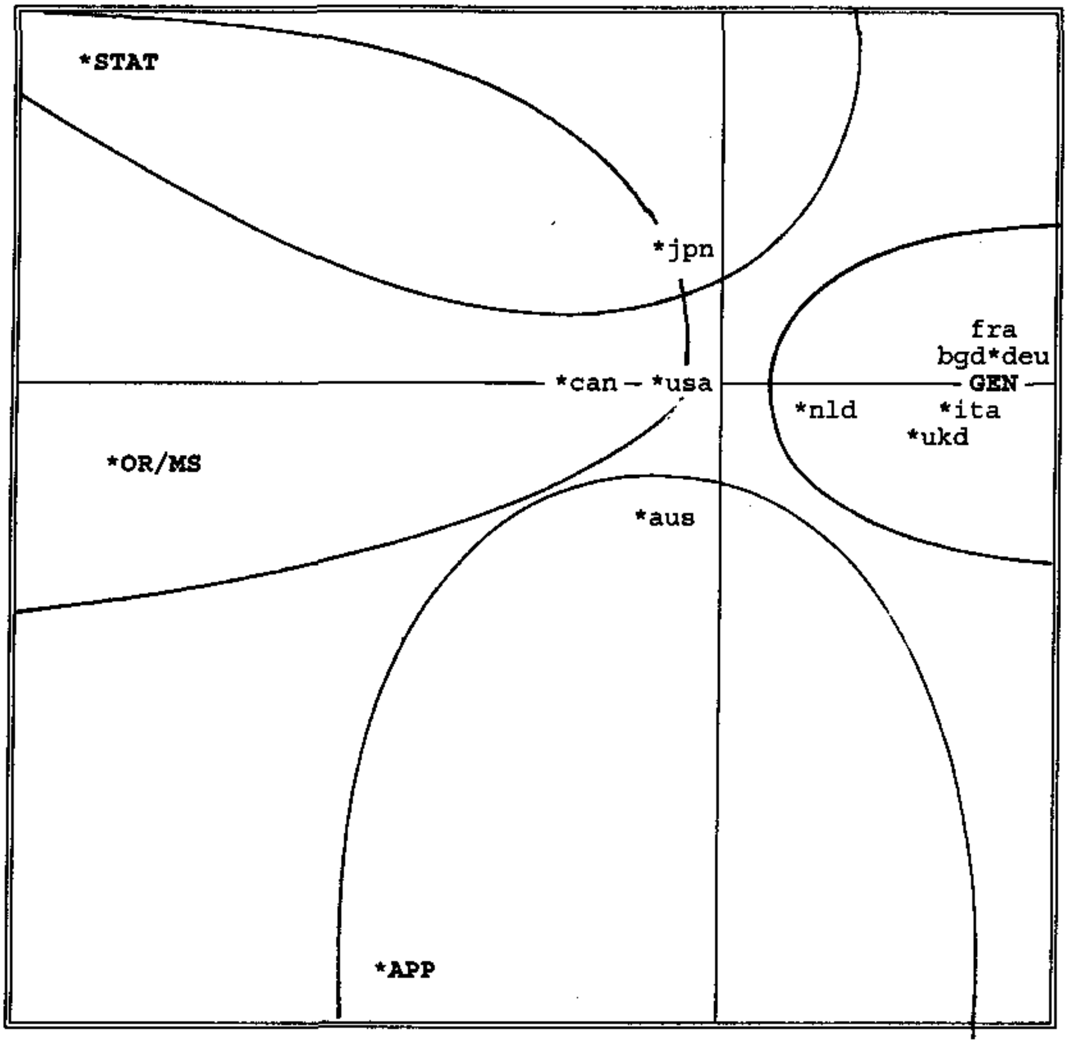


Fig. 5.6: Correspondence Analysis of transnational cooperation in Mathematics subfields

On the cloud of subfields, this axis represents the polarity between *Applied Mathematics* and *Probability & Statistics. Applied Mathematics* is projected on this axis with negative coordinate, whereas *Probability & Statistics* is projected on this axis with positive coordinate.

On the country cloud, this axis represents the polarity between Australia and Japan. Japan is projected on this axis with positive coordinate and is therefore correlated to *Probability & Statistics.* Australia is projected on this axis with negative coordinate and is therefore correlated to *Applied Mathematics* in its cooperation with India.

6 Transnational Links in Physics

This chapter examines the pattern of India's transnational links during five (indexing) years: 1990 – 1994 in thirteen subfields of Physics.

1. General Physics (*GEN*)
2. Acoustics (*ACU*)
3. Applied Physics (*APP*)
4. Astronomy/Astrophysics (*AST*)
5. Chemical Physics (Atomic, Molecular and Chemical Physics) (*CHM*)
6. Crystallography (*CRY*)
7. Fluids & Plasmas (*FLU*)
8. Mathematical Physics (*MAT*)
9. Microscopy (*MIC*)
10. Nuclear and Particle Physics (*NUC*)
11. Optics (*OPT*)
12. Solid State Physics (*SOL*)
13. Spectroscopy (*SPC*)

During this period, India had published 11,748 articles (*Articles, Reviews, Notes* and *Letters*) in the *SCI* – covered journals in Physics. Of these 2,176 (18.53%) articles were cosigned by authors from 69 countries, indicating a total of 3,360 transnational links. Many of these countries had less than five links with India; these countries may be designated as '*transients*'. The names of '*non - transient*' countries are given in Table 6.1. In all tables and figures in this chapter, the countries would be identified by their *ISO* codes and Physics subfields by their abbreviations listed above.

Table 6.1 presents the data on cooperation links (*COP's*) of *non-transient* countries aggregated over all subfields of Physics. In this table, the countries are ranked by their cooperation links with India. The distribution of links among these countries is highly skewed. The top ten countries: USA, Germany, UK, Italy, France, Canada, Japan, Russia (including *CIS* countries), Switzerland and Netherlands account for 77% of India's all transnational links in Physics.

Table 6.1
Cooperation Links in *Physics*

Country	*No. of Links*	*%*	*Country*	*No. of Links*	*%*	*Country*	*No. of Links*	*%*
USA	822	24.46	HUN	52	1.55	MEX	13	0.39
DEU	385	11.46	BRA	46	1.37	TWN	13	0.39
UKD	268	7.98	BGR	40	1.19	ZAF	12	0.36
ITA	253	7.53	SWE	40	1.19	AUT	11	0.33
FRA	224	6.67	BEL	39	1.16	DNK	11	0.33
CAN	187	5.57	KOR	27	0.80	ISR	11	0.33
JPN	138	4.11	CYP	25	0.74	MYS	11	0.33
SUN	130	3.87	FIN	22	0.65	GRC	10	0.30
CHE	108	3.21	CHL	19	0.57	YUG	10	0.30
NLD	83	2.47	ROM	18	0.54	LBY	7	0.21
ESP	79	2.35	POL	17	0.51	NZL	7	0.21
PRC	76	2.26	CSK	14	0.42	ARG	6	0.18
AUS	52	1.55	BGD	13	0.39	IRQ	6	0.18

Inter - Field Differences in Transnational Cooperation

Figure 6.1 presents the distribution of articles, internationally coauthored articles (*ICOA*) and cooperation links (*COP*) in different subfields. It can be easily seen from the figure, that the proportions of articles, *ICOA*'s and *COP*'s do not match with each other. For example, *Applied Physics* accounts for 15.47% of all articles, but it accounts for 9.70% of all

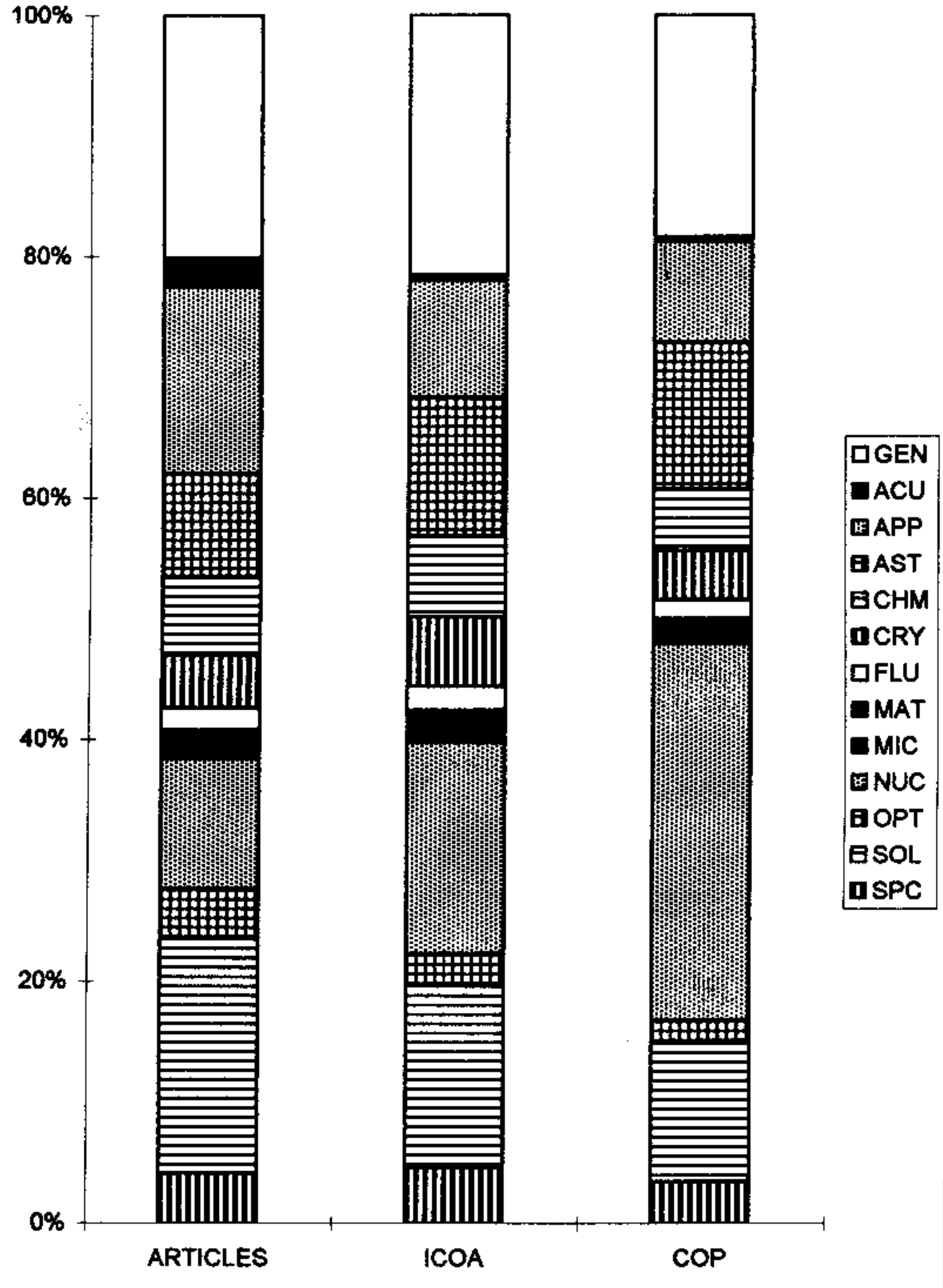


Fig. 6.1: Distribution of articles, internationally coauthored articles (ICOA) and cooperation links (COP) in different subfields of Physics

ICOA's and 8.36% of all cooperation links. On the other hand, *Nuclear & Particle Physics* accounts for 10.35% of all articles, 17.5% of all *ICOA*'s and 29.94% of all *COP*'s. This means that all the subfields do not have the same propensity for transnational cooperation.

If the proportion of *ICOA*'s is greater than that of articles in a given subfield, it implies that the particular field has above average level of internationalization and *vice versa*. If the proportion of *COP*'s is greater than that of *ICOA*'s in a subfield, it indicates greater incidence of multicountry cooperation in that subfield than expected on the basis of publication output. However, we can assess the inter - field (and also inter - country) differences in transnational cooperation more systematically through the following *relational* indicators:

(i.) Internationalization Index (*INI*)

(ii.) Cooperation Index (*COI*)

(iii.) Cooperation Extensiveness Index (*CEI*)

(iv.) Affinity Index (*AFI*)

These indicators have been defined in Chapter 4. Table 6.2 presents the data on the output of articles, internationally coauthored articles (*ICOA*) and cooperation links (*COP*) in different subfields of Physics. The values of relational indicators, *viz. INI*, *COI* and *CEI* are also given in the table.

The values of *INI* indicate that *Nuclear & Particle Physics* is the most internationalized subfield, followed by *Astronomy & Astrophysics*, *Fluids & Plasmas*, *Spectroscopy* and *Mathematical Physics* in that order. About 30% of articles in *Nuclear & Particle Physics* are internationally coauthored, whereas about one fourth of articles in *Astronomy & Astrophysics* are internationally coauthored, and about one fifth of articles in *Fluids & Plasmas*, *Spectroscopy* and *Mathematical Physics* each are internationally coauthored.

Acoustics is the least internationalized subfield; hardly 4% of articles in this area are internationally coauthored.

Table 6.2
Publication Output and Cooperation Links in *Physics* subfields (1990-1994)

Subfield	*No. of Articles*	*ICOA*	*No. of Links*	*Internationalization Index INI %*	*Cooperation Index COI %*	*Cooperation Extensiveness Index CEI*
GEN	2365	469	619	19.83	26.17	1.32
ACU	287	11	12	3.83	4.81	1.09
APP	1817	211	281	11.61	15.46	1.33
AST	1001	248	409	24.78	40.86	1.65
CHM	759	147	172	19.37	22.66	1.17
CRY	515	124	137	24.08	26.60	1.10
FLU	217	43	52	19.81	23.96	1.21
MAT	264	54	64	20.45	24.24	1.18
MIC	12	4	5	-	-	-
NUC	1265	381	1046	30.12	82.69	2.74
OPT	479	56	62	11.69	12.94	1.11
SOL	2283	328	386	14.36	16.91	1.18
SPC	482	100	115	20.75	23.86	1.15
Total	11746	2176	3360	18.53	28.60	1.54

Nuclear & Particle Physics has the highest incidence of cooperation links - about 83 links per 100 articles. The value of *COI* is far greater than that of *INI* (30.1%), implying greater incidence of multicountry cooperation in this subfield. This is also confirmed from the value of *CEI* (2.74) which is far greater than 1. Thus, transnational cooperation in *Nuclear & Particle Physics* is not only more frequent, it is also more multilateral. After *Nuclear & Particle Physics*, *Astronomy & Astrophysics* has the highest incidence of cooperation links - about 41 links per 100 articles . The value of *COI* (40.86%) is far greater than that of *INI* (24.78%), which implies greater incidence of multicountry cooperation in this area. This is also confirmed from the value of *CEI* (1.65) which is much greater than 1. In other words, transnational cooperation in this area is both frequent and multilateral.

Acoustics has the lowest value of *COI* (4.81) which is quite close to that of *INI* (3.83). This means that transnational cooperation in this area is not only infrequent, but it is also bilateral. This finding is also confirmed from the value of *CEI* (1.09) which is close to 1.

Crystallography presents an entirely different picture. The incidence of transnational cooperation is high in this area, but it is hardly multilateral.

We can summarize these results by constructing a typology of transnational cooperation.

Typology of Transnational Cooperation

Frequency of Cooperation	*Nature of Cooperation*: *Multilateral* ($CEI > 1.20$)	*Nature of Cooperation*: *Bilateral* ($CEI \leq 1.20$)
Frequent ($COP > 20.0$)	General Physics Astrophysics Fluids & Plasmas Nuclear Physics	Chemical Physics Crystallography Mathematical Physics Spectroscopy
Infrequent ($COP \leq 20.0$)	Applied Physics	Acoustics Optics Solid State Physics

Inter - country Differences in Transnational Cooperation

Inter - country differences in India's cooperation in Physics were examined by computing the *Affinity Index* (*AFI*). Figure 6.2 depicts India's affinities towards its 14 major partner countries, aggregated over all subfields of Physics: USA, Germany, UK, Italy, France, Canada, Japan, Russia (including CIS countries), Switzerland, Netherlands, Spain, China, Australia, Hungary. These countries were identified on the basis of *Affinity Index* ≥ 2.

USA occupies the most important position in India's international cooperation in Physics. The same is also true for almost all other countries in the world. About 24% of India's international cooperation in Physics is conducted with USA. This country is also the most important partner of India in each subfield of Physics.

Figure 6.3 represents India's affinities in eleven subfields[1] separately towards each of its six major partners (USA, Germany, UK, Italy, France, Canada). It can be easily seen from these figures that India's affinities towards different countries vary across fields. Figure 6.3 indicates that India had the highest affinity with USA in *Optics* (including Lasers) (*AFI* = 35%), followed by *Spectroscopy* (*AFI* = 34%) and *Astronomy & Astrophysics* (*AFI* = 32%) in that order. It has the lowest affinity towards this country in *Nuclear & Particle Physics* (*AFI* = 16%).

Figure 6.3 indicates that India has the highest affinity with Germany in *Chemical Physics* and the lowest affinity in *Crystallography*.

It can be easily seen from Figure 6.3, that India has the highest affinity with UK in *Astronomy & Astrophysics, Crystallography, Optics and Solid State Physics* (*AFI* = 15% for each of these subfields); and the lowest affinity in *Nuclear & Particle Physics* (*AFI* = 2%).

With Italy, India has the highest affinity in *Spectroscopy* (*AFI* = 11%) and the lowest affinity in *Chemical Physics* (*AFI* = 2%).

With France, India has the highest affinity in *Solid State Physics* (*AFI* = 13%) and the lowest affinity in *Fluids & Plasmas* (*AFI* = 0%).

India has the highest affinity with Canada in *Mathematical Physics* (*AFI* = 17%) and the lowest affinity in *Nuclear & Particle Physics* (*AFI* = 3%).

Figure 6.4 indicates India's affinities towards its major partners (*AFI* ≥ 2%) separately for each subfield of Physics. This figure is self – explanatory and needs no elaboration.

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[1] *Acoustics* and *Microscopy* have been excluded from further analysis as these areas have very few links.

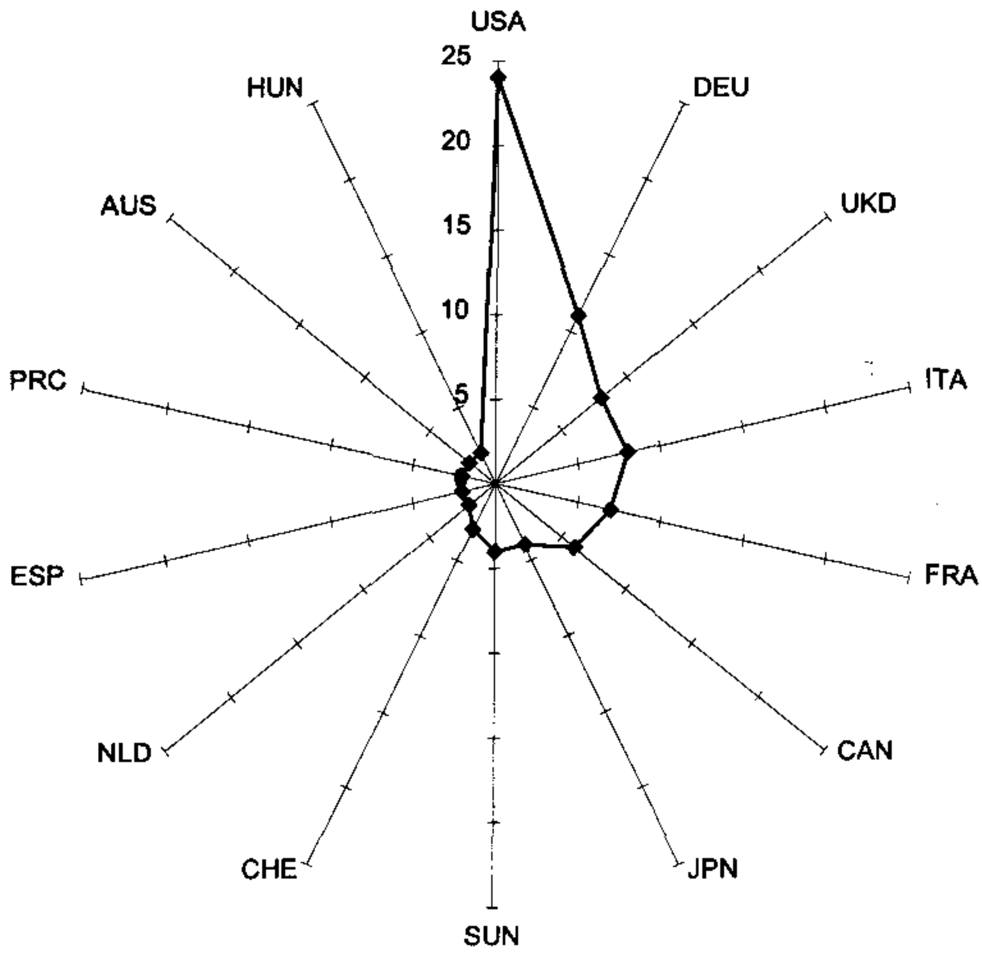


Fig. 6.2: India's Linkages in Physics (1990-1994)
(Affinity Index)

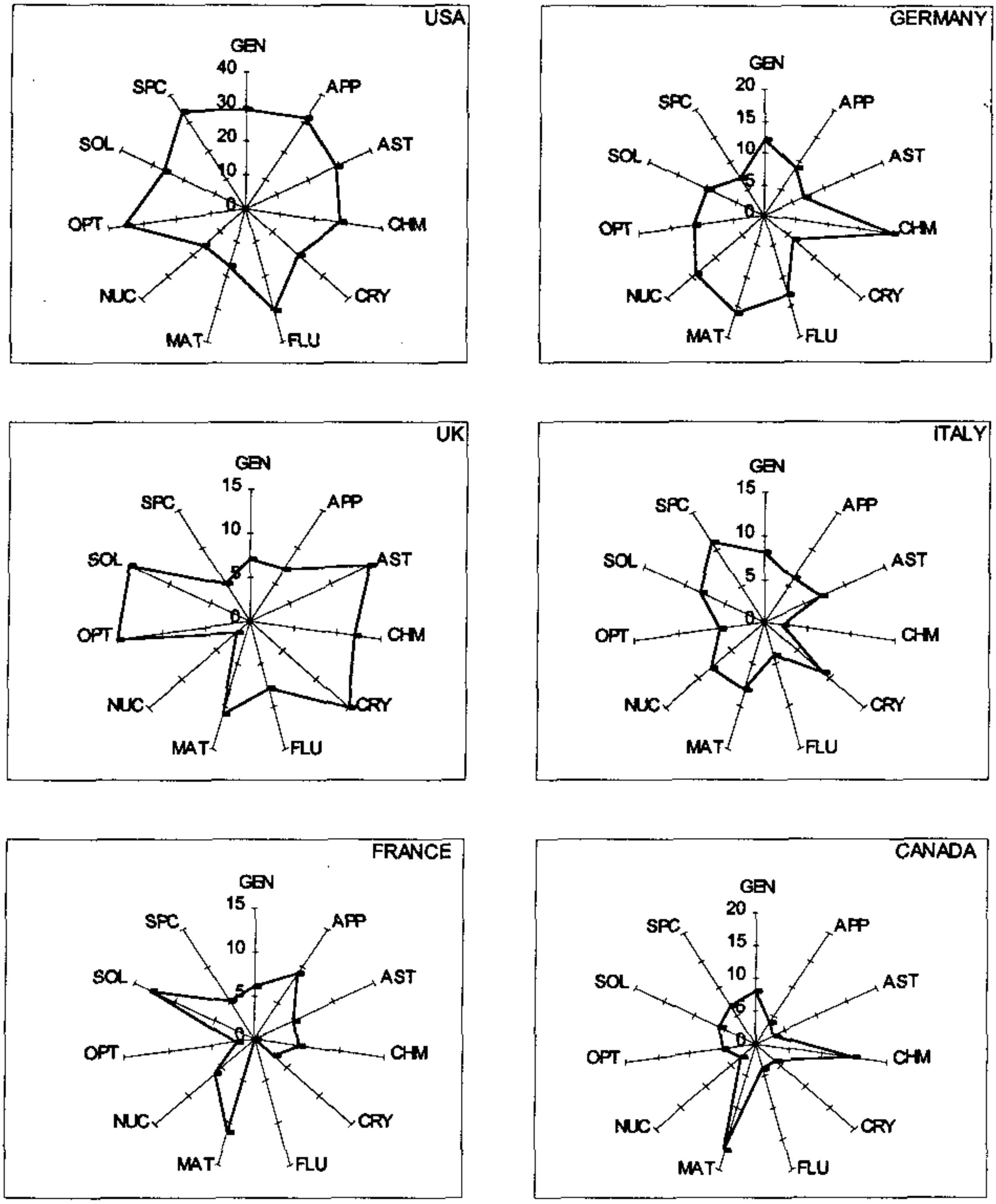


Fig. 6.3: India's affinities towards major cooperating countries in different subfields of Physics (1990-1994) (Affinity Index)

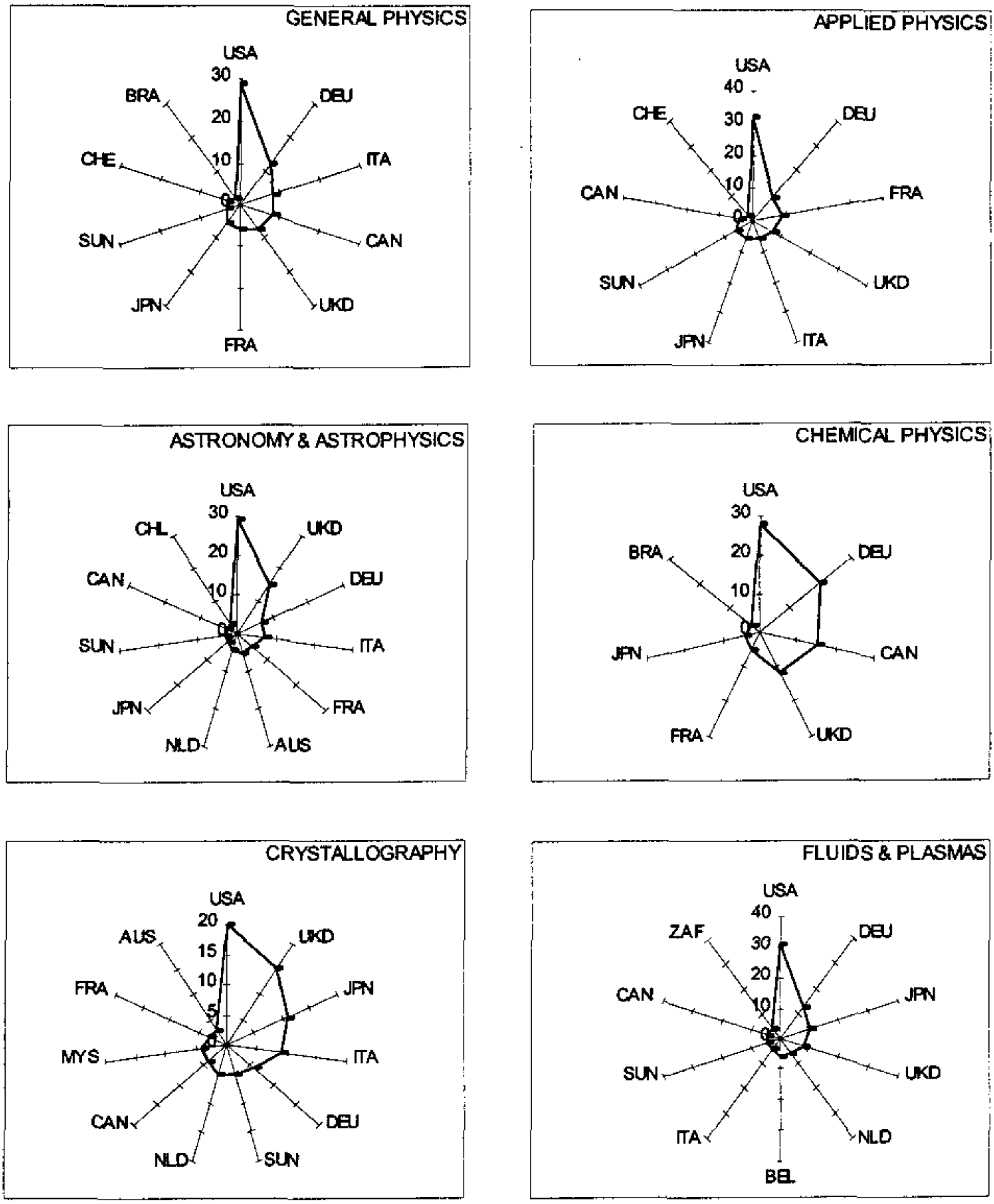


Fig. 6.4: India's linkages in different subfields of Physics (1990-1994)
(Affinity Index)

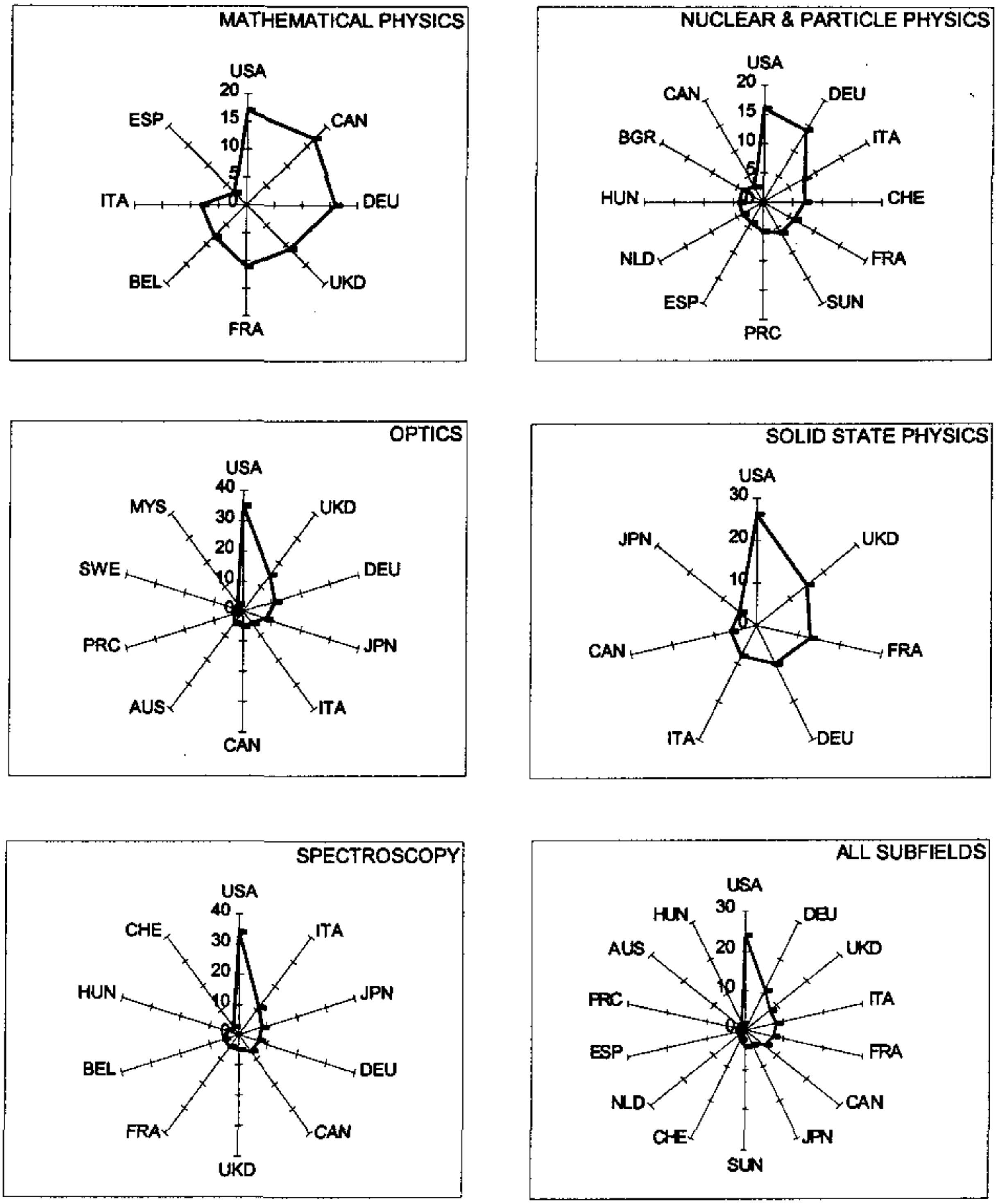


Fig. 6.4 (Contd.): India's linkages in different subfields of Physics (1990-1994)
(Affinity Index)

Structure of Transnational Cooperation

The foregoing country - by - country and field - by - field comparisons of India's affinities towards its major partners are quite enlightening, but they are also time - consuming. Moreover, they do not reveal the multidimensional structure of the data. The multivariate structure of relationships of India's twenty major partners with eleven subfields of *Physics* (Table 6.3) was analyzed through Correspondence Analysis, using the computer program SimCA. As a result of Correspondence Analysis, each subfield in the high - dimensional space is projected into the low - dimensional space of 20 countries, whereas each country is projected into the conjugate space of eleven subfields. Two subfields, *Acoustics* and *Microscopy* were excluded from the analysis as there were few links in these subfields. Correspondence Analysis shows how India's significant partners are placed relative to each other and different research areas of *Physics*. The typicality of the cooperation profiles of different countries and different fields was assessed by computing the χ^2 - distance from the barycenter, using the program CORAN.

Typicality of Countries

When 25 countries are projected into the 11 - dimensional space of disciplinary areas, the distances (χ^2 - metrics) of the countries from the barycenter of the multidimensional system in the full space (which reflects average behaviour) can be evaluated. Simultaneously, subfields are projected into the 20 - dimensional space of countries. Similarly, the distances of subfields from the barycenter can be evaluated.

Figure 6.5 indicates the χ^2 - distances of different countries from the barycenter. None of the countries is located at the barycenter or even in its close proximity. USA (d = .07), DEU (d = .07) and Italy (d = .07) are located nearest to the barycenter. These countries distribute their cooperation links with India more evenly in different subfields than do the rest of the countries. Scientifically small countries are projected far away from the barycenter. Bulgaria and Cyprus are located at the extreme end (d = 1.93), indicating a highly *'atypical'* profile. Other countries having a highly *'atypical'* profile are: Belgium (d = 1.43), Hungary (d = 1.30) and Korea (d = 1.03). India's cooperation links with these countries are highly unevenly distributed among the eleven subfields.

Table 6.3
Distribution of Linkages in *Physics* subfields

Country	*GEN*	*APP*	*AST*	*CHM*	*CRY*	*FLU*	*MAT*	*NUC*	*OPT*	*SOL*	*SPC*
USA	182	90	117	49	28	16	11	165	22	101	39
DEU	77	25	27	34	8	7	10	142	7	40	8
UKD	44	19	62	21	20	4	7	16	9	57	6
ITA	49	16	29	4	12	2	5	88	3	31	13
FRA	36	26	19	8	4	0	7	63	1	50	6
CAN	47	11	14	26	6	2	11	35	3	22	8
JPN	29	18	11	7	15	5	1	16	5	21	9
SUN	21	18	14	1	7	2	1	58	0	6	2
CHE	17	6	4	3	2	0	0	72	0	1	3
NLD	7	1	17	0	7	3	1	43	1	1	1
ESP	7	8	8	1	3	0	2	47	0	2	1
PRC	6	4	4	1	0	0	0	56	2	3	0
AUS	7	4	19	2	4	0	0	7	3	4	2
HUN	2	4	0	0	0	0	0	41	0	0	5
BRA	14	3	8	5	0	0	0	12	0	4	0
SWE	8	3	1	2	1	0	0	14	2	8	1
BEL	6	0	5	1	2	3	5	8	0	3	6
BGR	0	1	0	0	0	0	0	37	0	0	0
KOR	2	2	2	0	0	0	0	23	1	0	0
CYP	1	0	0	0	0	0	0	24	0	0	0

Typicality of Fields

Figure 6.5 indicates the χ^2 – distances of different subfields. None of the subfields is located at the barycenter or even close to it, implying that none of the subfields is proximate to the average profile (i.e. the average proportion of cooperation links).

Of all the eleven subfields, *General Physics* (d = .09) is situated nearest to the barycenter, with *Applied Physics* (d = .14) as a close challenger. This implies that India's cooperation in these subfields is more widespread and more evenly distributed among the twenty countries.

Mathematical Physics has the most *'atypical'* profile. It is situated farthest from the barycenter (d = .88), with *Fluids & Plasmas* as a close neighbour. Cooperation links in these two areas are not widespread and are highly unevenly distributed among the countries.

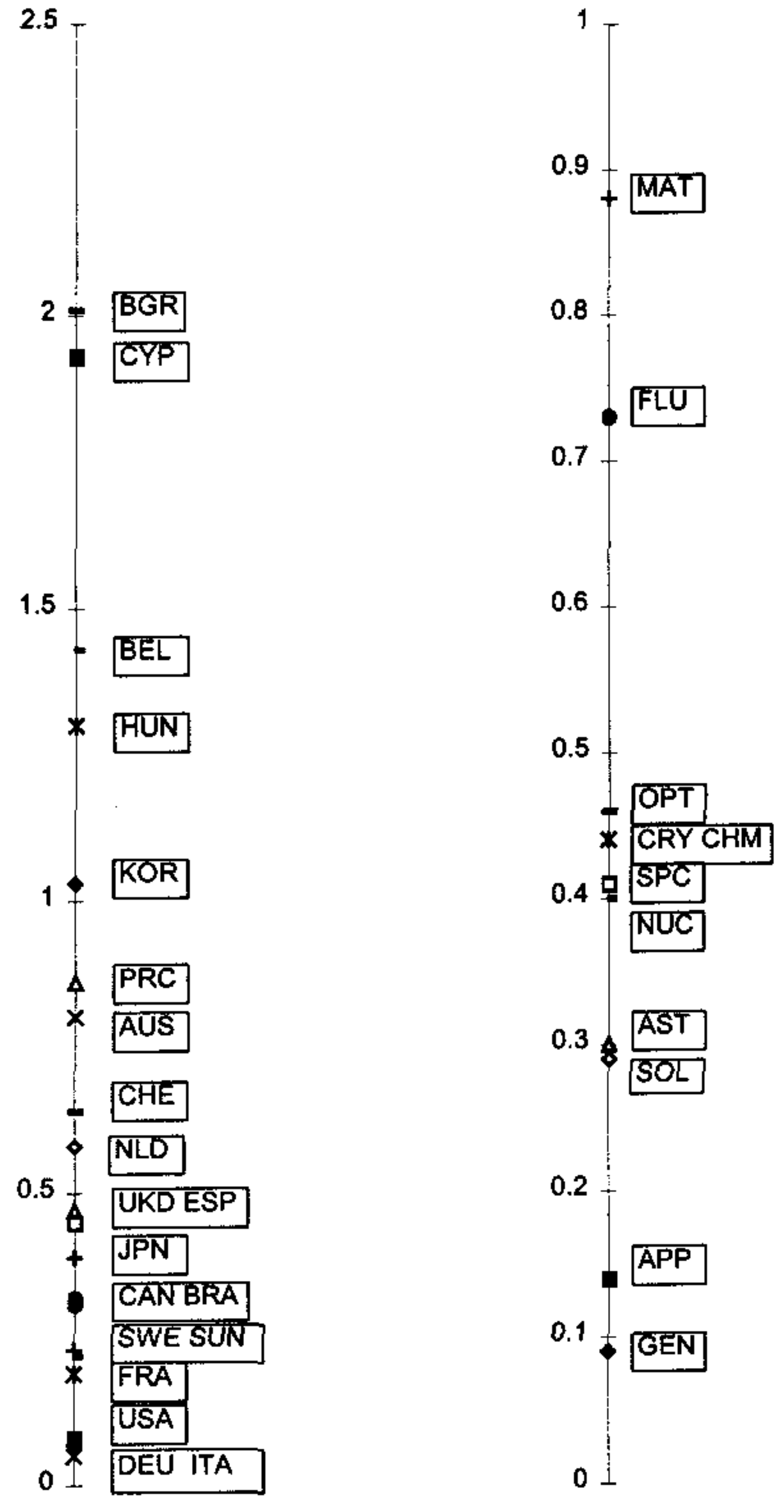


Fig. 6.5: Chi square distance from the barycenter

Results of Correspondence Analysis

The results of Correspondence Analysis are presented in Tables 6.4 and 6.5. Eigen values computed by the program indicate that the first two factorial axes account for 73% of the total variance in the multidimensional data. Thus, the two - dimensional factorial map constituted by ϕ_1 and ϕ_2 axes (Figure 6.6) represents the main features of the multidimensional data. The first two eigen values are quite large, which implies that the set of countries differ strongly in their orientation to collaboration with India in different subfields of *Physics*. The variation in the amplitudes of profiles is greater along the first axis than along the second axis, since the first axis accounts for greater variance than the second axis.

Factor ϕ_1: This first factorial axis, accounting for 60.8% of the total variance, represents the most important features of the multidimensional data.

On the cloud of subfields, this factor is constituted by *Nuclear & Particle Physics* (AC=65.8%) and *Solid State Physics* (AC = 10.5%). These subfields are also quite well represented on this axis as may be seen from the values of their relative contributions ($Cos^2\phi$): *Nuclear & Particle Physics* (RC=0.997); *Solid State Physics* (RC =0.604). *Nuclear & Particle Physics* is projected on this axis with positive coordinate, and is opposed to *Solid State Physics*. This implies that the countries which emphasize *Solid State Physics* in their collaboration with India tend to de-emphasize *Nuclear & Particle Physics* and *vice versa.*

The countries correlated to this axis can be classified into two clusters, depending upon the signs of the coordinates of their projection on this axis:

Cluster *I: UK, USA, Japan.*

Cluster *II: Russia, Switzerland, Spain, China, Korea, Bulgaria, Cyprus, Hungary.*

Cluster I countries are projected on this axis with positive coordinates and are therefore correlated to *Solid State Physics* and anticorrelated to *Nuclear & Particle Physics.*

Cluster II countries are projected on this axis with positive coordinates. These countries are therefore correlated to *Nuclear & Particle Physics* and anticorrelated to *Solid State Physics.*

Table 6.4
Contributions of explicative points to the composition of the first two factorial axes (Absolute contribution, *permill*)

Cloud	*Explicative points with positive coordinates*	*Explicative points with negative coordinates*
	Axis 1 ($\lambda_1 = 0.193700$, $\tau_1 = 60.81\%$)	
Subfields	Solid State Physics (105)	Nuclear Physics (656)
Countries	USA (74) UK (167)	Switzerland (111) Bulgaria (117) Spain (50) Korea (South) (60) China (10) Cyprus (79) Hungary (97)
	Axis 2 ($\lambda_2 = 0.038874$, $\tau_2 = 12.20\%$)	
Subfields	Astronomy & Astrophysics (401) Crystallography (142)	Chemical Physics (214) Mathematical Physics (112)
Countries	UK (88) Netherlands (173) Australia (202)	Germany (136) Canada (275)

Table 6.5
Contributions of the explained points to the eccentricities of the first two factorial axes (Relative contribution, permill)

Cloud	*Explained points with positive coordinates*	*Explained points with negative coordinates*
	Axis 1 (λ_1 = 0.193700, τ_1 = 60.81%)	
Subfields	General Physics (493) Astronomy & Astrophysics (415) Solid State Physics (604)	Nuclear Physics (997)
Countries	USA (717) UK (783) Japan (436)	Russia (477) Hungary (850) Switzerland (955) Bulgria (974) Spain (836) Korea (936) China (931) Cyprus (970)
	Axis 2 (λ_2 = 0.038874, τ_2 = 12.20%)	
Subfields	Astronomy & Astrophysics (428)	Chemical Physics (349) Crystallography (322)
Countries	Spain (439) Australia (573)	Germany (560) Canada (550)

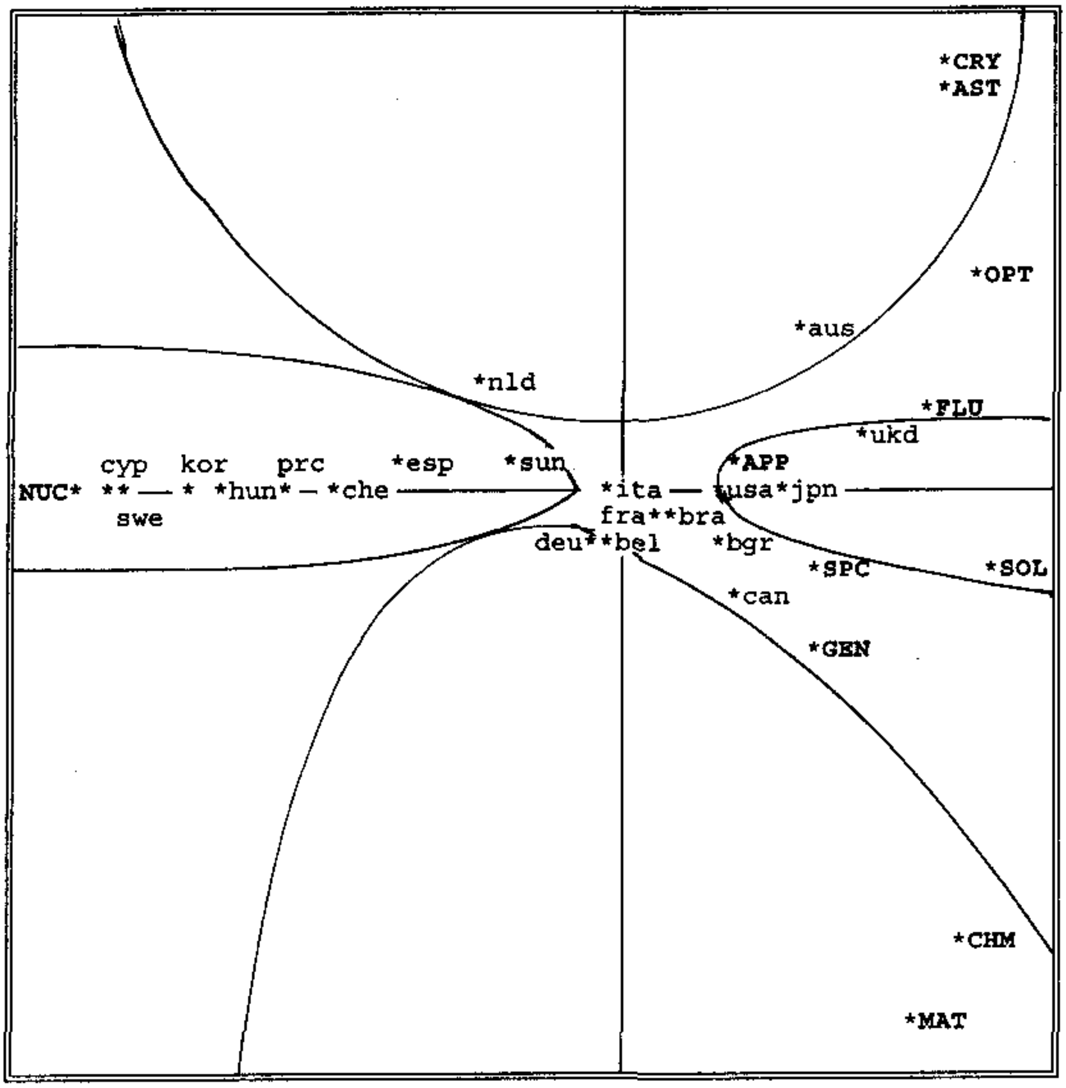


Fig. 6.6: Correspondence analysis of transnational cooperation in Physics subfields

Nuclear & Particle Physics and *Solid State Physics* are the two subfields which attract India's partners most. Three major countries USA, UK and Japan prefer to collaborate with India *in Solid State Physics*, whereas Russia, Switzerland, China, Spain, Cyprus, Bulgaria and Hungary give greater importance to *Nuclear & Particle Physics* in their bilateral cooperation with India.

Factor ϕ_2: The second factorial axis, accounting for 12.2% of the total variance, constitutes the second most important element of the multidimensional data.

On the cloud of subfields, this factor is controlled by *Astronomy & Astrophysics* (AC=40.1%), *Chemical Physics* (AC = 21.4%), *Crystallography* (AC = 14.2%) and *Mathematical Physics* (AC = 11.2%). *Astronomy & Astrophysics* and *Crystallography* are projected on this axis with positive coordinates, whereas *Chemical Physics* and *Mathematical Physics* are projected on this axis with negative coordinates.

On the country cloud, Germany, Canada, Netherlands and Australia are correlated to the second factorial axis.

Netherlands and Australia are projected on this axis with positive coordinates. These countries are therefore correlated to *Astronomy & Astrophysics* and *Crystallography* in their cooperation with India. Germany and Canada are projected on this axis with negative coordinates. These countries have shown greater interest in *Chemical Physics* and *Mathematical Physics* in their cooperation with India.

7 Transnational Links in Chemistry

This chapter seeks to analyze the patterns of India's research output and transnational links in different subfields of *Chemistry*: *General Chemistry* (*GEN*), *Analytical Chemistry* (*ANA*), *Applied Chemistry* (*APP*), *Electrochemistry* (*ELE*), *Inorganic Chemistry* (*INO*), *Organic Chemistry* (*ORG*), *Physical Chemistry* (*PHY*), *Polymer Chemistry* (*POL*).

General Overview of the Data

During the five - year period: 1990 - 1994, Indian scientists had published 11,660 articles in *Chemistry* in the mainstream journals covered by the *Science Citation Index*. Of these, 802 articles were cosigned by authors from 44 countries, accounting for 862 cooperation links. Twenty four countries had less than five links with India.

Table 7.1 presents the data on cooperation links (*COP's*) of significant countries (which had more than five links), aggregated over all subfields of *Chemistry*. In this table, the countries are ranked by the number of their cooperation links with India.

It can be easily seen that the distribution of links is highly skewed; the top five countries (USA, Germany, UK, Japan and France) account for about 68.2% of India's transnational links in *Chemistry*.

Table 7.1
India's Cooperation Links with Significant Partners

Country	*No. of Links*	*%*	*Country*	*No. of Links*	*%*	*Country*	*No. of Links*	*%*
USA	290	36.16	AUS	34	4.24	HUN	9	1.12
DEU	93	11.60	SUN	20	2.49	SWE	9	1.12
UKD	81	10.10	DNK	14	1.75	BEL	7	0.87
JPN	77	9.60	AUT	13	1.62	POL	7	0.87
FRA	47	5.86	CSK	13	1.62	BGD	6	0.75
CAN	36	4.49	ESP	13	1.62	NLD	6	0.75
ITA	36	4.49	CHE	12	1.50			

Inter - Field Differences in Transnational Cooperation

Figure 7.1 presents the distribution of articles, internationally coauthored articles (*ICOA*) and cooperation links (*COP*) in different subfields. While the proportions of *ICOA's* and *COP's* in different subfields almost match with each other, they do not always match with the distribution of articles. For example, *Physical Chemistry* accounts for 14.3% of all articles in *Chemistry*, but it accounts for 19.2% of all *ICOA's* and *COP's*. The subfield *Polymers* accounts for 12.2% of all articles, but it accounts for 9.3% of all *ICOA's* and 9.2% of all *ICOP's*.

Table 7.2 presents the data on the output of articles, internationally coauthored articles and transnational links and associated indicators (*INI*, *COI*, *CEI*) for different subfields of *Chemistry*.

Table 7.2 shows that *Electrochemistry* is the most internationalized subfield, whereas *Inorganic Chemistry* is the least internationalized subfield. The values of *COI* are almost equal to those of *INI* for each subfield, indicating that transnational links are bilateral. This is also confirmed from the values of *CEI* which are close to 1. Taken together, these results imply that India's transnational links in different subfields of *Chemistry* are not only infrequent, but also are bilateral.

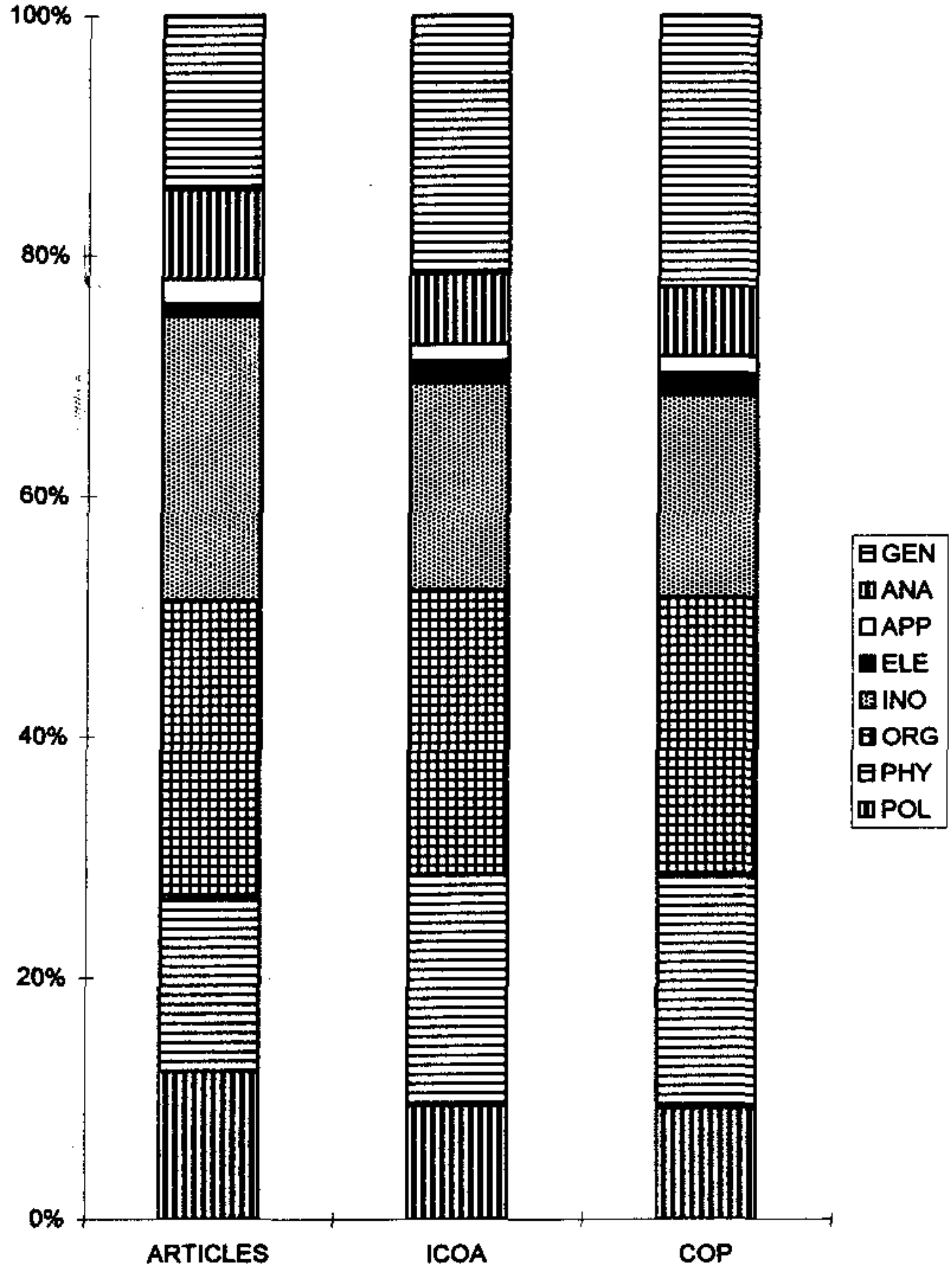


Fig. 7.1: Distribution of articles, internationally coauthored articles (ICOA) and cooperation links (COP) in different subfields of Chemistry

Table 7.2
Publication Output and Cooperation Links in *Chemistry* subfields (1990-1994)

Subfield	*No. of Articles*	*ICOA*	*No. of Links*	*Internationalization Index INI %*	*Cooperation Index COI %*	*Cooperation Extensiveness Index CEI*
General Chemistry	1698	173	195	10.19	11.48	1.13
Analytical Chemistry	867	47	50	5.42	5.77	1.06
Applied Chemistry	237	11	12	4.64	5.06	1.09
Electrochemistry	123	15	16	12.19	13.01	1.07
Inorganic Chemistry	2754	138	145	5.01	5.26	1.05
Organic Chemistry	2893	189	199	6.53	6.88	1.05
Physical Chemistry	1664	154	166	9.25	9.98	1.08
Polymers	1424	75	79	6.13	5.55	1.05
Total	11660	802	862	6.88	7.39	1.07

Inter - Country Differences in Transnational Cooperation

Inter - country differences in transnational cooperation were assessed by computing the *Affinity Index* (AFI). Figure 7.2 shows India's affinities towards its eight major partners, aggregated over all subfields of *Chemistry*: USA, Germany, UK, Japan, France, Canada, Italy and Australia.

Figure 7.3 represents India's affinities in eight subfields of *Chemistry* separately for each of its five top most partners (USA, Germany, UK, Japan and France). It can be easily seen from these figures that affinities towards different countries covary with subfields.

Country	*Subfields of*	
	Highest affinity	*Lowest affinity*
USA	Inorganic Chemistry Polymers	Electrochemistry
Germany	Electrochemistry	Polymers
UK	Applied Chemistry	Electrochemistry
Japan	Analytical Chemistry	Electrochemistry Polymers
France	Polymers	Applied Chemistry

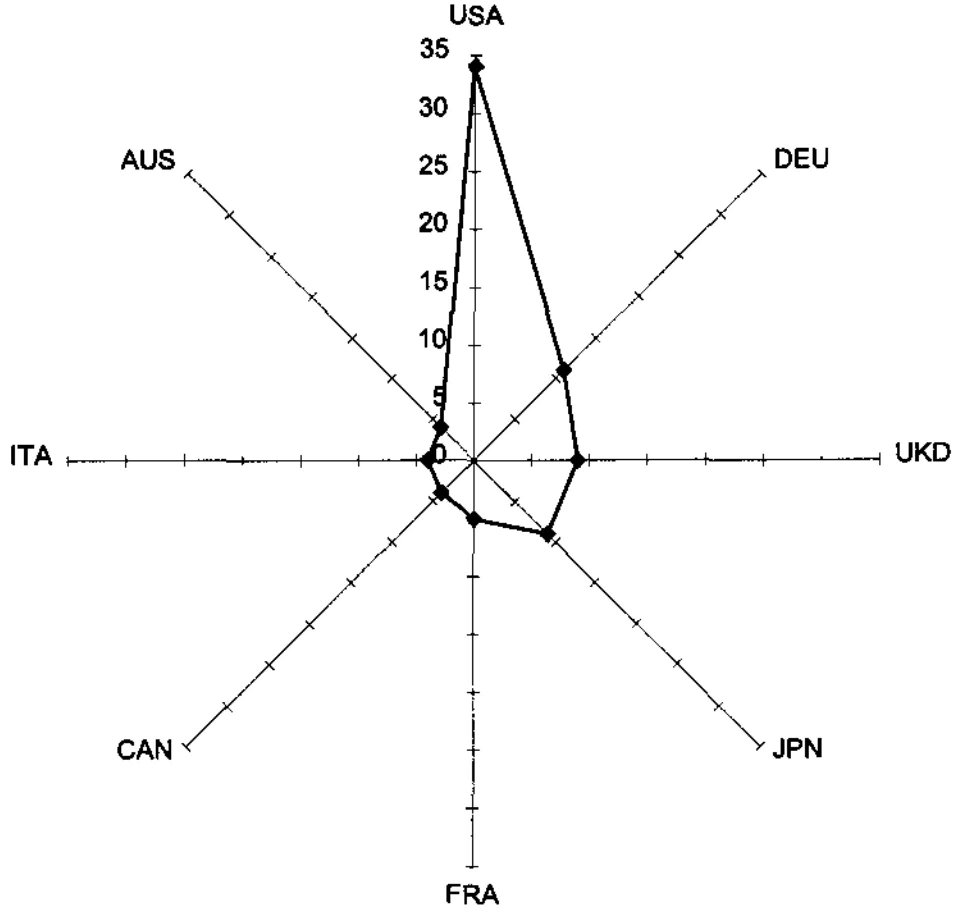


Fig. 7.2: India's linkages in Chemistry (1990-1994)
(Affinity Index)

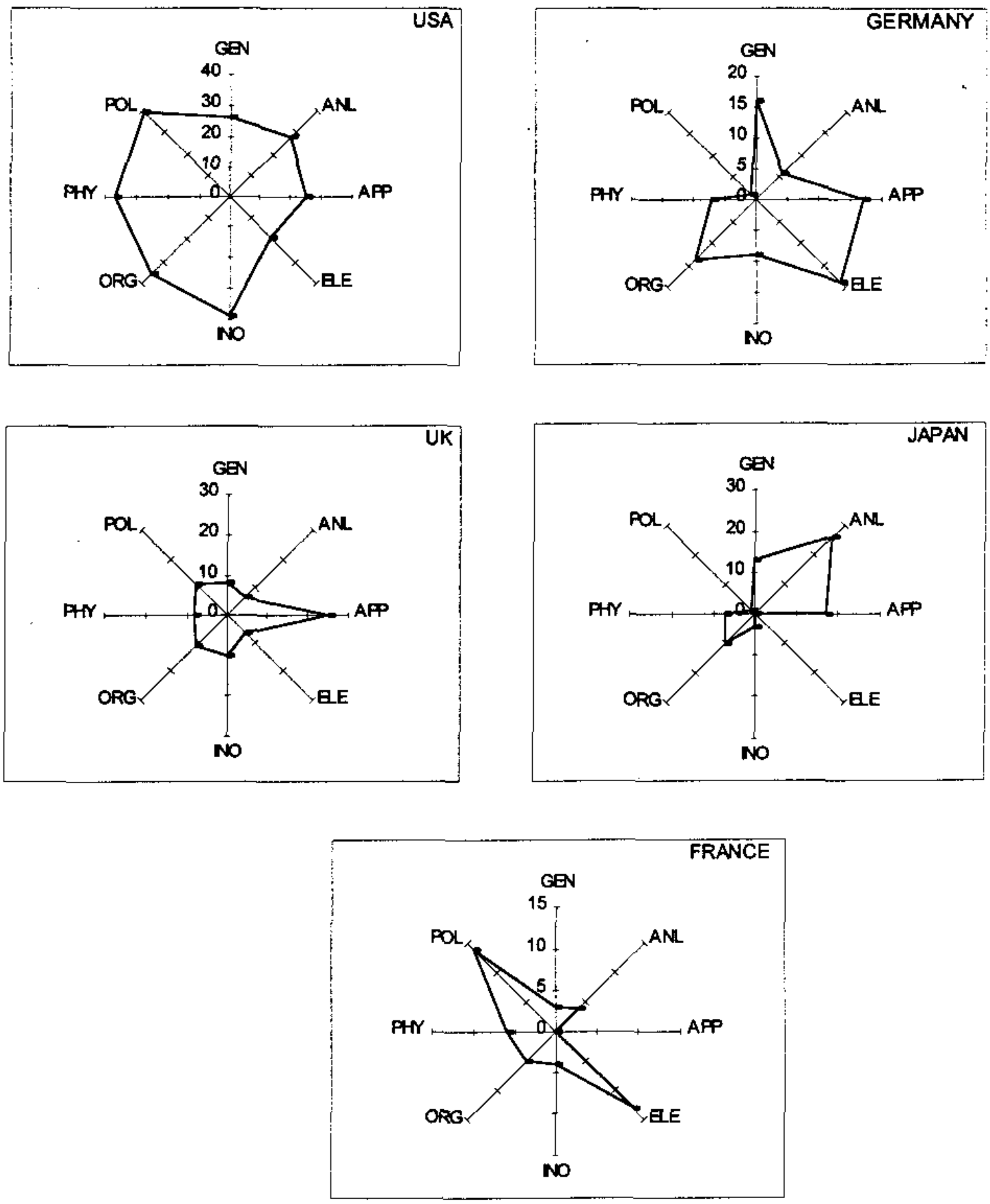


Fig. 7.3: India's affinities towards major cooperating countries in different subfields of Chemistry (1990-1994) (Affinity Index)

Figure 7.4 indicates India's affinities towards its major partners ($AFI \geq 2$) separately for each subfield. This figure is self - explanatory and any elaboration would be redundant.

Structure of Transnational Cooperation

Correspondence Analysis was performed to examine the structure of the multidimensional data on India's links with its fourteen major partners in different subfields of *Chemistry*, using the computer program SimCA. Five countries (Denmark, Austria, Czechoslovakia, Spain and Switzerland) which had less than ten links with India were treated as supplementary elements. Supplementary elements do not have any influence on the determination of factorial axes, but their coordinates and relative contributions ($cos^2\phi$) to the eccentricities of the factorial axes are computed by the program. Correspondence Analysis shows how India's significant partners are placed relative to each other and different research areas of *Chemistry*.

Eigen values computed by the program indicate that the total variance ($\Sigma\lambda_i$ = .20897) is sufficiently large, which implies considerable variations in the amplitudes of cooperation profiles of nine countries in eight subfields of *Chemistry*. The first three factorial axes, accounting for 84.5% of the total variance in the multidimensional system, provide the most parsimonious representation of the data. All the subfields and countries (except Denmark, Czechoslovakia and Spain) are well represented in the three - dimensional subspace.

The results of Correspondence Analysis are summarized in Tables 7.3 and 7.4.

The first two factorial axes account for about 65% of the variance in the multidimensional data. Thus, the two - dimensional factorial map constituted by ϕ_1 and ϕ_2 axes (Figure 7.5) represents the main features of the multidimensional data.

Factor ϕ_1: The first factorial axis is characterized by the opposition between *General Chemistry* and *Analytical Chemistry* on the one hand and *Physical Chemistry* and *Polymers* on the other.

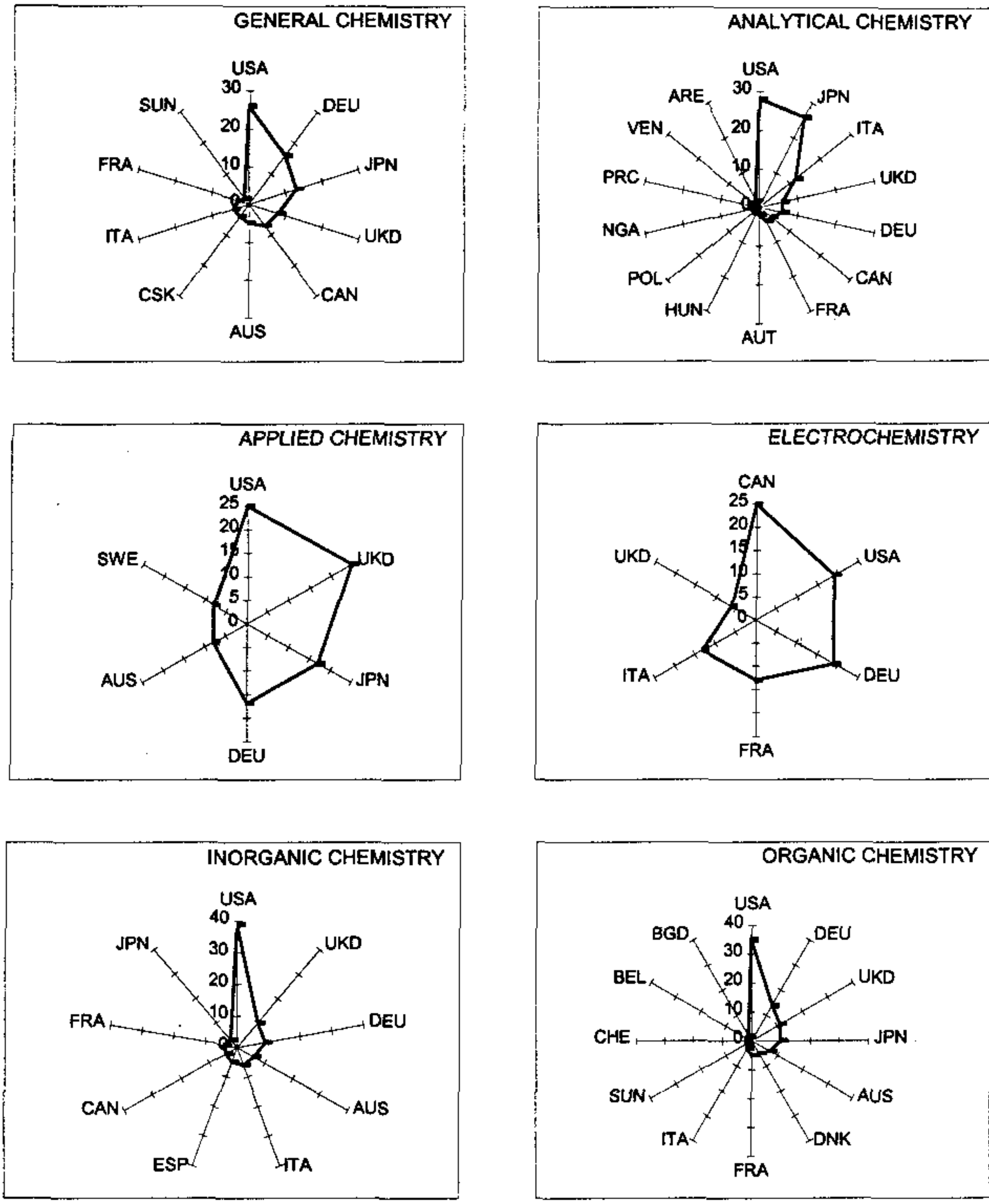


Fig. 7.4: India's linkages in different subfields of Chemistry (1990-1994)
(Affinity Index)

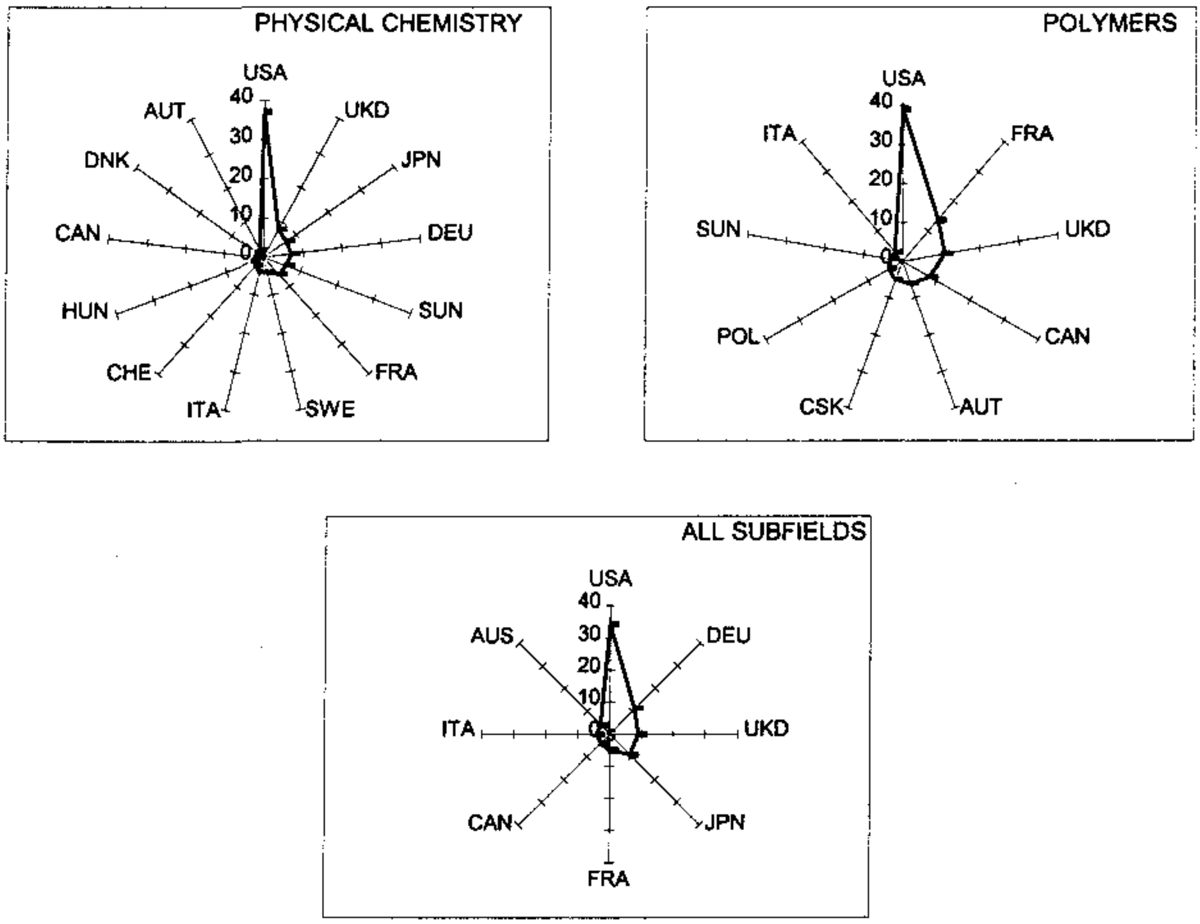


Fig. 7.4 (Contd.): India's linkages in different subfields of Chemistry (1990-1994)
(Affinity Index)

Table 7.3
Contributions of explicative points to the composition of the factorial axes (Ctr)*

Cloud	*Explicative points with positive coordinates*	*Explicative points with negative coordinates*
	Axis 1 (λ_1 = .080272, τ_1 = 38.41%)	
Subfields	General Chemistry (234) Analytical Chemistry (139)	Physical Chemistry (129) Polymer (384)
Countries	Japan (401) Germany (160)	France (160) USA (11.6)
	Axis 2 (λ_2 = .054725, τ_2 = 26.19%)	
Subfields	Organic Chemistry (230)	Electrochemistry (443) Analytical Chemistry (134)
Countries	Australia (116)	Canada (563), Italy (140)
	Axis 3 (λ_3 = .041644 , τ_3 = 19.93%)	
Subfields	–	Analytical Chemistry (387) Physical Chemistry (317)
Countries	Germany (135) Canada (135) Australia (221)	Japan (282) Russia (134)

**Note*: Values are in permills

Table 7.4
Contributions of explained points to the eccentricities of the factorial axes ($cos^2\Phi$)*

Cloud	*Explained points with positive coordinates*	*Explained points with negative coordinates*
	Axis *1* (λ_1 = *.080272*, τ_1 = *38.41%*)	
Subfields	General Chemistry (698) Applied Chemistry (321)	Physical Chemistry (345) Polymer (785)
Countries	Germany (554) Japan (695)	USA (636) France (682) Austria (475), Russia (296)
	Axis 2 (λ_2= .054725, τ_2 = 26.19%)	
Subfields	Organic Chemistry (675)	Electrochemistry (781) Analytical Chemistry (286)
Countries	UK (299) Australia (321) Denmark (396) Switzerland (253)	Canada (816) Italy (447)
	Axis 3 (λ_3 = .041644 , τ_3 = 19.93%)	
Subfields	—	Analytical Chemistry (411) Physical Chemistry (440)
Countries	Australia (466)	Japan (254) Russia (267)

**Note*: Values are in permills

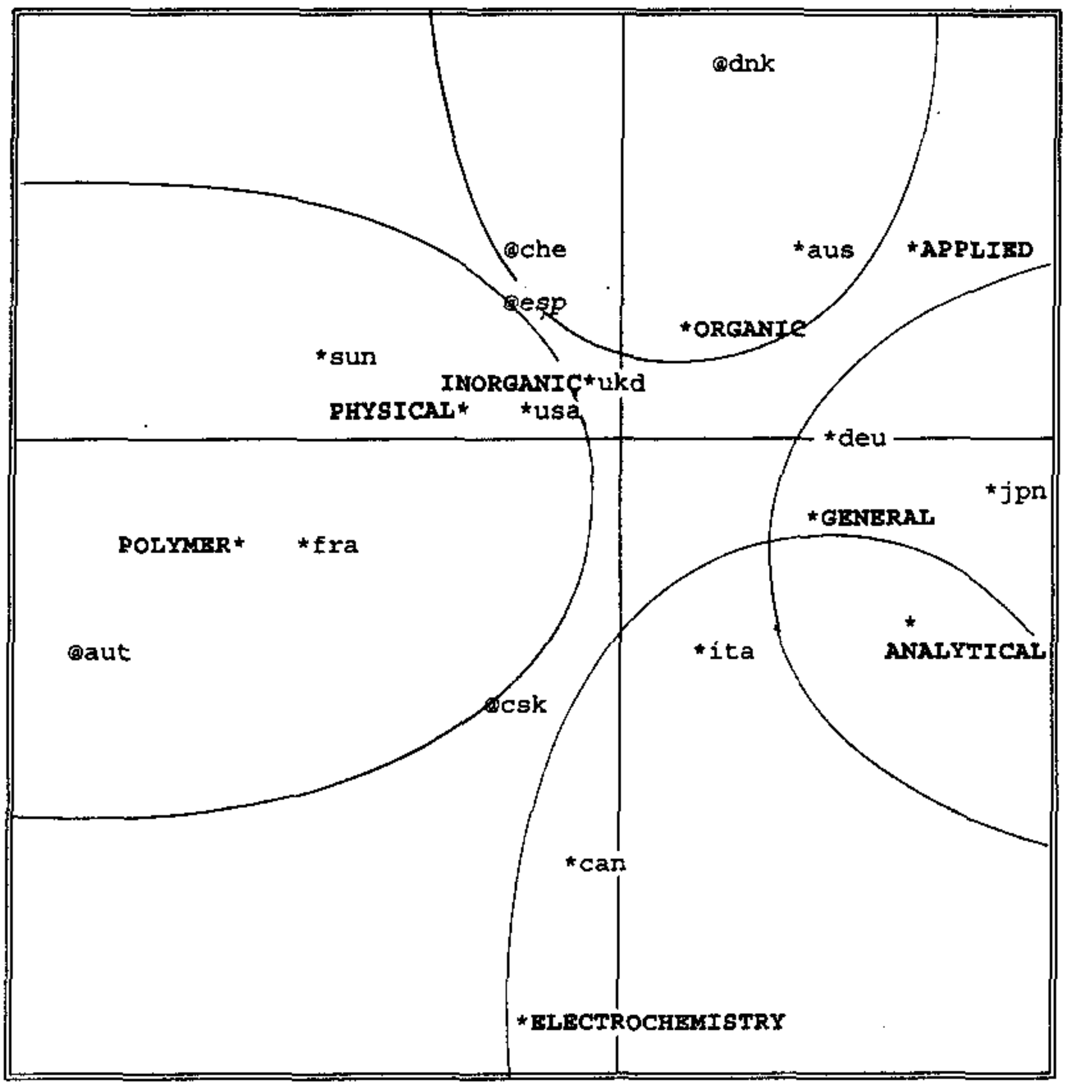


Fig. 7.5: Correspondence Analysis of transnational cooperation in Chemistry subfields

Notes:
Horizontal axis is dimension 1 with inertia = 0.0803 (38.4%)
Vertical axis is dimension 2 with inertia = 0.0547 (26.2%)
64.6% of total inertia is represented in the above map
* *Principal variables* @ *Supplementary variables*

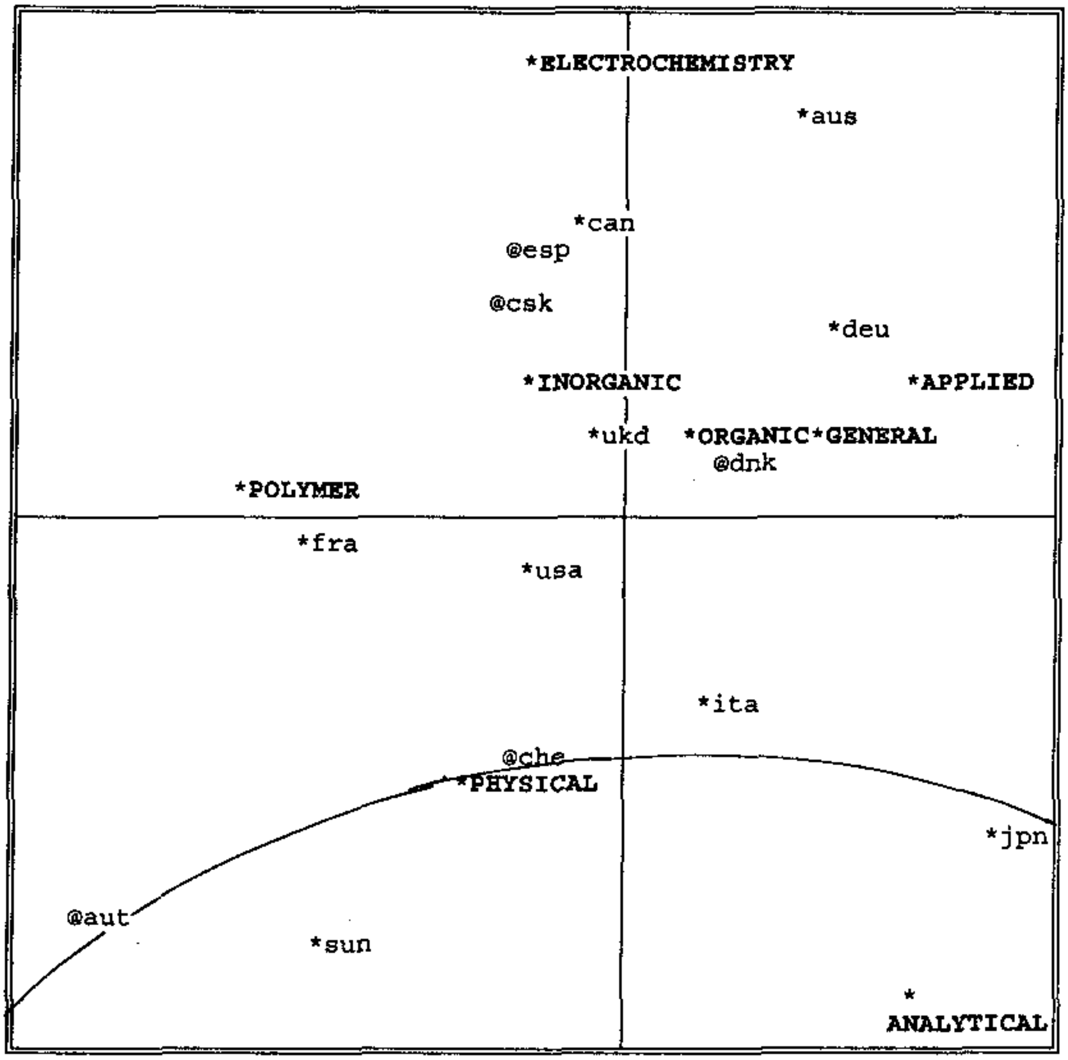


Fig. 7.6: Correspondence Analysis of transnational cooperation in Chemistry subfields

Notes:
Horizontal axis is dimension 1 with inertia = 0.0803 (38.4%)
Vertical axis is dimension 3 with inertia = 0.0416 (19.9%)
58.3% of total inertia is represented in the above map
* Principal variables @ Supplementary variables

Germany and Japan have stronger preference for collaboration in *General Chemistry* and *Analytical Chemistry*. USA, France, Russia and Austria on the other hand have stronger preference for collaboration in *Physical Chemistry / Polymers*, depending on their proximities to the poles of these subfields. France and Austria give about the same importance to both *Physical Chemistry* and *Polymers*, whereas USA and Russia give greater importance to *Physical Chemistry* in their cooperation with India.

Factor ϕ_2: The second factorial axis is characterized by the opposition between *Organic Chemistry* on the one hand and *Analytical Chemistry* and *Electrochemistry* on the other.

Canada and Italy collaborate with India mainly in *Analytical Chemistry* and *Electrochemistry*, whereas UK, Australia, Denmark and Switzerland collaborate with India mainly in *Organic Chemistry*. Canada is located close to the pole of *Electrochemistry* and gives particularly greater importance to this subfield in its cooperation with India. Italy, which is situated close to the pole of *Analytical Chemistry* gives greater importance to this subfield in its cooperation with India.

Factor ϕ_3: The third factorial axis does not reflect polarity between the subfields of *Chemistry*. It is mainly influenced by *Analytical Cnemistry* and *Physical Chemistry*, which are projected on this axis with negative coordinates (Figure 7.6).

Japan and Russia are correlated to this axis. These countries give greater importance to *Analytical Chemistry* and *Physical Chemistry* in their cooperation with India, depending upon their proximities to the poles of these subfields. While Japan gives equal importance to both these subfields, Russia gives greater importance to *Physical Chemistry*. Australia is anticorrelated to these subfields.

The results of Correspondence Analysis are summarized in the *Infographic Map* (Figure 7.7).

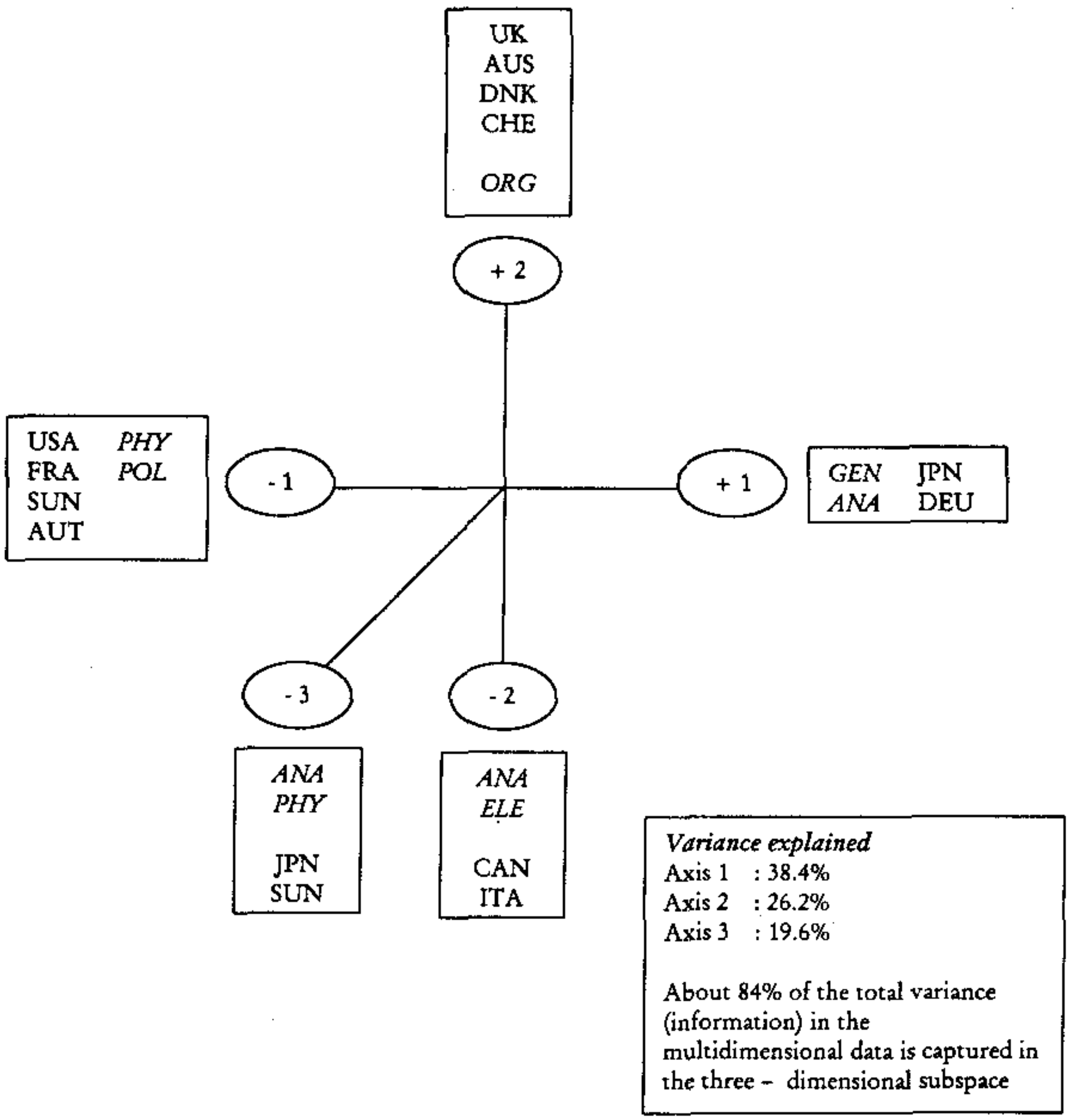


Fig. 7.7: Summary of correspondence analysis

8 Transnational Links in Biology

This chapter analyzes the patterns of research output and transnational linkages of India in different subfields[1] of *Biology*: *General Biology* (*GNB*); *Botany* (*BOT*); *Ecology* (*ECO*); *Entomology* (*ENT*); *Marine Biology and Hydrobiology* (*HYD*); *Miscellaneous Biology* (*MIB*); *General Zoology* (*ZOO*); *Miscellaneous Zoology* (*MIZ*).

General Overview of the Data

During the five - year period: 1990 - 1994, India had published 2827 articles in *Biology* journals covered by the *Science Citation Index*. Of these, 405 articles (14.3%) were internationally coauthored, involving cooperation with 51 countries and indicating an aggregate of 443 transnational links.

Table 8.1 presents the data on transnational links with 14 countries (which had at least five coauthorship links with India) in different subfields of *Biology*. The distribution of links is highly skewed; the top five countries (USA, UK, Germany, Japan and Canada) account for more than two thirds (68.6%) of all transnational links in *Biology*.

Inter - Field Differences in Transnational Cooperation

The component - bar - charts in Figure 8.1 indicate the distribution of articles, internationally coauthored articles (*ICOA*) and cooperation links (*COP*) in different subfields of *Biology*.

[1] This classification of *Biology* into various subfields, which is based on the *SCI* - classification of journals, is rather vague.

Table 8.1
Cooperation Links of India in *Biology*

Country	*No. of Links*	*%*	*Country*	*No. of Links*	*%*	*Country*	*No. of Links*	*%*
USA	120	26.97	AUS	17	3.82	KEN	5	1.12
UKD	62	13.93	FRA	15	3.37	NLD	5	1.12
DEU	49	11.01	SYR	11	2.47	PAK	5	1.12
JPN	42	9.48	BEL	10	2.25	POL	5	1.12
CAN	32	7.19	DNK	7	1.57			

Table 8.2 presents the data on the output of articles, internationally coauthored articles (*ICOA*) and transnational links (*COP*) and associated indicators for different subfields of *Biology*.

Table 8.2
Publication Output and Cooperation Links in *Biology* subfields (1990-1994)

Subfield	*No. of Articles*	*ICOA*	*No. of Links*	*Internationalization Index INI %*	*Cooperation Index COI %*	*Cooperation Extensiveness Index CEI*
General Biology	192	20	20	10.42	10.42	1.00
Botany	1793	264	291	14.72	16.23	1.10
Ecology	116	13	14	11.21	12.07	1.08
Entomology	210	27	32	12.86	15.24	1.18
Hydrobiology	297	36	40	12.12	13.47	1.11
Miscellaneous Biology	42	13	14	36.95	33.33	1.08
Zoology	113	22	22	19.46	19.47	1.00
Miscellaneous Biology	62	10	10	16.13	16.13	1.00
Total	2827	405	443	14.33	15.67	1.09

General Biology, *Ecology*, *Entomology*, *Hydrobiology* have less than average values of internationalization index. On the other hand, *Botany*, *Miscellaneous Biology*, *Zoology* and *Miscellaneous Zoology* have above average values of internationalization index. These subfields attract more international cooperation. This trend is also confirmed from the values of *COI*.

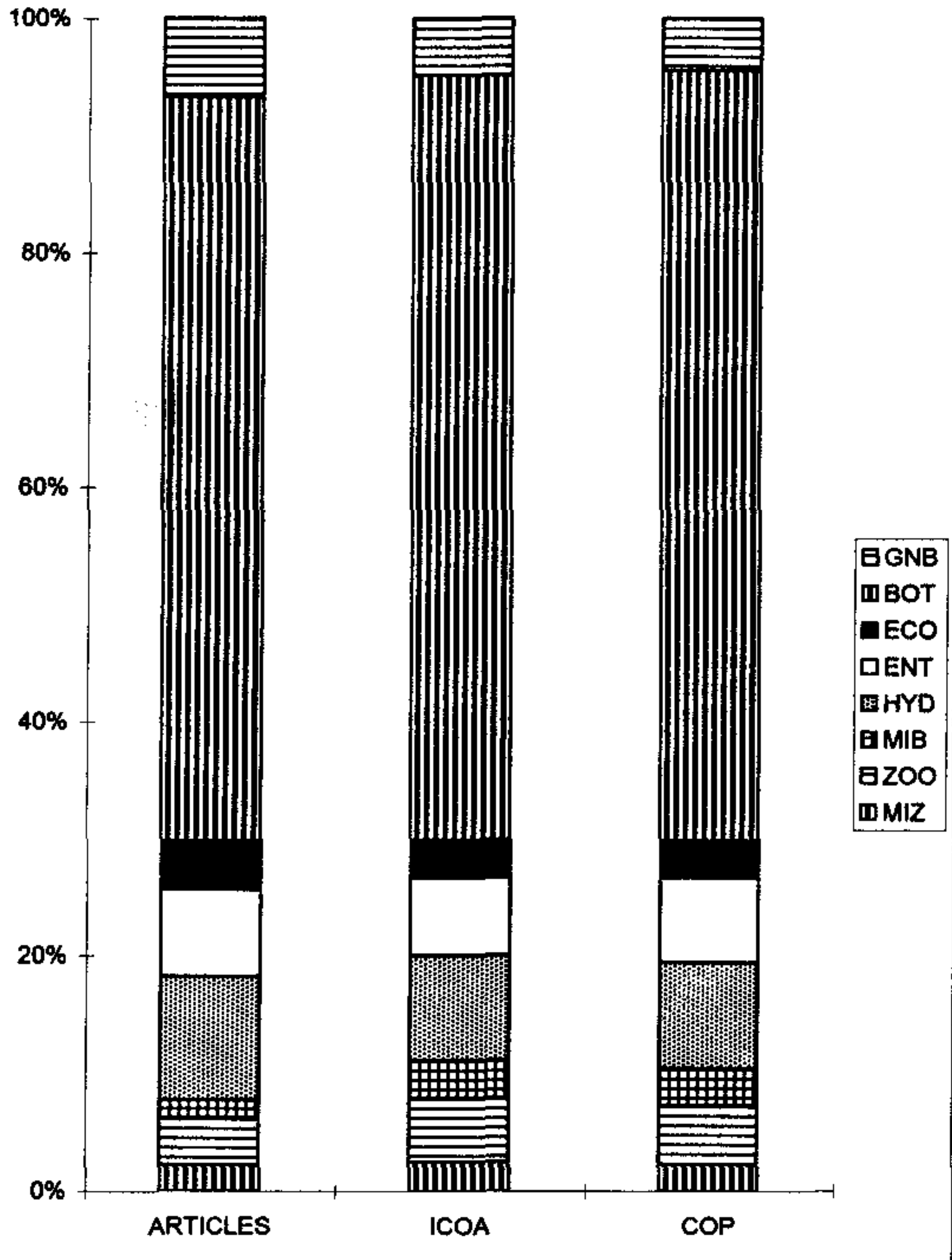


Fig. 8.1: Distribution of articles, internationally coauthored articles (ICOA) and cooperation links (COP) in different subfields of Biology

Inter - Country Differences in Transnational Cooperation

Inter – country differences in transnational cooperation were assessed by computing the *Affinity Index* (*AFI*). Figure 8.2 depicts India's affinities towards its nine major partners, aggregated over all subfields of *Biology*: USA, UK, Germany, Japan, Canada, Australia, France, Syria and Belgium.

USA occupies the most important position in India's transnational cooperation. About 27% of all internationally coauthored articles involve cooperation with USA. UK , which occupies the second rank, is far behind, accounting for 14% of India's internationally coauthored articles.

Figure 8.3 represents India's affinities in eight subfields for each of its five major partners (USA, UK, Germany, Japan, Canada).

It can be easily seen from this figure that affinities towards different countries covary with subfields.

Country	*Subfields of* *Highest affinity*	*Lowest affinity*
USA	Entomology	Hydrobiology
UK	Ecology	Miscellaneous Zoology
Germany	Zoology	Ecology
Japan	Hydrobiology	Entomology Miscellaneous Zoology
Canada	Miscellaneous Biology	Miscellaneous Zoology

Figure 8.4 indicates India's affinities towards its nine major partners (USA, UK, Germany, Japan, Canada, Australia, France, Syria and Belgium) separately for each subfield. This figure is self – explanatory and needs no elaboration.

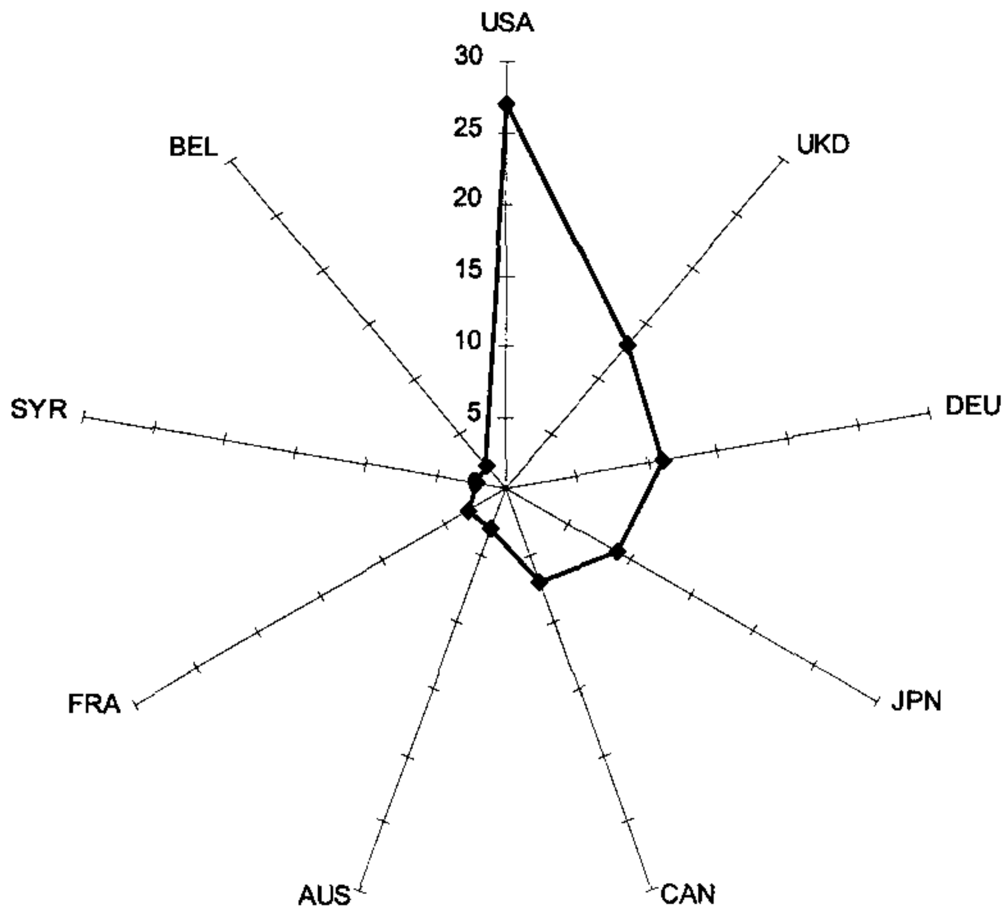


Fig. 8.2: India's linkages in Biology (1990-1994)
(Affinity Index)

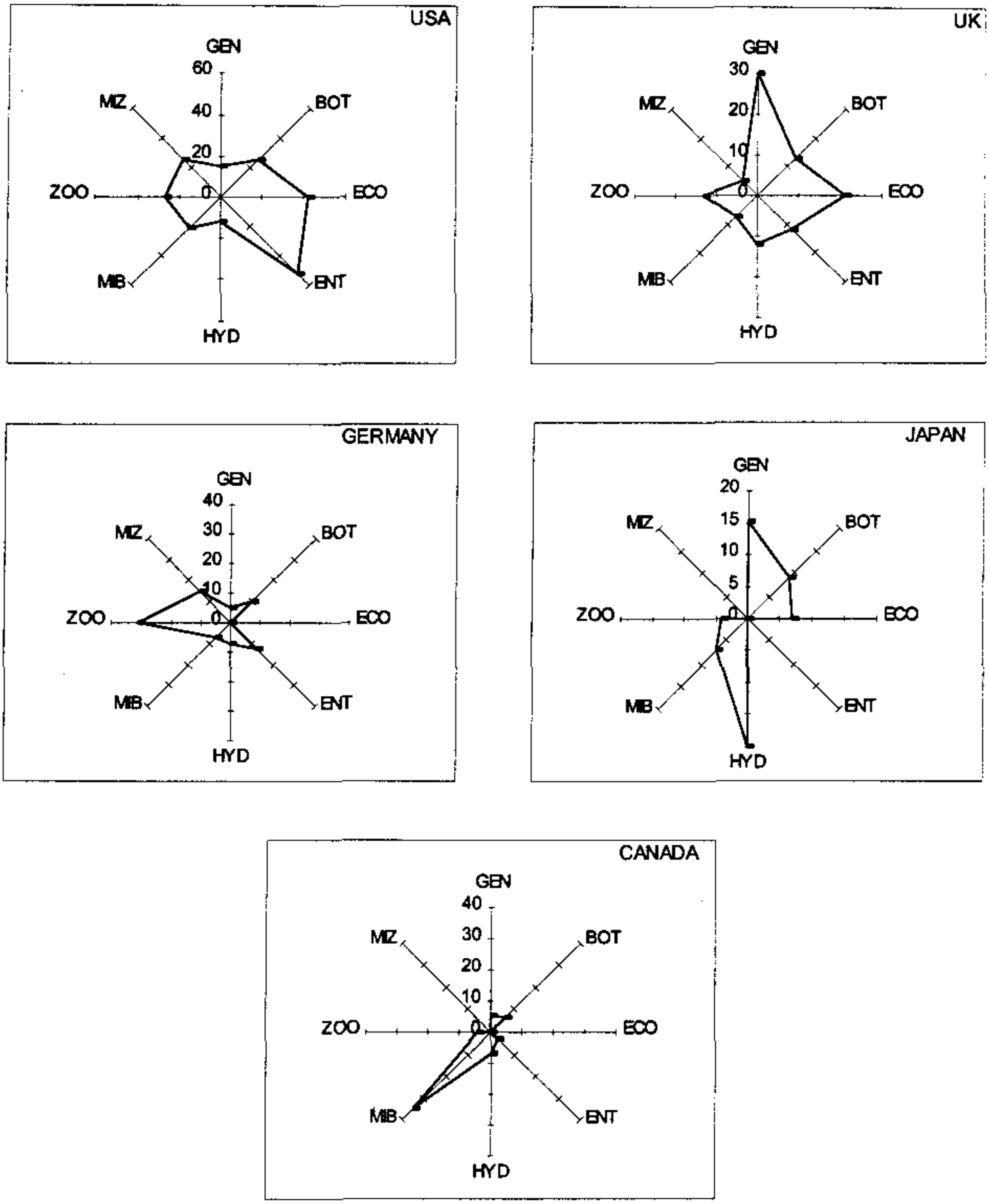


Fig. 8.3: India's affinities towards major cooperating countries in different subfields of Biology (1990-1994)
(Affinity Index)

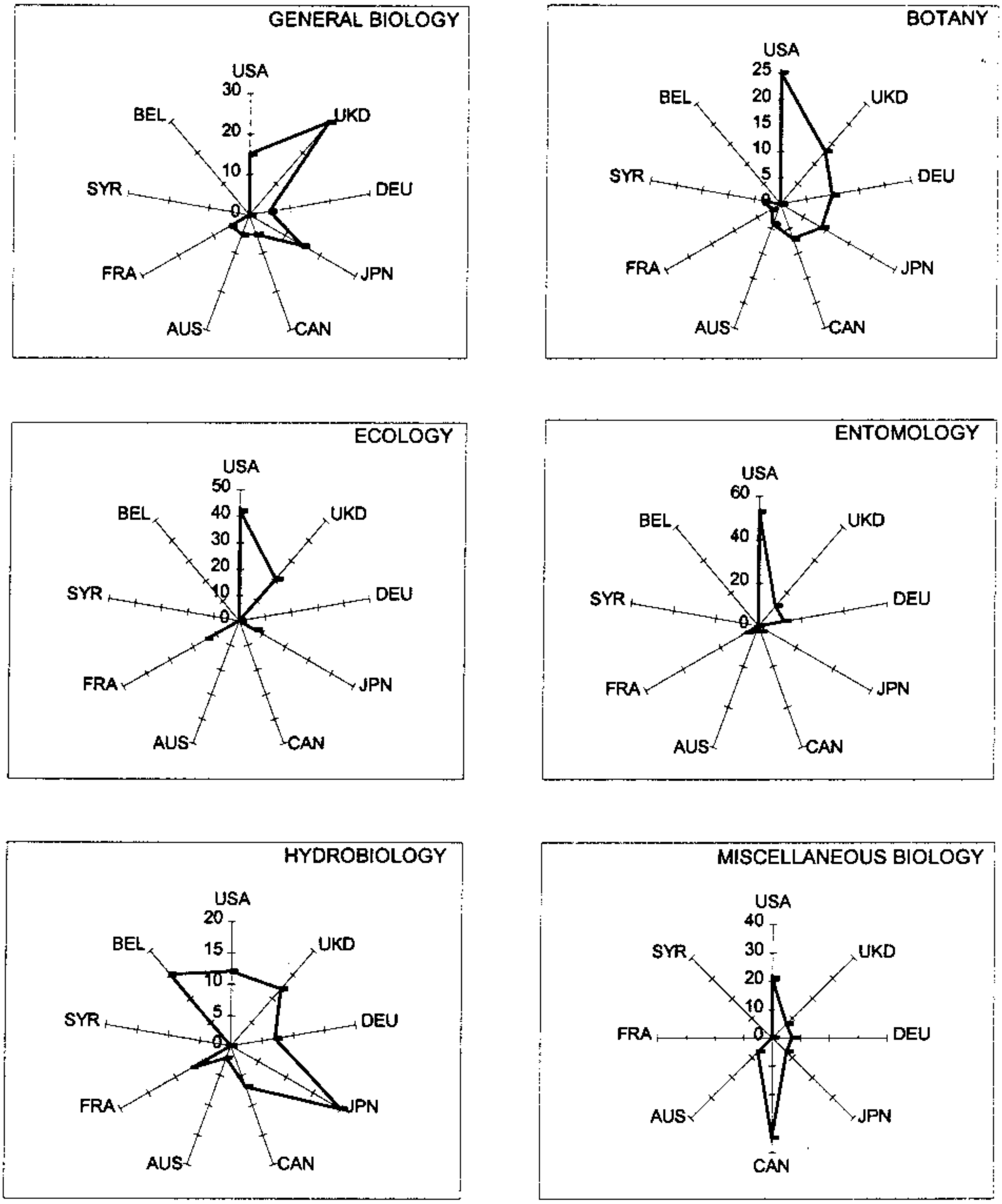
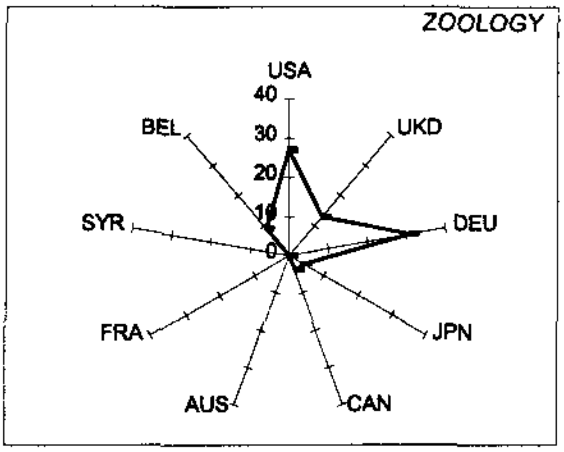
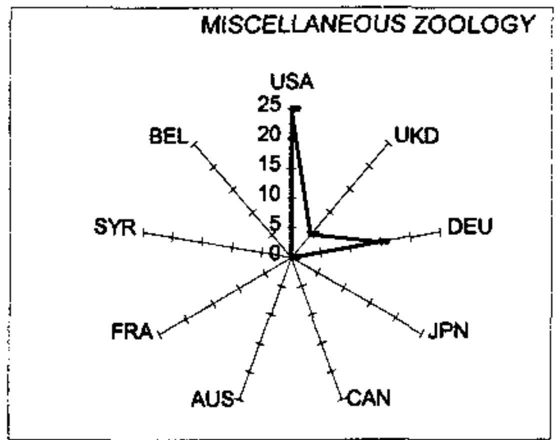


Fig. 8.4: India's linkages in different subfields of Biology (1990-1994)
(Affinity Index)





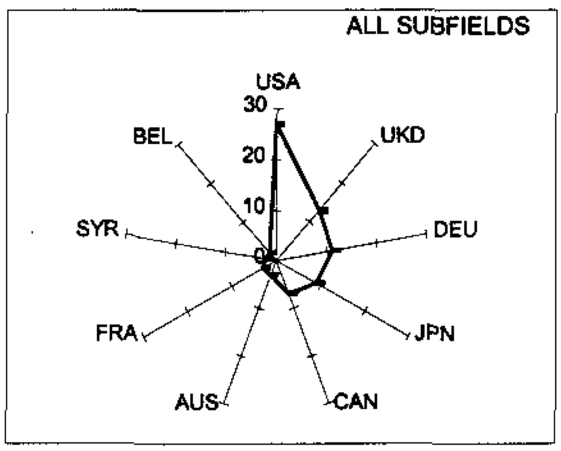


Fig. 8.4 (Contd.): India's linkages in different subfields of Biology (1990-1994)
(Affinity Index)

Structure of Transnational Cooperation

The structure of India's links with its nine major cooperating countries (USA, UK, Germany, Japan, Canada, Australia, France, Syria and Belgium) in eight subfields of *Biology* was analyzed through correspondence analysis, using the computer program SimCA. Correspondence Analysis shows how India's significant partners are placed relative to each other and different research areas of *Biology*.

Eigen values computed by the program indicate that the total variance ($\Sigma\lambda i = 0.315326$) is large. This means wide variations in the amplitude of cooperation profiles of these countries. The first three factorial axes account for 85% of the total variance in the multidimensional data, and hence provide a parsimonious representation of the data.

The numerical results of Correspondence Analysis are summarized in Tables 8.3 and 8.4.

The first two factorial axes account for about 67% of the variance in the multidimensional data. Hence the two – dimensional factorial map constituted by ϕ_1 and ϕ_2 axes (Figure 8.5) represents the main features of the multidimensional data.

Factor ϕ_1: The first factorial axis, accounting for 42.6% of the total variance, constitutes the most important element of the multidimensional structure. This factor does not reflect a polarity. It is dominated by *Hydrobiology*, which contributes about 78% of the variance to the composition of the first axis. Japan and Belgium are strongly correlated to this axis. These countries collaborate with India mainly in *Hydrobiology*. USA is anticorrelated to *Hydrobiology* and gives the least importance to this area in its relationship with India.

Factor ϕ_2: The second factorial axis reflects a polarity. It is characterized by the opposition between *Entomology*, *Zoology* and *Miscellaneous Zoology* on the one hand and *Miscellaneous Biology* on the other.

USA and Germany are associated with *Entomology*, *Zoology* and *Miscellaneous Zoology*. These fields are quite prominent in their cooperation links with India. Canada and Australia emphasize *Miscellaneous Biology* in their cooperation links with India.

Table 8.3
Contributions of explicative points to the composition of the first three factorial axes (Absolute contribution, permill)

Cloud	*Explicative points with positive coordinates*	*Explicative points with negative coordinates*
	Axis 1 (λ_1 = .0134358, τ_1 = 42.61%)	
Subfields	—	Hydrobiology (779)
Countries	USA (149)	Japan (113) Belgium(688)
	Axis 2 (λ_2= .076266, τ_2 = 24.19%)	
Subfields	Entomology (189) Zoology (182) Miscellaneous Zoology (144)	Miscellaneous Biology (340)
Countries	USA (137) Germany (122)	Canada (441) Australia (90)
	Axis 3 (λ_3 = .058414, τ_3 = 18.52%)	
Subfields	General Biology (150) Ecology (318)	Zoology(304)
Countries	UK (117) France (368)	Germany (365)

Table 8.4
Contributions of the explained points to the eccentricities of the first three factorial axes (Relative contribution, permill)

Cloud	*Explained points with positive coordinates*	*Explained points with negative coordinates*
	Axis 1 (λ_1 = .0134358, τ_1 = 42.61%)	
Subfields	Botany (424) Entomology (330)	Hydrobiology (980)
Countries	USA	Japan Belgium
	Axis 2 (λ_2 = .076266, τ_2 = 24.19%)	
Subfields	Entomology (418) Zoology (354) Miscellaneous Zoology (542)	Miscellaneous Biology (542)
Countries	USA (295) Germany (270)	Canada (678) Australia (765)
	Axis 3 (λ_3 = .058414, τ_3 = 18.52%)	
Subfields	General Biology (923) Ecology (668)	Zoology (454)
Countries	UK (459) France (668)	Germany (625)

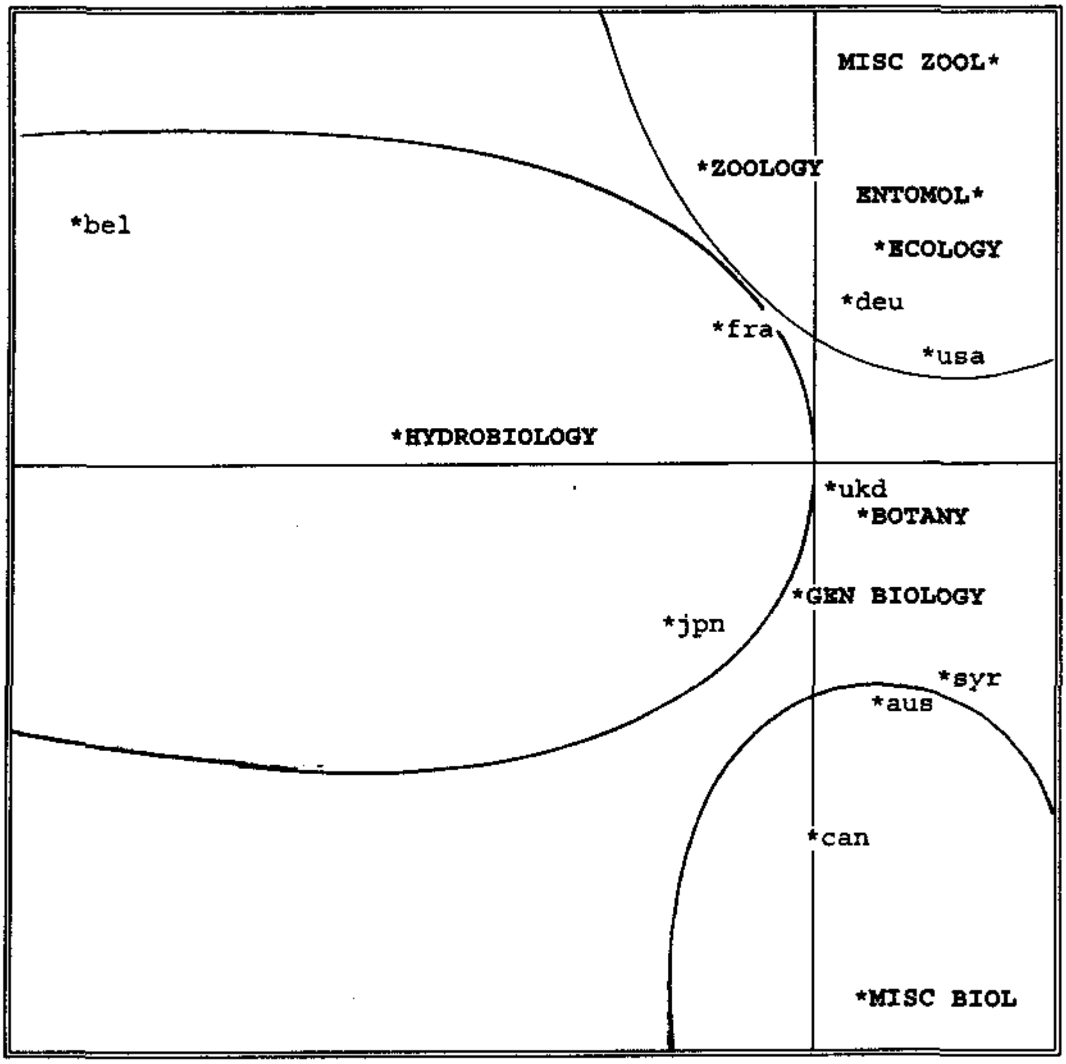


Fig. 8.5: Correspondence Analysis of transnational cooperation in Biology subfields

Factor ϕ_3: On the cloud of research fields, this factor is composed of *General Biology*, *Ecology* and *Zoology*, which together account for 76% of its variance. *Zoology* is opposed to *General Biology* and *Ecology*.

UK, Germany and France are strongly correlated to this axis. UK and France give prominence to *General Biology* and *Ecology* in their links with India, whereas Germany's links are stronger in *Zoology*.

9 Transnational Links in Earth & Atmospheric Sciences

This chapter examines the patterns of research output and transnational links of Indian institutions in different subfields of *Earth & Atmospheric Sciences* based on coauthored publications during 1990 - 1994:

1. Earth & Planetary Sciences (*EPS*)
2. Environmental Sciences (*ENV*)
3. Geology (*GEO*)
4. Metereology and Atmospheric Sciences (*MET*)
5. Oceanography & Limnology (*OCN*)
6. Remote Sensing (*REM*)

General Overview of the Data

During these five years, India had published 2198 articles in *Earth & Atmospheric Sciences* in the mainstream journals, covered by the *Science Citation Index*. Of these, 350 articles (15.9%) were cosigned by authors from 36 countries, indicating an aggregate of 436 transnational links (19.8%).

Table 9.1 presents the data on transnational links with 13 countries which had at least five cooperation links with India. It can be easily seen that the distribution of links is highly skewed; the top five countries (USA, UK, Germany, Japan and Canada) account for about two thirds of India's transnational links in this field.

Table 9.1
Cooperation Links of India in *Earth & Atmospheric Sciences*

Country	*No. of Links*	%	*Country*	No. of Links	%	*Country*	*No. of Links*	%
USA	130	29.81	FRA	23	5.27	BEL	9	2.06
UKD	50	11.46	SUN	22	5.05	SWE	7	1.61
DEU	38	8.72	AUS	14	3.21	ITA	6	1.38
JPN	32	7.34	NLD	10	2.29	BRA	5	1.15
CAN	28	6.42						

The component - bar - charts in Figure 9.1 indicate the distribution of research output (articles), internationally coauthored articles (*ICOA*) and cooperative links (*COP*) in different subfields of *Earth & Atmospheric Sciences*.

Inter - Field Differences in Transnational Cooperation

Table 9.2 presents the data on the output of articles, internationally coauthored articles (*ICOA*) and transnational cooperation links (*COP*) and associated indicators for different subfields of *Earth & Atmospheric Sciences*.

There are wide variations in the distribution of articles and transnational links between the subfields. *Environment* accounts for about 40% of the articles, but it accounts for only 26% of *ICOA*'s and 22.2% of transnational links. *Geology* accounts for only 13% of the articles, but it accounts for 26% of transnational links. *Oceanography & Limnology* accounts for 5% of articles and the same proportions of *ICOA*'s and transnational links.

Table 9.2 indicates wide variations in the internationalization of different subfields of *EAS*. *Geology* is the most internationalized subfield; about one third of all articles (30.4%) in this area are internationally coauthored. On the other hand, *Remote Sensing* is the least internationalized area; only 6.6% of articles in this area are internationally coauthored.

Geology, *Metereology* and *Earth & Planetary Science* have above average (average for the field) level of internationalization, whereas *Remote Sensing*, *Oceanography & Limnology* and *Environment* have below average level of internationalization. A similar trend is observed when we compare the various subfields on the basis of *Cooperation Index* (*COI*).

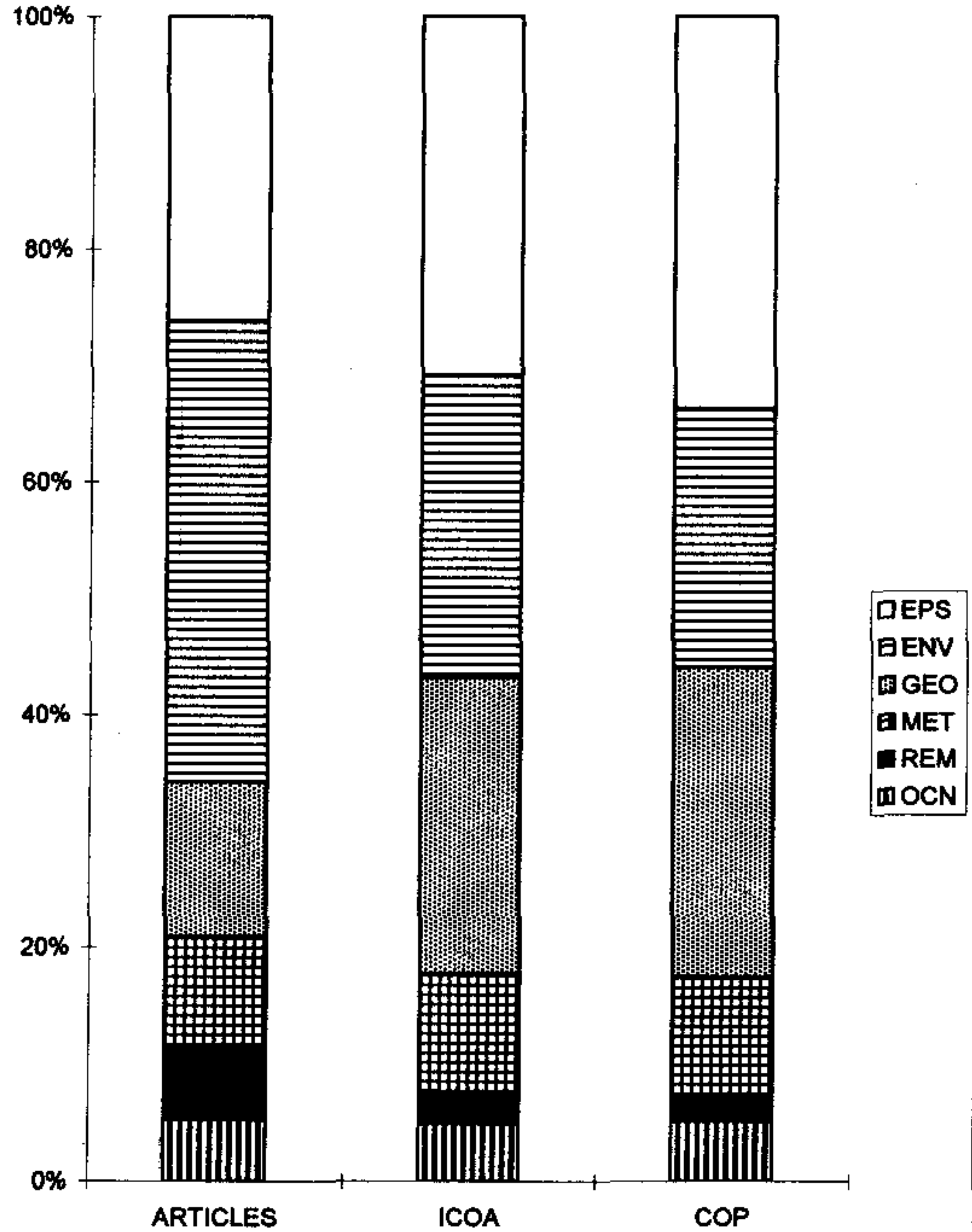


Fig. 9.1: Distribution of articles, internationally coauthored articles (ICOA) and cooperation links (COP) in different subfields of Earth & Atmospheric Sciences

Except *Remote Sensing* and *Environment*, all the areas have *Cooperation Extensiveness Index* (*CEI*) far greater than 1, which implies multilateral cooperation.

Table 9.2
Publication Output and Cooperation Links in *Earth & Atmospheric Sciences* subfields (1990-1994)

Subfield	*No. of Articles*	*ICOA*	*No. of Links*	*Internationalization Index INI %*	*Cooperation Index COI %*	*Cooperation Extensiveness Index CEI*
EPS	575	108	147	18.78	25.57	1.36
ENV	871	91	97	10.45	11.14	1.07
GEO	293	89	116	30.38	39.59	1.30
MET	209	36	45	17.22	21.53	1.25
OCN	114	17	22	14.91	19.30	1.29
REM	136	9	9	6.62	6.62	1.00
Total	2198	350	436	15.92	19.84	1.25

Inter – Country Differences in Transnational Cooperation

Inter – country differences in transnational cooperation were assessed by computing the *Affinity Index* (*AFI*). Figure 9.2 depicts India's affinities towards its nine major partners (USA, UK, Germany, Japan, Canada, France, Russia, Australia, Netherlands) aggregated over all subfields of *Earth & Atmospheric Sciences* (*EAS*).

USA occupies the first rank, accounting for 29.82% of all transnational links in *EAS*, followed by UK (11.47%), Germany (8.72%), Japan (7.34%), Canada (6.42%) and France (5.28%).

Figure 9.3 represents India's affinities in six subfields (*EPS*, *ENV*, *MET*, *OCN*, *REM* and *GEO*) for each of its five major partners – USA, UK, Germany, Japan and Canada. This figure indicates the variations in the importance of different subfields in India's cooperation with these five countries. Affinity profiles of USA and UK are less differentiated than those of Germany, Japan and Canada.

Figure 9.4 indicates India's affinities towards its nine major partners separately for each subfield. This figure is self – explanatory and any elaboration would be redundant. Affinity profile of *Geology* is less differentiated than those of other subfields.

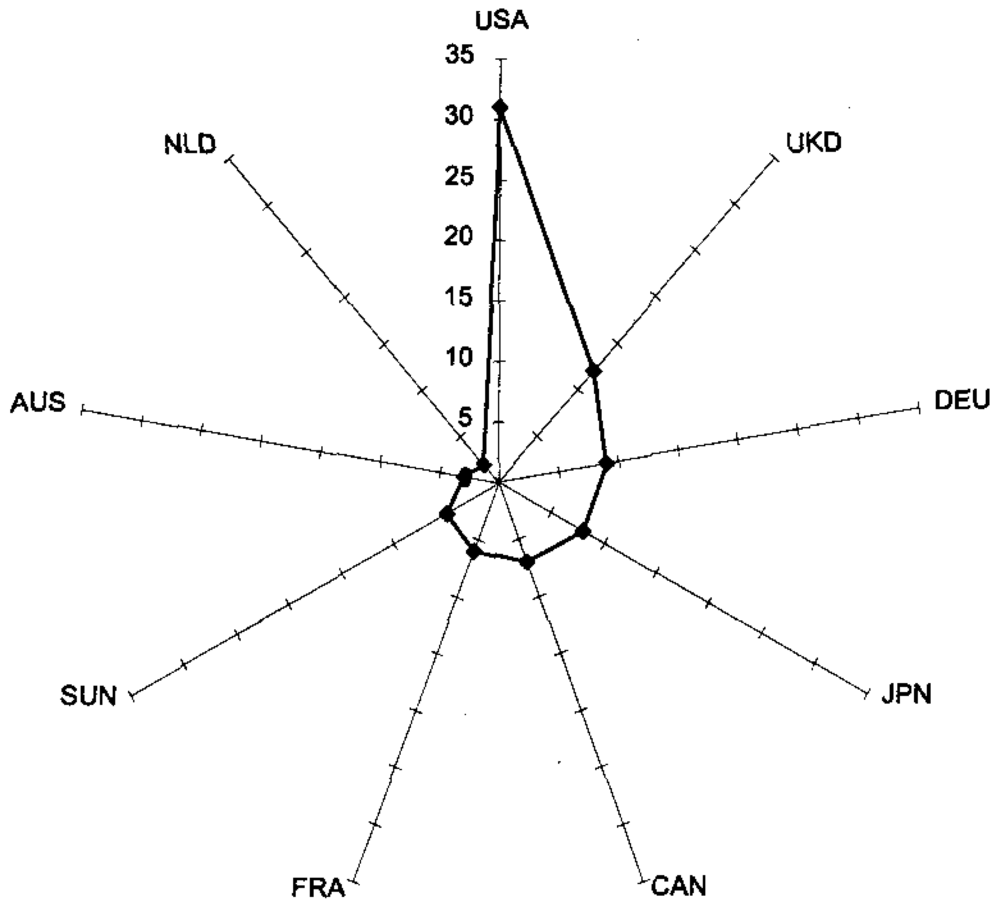


Fig. 9.2: India's linkages in Earth & Atmospheric Sciences (1990-1994)
(Affinity Index)

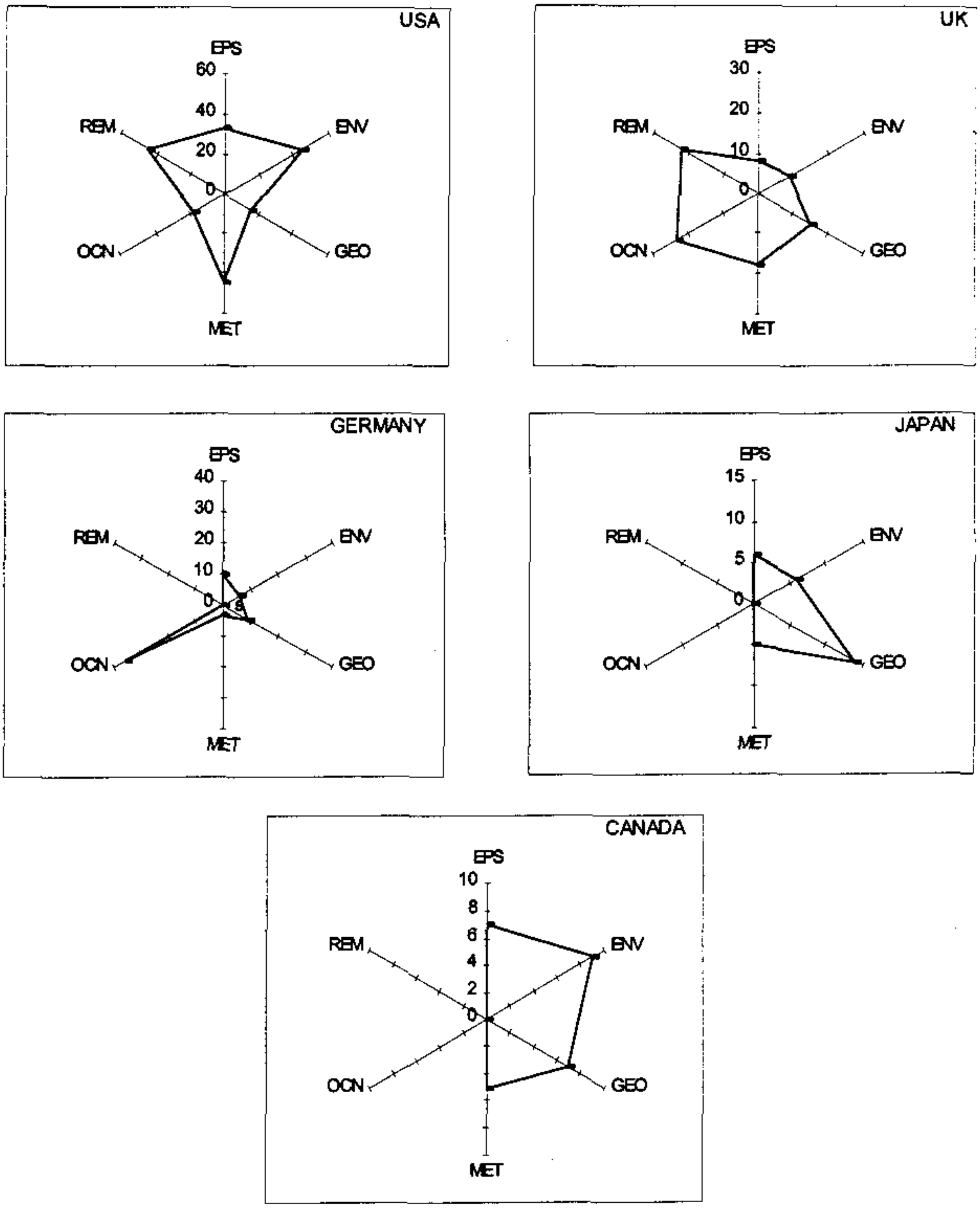


Fig. 9.3: India's affinities towards major cooperating countries in different subfields of Earth & Atmospheric Sciences (1990-1994)
(Affinity Index)

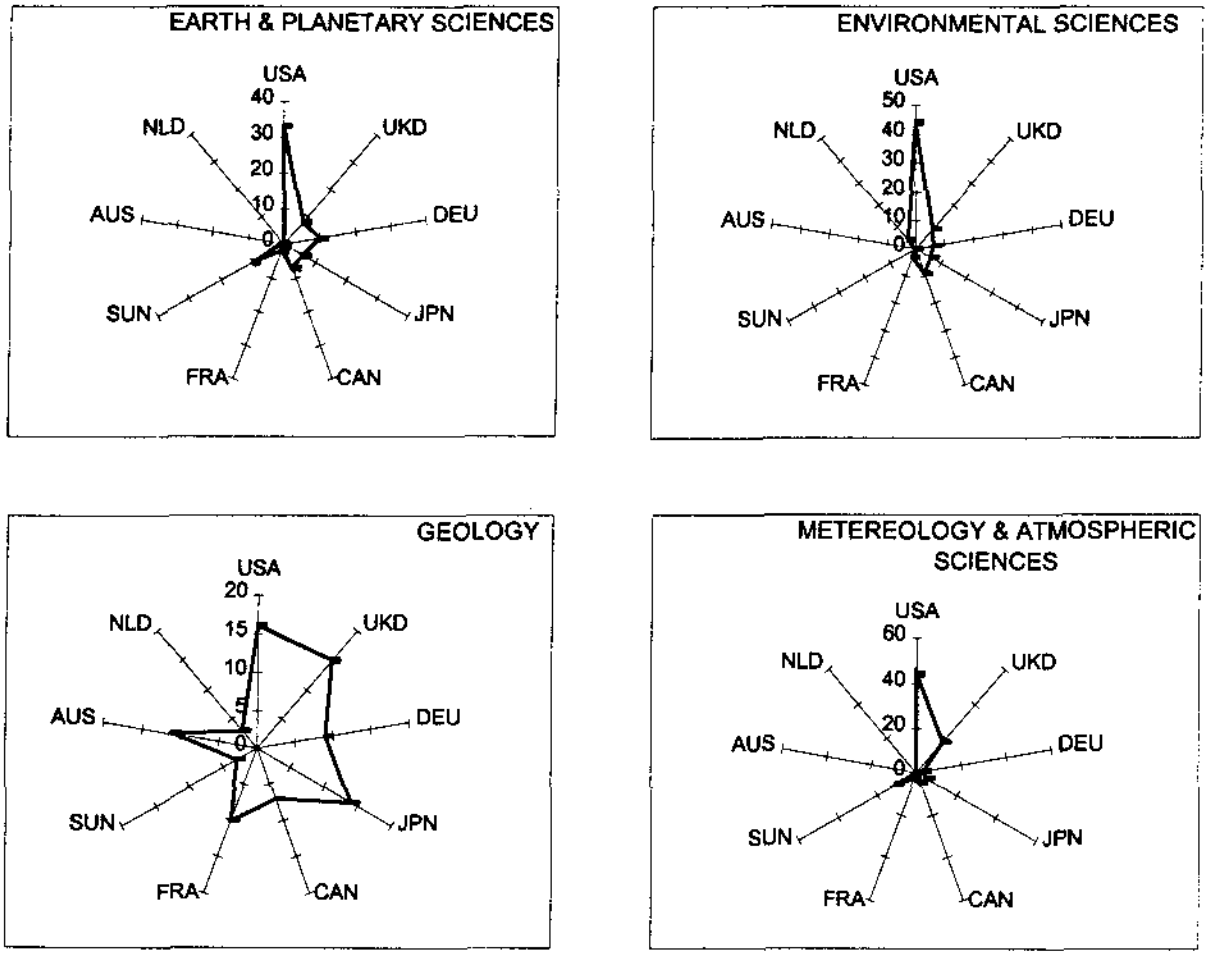


Fig. 9.4: India's linkages in different subfields of Earth & Atmospheric Sciences (1990-1994) (Affinity Index)

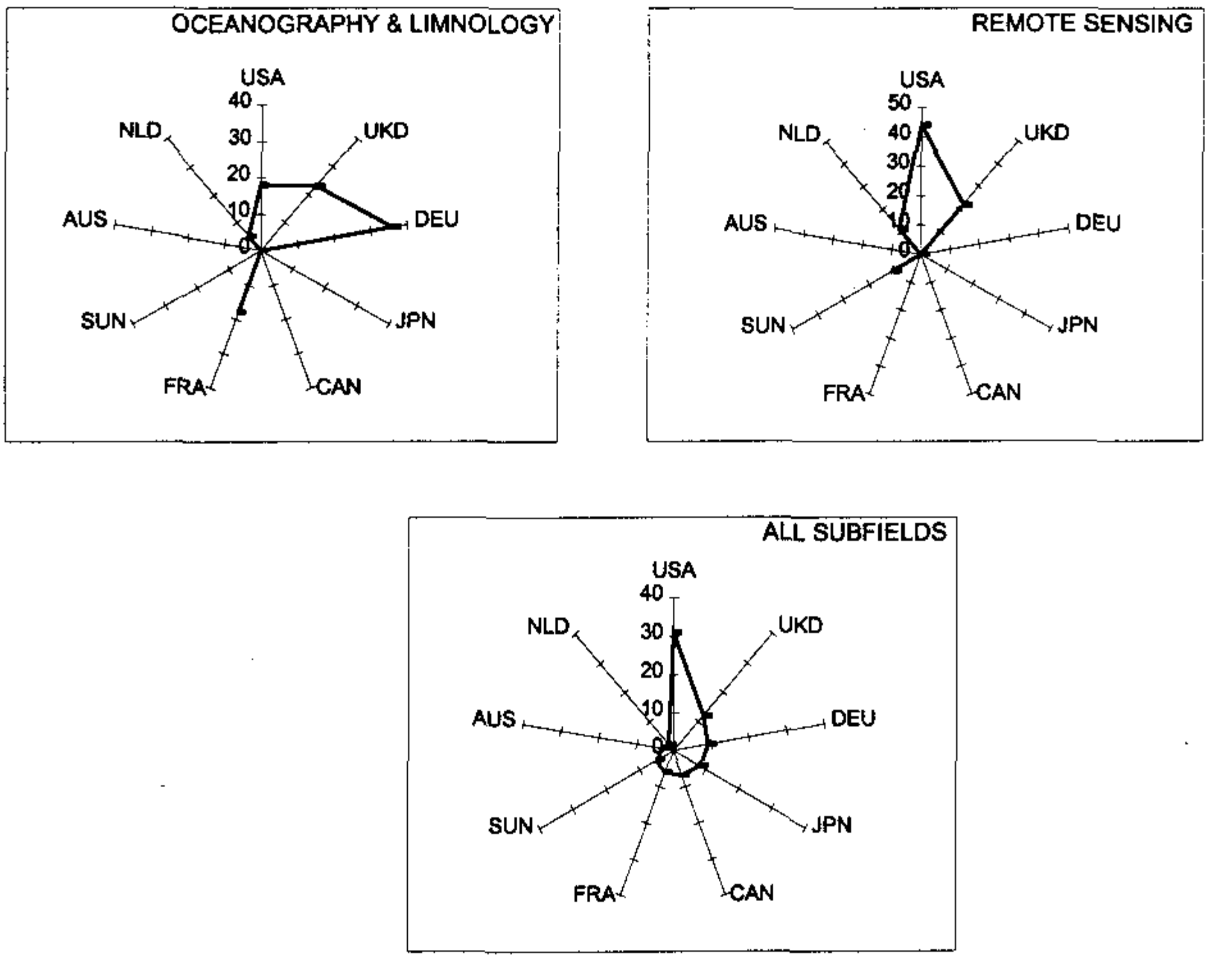


Fig. 9.4 (Contd.): India's linkages in different subfields of Earth & Atmospheric Sciences (1990-1994) (Affinity Index)

Structure of Transnational Cooperation

The multivariate structure of India's relationships with its thirteen significant cooperating countries (*viz.* USA, UK, Germany, Japan, Canada, France, Russia, Australia, Netherlands, Belgium, Sweden, Italy and Brazil) and subfields of *EAS* was analyzed through Correspondence Analysis, using the computer program SimCA. Four countries – Belgium, Sweden, Italy and Brazil – had less than ten cooperation links with India. These countries were treated as supplementary variables in the Correspondence Analysis. Supplementary variables do not have any influence on the geometric orientation of the factorial axes, but they are projected in the low – dimensional factorial space. Their coordinates and contributions to the eccentricities of the factorial axes are computed by the program. As a result of Correspondence Analysis, each subfield in the high – dimensional space is projected into the low – dimensional subspace of nine countries, whereas each country is projected into the conjugate subspace of six research fields. Correspondence Analysis shows how India's significant partners are placed relative to each other and different research areas of *Earth & Atmospheric Sciences*.

Eigen values issued from the Correspondence Analysis indicate that the total variance is large ($\Sigma\lambda i = 0.314753$), implying wide variations in the amplitudes of profiles. The first three factorial axes $\phi_1 - \phi_3$, which account for more than 91% of the total variance, yield the most parsimonious representation of the multidimensional data. The results of Correspondence Analysis are summarized in Tables 9.3 and 9.4.

Figure 9.5 represents the two – dimensional factorial map spanned by ϕ_1 and ϕ_2 axes, summing up 73.9% of the total variance. The third factorial axis, ϕ_3, accounts for 18.22% of the total variance. Thus, the two – dimensional factorial map reveals the main features of the multidimensional data. The third factorial axis, ϕ_3, represents complementary data for further analysis. All the subfields, except *Remote Sensing*, are quite well represented in the three – dimensional subspace spanned by the first three factorial axes.

Table 9.3
Contributions of explicative points to the composition of the factorial axes (Absolute contribution, permill)

Cloud	*Explicative points with positive coordinates*	*Explicative points with negative coordinates*
	Axis 1 (λ_1 = 0.158080, τ_1 = 50.22%)	
Subfields	Geology (584)	Earth & Planetary Sciences (132) Environment (174)
Countries	France (175) Australia (348)	USA (325)
	Axis 2 (λ_2= .074566, τ_2 = 23.69%)	
Subfields	Oceanography & Limnology (863)	—
Countries	Germany (433)	Japan (153) Australia (192)
	Axis 3 (λ_3 = .57364, τ_3 =18.22%)	
Subfields	Environment (526)	Earth & Planetary Sciences (430)
Countries	Netherlands (252)	Russia (562)

Table 9.4
Contributions of the explained points to the eccentricities of the factorial axes ($Cos^2\Phi$) (permills)

Cloud	*Explained points with positive coordinates*	*Explained points with negative coordinates*
	Axis 1 (λ_1 = 0.158080, τ_1 = 50.22%)	
Subfields	Geology (909)	Earth & Planetary Sciences (437) Meterology (551) Environment (415)
Countries	Australia (788) Japan(391) France (813)	USA (931) Belgium (401) Italy (327)
	Axis 2 (λ_2= .074566, τ_2 = 23.69%)	
Subfields	Oceanography & Limnology (806)	—
Countries	Germany (717)	Canada (380)) Sweden (339) Japan (554)
	Axis 3 (λ_3 = .057364, τ_3 = 18.22%)	
Subfields	Environment (550)	Earth & Planetary Sciences (518)
Countries	Netherlands (623)	Russia (710) Italy (383) Brazil (434)

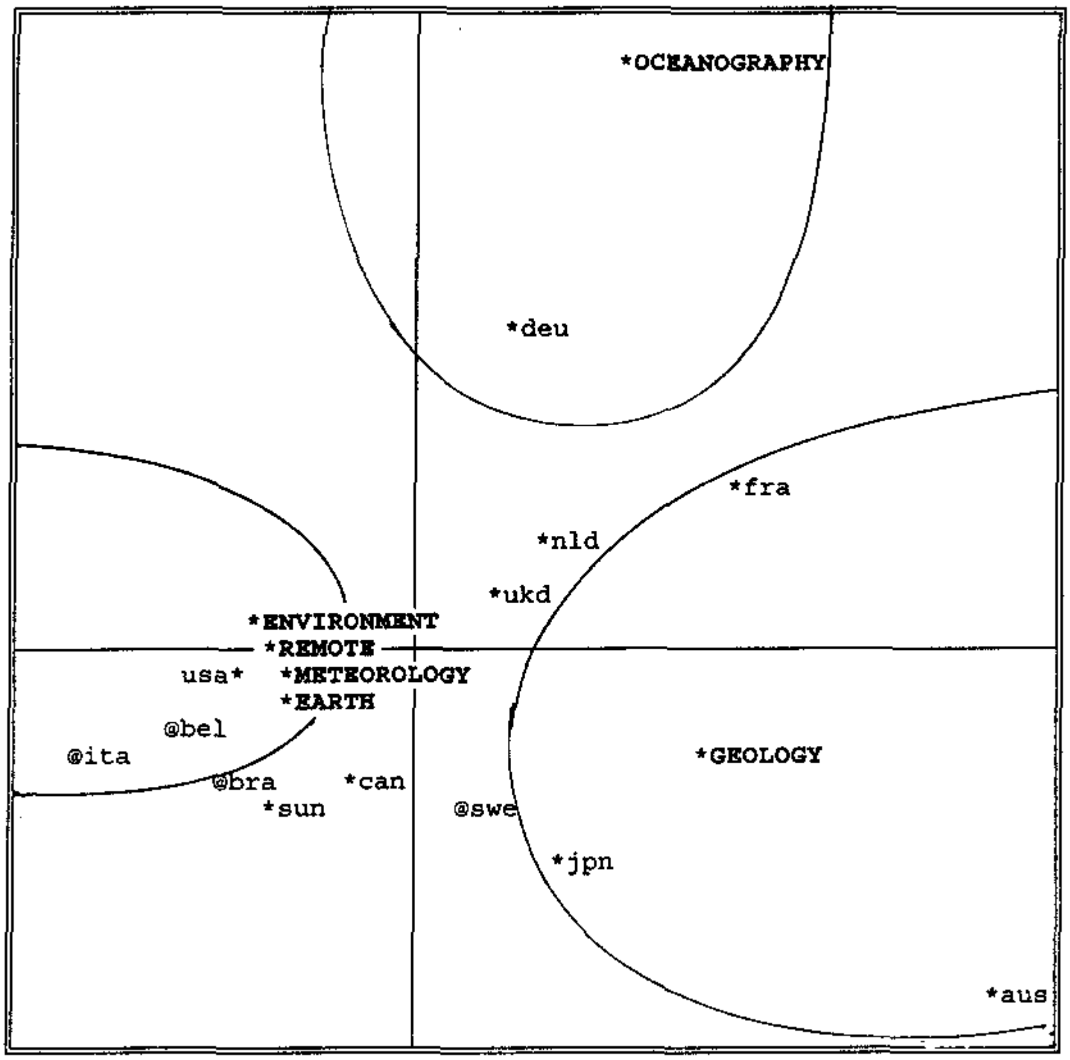


Fig. 9.5: Correspondence Analysis of transnational cooperation in Earth & Atmospheric Sciences subfields

Notes:
Horizontal axis is dimension 1 with inertia = 0.1581 (50.2%)
Vertical axis is dimension 2 with inertia = 0.0746 (23.7%)
* Principal variables @ Supplementary variables

It can be easily seen from the figure that *Oceanography* is projected quite far away from the barycenter, which implies uneven distribution of links in this area among the cooperating countries. UK is projected quite close to the barycenter; it has more or less a balanced profile of cooperation. On the other hand, Australia is projected at the edge of the map, quite far away from the barycenter. This country has a highly skewed profile of cooperation with India.

Factor ϕ_1: The first factorial axis, accounting for 50.2% of the total variance constitutes the most important element of the multivariate structure of relationships between countries and subfields.

On the cloud of subfields, this factorial axis is characterized by the opposition between *Geology*, which is projected on this axis with positive coordinate, and *Earth and Planetary Sciences, Meterology* and *Environment*, which are projected with negative coordinates.

On the country cloud, this factorial axis is characterized by the opposition between USA, Belgium and Italy on the one hand and Australia, France and Japan on the other. USA, Belgium and Italy collaborate with India mainly in *Earth and Planetary Sciences* and *Environment*. On the other hand, Australia, France and Japan give greater importance to *Geology* in their cooperation with India.

Factor ϕ_2: The second factorial axis, accounting for 23.7% of the total variance, constitutes the second most important element of the data structure.

On the cloud of subfields, this factor does not represent polarity. It is characterized by *Oceanography*, which is projected on this axis with positive coordinate.

On the country cloud, this factor is correlated to Germany, Japan, Canada and Sweden. Germany is projected on this axis with positive coordinate and is therefore, correlated to *Oceanography & Limnology*. Japan, Canada and Sweden are projected on this axis with negative coordinates. *Oceanography & Limnology* does not receive any importance in the cooperation links of these countries with India.

Factor ϕ_3: The third factorial axis accounts for 18.3% of the total variance. Figure 9.6 presents the two – dimensional factorial map spanned by ϕ_1 and ϕ_3 axes.

On the cloud of subfields, this factor is characterized by the opposition between *Earth & Planetary Sciences* and *Environment*. These two subfields were associated with each other on the first factorial axes. *Environment* is better represented on this axis than on any of the first two axes. *Earth & Planetary Sciences* is projected on this axis with negative coordinate, whereas *Environment* is projected on this axis with positive coordinate.

On the country cloud, this factorial axis is characterized by the opposition between Russia, Italy and Brazil is on the one hand and Netherlands on the other. Netherlands collaborates with India mainly in *Environment*, whereas Russia, Italy and Brazil deemphasize this area in their bilateral cooperation with India. These countries prefer to collaborate with India in *Earth & Planetary Sciences*.

The results of Correspondence Analysis are summarized in Figure 9.7.

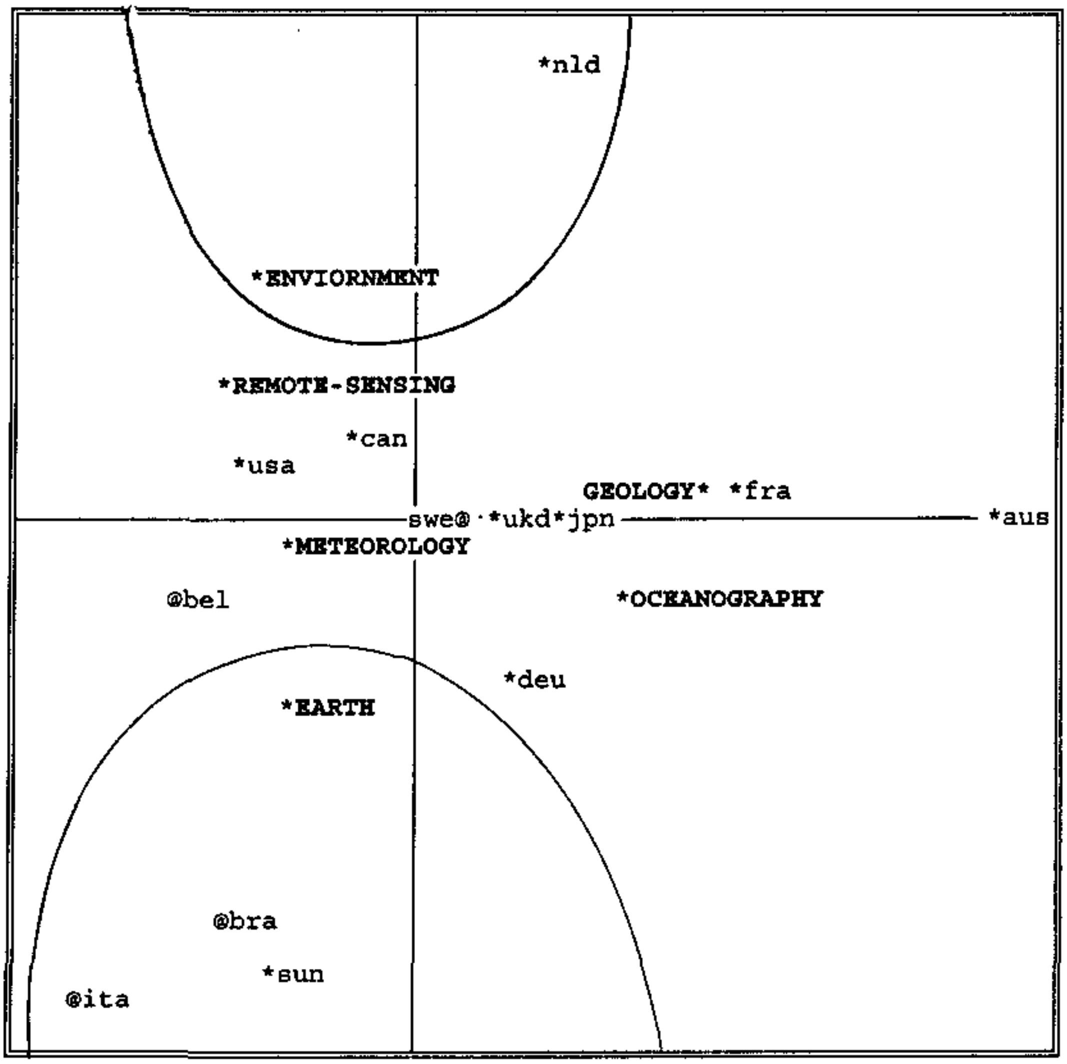


Fig. 9.6: Correspondence Analysis of transnational cooperation in Earth & Atmospheric Sciences subfields

Notes:
Horizontal axis is dimension 1 with inertia = 0.1581 (50.2%)
Vertical axis is dimension 3 with inertia = 0.0574 (18.2%)
* Principal variables @ Supplementary variables

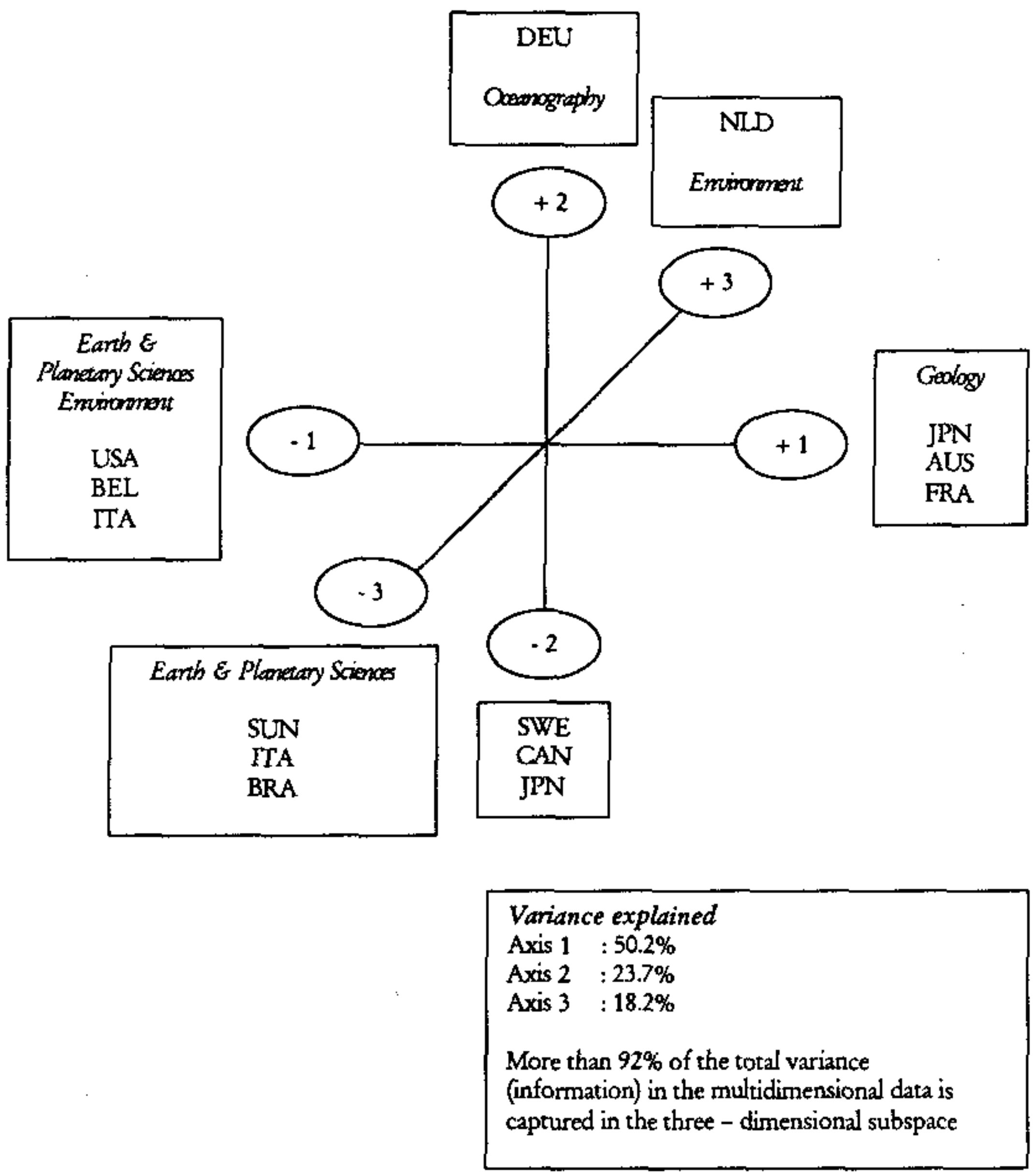


Fig. 9.7: Summary of correspondence analysis

10 Transnational Links in Food & Agriculture Research

This chapter analyzes the patterns of India's research output and transnational cooperation in different subfields of agriculture: *General Agriculture* (*GENAG*), *Agricultural Economics & Policy* (*ECON*), *Dairy & Animal Sciences* (*DAIRY*), *Agricultural Soil Science* (*SOIL*), *Forestry* (*FORES*), *Horticulture* (*HORT*) and *Food Science & Technology* (*FOOD*).

General Overview of the Data

During the five - year period 1990 - 1994, India had published 1673 articles in the influential journals in *Food & Agriculture Research* that are covered by the *Science Citation Index*. Of these, 219 (13.1%) articles were internationally coauthored, indicating an aggregate of 258 transnational cooperation links spanning over 34 countries.

Table 10.1 presents the data on transnational links with 13 countries, which had at least five coauthorship links with India. The distribution of links is skewed. The top five countries, viz. USA, UK, Germany, Australia and Niger account for about 60% of all transnational cooperation links in *Food & Agriculture Research*.

Inter - Field Differences in Transnational Cooperation

Figure 10.1 indicates the distribution of articles, internationally coauthored articles (*ICOA*) and transnational cooperation links (*COP*) in different subfields of *Food & Agriculture Research*.

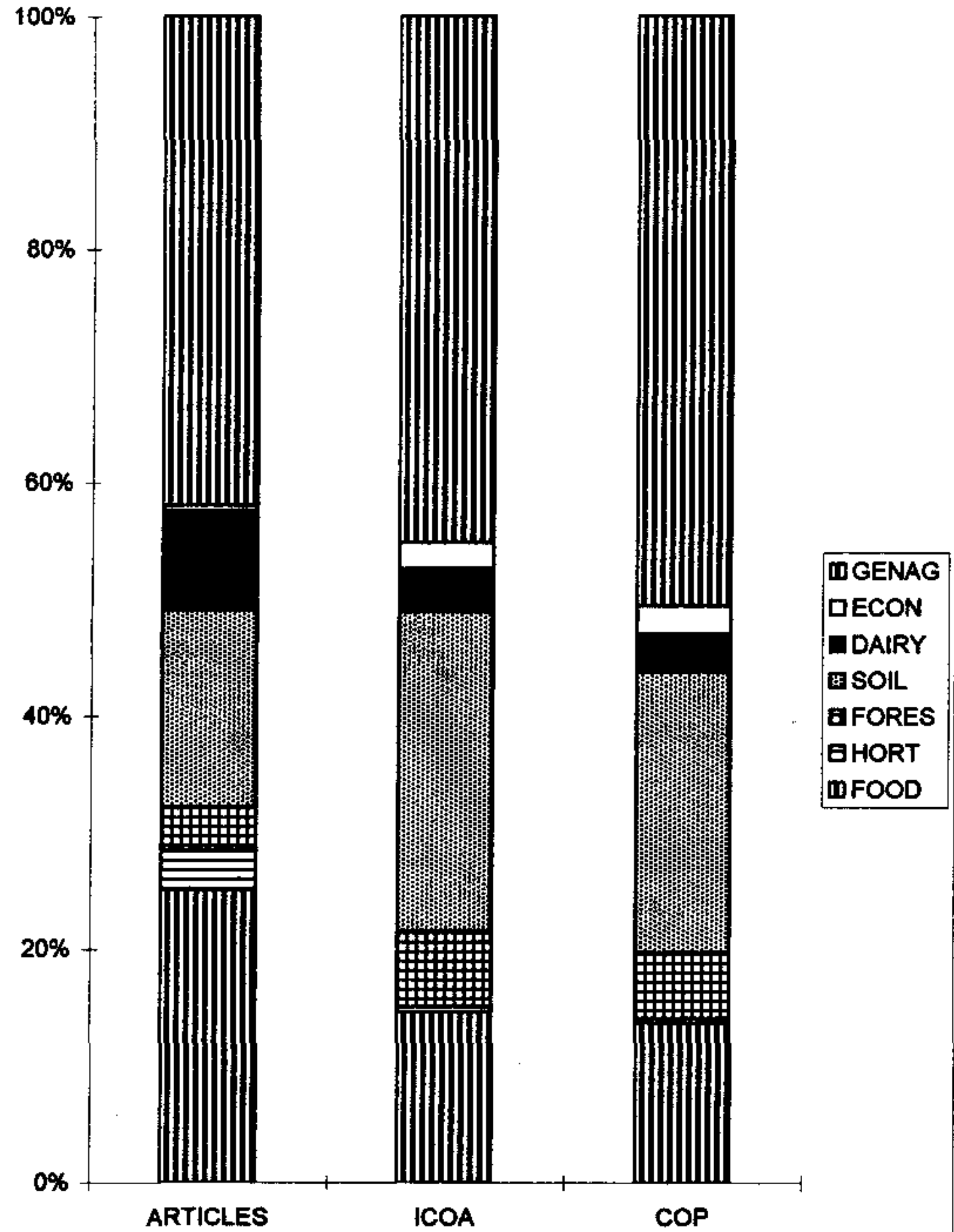


Fig. 10.1: Distribution of articles, internationally coauthored articles (ICOA) and cooperation links (COP) in different subfields of Food & Agriculture Research

Table 10.1
India's Cooperation Links with Significant Countries in *Food & Agriculture Research*

Country	*No. of Links*	%	*Country*	*No. of Links*	%	*Country*	*No. of Links*	%
USA	58	22.48	PHL	16	6.20	THA	6	2.32
UKD	34	13.18	CAN	13	5.04	NLD	5	1.94
DEU	23	8.91	SYR	8	3.10	NPL	5	1.94
AUS	19	7.36	FRA	7	2.71	21 other countries	40	15.58
NGR	18	6.98	JPN	6	2.32			

Table 10.2 presents the data on the output of articles, internationally coauthored articles (*ICOA*) and transnational cooperation links (*COP*) and associated indicators (viz. *Internationalization Index, INI*; *Cooperation Index, COI*; and *Cooperation Extensiveness Index, CEI*) for different subfields. These indicators are defined in Chapter 4.

Table 10.2
Publication Output and Cooperation Links in Different Subfields of *Food & Agriculture Research* (1990 - 1994)

Subfield	*No. of Articles*	*ICOA*	*No. of Links*	*Internationalization Index INI %*	*Cooperation Index COI %*	*Cooperation Extensiveness Index CEI*
General Agriculture	703	99	126	14.08	17.92	1.27
Agricultural Economics & Policy	7	5	6	71.43	85.71	1.20
Dairy & Animal Science	143	8	8	5.59	6.99	1.25
Soil Science	282	60	60	21.28	23.40	1.10
Forestry	62	14	23	22.58	24.19	1.67
Horticulture	58	1	1	1.72	1.72	1.00
Food Science & Technology	418	32	34	7.66	8.13	1.06
Total	1673	219	258	13.09	15.42	1.18

Dairy & Animal Sciences and *Food Science & Technology* have less than average values of *Internationalization Index* (*INI*), whereas *Soil Science*, *Forestry* and *Agricultural Economics & Policy* have above average values of *Internationalization Index*. *General Agriculture* has about the average level of *Internationalization Index*. The values of *COI* also reveal a similar trend. The values of *CEI* indicate that *General Agriculture*, *Agricultural Economics & Policy* and *Dairy & Animal Sciences* involve relatively more frequent multilateral cooperation than the other subfields. *Forestry* has more multilateral links than any other subfield.

Inter - Country Differences in Transnational Cooperation

Inter - country differences in transnational cooperation were assessed by computing the *Affinity Index* (*AFI*). Figure 10.2 depicts India's affinities towards its thirteen significant partners in *Food & Agriculture Research* (all subfields combined together).

USA occupies the most important position in India's transnational cooperation in this field. About 22.5% of India's transnational links in this field are with USA. UK occupies the second position, accounting for 18% of all transnational links.

Figure 10.3 represents India's affinities for each of its five topmost partners in five subfields - *General Agriculture*, *Dairy & Animal Sciences*, *Soil Science*, *Forestry* and *Food & Agriculture.* Figure 10.4 represents India's affinities towards its seven major partners (USA, UK, Germany, Australia, Niger, Philippines and Canada) separately for each subfield. This figure indicates the variations in the prominence of different subfields in India's cooperation with its major partners. This figure is self - explanatory and any elaboration would be redundant.

Country	*Subfields of*	
	Highest affinity	*Lowest affinity*
USA	Food Science & Technology	Dairy & Animal Sciences
UK	Forestry	Dairy & Animal Sciences
Germany	Dairy & Animal Sciences	Forestry
Australia	General Agriculture	Dairy & Animal Sciences Food Science & Technology Forestry
Niger	General Agriculture	Dairy & Animal Sciences Food Science & Technology

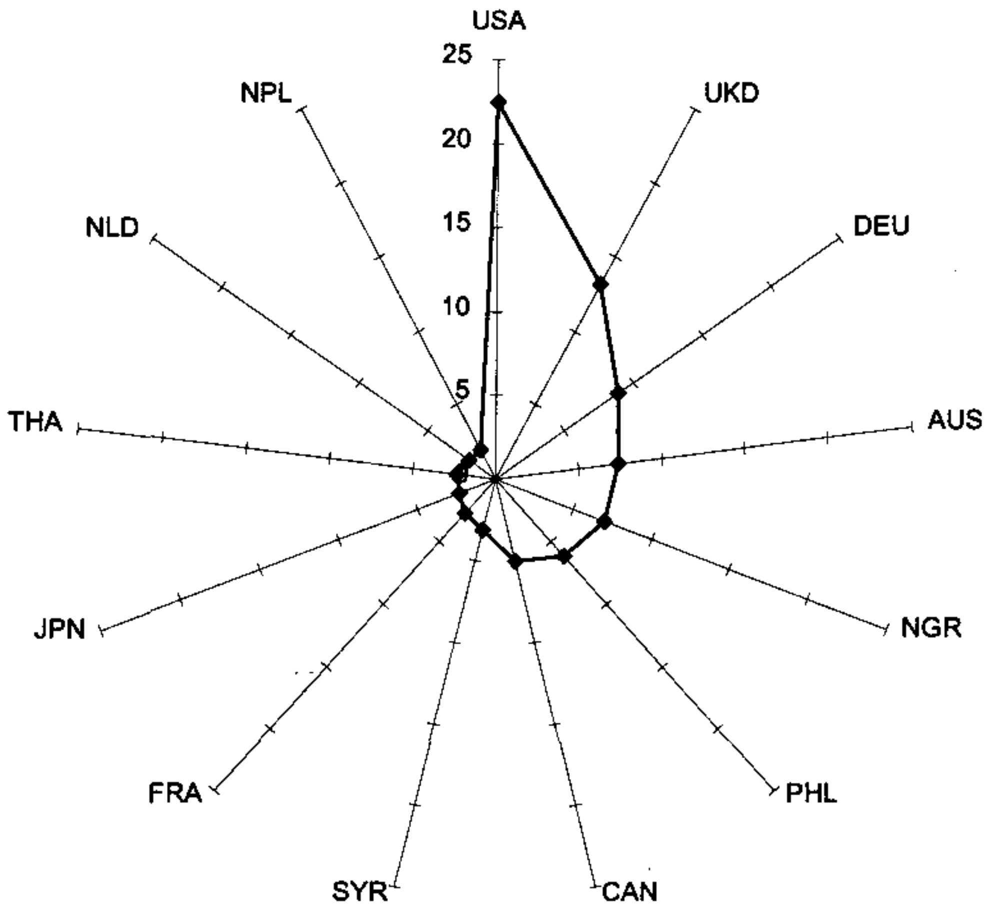


Fig. 10.2: India's linkages in Food & Agriculture Research (1990-1994)
(Affinity Index)

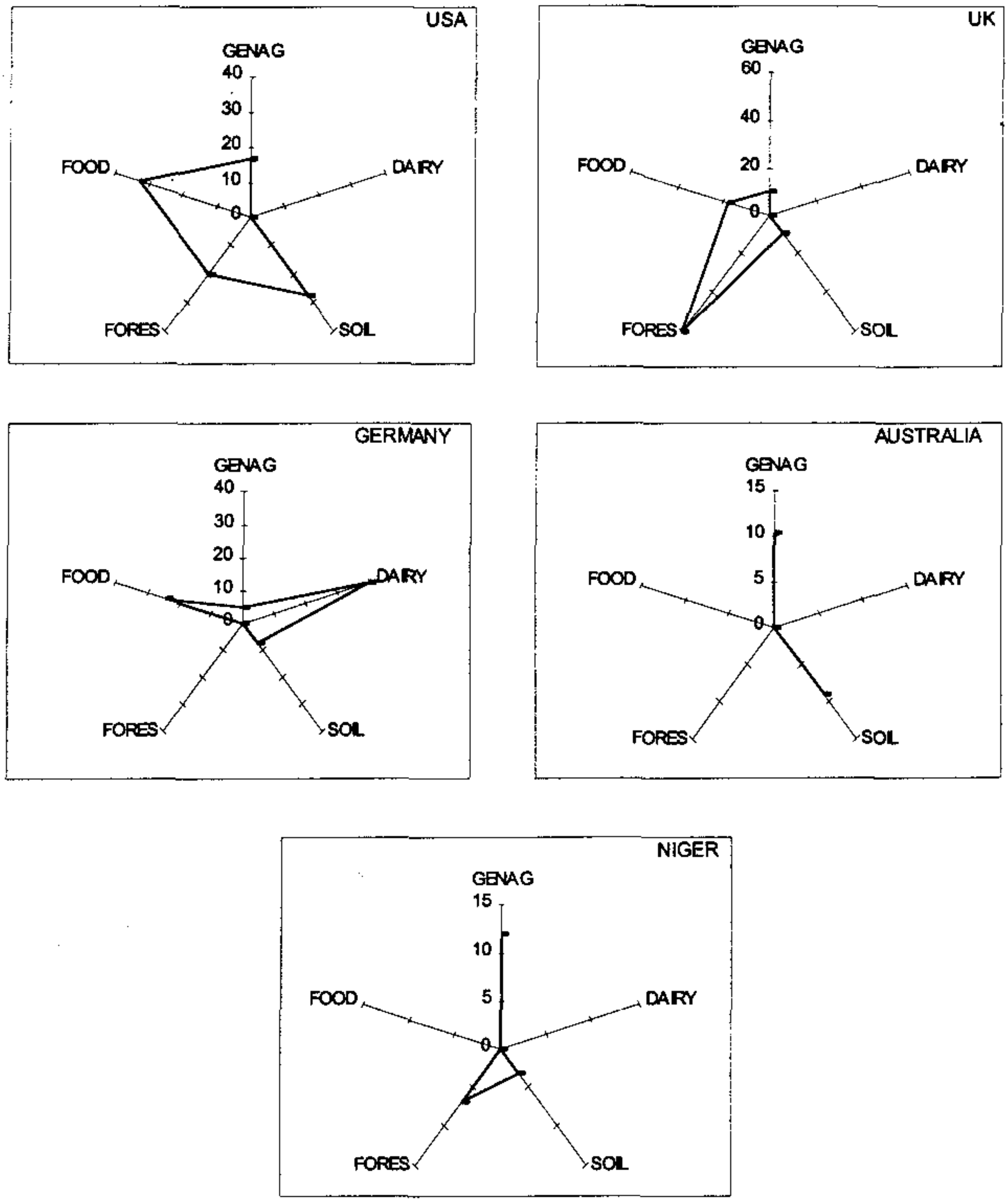


Fig. 10.3: India's affinities towards major cooperating countries in different subfields of Food & Agriculture Research (1990-1994)
(Affinity Index)

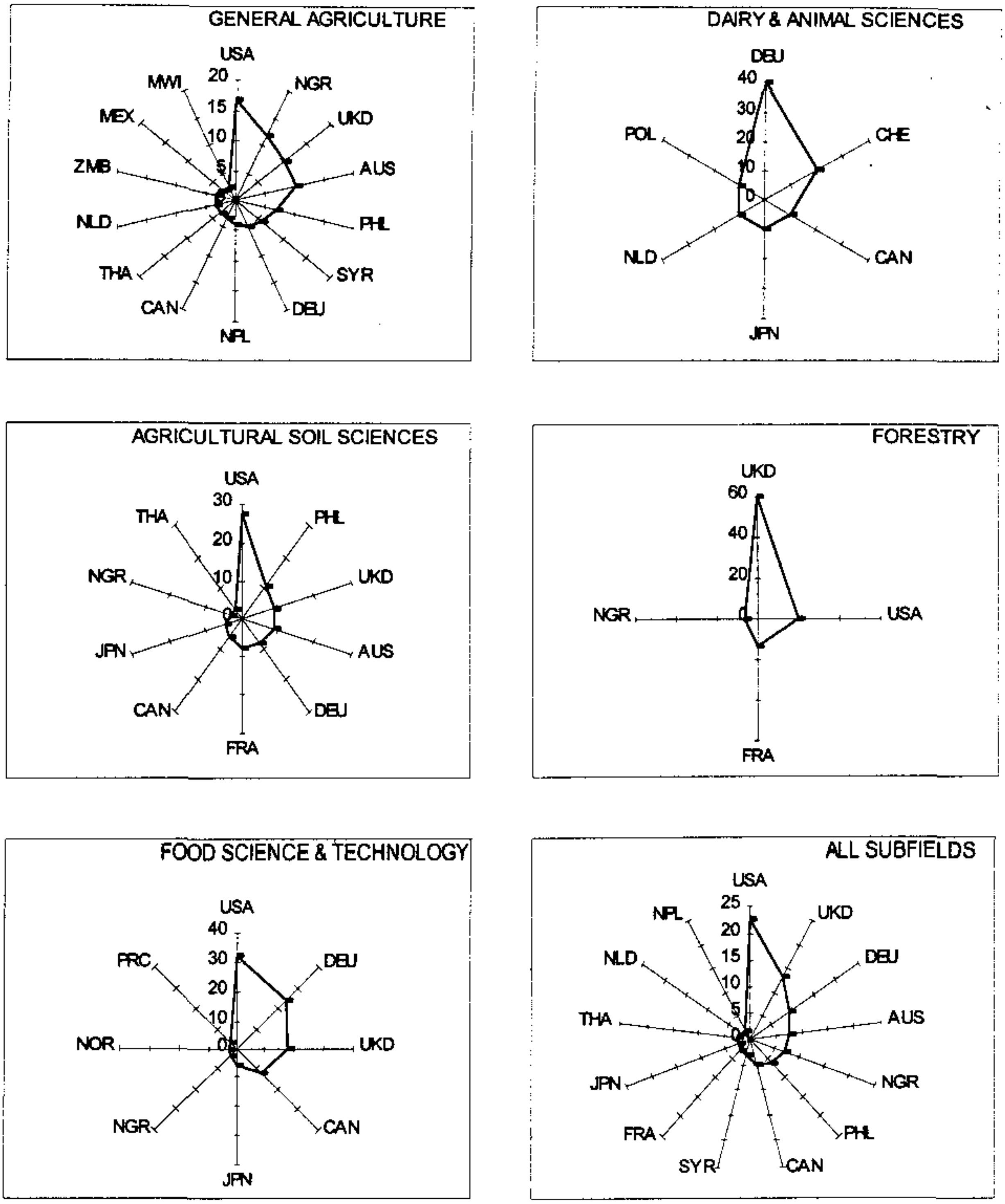


Fig. 10.4: India's linkages in different subfields of Food & Agriculture Research (1990-1994)
(Affinity Index)

Structure of Transnational Cooperation

The structure of India's cooperation with thirteen significant countries in six subfields of *Food & Agriculture Research* was explored through Correspondence Analysis, using the computer program SimCA. Six countries, which had less than ten links were treated as supplementary elements in the Correspondence Analysis. Supplementary elements do not have any influence on the determination of the factorial axes, but their coordinates and relative contributions to the eccentricities of the factorial axes are computed by the program. Correspondence Analysis shows how India's significant partners are placed relative to each other and different research areas of *Food & Agriculture Research*.

Eigen values computed by the program indicate that the total variance ($\Sigma\lambda i = 0.487174$) is quite large, implying wide variations in the amplitudes of profiles of India's links with the set of seven countries (principal elements). The first three factorial axes account for about 95% of the total variance in the multidimensional data. All research fields and all countries (except France) are quite well - represented in the three - dimensional subspace.

The results of Correspondence Analysis are presented in Tables 10.3 and 10.4.

Figure 10.5 represents the two - dimensional factorial map spanned by ϕ_1 and ϕ_2 axes, summing up 77.4% of the total variance. The third factorial axis accounts for 17.8% of the total variance. Thus, the two - dimensional factorial map (ϕ_1, ϕ_2) reveals the main features of the multidimensional data, whereas the third factorial axis represents complementary data for further analysis.

Factor ϕ_1: The first factorial axis, accounting for 46.9% of the total variance, constitutes the most important element of the multivariate structure of relationships between countries and subfields.

Table 10.3
Contributions of explicative points to the composition of the factorial axes (Ctr)*

Cloud	*Explicative points with positive coordinates*	*Explicative points with negative coordinates*
	Axis 1 (λ_1 = 0.228566, τ_1 = 46.92%)	
Subfields	General Agriculture (170)	Dairy & Animal Sciences (470) Food Science & Technology (310)
Countries	Niger (137)	Germany (601)
	Axis 2 (λ_2 = 0.148645, τ_2 = 30.51%)	
Subfields	Forestry (764)	—
Countries	UK (676)	Australia (145)
	Axis 3 (λ_3 = 0.086615, τ_3 = 17.78%)	
Subfields	Agricultural Economics & Policy (471) Soil Sciences (131)	Dairy & Animal Sciences (186)
Countries	USA (589)	Niger (210)

*Note: values are in permills

Table 10.4
Contributions of the explained points to the eccentricities of the factorial axes ($Cos^2\phi$)*

Cloud	*Explained points with positive coordinates*	*Explained points with negative coordinates*
	Axis 1 (λ_1 = 0.228566, τ_1 = 46.92%)	
Subfields	General Agriculture (572)	Dairy & Animal Sciences (848) Food Science & Technology (814)
Countries	Niger (494) Australia (429) Philippines(786) Syria (381) Thailand (417) Nepal (309)	Germany (921) Canada (836) Japan (800)
	Axis 2 (λ_2 = 0.148645, τ_2 = 30.51%)	
Subfields	Forestry (891)	—
Countries	UK (879)	Australia (492) Philippines (482) Syria (271) Thailand (504)
	Axis 3 (λ_3 = 0.086615, τ_3 = 17.78%)	
Subfields	Agricultural Economics & Policy (862) Soil Sciences (131)	—
Countries	USA (966)	Niger (287) Netherlands (507) Nepal (263)

* Note: values are in permills

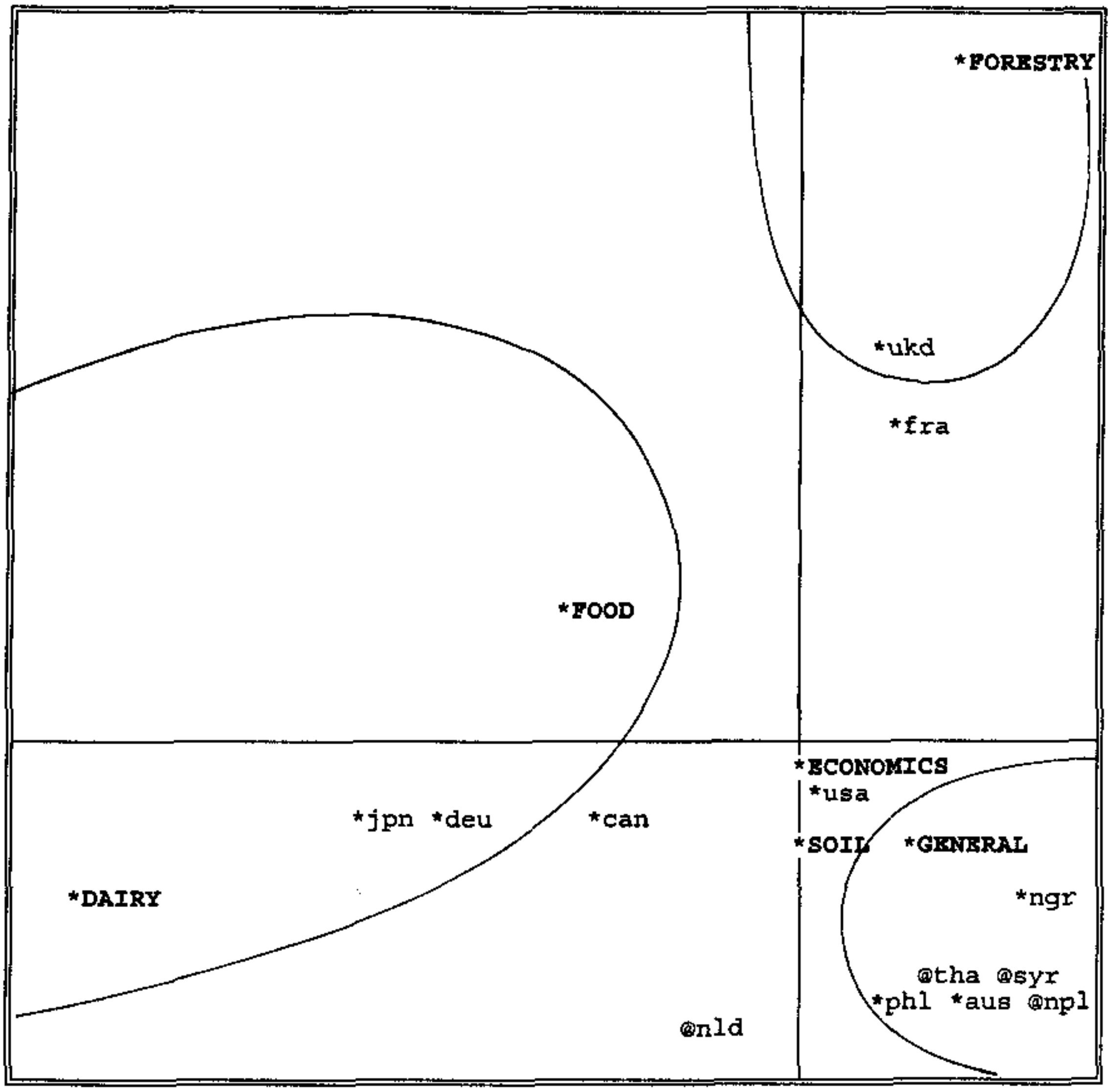


Fig. 10.5: Correspondence Analysis of transnational cooperation in Food & Agriculture Research subfields

Notes:
Horizontal axis is dimension 1 with inertia = 0.2286 (46.9%)
Vertical axis is dimension 2 with inertia = 0.1486 (30.5%)
* Principal variables @ Supplementary variables

On the cloud of subfields, this axis is characterized by the opposition between *General Agriculture*, which is projected with positive coordinate, and *Dairy & Animal Sciences* and *Food Science & Technology*, which are projected with negative coordinates.

On the country cloud, this factor is characterized by the opposition between Japan, Germany and Canada on the one hand and Niger, Australia, Philippines, Syria, Thailand and Nepal on the other. The latter five countries, which are projected with positive coordinates, are correlated to *General Agriculture.* These countries collaborate with India mainly in *General Agriculture.* All these countries have more than two thirds of cooperation links with India in this subfield. Japan, Germany and Canada, which are projected on this axis, with negative coordinates have strong preference for collaboration in *Dairy & Animal Sciences* and *Food Science & Technology.*

Factor ϕ_2: The second factorial axis accounting for 30.5% of the total variance constitutes the second most important element of the multivariate structure of the data. This factor does not have polarity. On the cloud of subfields, this factor is associated with *Forestry.* Only one country, viz. UK is correlated to this factor. UK is the most prominent collaborating country in this area.

Factor ϕ_3: The third factorial axis accounts for 17.8% of the total variance. Figure 10.6 presents a two – dimensional factorial map constituted by ϕ_1 and ϕ_3 axes.

This axis does not have a polarity. On the cloud of subfields, this factor is associated with *Agricultural Economics & Policy* and *Soil Science.* On the country cloud this axis is correlated to USA and anticorrelated to Niger, Netherlands and Nepal.

The results of Correspondence Analysis are summarized in Figure 10.7.

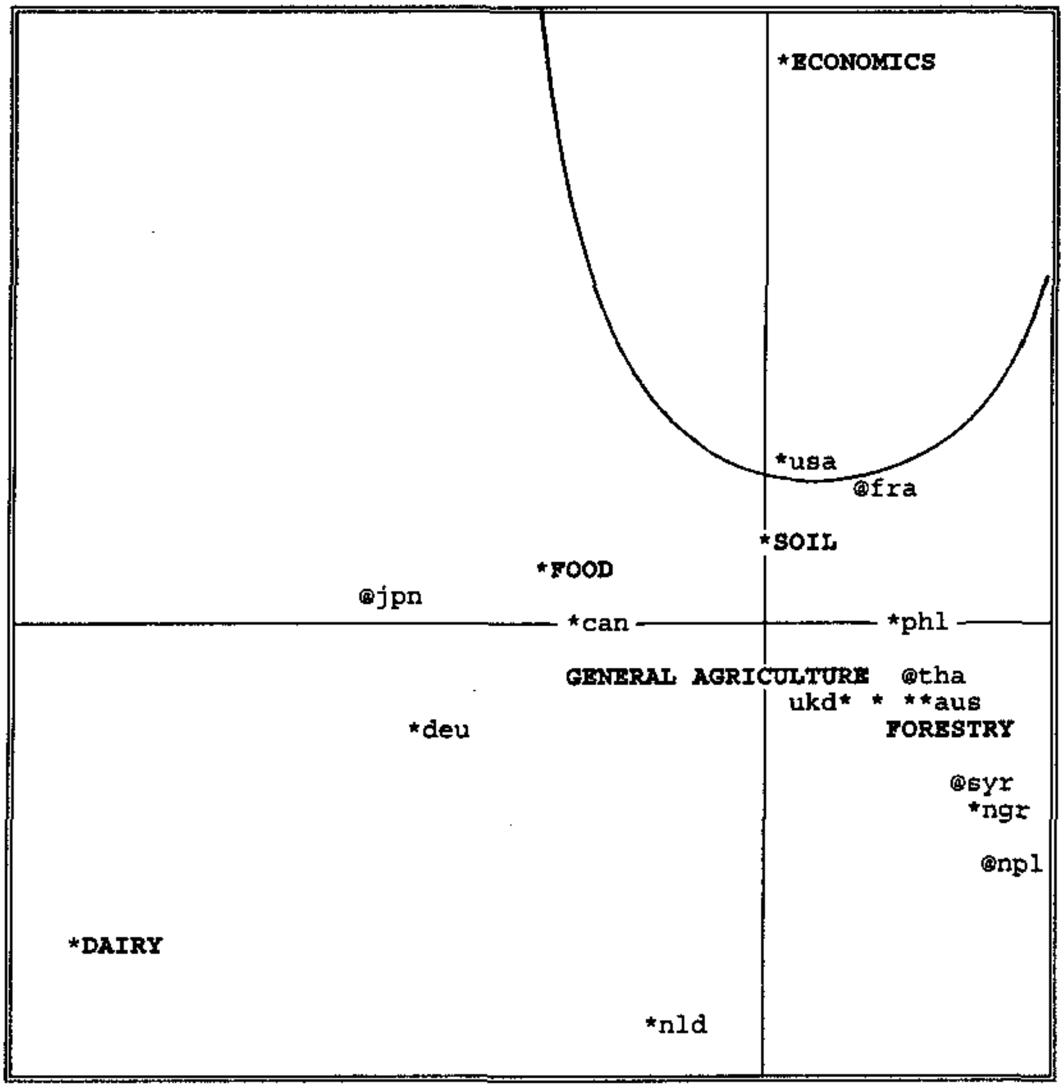
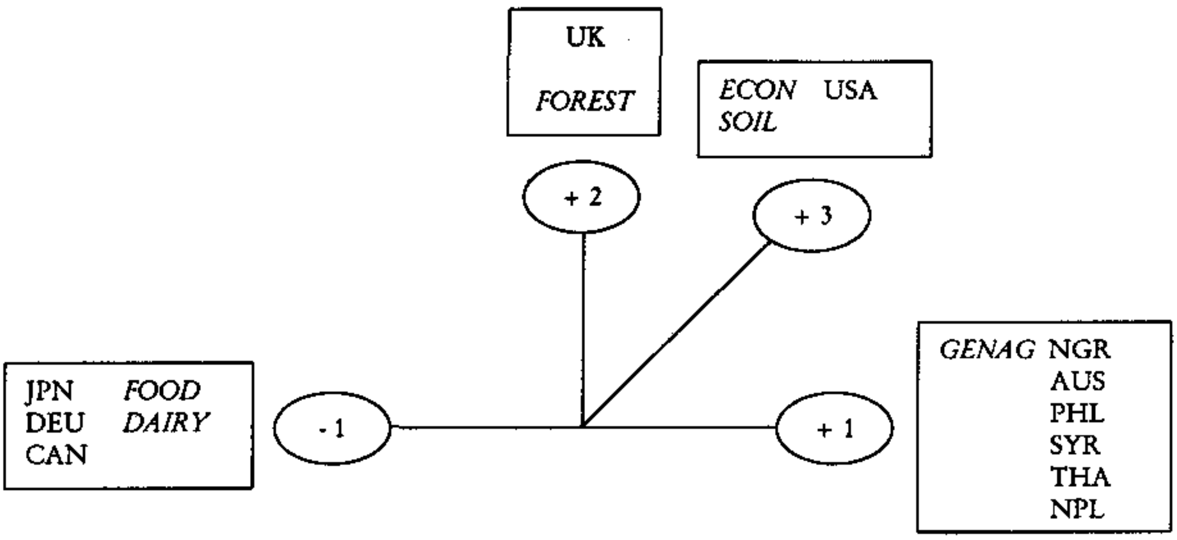


Fig. 10.6: Correspondence Analysis of transnational cooperation in Food and Agriculture Research subfields

Notes:
Horizontal axis is dimension 1 with inertia = 0.2286 (46.9%)
Vertical axis is dimension 3 with inertia = 0.0866 (17.8%)
* Principal Variables @ Supplementary variables



Variance explained
Axis 1 : 46.9%
Axis 2 : 30.5%
Axis 3 : 17.8%

More than 95% of the total variance (information) in the multidimensional data is captured in the three - dimensional subspace

Fig. 10.7: Summary of correspondence analysis

11 Transnational Links in Clinical Medicine

During the five - year period, 1990 - 1994, India had contributed 7885 articles (*Articles*, *Reviews*, *Notes* and *Letters*) in the mainstream literature in different subfields of *Clinical Medicine*. Of these, 744 articles (9.44%) were internationally coauthored, indicating a total of 1005 cooperation links (12.75%), spanning over 77 countries:

1. General & Internal Medicine (*INM*)
2. Addictive Diseases (*ADD*)
3. Allergy (*ALL*)
4. Anesthesiology (*ANE*)
5. Arthritis & Rheumatism (*ART*)
6. Cardiovascular System (*CAR*)
7. Dentistry (*DEN*)
8. Dermatology & Venereal Diseases (*DER*)
9. Endocrinology (*END*)
10. Fertility (*FER*)
11. Gastroenterology (*GAS*)
12. Geriatrics (*GER*)
13. Hematology (*HEM*)
14. Hygiene & Public Health (*HYG*)
15. Immunology (*IMM*)
16. Miscellaneous Clinical Medicine (*MCM*)
17. Nephrology (*NEP*)
18. Neurology & Neurosurgery (*NEU*)
19. Obsteretics & Gynaecology (*GYN*)
20. Oncology (*ONC*)
21. Ophthalmology (*OPT*)
22. Orthopaedics (*ORP*)
23. Otorhinolaryngology (*OTO*)
24. Pathology (*PAT*)
25. Pediatrics (*PED*)
26. Pharmacology & Pharmacy (*PHA*)
27. Psychiatry (*PSY*)
28. Radiology & Nuclear Medicine (*RAD*)

29. Respiratory System (*RES*)
30. Surgery (*SUR*)
31. Tropical Medicine (*TRO*)
32. Urology (*URO*)
33. Veterinary Medicine (*VET*)

The distribution of cooperation links among the partner countries is highly skewed. USA alone accounted for more than 30% of links. Only thirteen countries had ≥ 10 cooperation links. *The names of these countries are given in* Table *11.1.*

Table 11.1
India's Cooperation Links with Major Partners in *Clinical Medicine*

Country	*No. of Links*	*%*	*Country*	*No. of Links*	*%*	*Country*	*No. of Links*	*%*
USA	305	30.35	SWE	36	3.58	NLD	14	1.39
UKD	182	18.11	ITA	24	2.39	AUT	10	1.00
DEU	79	7.86	CHE	23	2.29	BGD	10	1.00
JPN	48	4.78	AUS	21	2.09	64 other countries	192	19.10
CAN	40	3.98	FRA	21	2.09			

Inter - Field Differences in Transnational Cooperation

Figure 11.1 depicts the distribution of articles, internationally coauthored articles (*ICOA*'s) and transnational cooperation links (*COP*) in different subfields of *Clinical Medicine*. It can be easily seen that the proportions of articles and *ICOA*'s/*COP*'s do not always match with each other. For example, *Internal Medicine* accounts for 14.7% of all articles, but it accounts for 10.9% of *ICOA*'s and 15.2% of *COP*'s. This means, that the incidence of internationally coauthored articles in this subfield is greater than the average for the entire field, and it also attracts more than average number of cooperation links. On the other hand, *Oncology* accounts for 6.95% of all articles, but it accounts for 9.40% of *ICOA*'s and 8.76% of cooperation links. This means that the incidence of internationally coauthored articles in *Oncology* is about the average for *Clinical Medicine* as a whole, but it attracts less than average number of cooperation links. These results imply that international cooperation is not only more frequent in *Internal Medicine*, but it also tends to be multilateral; on the other hand, international cooperation in *Oncology* tends to be less frequent and bilateral.

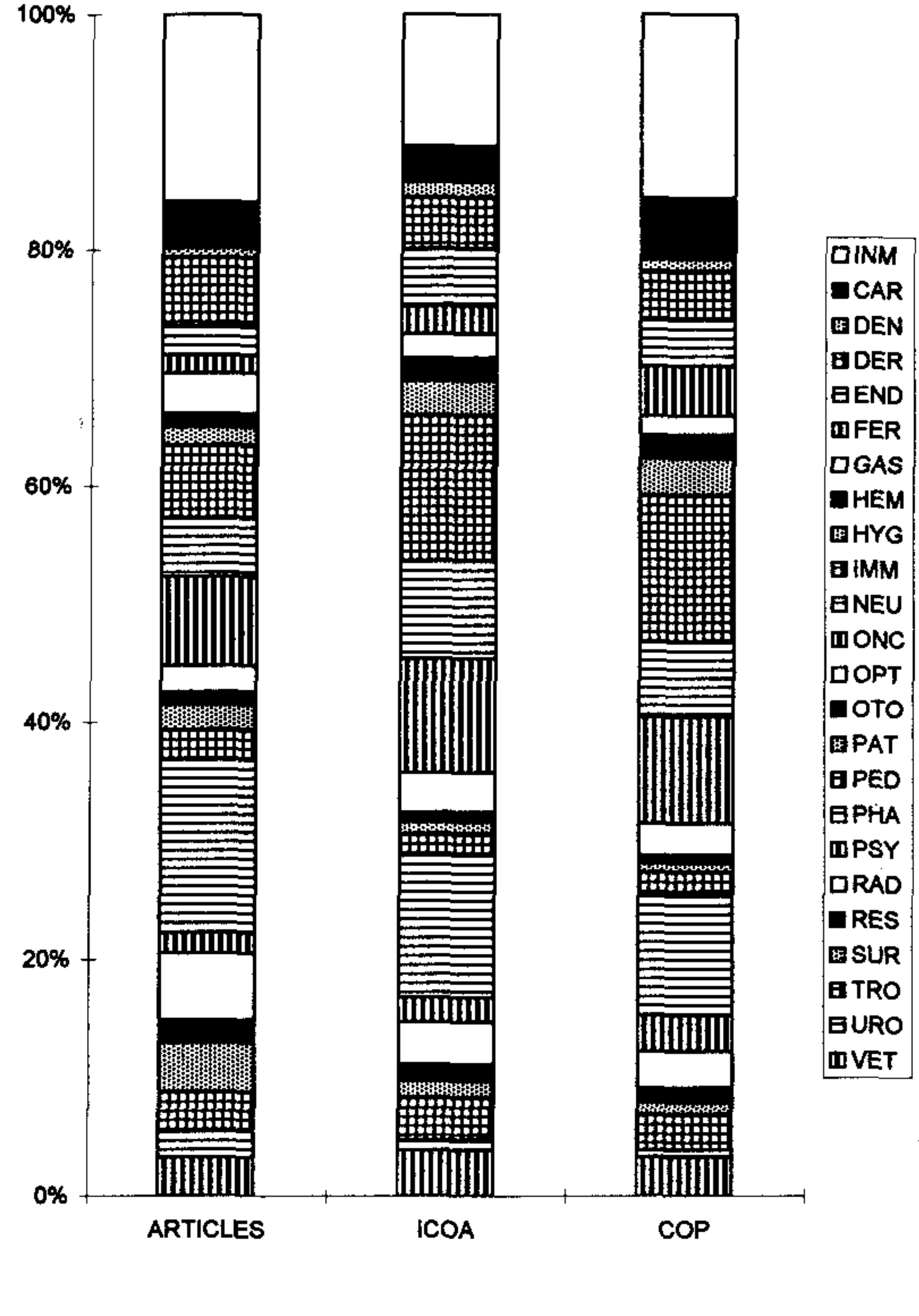


Fig. 11.1: Distribution of articles, internationally coauthored articles (ICOA) and cooperation links (COP) in different subfields of Clinical Medicine

The ranking of top ten subfields in terms of proportions of articles, internationally coauthored articles and transnational cooperation links may be visualized from the following table:

Table 11.2
Ranking of Subfields according to Proportions of Articles, ICOA's and COP's

	Ranking by proportions of		
Rank	*Articles*	*ICOA's*	*COP's*
1.	INM	INM	INM
2.	PHA	PHA	IMM
3.	ONC	IMM	PHA
4.	IMM	ONC	ONC
5.	DER	NEU	NEU
6.	RAD	FER	CAR
7.	NEU	END	FER
8.	SUR	DER	END
9.	CAR	VET	DER
10.	GAS	TROP/ RAD	VET

Endocrinology, *Fertility* and *Veterinary Medicine* are not very important subfields in terms of research output, but they are quite important in attracting international cooperation. *Fertility* ranks fifteenth in terms of publication output, but it ranks sixth in terms of internationally coauthored articles and seventh in terms of transnational links. This is possibly due to the role of international agencies in research related to population control.

The following indices were computed to assess inter - field differences more systematically:

(i.) Internationalization Index (*INI*)
(ii.) Cooperation Index (*COI*)
(iii.) Cooperation Extensiveness Index (*CEI*)

These indices are defined in Chapter 4. Table 11.3 presents the data on the output of articles, internationally co-authored articles (*ICOA*) and transnational cooperation links (*COP*) and associated indicators for different subfields.

Immunology is the most internationalized subfield of *Clinical Medicine*, followed by *Hygiene & Public Health* and *Endocrinology*. About one fifth of articles in each of these subfields are internationally coauthored. *Addictive Diseases*, *Dentistry*, *Endocrinology*, *Hematology*, *Hygiene & Public Health*, *Immunology*, *Neurology*, *Oncology*, *Ophthalmology*, *Psychiatry*, *Tropical Medicine* and *Veterinary Medicine* have above average levels of internationalization. These subfields have more than average incidence of *ICOA*'s. The values of *COI* reveal a similar but not an identical trend. For instance, *Internal Medicine* and *Cardiovascular System* have less than average values of *INI*, but they have more than average values of *COI*, which means that these subfields have less than average incidence of *ICOA*'s but more than average incidence of transnational cooperation links.

The values of *CEI* for the following subfields exceed the average for *Clinical Medicine* (1.35): *Internal Medicine*, *Allergy*, *Cardiovascular System*, *Fertility*, *Hematology*, *Hygiene & Public Health*, *Immunology*, *Pediatrics* and *Psychiatry*. These subfields attract more than expected incidence of multilateral cooperation.

Inter - Country Differences in Transnational Cooperation

Inter - country differences in transnational cooperation were assessed by computing the *Affinity Index* (*AFI*). Figure 11.2 depicts India's affinities towards its thirteen significant partners, which had at least ten cooperation links in *Clinical Medicine*. USA occupies the most prominent position in India's transnational cooperation in this field.

Figure 11.3 depicts India's affinities for each of its major partners in 24 subfields of *Clinical Medicine*. Affinity indices for smaller subfields were not computed as they are not interpretable.

Table 11.3
Publication Output and Cooperation Links in Subfields of *Clinical Medicine* (1990-1994)

Subfield	*No. of Articles*	*ICOA*	*No. of Links*	*Internationalization Index** *INI* %	*Cooperation Index** *COI* %	*Cooperation Extensiveness Index** *CEI*
INM	1159	81	153	6.99	13.20	1.89
ADD	21	4	5	19.04	23.81	1.25
ALL	33	2	3	-	-	-
ANE	108	3	3	-	-	-
ART	23	1	2	-	-	-
CAR	289	22	51	7.61	17.65	2.32
DEN	57	9	10	15.79	17.54	1.11
DER	426	32	39	7.51	9.15	1.22
END	181	35	39	19.34	21.55	1.11
FER	110	17	42	15.45	38.18	2.47
GAS	252	15	15	5.96	5.96	1.00
GER	47	1	1	-	-	-
HEM	81	14	20	17.28	24.69	1.43
HYG	108	21	30	19.44	27.78	1.43
IMM	452	89	121	19.69	26.77	1.36
MCM	68	4	4	-	-	-
NEP	47	1	5	2.13	10.64	5.00
NEU	367	60	63	16.35	17.17	1.05
GYN	115	3	3	-	-	-
ONC	548	70	88	12.77	16.06	1.26
OPT	163	24	26	14.72	15.95	1.08
ORP	39	2	2	-	-	-
OTO	79	6	7	7.59	8.86	1.17
PAT	156	7	7	4.49	4.49	1.00
PED	177	13	19	7.34	10.73	1.46
PHA	1071	87	99	8.12	9.24	1.14
PSY	126	15	30	11.90	23.81	2.00
RAD	413	26	30	6.29	7.26	1.15
RES	141	10	12	7.09	8.51	1.20
SUR	301	10	10	3.32	3.32	1.00
TRO	235	26	29	11.06	12.34	1.11
URO	168	6	6	3.57	3.57	1.00
VET	237	28	32	11.81	13.50	1.14
Total	7885	744	1005	9.44	12.75	1.35

*Note: Indices are computed only when the number of links is at least 5.

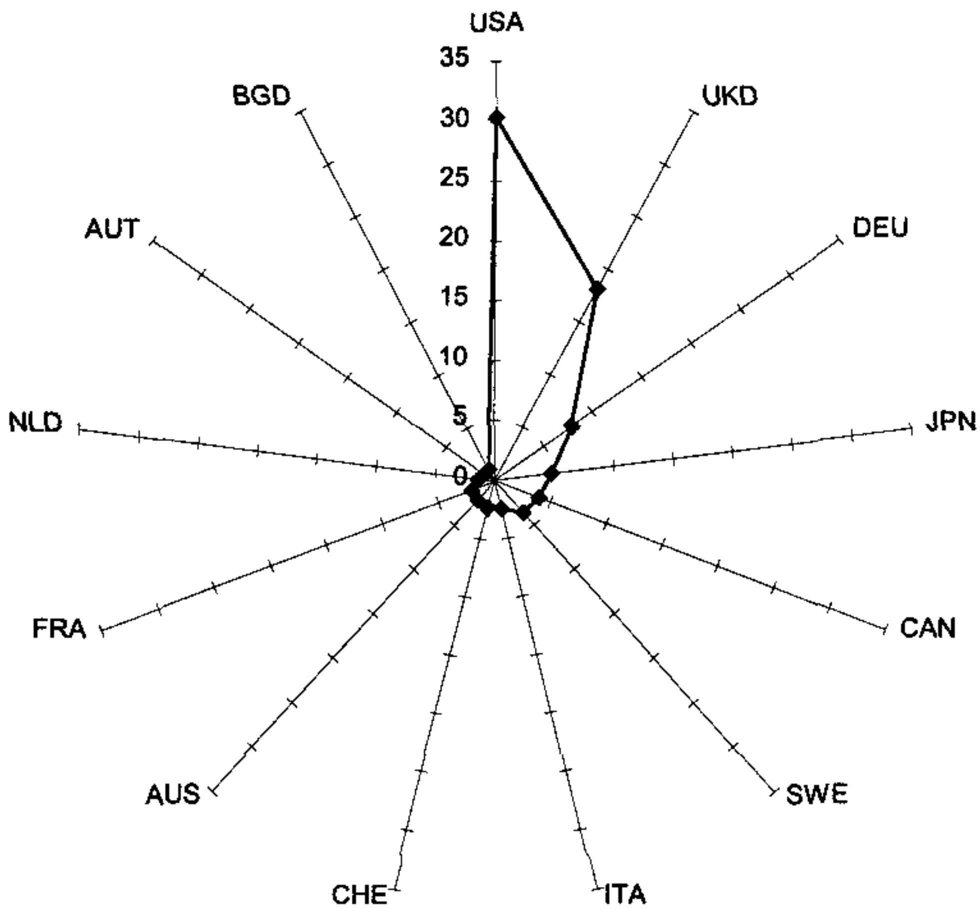


Fig. 11.2: India's linkages in Clinical Medicine (1990-1994)
(Affinity Index)

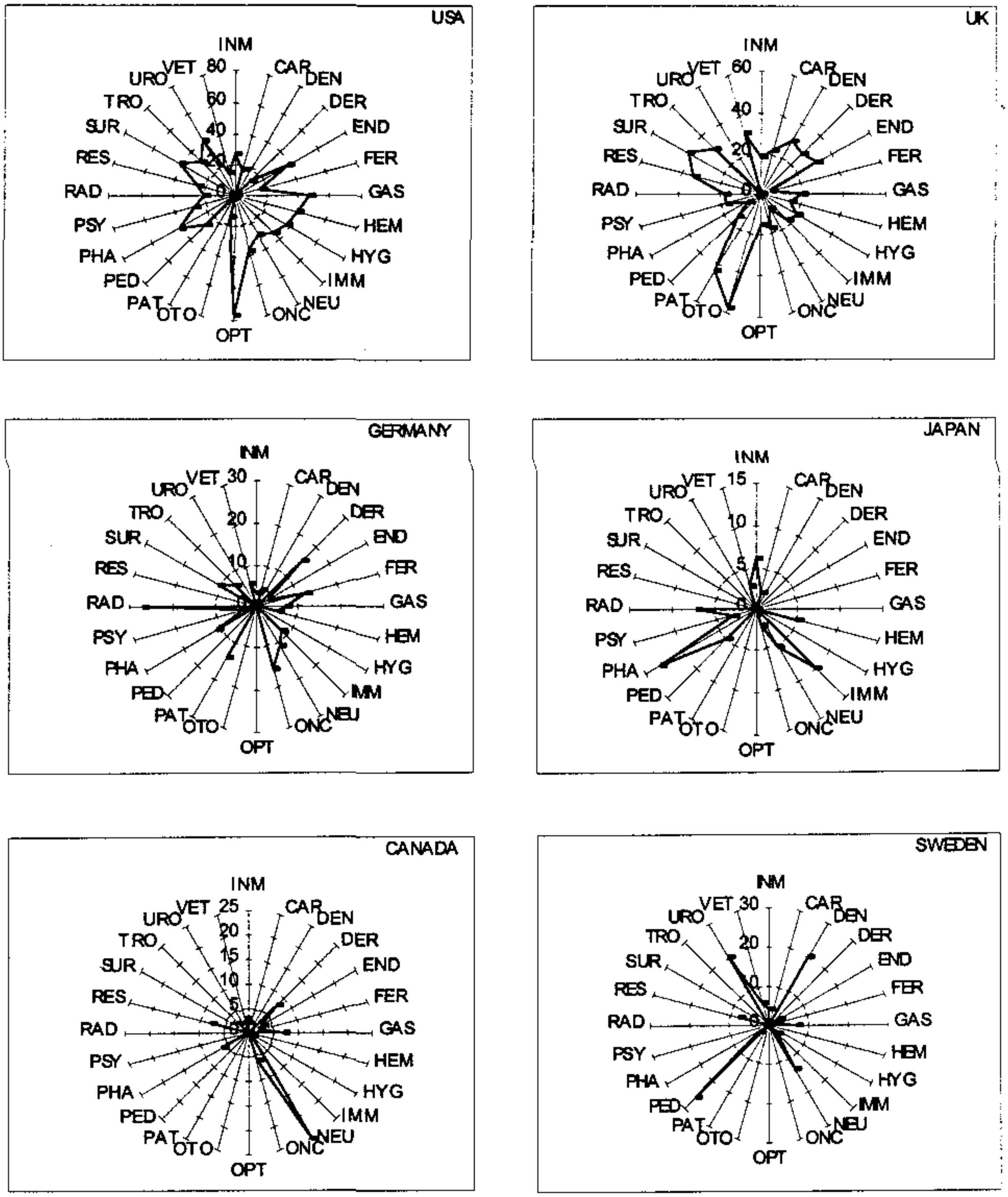


Fig. 11.3: India's affinities with major cooperating countries in different subfields of *Clinical Medicine* (1990-1994)
(Affinity Index)

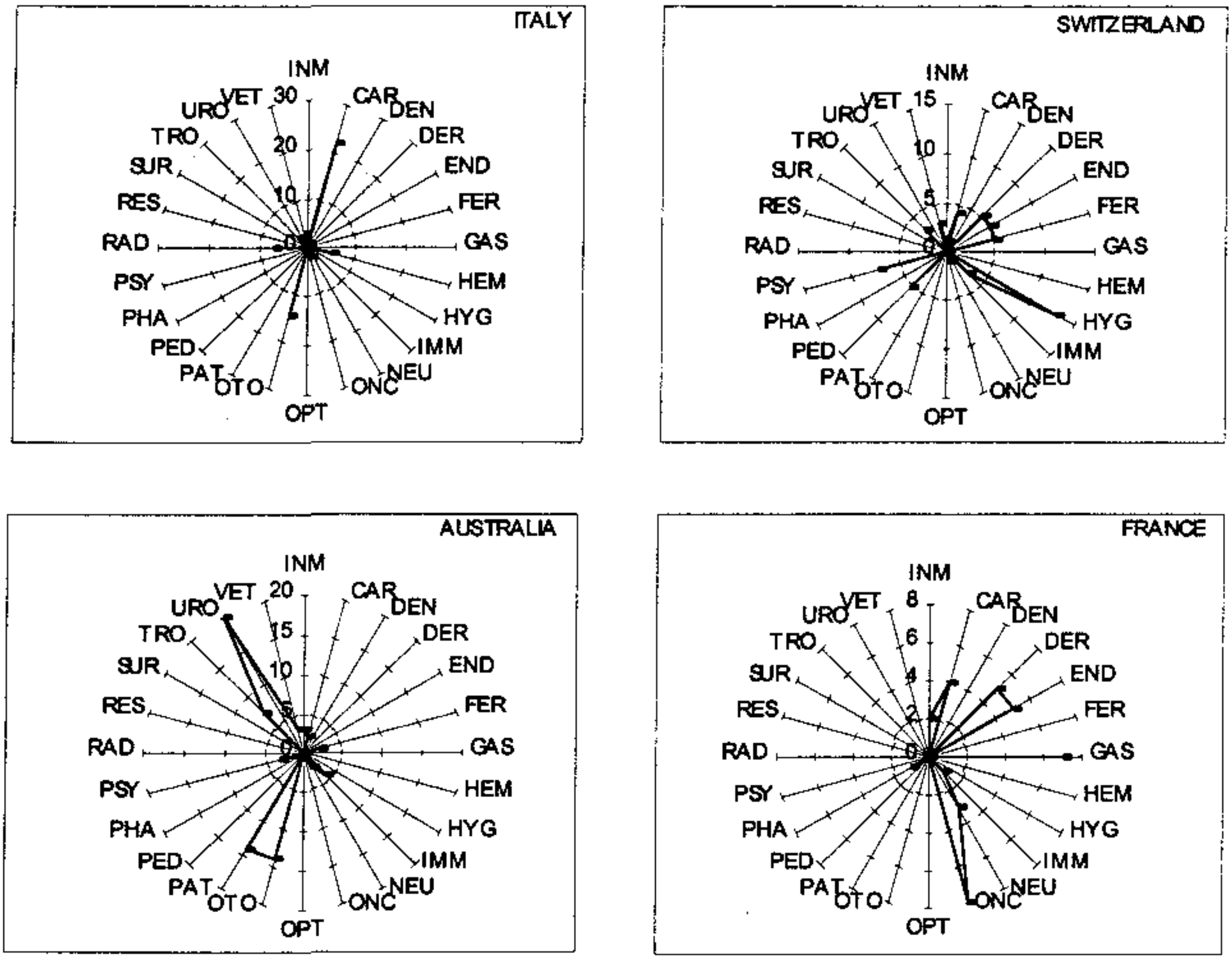
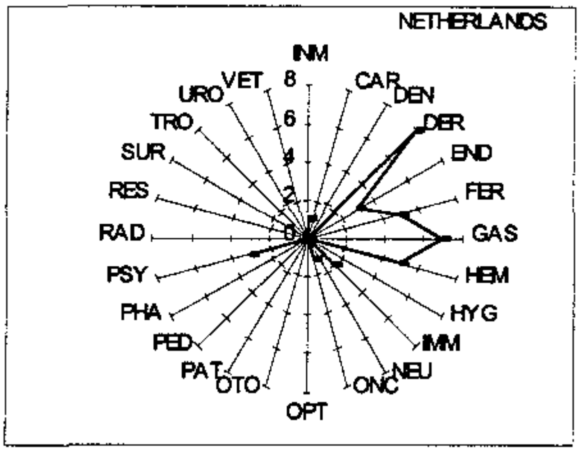
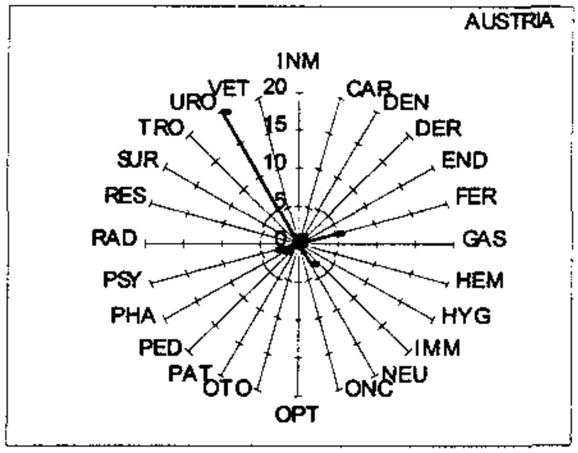


Fig. 11.3 (Contd.): India's affinities with major cooperating countries in different subfields of Clinical Medicine (1990-1994)
(Affinity Index)





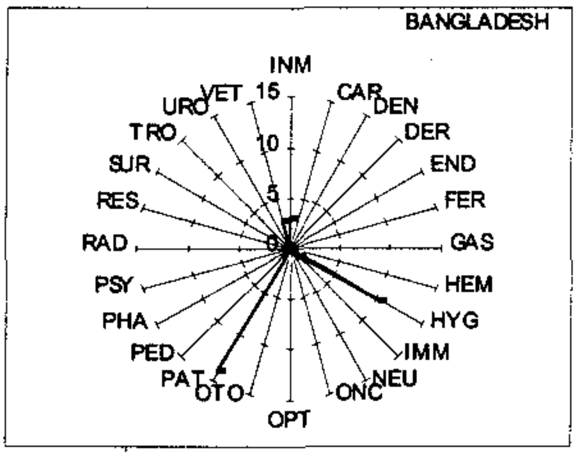


Fig. 11.3 (Contd.): India's affinities with major cooperating countries in different subfields of Clinical Medicine (1990-1994)
(Affinity Index)

Figure 11.4 represents India's affinities towards its significant partners separately for each of the following (major) subfields: (i) *General & Internal Medicine*; (ii) *Cardiovascular System*; (iii) *Dermatology & Venereal Diseases*; (iv) *Endocrinology* (v) *Hygiene & Public Health*; (vi) *Immunology*; (vii) *Neurology & Neurosurgery*; (viii) *Oncology*; (ix) *Ophthalmology*; (x) *Pharmacy*; (xi) *Radiology & Nuclear Medicine*; (xii) *Urology*; and (xiii) *Veterinary Medicine*. This figure is self - explanatory and any elaboration would be redundant. The following trends can be observed:

Country	*Subfields of Highest Affinities*	
	First Rank	***Second Rank***
USA	Ophthalmology	Gastroenterology
UK	Otorhinolaryngology	Pathology
Germany	Radiology & Nuclear Medicine	Dermatology
Japan	Pharmacology & Pharmacy	Immunology
Canada	Neurology & Neurosurgery	Respiratory System
Sweden	Pediatrics	Dentistry/ Urology
Italy	Cardiovascular System	Otorhinolaryngology
Switzerland	Hygiene & Public Health	Psychiatry
Australia	Urology	Pathology/ Otorhinolaryngology
France	Oncology	Dermatology/ Endocrinology
Netherlands	Dermatology	Gastroenterology
Austria	Urology	Fertility
Bangladesh	Pathology	Hygiene & Public Health

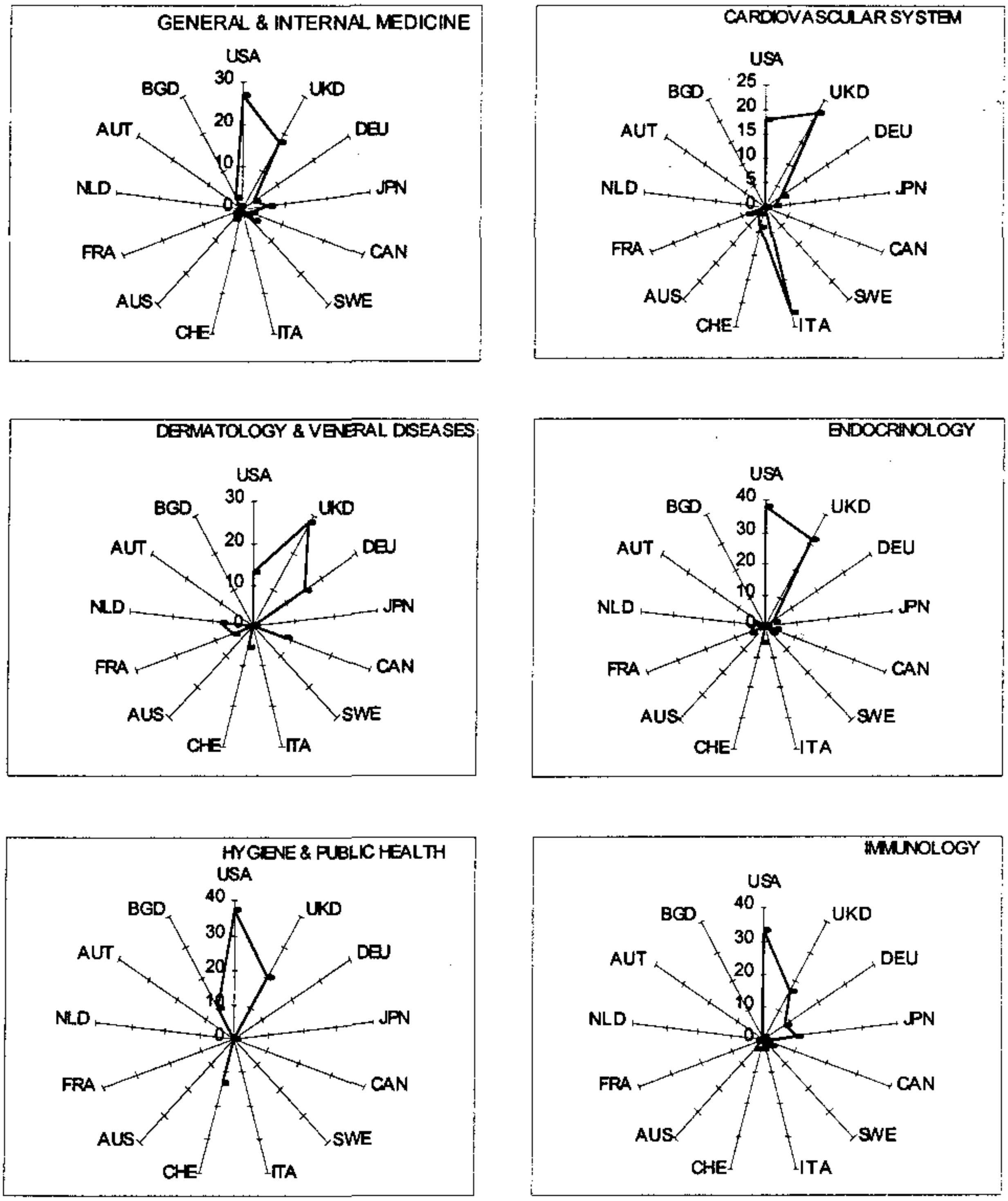


Fig. 11.4: India's linkages in different subfields of Clinical Medicine (1990-1994)
(Affinity Index)

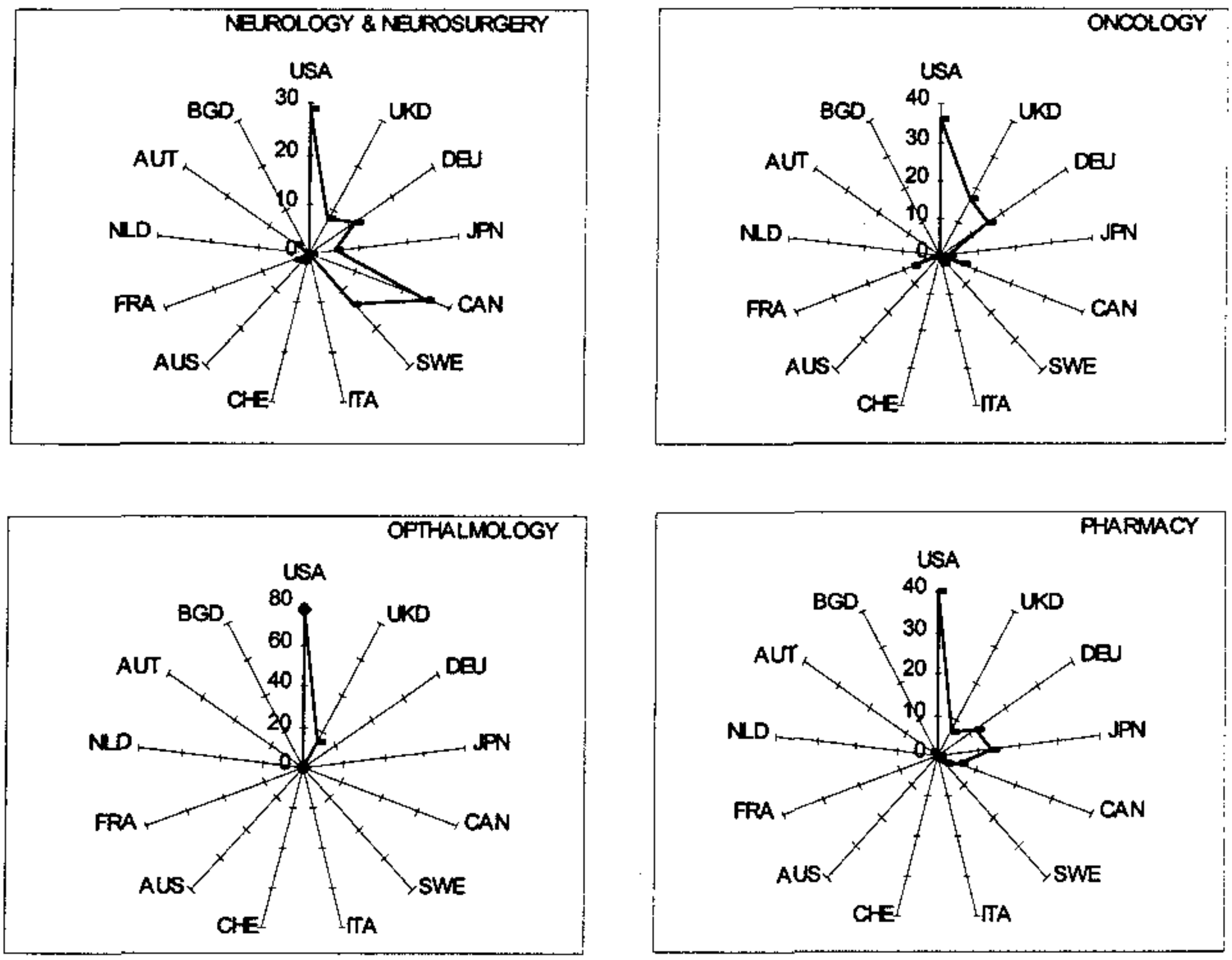


Fig. 11.4 (Contd.): India's linkages in different subfields of Clinical Medicine (1990-1994) (Affinity Index)

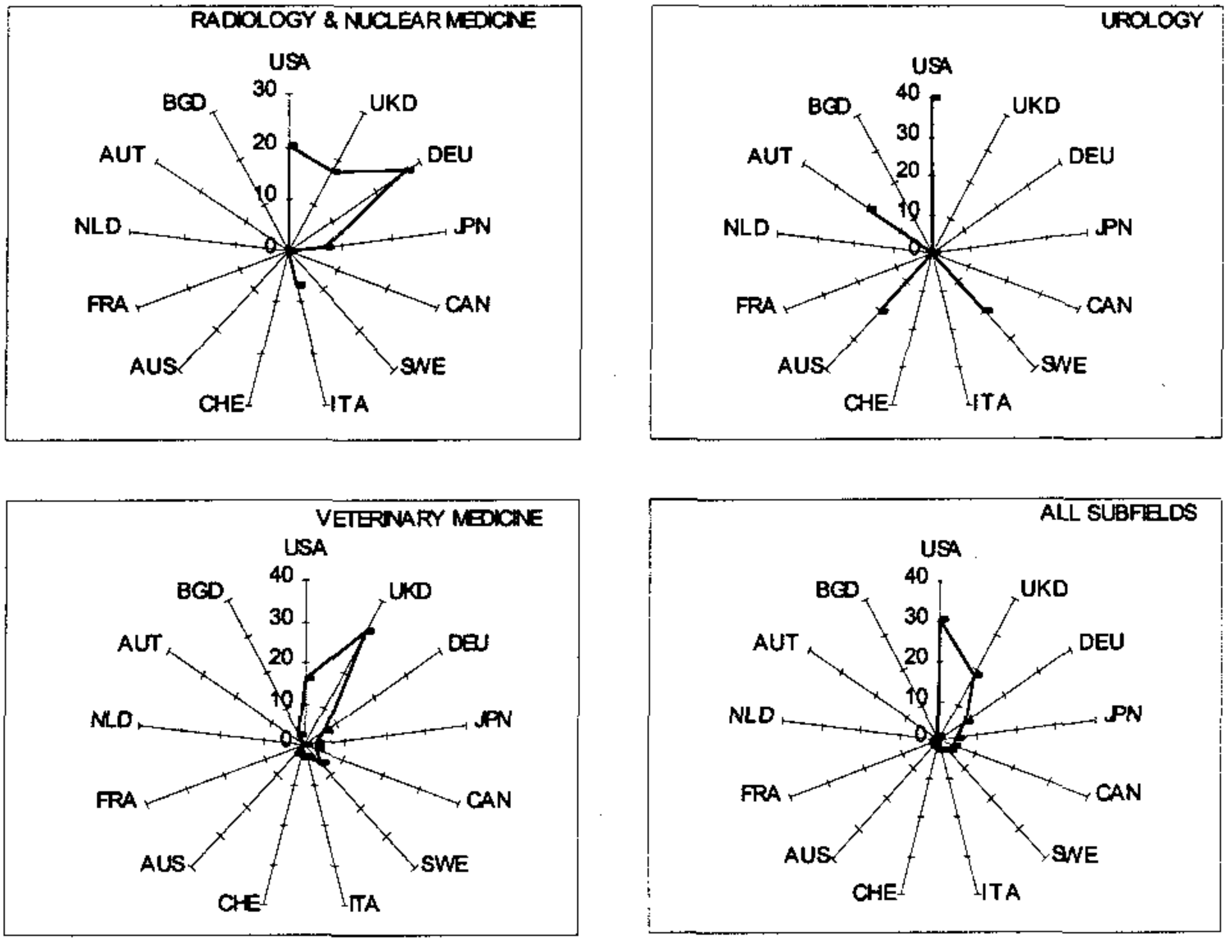


Fig. 11.4 (Contd.): India's linkages in different subfields of Clinical Medicine (1990-1994)
(Affinity Index)

Structure of Transnational Cooperation

The foregoing country - by - county and field - by - field analyses are quite enlightening, but they are also time - consuming. Further, they only provide unidimensional views of the data and fail to reveal its multidimensional structure. The multidimensional structure of India's relationships with its thirteen significant partners in 24 *Clinical Medicine* subfields (*INM*, *CAR*, *DEN*, *DER*, *END*, *FER*, *GAS*, *HEM*, *HYG*, *IMM*, *NEU*, *ONC*, *OPT*, *OTO*, *PAT*, *PED*, *PHA*, *PSY*, *RAD*, *RES*, *SUR*, *TRO*, *URO*, and *VET*) was analyzed through Correspondence Analysis. Four subfields, viz. *Urology*, *Pediatrics*, *Pathology* and *Otorhinolaryngology* were treated as supplementary variables in the Correspondence Analysis. Correspondence Analysis shows how India's significant partners are placed relative to each other and different research areas of *Clinical Medicine*.

Eigen values issued from the Correspondence Analysis indicate that the total variance ($\Sigma\lambda i = 0.676739$) is quite large, implying wide variations in the amplitudes of cooperation profiles of different partners. The first four factorial axes account for about 70% of the total variance. The remaining axes accounting for successively smaller amounts of variance provide information of an idiosyncratic nature, which does not have any bearing on the structure of the multidimensional data. The first two factorial axes accounting for 45% of the total variance, represent the most essential features of the multidimensional data, while the third and fourth axes provide complementary information for further elaboration.

The numerical results of Correspondence Analysis are summarized in Tables 11.4 and 11.5. Figures 11.5 and 11.6 represent the two - dimensional factorial maps constituted by ϕ_1 and ϕ_2 axes separately for subfields and countries. The representation of countries and subfields in two different graphics was done to avoid the cluttering of points in the same graphic. However, these two graphics are superimposable.

Table 11.4
Contributions of explicative points to the composition of the first four factorial axes (Absolute contribution; permill)

Cloud	*Explicative points with positive coordinates*	*Explicative points with negative coordinates*
	Axis 1 (λ_1 = 0.180062, τ_1 = 26.61%)	
Subfields	Pharmacology (373) Neurology (641)	Cardiovascular System (448)
Countries	Canada (277) Sweden (115)	Italy (406) UK (751)
	Axis 2 (λ_2 = 0 124487, τ_2 = 18.40%)	
Subfields	Hygiene & Public Health (3481)	Cardiovascular System (320) Neurology (161)
Countries	Bangladesh (151)	Italy (406) Canada (143)
	Axis 3 (λ_3 = 0.090802, τ_3 = 13.42%)	
Subfields	Dentistry (158) Veterinary Medicine (83) Neurology (107)	Pharmacology (233)
Countries	UK (164) Sweden (211)	USA (157) Japan (184)
	Axis 4 (λ_4 = 0.0079590, τ_4 = 11.76%)	
Subfields	Internal Medicine (92) Pharmacology (62)	Oncology (110) Dermatology (346) Fertility (154)
Countries	Japan (147) Sweden (147)	Germany (176) Netherlands (249)

Table 11.5
Contributions of the explained points to the eccentricities of the first four factorial axes (Relative contribution, permill)

Cloud	*Explained points with positive coordinates*	*Explained points with negative coordinates*
	Axis 1 (λ_1 = 0.180062, τ_1 = 26.61%)	
Subfields	Neurology (644) Pharmacology (278)	Cardiovascular System (629) Otorhinolaryngology (377)
Countries	Canada (575) Sweden (333)	UK (292) Italy (557)
	Axis 2 (λ_2 = 0 124487, τ_2 = 18.40%)	
Subfields	Cardiovascular System (310)	Hygiene & Public Health (462) Psychiatry (267)
Countries	Italy (385)	Bangladesh (364)
	Axis 3 (λ_3 = 0.090802, τ_3 = 13.42%)	
Subfields	Dentistry (437) Respiratory System (437) Veterinary Medicine (513)	Pharmacology (511)
Countries	UK (323) Sweden (309)	USA (357) Japan (366)
	Axis 4 (λ_4 = 0.0079590, τ_4 = 11.76%)	
Subfields	Internal Medicine (356)	Oncology (301) Dermatology (750) Fertility (309)
Countries	Japan (256)	Germany (286) Netherlands (558)

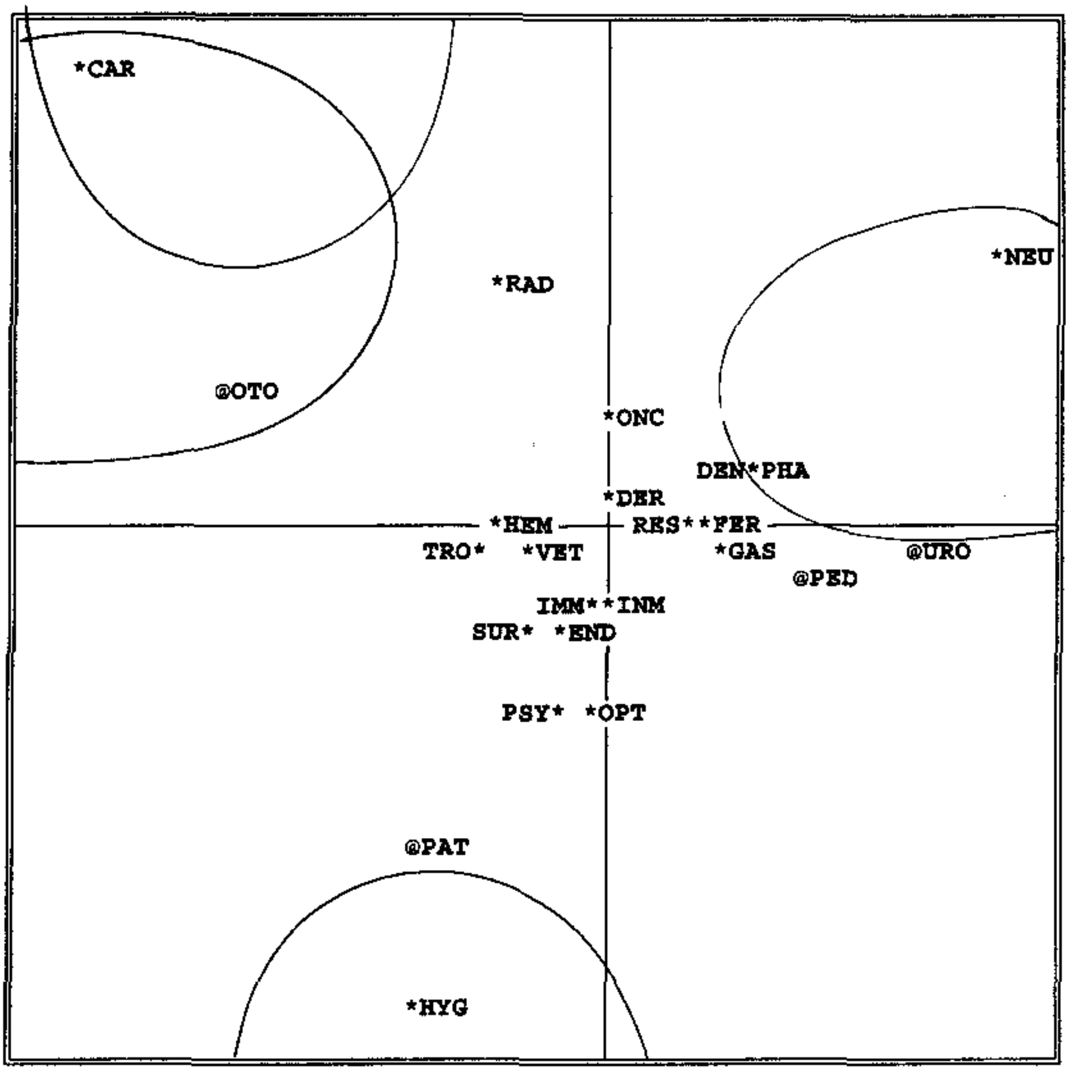


Fig. 11.5: Correspondence Analysis of transnational cooperation in Clinical Medicine (Subfields Points)

Notes:
Horizontal axis is dimension 1 with inertia = 0.1801 (26.6%)
Vertical axis is dimension 2 with inertia = 0.1245 (18.4%)
* Principal variables @ Supplementary variables

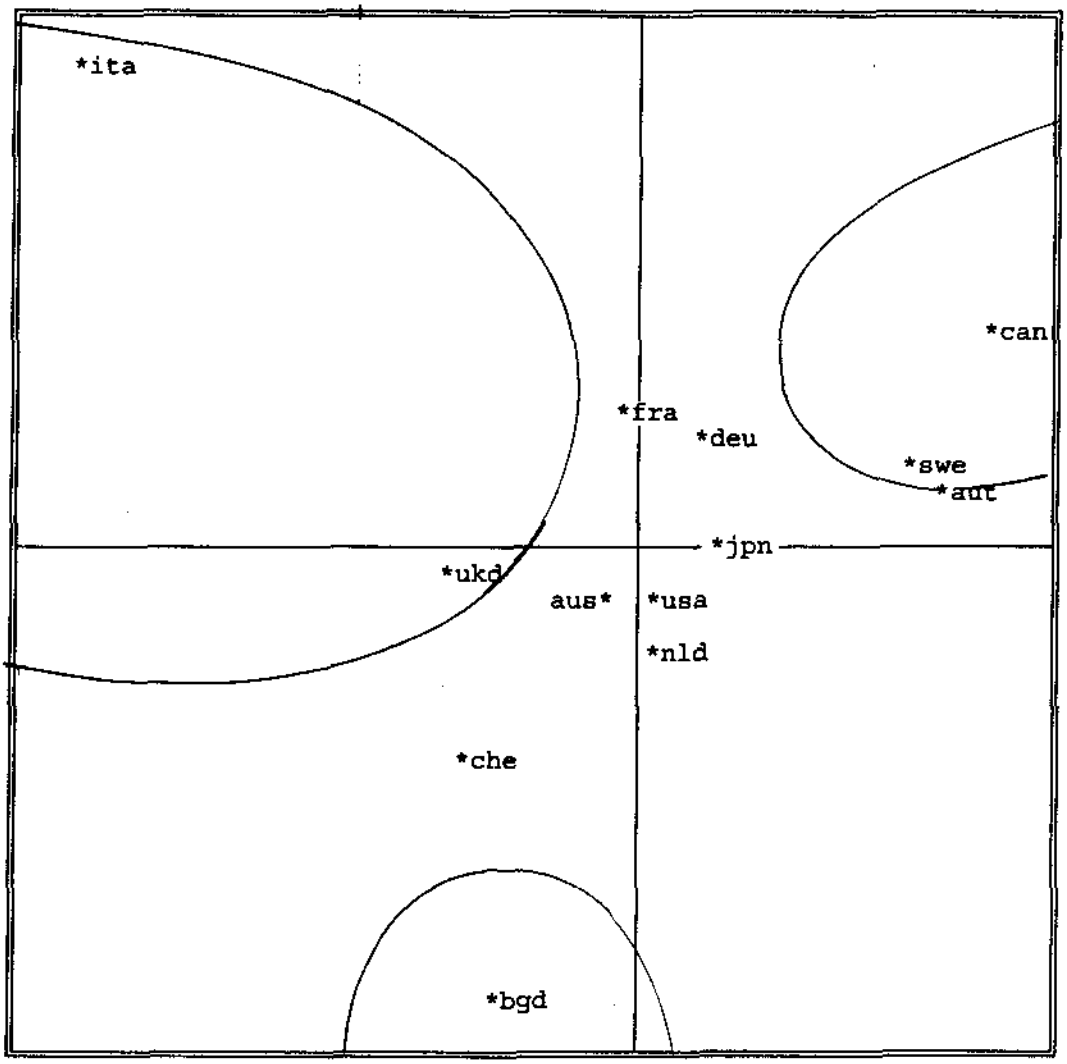


Fig. 11.6: Correspondence Analysis of transnational cooperation in Clinical Medicine subfields (Country Points)

Notes:
Horizontal axis is dimension 1 with inertia = 0.1801 (26.6%)
Vertical axis is dimension 2 with inertia = 0.1245 (18.4%)

Factor ϕ_1: The first factorial axis accounting for about 27% of the total variance represents the basic features of the data.

On the cloud of subfields, this axis is characterized by the opposition between *Pharmacology* and *Neurology* on the one hand and *Cardiovascular System* and *Otorhinolaryngology* on the other. *Pharmacology* and *Neurology* are projected on this axis with positive coordinates, whereas *Cardiovascular System* and *Otorhinolaryngology* are projected with negative coordinates.

On the country cloud, this axis is characterized by the opposition between Canada and Sweden on the one hand and Italy and UK on the other. Canada and Sweden are projected on this axis with positive coordinates and are therefore correlated to *Pharmacology* and *Neurology*. India collaborates with these countries mainly in these two subfields. Italy and UK, which are projected with negative coordinates, are correlated to *Cardiovascular System* and *Otorhinolaryngology*.

Factor ϕ_2: This factor accounts for 18.4% of the total variance.

This factor is characterized by the polarity between *Cardiovascular System* (which is projected with positive coordinate) and *Hygiene & Public Health* (which is projected on this axis with negative coordinates).

On the country cloud, this factor is characterized by the opposition between Italy and Bangladesh. Italy is correlated to *Cardiovascular System*, whereas Bangladesh is correlated by *Hygiene & Public Health*.

Factor ϕ_3: The third factorial axis accounts for 13.4% of the total variance.

On the cloud of subfields, this factor is characterized by the polarity between *Dentistry*, *Veterinary Medicine*, *Neurology* and *Respiratory System* (positive coordinates) on the one hand and *Pharmacology* (negative coordinate) on the other. It may be recalled that

Neurology and *Pharmacology* were associated on the first factorial axis, whereas these subfields are opposed to each other on this axis. However, the opposition is less strong, since the third factorial axis explains less variance than the first factorial axis.

On the country cloud, this factor is characterized by the opposition between UK and Sweden on the one hand and USA and Japan on the other. UK and Sweden are projected on this axis with positive coordinates and are therefore correlated to *Dentistry*, *Veterinary Medicine*, *Neurology* and *Respiratory System*. These subfields are prominent in the cooperation profiles of these countries.

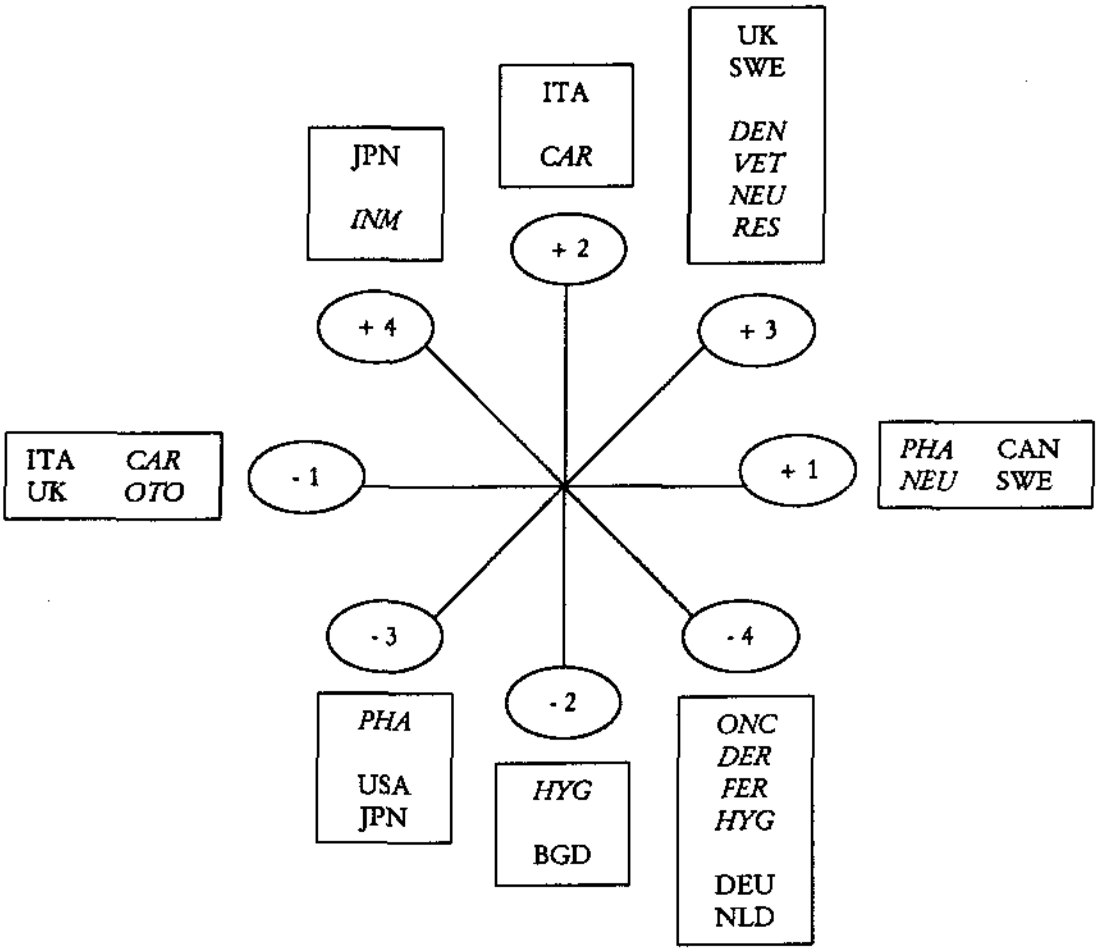
USA and Japan, which are projected on this axis with negative coordinates, are correlated to *Pharmacology* and anticorrelated to *Dentistry*, *Veterinary Medicine*, *Respiratory System* and *Neurology*. The latter subfields are not prominent in the cooperation profiles of these countries.

Factor ϕ_4: This factor accounts for 11.7% of the total variance.

On the cloud of subfields, this factor is characterized by the polarity between *Internal Medicine* (projected with positive coordinate) on the one hand and *Oncology*, *Dermatology* and *Fertility* (projected with negative coordinates) on the other.

On the country cloud, this factor represents the polarity between Japan on the one hand and Germany and Netherlands on the other. Japan is projected with positive coordinate and is therefore correlated to *Internal Medicine*. Germany and Netherlands, which are projected with negative coordinates, are correlated to *Oncology/Dermatology/Fertility*.

The results of Correspondence Analysis are summarized in Figure 11.7.



Variance explained
Axis 1 : 26.6%
Axis 2 : 18.4%
Axis 3 : 13.4%
Axis 4 : 11.7%

About 70% of the total variance (information) in the multidimensional data is captured in the four - dimensional subspace

Fig. 11.7: Summary of correspondence analysis

12 Transnational Links in Biomedical Research

This chapter examines the patterns of research output and transnational cooperation of Indian science in the area of Biomedical Research. This area has been classified into thirteen subfields:

1. General Biomedical Research (*GEN*)
2. Anatomy & Morphology (*ANA*)
3. Biochemistry & Molecular Biology (*BMB*)
4. Biomedical Engineering (*BEG*)
5. Biophysics (*BPH*)
6. Cell Biology, Cytology and Histology (*CYT*)
7. Embryology (*EMB*)
8. Genetics & Heredity (*G&H*)
9. Microbiology (*MIC*)
10. Nutrition & Dietetics (*NUT*)
11. Parasitology (*PAR*)
12. Physiology (*PHY*)
13. Virology (*VIR*)

General Overview of the Data

During the five - year period, 1990 - 1994, India had published 5010 articles in the mainstream journals in *Biomedical Research*, covered by the *Science Citation Index*. Of these, 666 (13.3%) articles were internationally coauthored, involving an aggregate of 831 cooperation links with 56 countries. Table 12.1 presents the data on India's cooperation links with twelve countries, each accounting for at least 1% of all transnational links in *Biomedical Research*. The distribution of links is highly skewed; the top five countries (USA, Germany, UK, Japan and France) account for about 88% of all transnational links in this field.

Table 12.1
India's Cooperation Links with Major Partners in *Biomedical Research*

Country	*No. of Links*	*%*	*Country*	*No. of Links*	*%*	*Country*	*No. of Links*	*%*
USA	313	37.67	FRA	40	4.81	NLD	15	1.81
DEU	94	11.31	CAN	39	4.69	MEX	11	1.32
UK	85	10.23	ITA	16	1.93	SUN	10	1.20
JPN	58	6.90	SWE	16	1.93	AUS	9	1.08

Inter - Field Differences in Transnational Cooperation

Inter - field differences in the distribution of articles, internationally coauthored articles (*ICOA*) and cooperation links (*COP*) in different subfields of *Biomedical Research* may be visualized from the component - bar - charts in Figure 12.1.

There is considerable mismatch between the proportions of articles, internationally coauthored articles and transnational cooperation links in different subfields. For example,

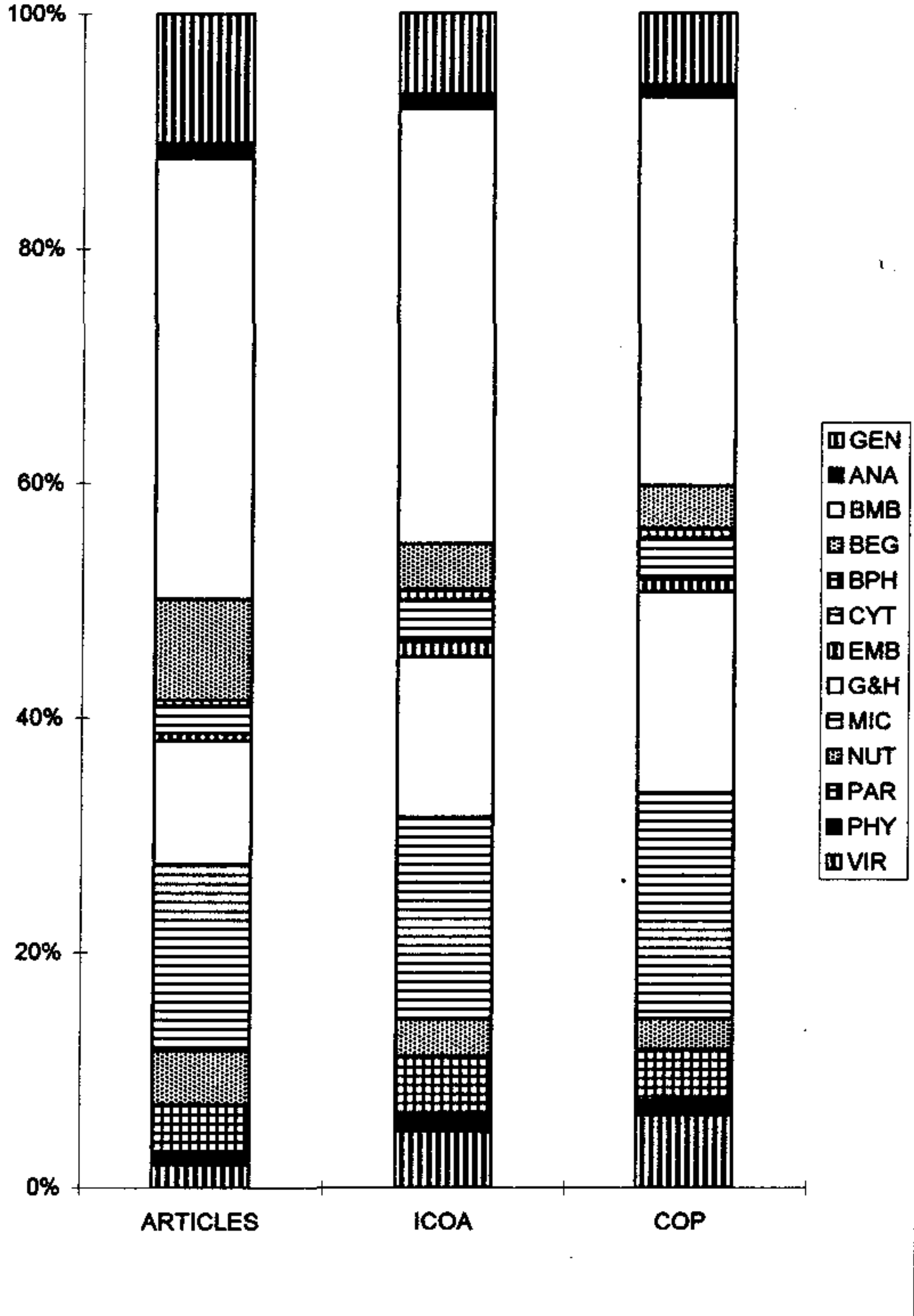


Fig. 12.1: Distribution of articles, internationally coauthored artilces (ICOA) and cooperation links (COP) in different subfields of Biomedical Research

General Biomedical Research accounts for 11.2% of all articles, but it accounts for much less proportion of internationally coauthored articles (7.1%) and still less proportion of cooperation links (6.1%). *Genetics & Heredity* accounts for 10.5% of all articles, but it accounts for a greater proportion of internationally coauthored articles (17.5%) and still greater proportion of cooperation links (19.3%). This means that *Genetics & Heredity* has greater propensity for attracting transnational partners than expected on the basis of research output in the area. Moreover the cooperation links tend to be multilateral. The same is also true for *Virology*. It accounts for 1.9% of all articles, but it accounts for 4.8% of all internationally coauthored articles and 8.1% of all cooperation links. However, we can discern these differences more systematically through the following three relational indicators.

(i.) Internationalization Index (*INI*)

(ii.) Cooperation Index *(COI)*

(iii.) Cooperation Extensiveness Index (*CEI*)

These indices are defined in Chapter 4.

Table 12.2 presents the data on the output of articles, internationally coauthored articles (*ICOA*) and transnational cooperation links (*COP*) and associated indicators, viz. *Internationalization Index* (*INI*), *Cooperation Index* (*COI*) and *Cooperation Extensiveness Index* (*CEI*).

It can be easily seen from the table that relatively smaller subfields, viz. *Virology*, *Embryology* and *Biophysics* are the three most internationalized areas of *Biomedical Research*; *Anatomy & Morphology* is an exception. The least internationalized subfield is *Biomedical Engineering*. The values of *CEI* indicate that *Virology*, *Genetics & Heredity*, *Microbiology* and *Cytology & Cell Biology* have a tendency towards multilateral cooperation.

Table 12.2
Publication Output and Cooperation Links in *Biomedical Research* subfields (1990-1994)

Subfield	*No. of Articles*	*ICOA*	*No. of Links*	*Internationalization Index INI %*	*Cooperation Index COI %*	*Cooperation Extensiveness Index CEI*
General Biomedical Research	555	47	51	8.47	9.19	1.08
Anatomy & Morphology	61	8	9	13.11	14.75	1.12
Biochemistry & Molecular Biology	1884	250	275	13.27	14.60	1.10
Biomedical Engineering	431	26	30	6.03	6.96	1.15
Biophysics	23	6	7	26.09	30.43	1.17
Cytology &Cell Biology	120	24	29	20.00	24.17	1.21
Embryology	31	9	9	29.03	29.03	1.00
Genetics & Heredity	528	92	142	17.42	26..89	1.54
Microbiology	793	116	159	14.63	20.18	1.38
Nutrition & Dietetics	230	21	22	9.13	9.57	1.05
Parasitology	205	33	36	16.10	17.56	1.09
Physiology	53	10	10	18.87	18.87	1.00
Virology	96	32	51	33.33	53.13	1.59
Total	5010	661	831	13.19	19.84	1.26

Inter – Country Differences in Transnational Cooperation

Inter – country differences in transnational cooperation were assessed by computing the *Affinity Index* (*AFI*). Figure 12.2 depicts India's affinities towards its twelve major partners (*AFI* $\geq$ 1.0) aggregated over all subfields of *Biomedical Research* viz. USA, Germany, UK, Japan, France, Canada, Italy, Sweden, Netherlands, Mexico, Russia and Australia. USA is the most important cooperating partner, accounting for about 38% of all cooperation links in the field, followed by Germany (11.3%), UK (10.2%), Japan (6.9%) and France (4.8%) in that order.

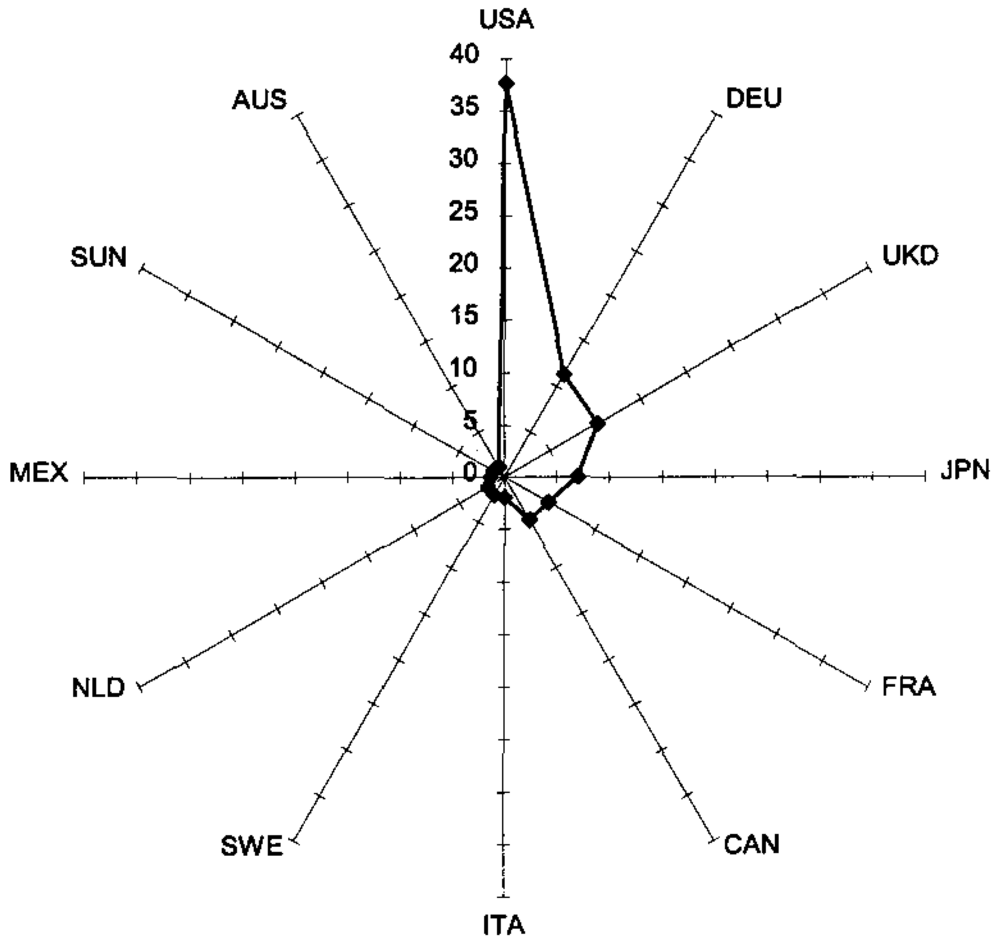


Fig. 12.2: India's linkages in Biomedical Research (1990-1994)
(Affinity Index)

Figure 12.3 presents sunray plots of India's affinities towards its five most important partners (USA, Germany, UK, Japan and France) in thirteen subfields of *Biomedical Research.*

Figure 12.4 presents sunray plots of India's affinities towards its twelve major partners separately for each subfield of *Biomedical Research.* If the affinity towards a country is the same for all the subfields, then the sunray plot is an equilateral polygon. The departure from this shape indicates the extent of differentiation in the affinity profile. The profile of USA is least differentiated, whereas the profiles of other countries exhibit considerable differentiation.

All these figures are self - explanatory and need no elaboration. However, the main trends are summarized below:

Country	*Subfields of*	
	Highest affinity	*Lowest affinity*
USA	General Biomedical Research	Cytology & Cell Biology
UK	Parasitology	Physiology
Germany	Cytology & Cell Biology	Biophysics Physiology Nutrition & Dietetics
Japan	Cytology & Cell Biology	Parasitology Physiology Biophysics Anatomy & Morphology
France	Biomedical Engineering Biophysics	Physiology

Subfield	Country	
	First rank	*Second rank*
General Biomedical Research	USA	DEU
Anatomy & Morphology	USA	DEU, UK, FRA
Biochemistry & Molecular Biology	USA	DEU
Biomedical Engineering	USA, DEU	FRA
Cell Biology	DEU	JPN
Embryology	USA, UK	JPN, CAN
Genetics & Heredity	USA	UK
Microbiology	USA	JPN
Nutrition & Dietetics	USA	CAN
Parasitology	UK	USA
Physiology	USA	CAN
Biophysics	USA	UK
Virology	USA	UK

Structure of Transnational Cooperations

The foregoing country - by - country and field - by - field comparisons of cooperation links through sunray plots of *Affinity Index* are quite enlightening, but they are also time consuming. They present only the unidimensional views of the multidimensional data. They do not indicate the structure of multivariate relationships between countries and research fields.

The structure of India's cooperation links with its twelve significant partners (USA, Germany, UK, Japan, France, Canada, Italy, Sweden, Netherlands, Mexico, Russia and Australia) in thirteen subfields of *Biomedical Research* was analyzed through Correspondence Analysis, using the program SimCA. The results of Correspondence Analysis are summarized in Tables 12.3 and 12.4. Correspondence Analysis shows how India's significant partners are placed relative to each other and different research areas of *Biomedical Research*.

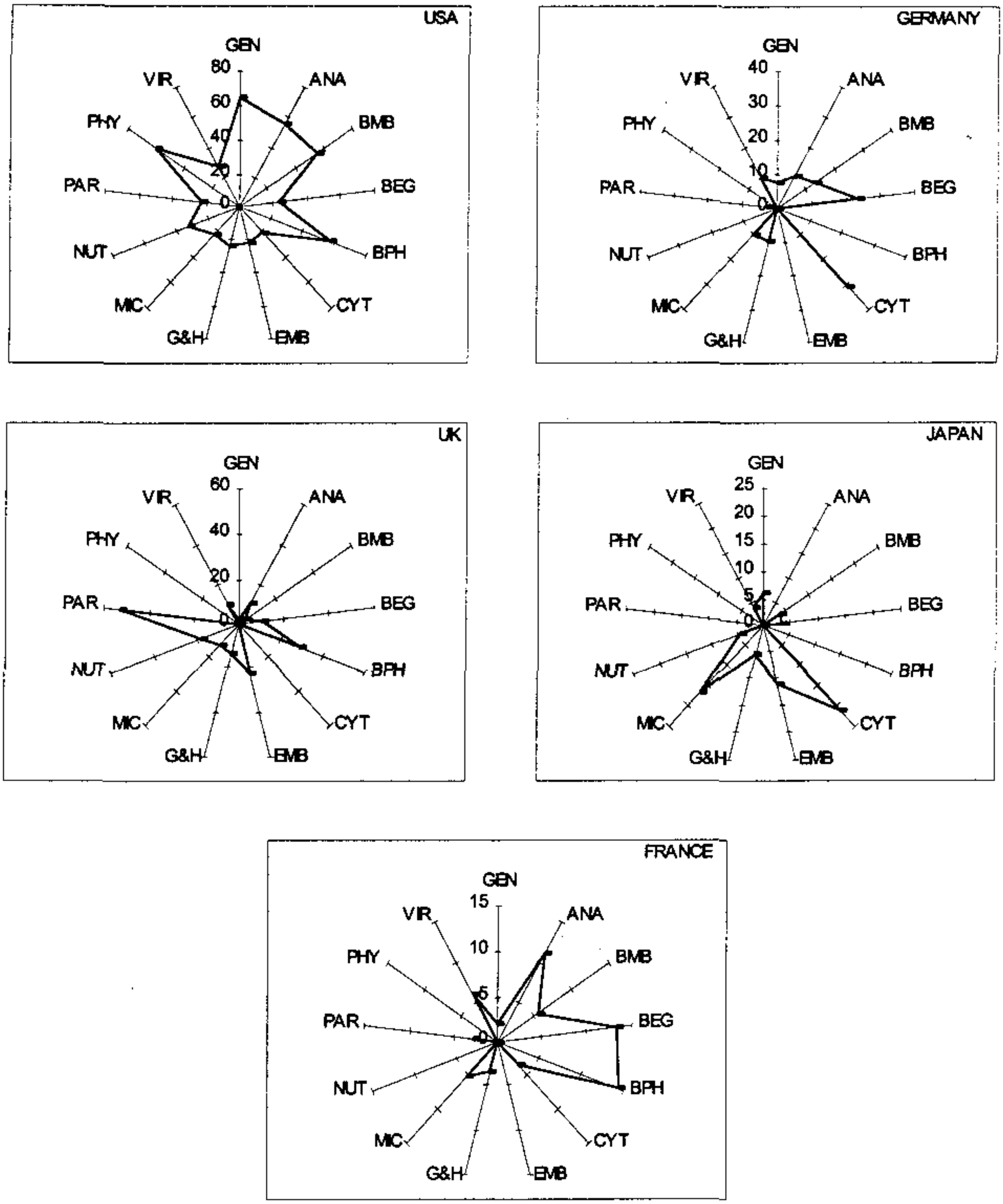


Fig. 12.3: India's affinities towards major cooperating countries in different subfields of Biomedical Research (1990-1994)
(Affinity Index)

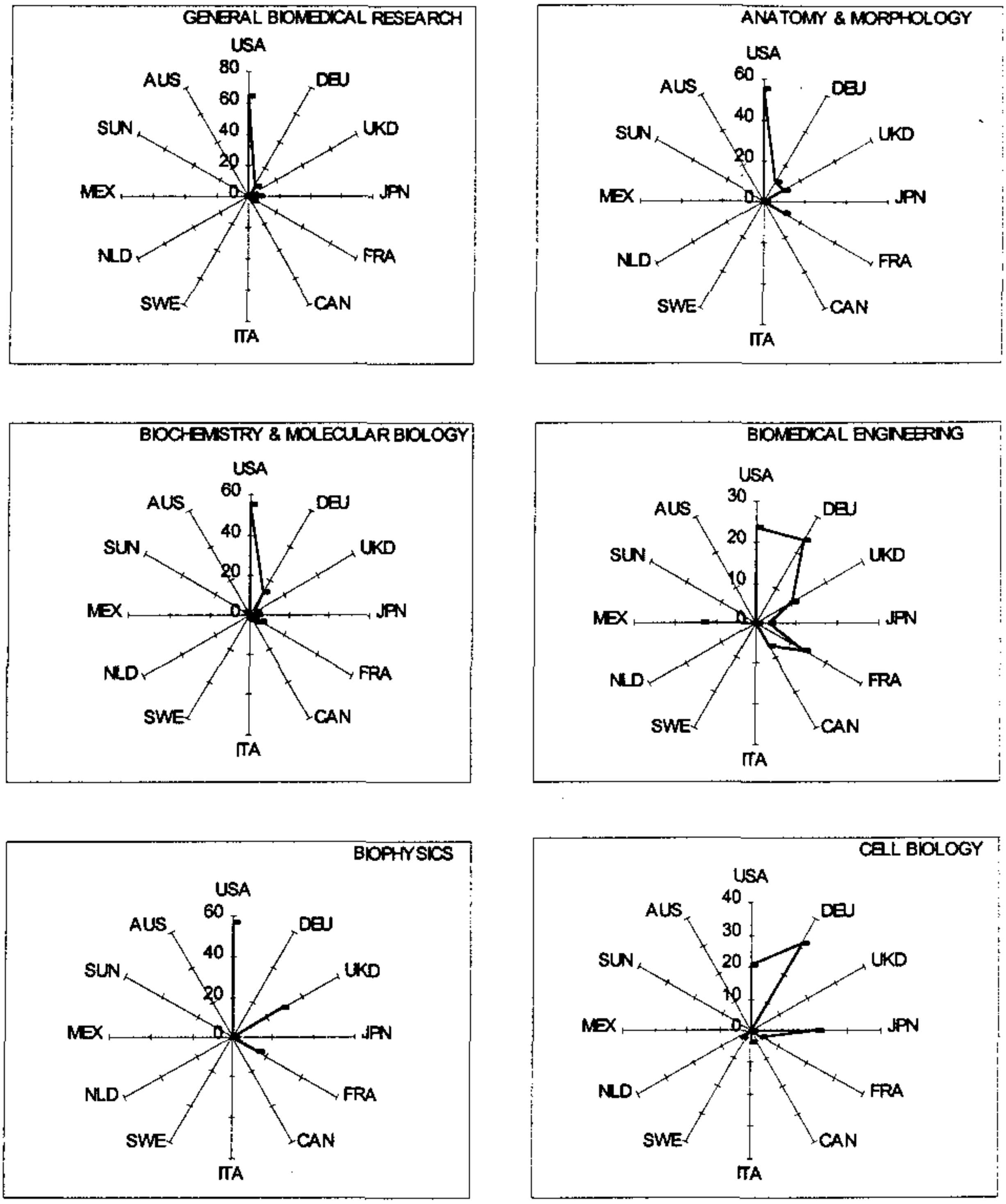


Fig. 12.4: India's linkages in different subfields of Biomedical Research (1990-1994) (Affinity Index)

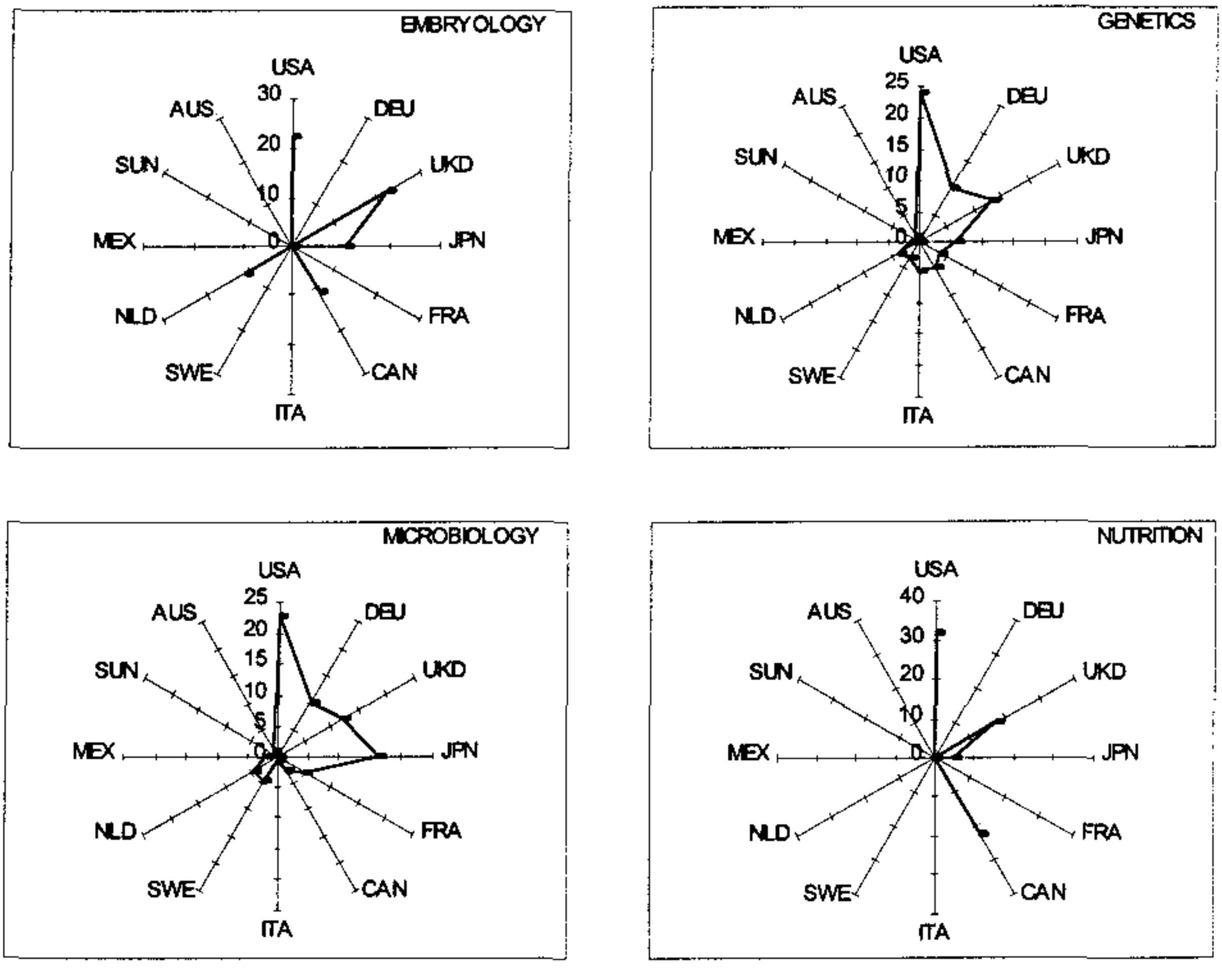


Fig. 12.4 (Contd.): India's linkages in different subfields of Biomedical Research (1990-1994)
(Affinity Index)

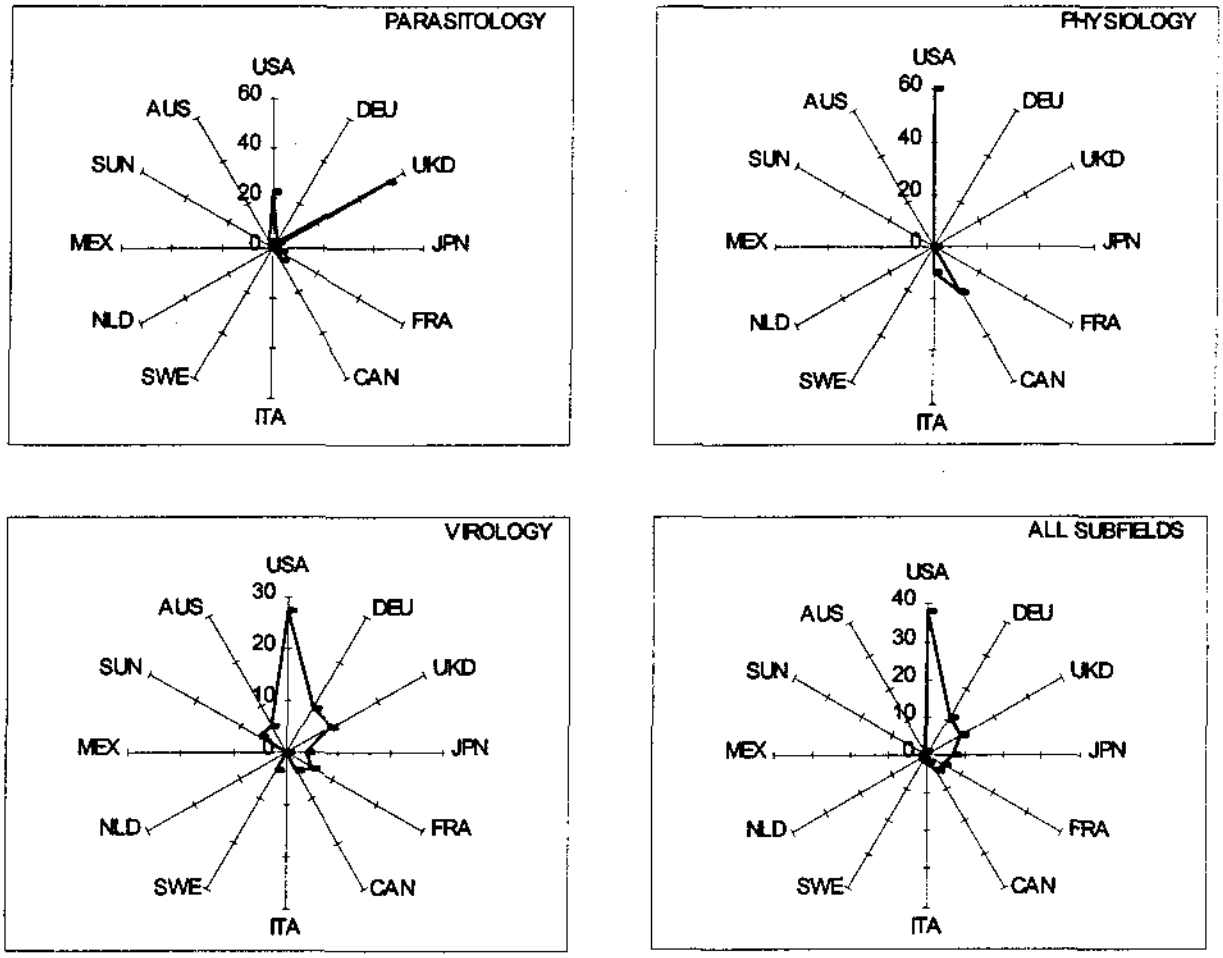


Fig. 12.4 (Contd.): India's linkages in different subfields of Biomedical Research (1990-1994) (Affinity Index)

Table 12.3
Contributions of explicative points to the composition of the factorial axes (Ctr)*

Cloud	*Explicative points with positive coordinates*	*Explicative points with negative coordinates*
	Axis 1 (λ_1 = 0.179103, τ_1 = 35.23%)	
Subfields	General Biomedical Research (77) Biochemistry & Molecular Biology (316)	Genetics (73) Microbiology (135) Parasitology (330)
Countries	USA (245)	UK (564)
	Axis 2 (λ_2 = 0.123290, τ_2 = 24.31%)	
Subfields	Nutrition (89) Parasitology (283)	Cell Biology (209) Microbiology (277)
Countries	UK (180)	Germany (117) Japan (343) Netherlands (100)
	Axis 3 (λ_3 = 0.061742, τ_3 = 12.18%)	
Subfields	–	Biomedical Engineering (881)
Countries	Japan (80)	France (82) Mexico (625)
	Axis 4 (λ_4 = 0.054072, τ_4 = 10.66%)	
Subfields	Virology (523)	Physiology (133) Nutrition (176)
Countries	Russia (274) Australia (232)	Canada (220)

*Note: values are in permills

Table 12.4
Contributions of the explained points to the eccentricities of the factorial axes ($Cos^2\phi$)*

Cloud	*Explained points with positive coordinates*	*Explained points with negative coordinates*
	Axis 1 (λ_1 = 0.179103, τ_1 = 35.23%)	
Subfields	General Biomedical Research (530) Biochemistry & Molecular Biology (896)	Embryology (405) Genetics (418) Microbiology (359) Parasitology (582)
Countries	USA (730)	UK (796) Netherlands (300)
	Axis 2 (λ_2 = 0.123290, τ_2 = 24.31%)	
Subfields	Biophysics (382) Nutrition (316) Parasitology (344)	Cell Biology (661) Microbiology (508)
Countries	—	Germany (456) Japan (706) Sweden (251) Netherlands (300)
	Axis 3 (λ_3 = 0.061742, τ_3 = 12.18%)	
Subfields	—	Biomedical Engineering (925)
Countries	—	France (393) Mexico (797)
	Axis 4 (λ_4 = 0.054072, τ_4 = 10.66%)	
Subfields	Virology (699)	Physiology (391) Nutrition (273)
Countries	Russia (525) Australia (515)	France (276) Canada (307)

* Note: values are in permills

Eigen values issued from the Correspondence Analysis indicate that the total variance ($\Sigma\lambda i$ = 0.507672) is quite large, which indicates that there are wide variations in the amplitudes of profiles of cooperation links of these countries. The first four factorial axes account for 82.5% of the total variance and hence provide a parsimonious representation of the data. The first two factorial axes indicate about 60% of the total variance. Thus, the two - dimensional factorial map (Fig. 12.5) spanned by ϕ_1 and ϕ_2 axes represents the most important features of the data. The third and fourth axes, respectively accounting for 12.2% and 10.7% of the total variance, provide complementary data for further elaboration. The remaining axes accounting for successively smaller amounts of variance represent information which does not have much bearing on the structure of multivariate relationships.

Factor ϕ_1: The first factorial axis, accounting for about 35% of the total variance, represents the most essential features of the structure of relationships between countries and subfields.

On the cloud of subfields, this factor is characterized by the polarity between *General Biomedical Research* and *Biochemistry & Molecular Biology* on the one hand and *Parasitology*, *Embryology*, *Microbiology* and *Genetics & Heredity* on the other.

On the country cloud, this axis represents the polarity between USA on the one hand and UK, Japan and Netherlands on the other.

The signs of coordinates of projection of subfields and countries on this axis indicate that USA is correlated to *General Biomedical Research* and *Biochemistry & Molecular Biology*, whereas UK, Japan and Netherlands are correlated to *Parasitology*, *Microbiology*, *Embryology* and *Genetics & Heredity*. UK's cooperation profile is prominent in all the four subfields, whereas Netherlands' profile is prominent in *Genetics & Heredity* and *Microbiology*.

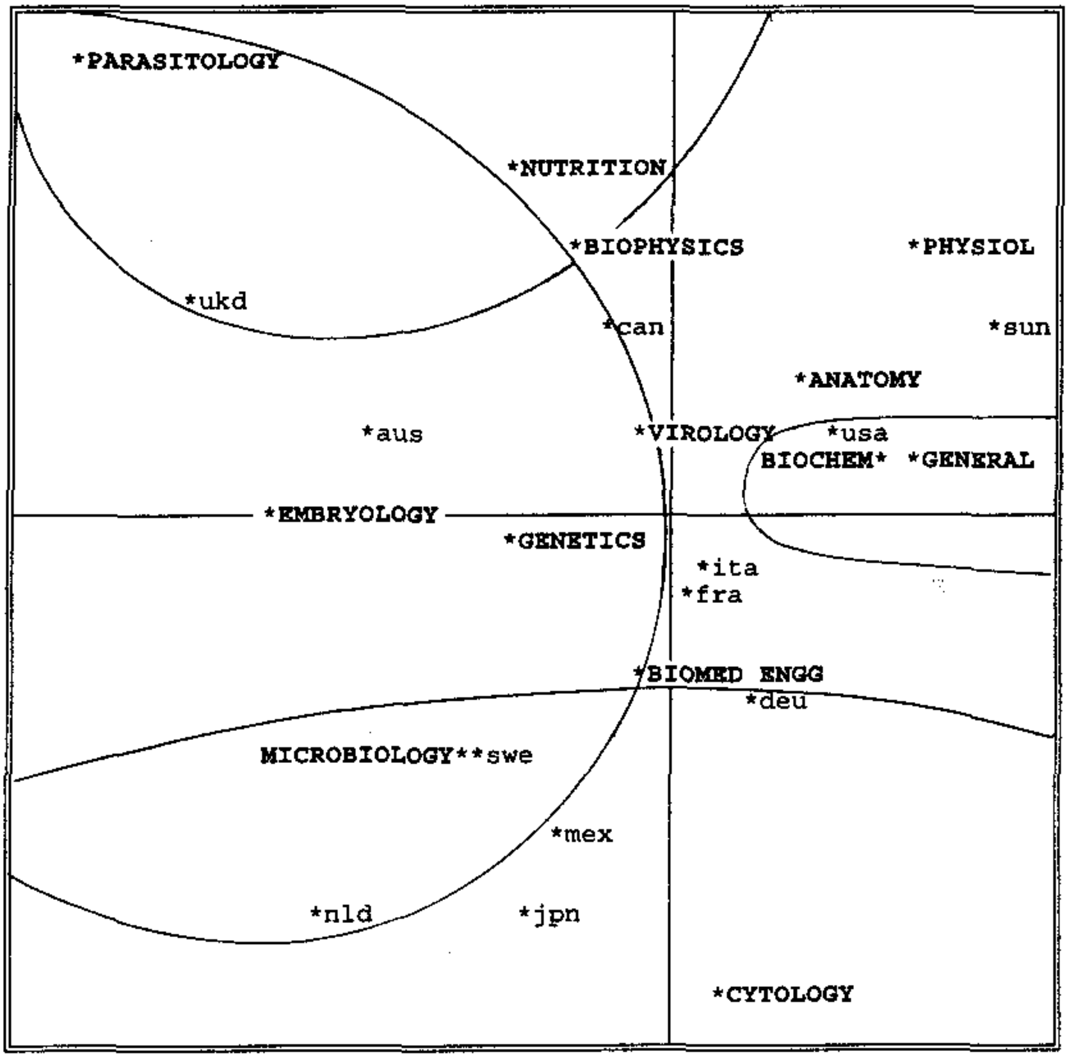


Fig. 12.5: Correspondence Analysis of transnational cooperation in Biomedical Research subfields

Notes:
Horizontal axis is dimension 1 with inertia = 0.1791 (35.3%)
Vertical axis is dimension 2 with inertia = 0.1233 (24.3%)

Factor ϕ_2: This axis, accounting for 24.3% of the total variance, is characterized by the opposition between *Parasitology* and *Nutrition & Dietetics* on the one hand and *Cytology & Cell Biology* and *Microbiology* on the other.

This axis is characterized by the opposition between UK on the one hand and Germany, Japan and Netherlands on the other. UK is correlated to *Parasitology* and *Nutrition & Dietetics*, whereas Germany, Japan and Netherlands are correlated to *Cytology & Cell Biology* and *Microbiology*.

Factor ϕ_3: This axis, accounting for 12.2% of the variance, does not exhibit polarity (Figure 12.6).

This axis is dominated by *Biomedical Engineering*. France and Mexico, are correlated to this axis. The cooperation profiles of these two countries are prominent in *Biomedical Engineering*. Mexico, which is located far away from the barycenter has relatively stronger preference for collaboration in this area than France.

Factor ϕ_4: This axis accounts for 10.7% of the total variance (Figure 12.7).

On the cloud of subfields, this axis represents the opposition between *Virology* on the one hand and *Nutrition & Dietetics* and *Physiology* on the other.

On the country cloud, this axis is characterized by the opposition between Australia and Russia on the one hand and Canada on the other.

Russia and Australia are correlated to *Virology*, whereas Canada is correlated to *Physiology* and *Nutrition & Dietetics*.

The complex overlapping structure of relationships between countries and *Biomedical Research* subfields, as revealed by the Correspondence Analysis of the data, is summarized in Figure 12.8.

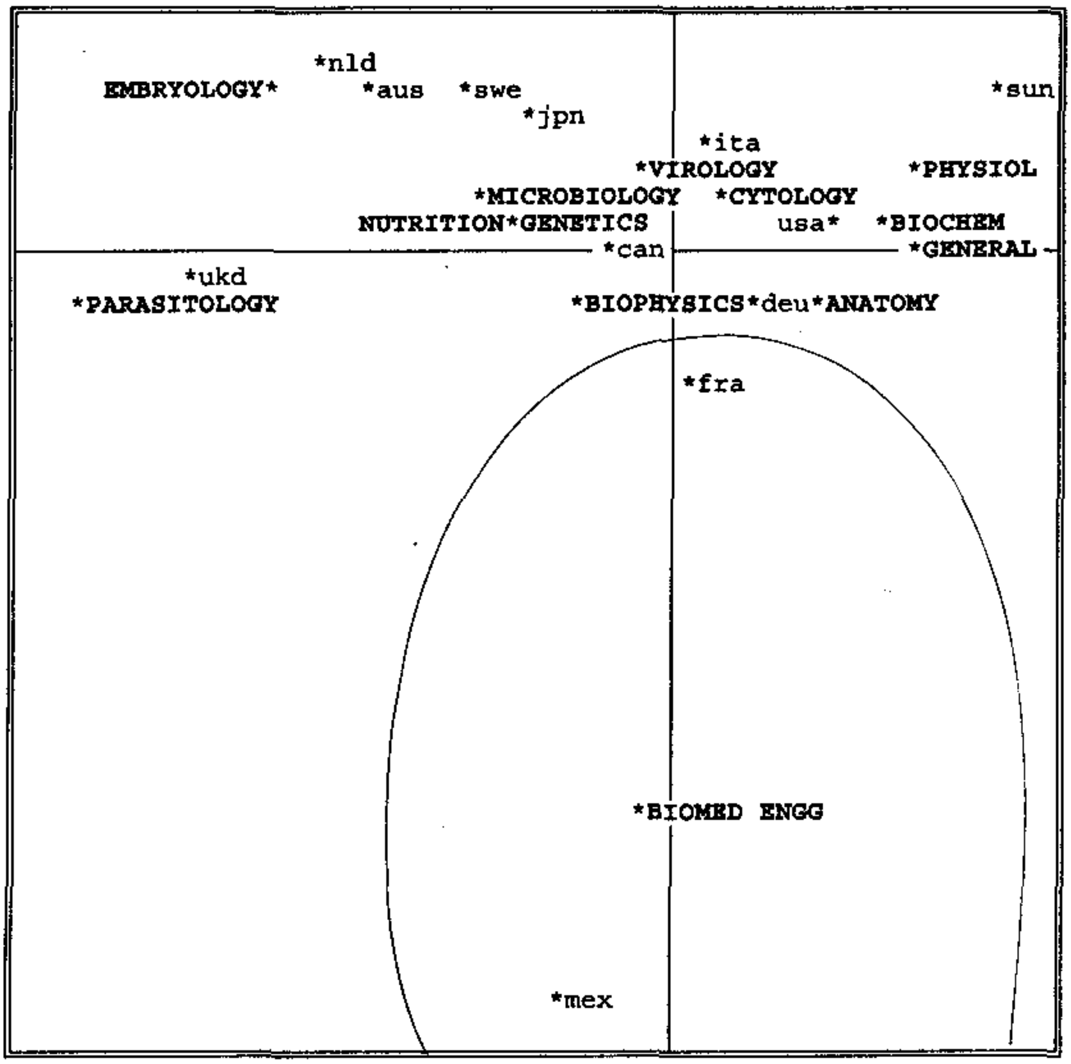


Fig. 12.6: Correspondence Analysis of transnational cooperation in Biomedical Research subfields

Notes:
Horizontal axis is dimension 1 with inertia = 0.1791 (35.3%)
Vertical axis is dimension 3 with inertia = 0.0617 (12.2%)

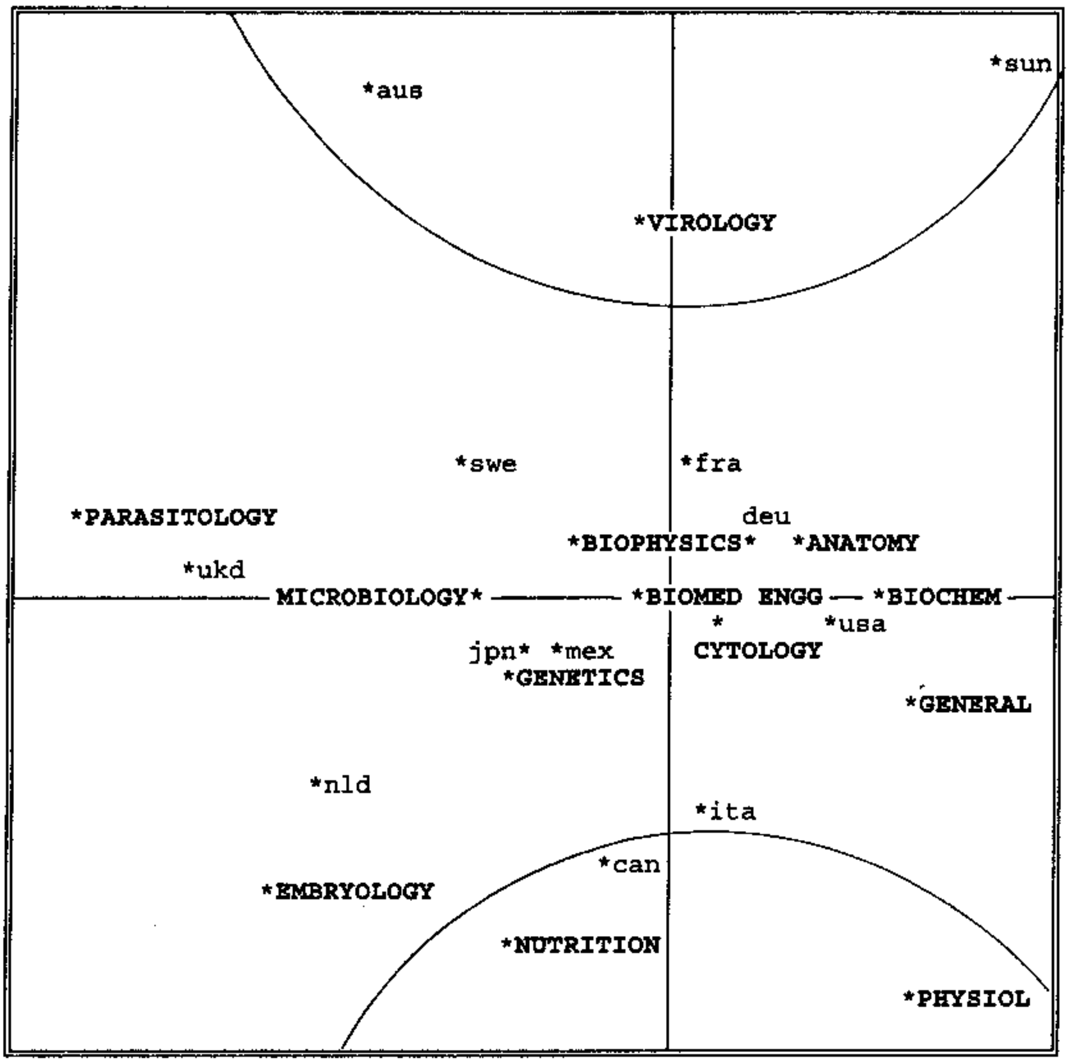


Fig. 12.7: Correspondence Analysis of transnational cooperation in Biomedical Research subfields

Notes:
Horizontal axis is dimension 1 with inertia = 0.1791 (35.3%)
Vertical axis is dimension 4 with inertia = 0.0541 (10.7%)

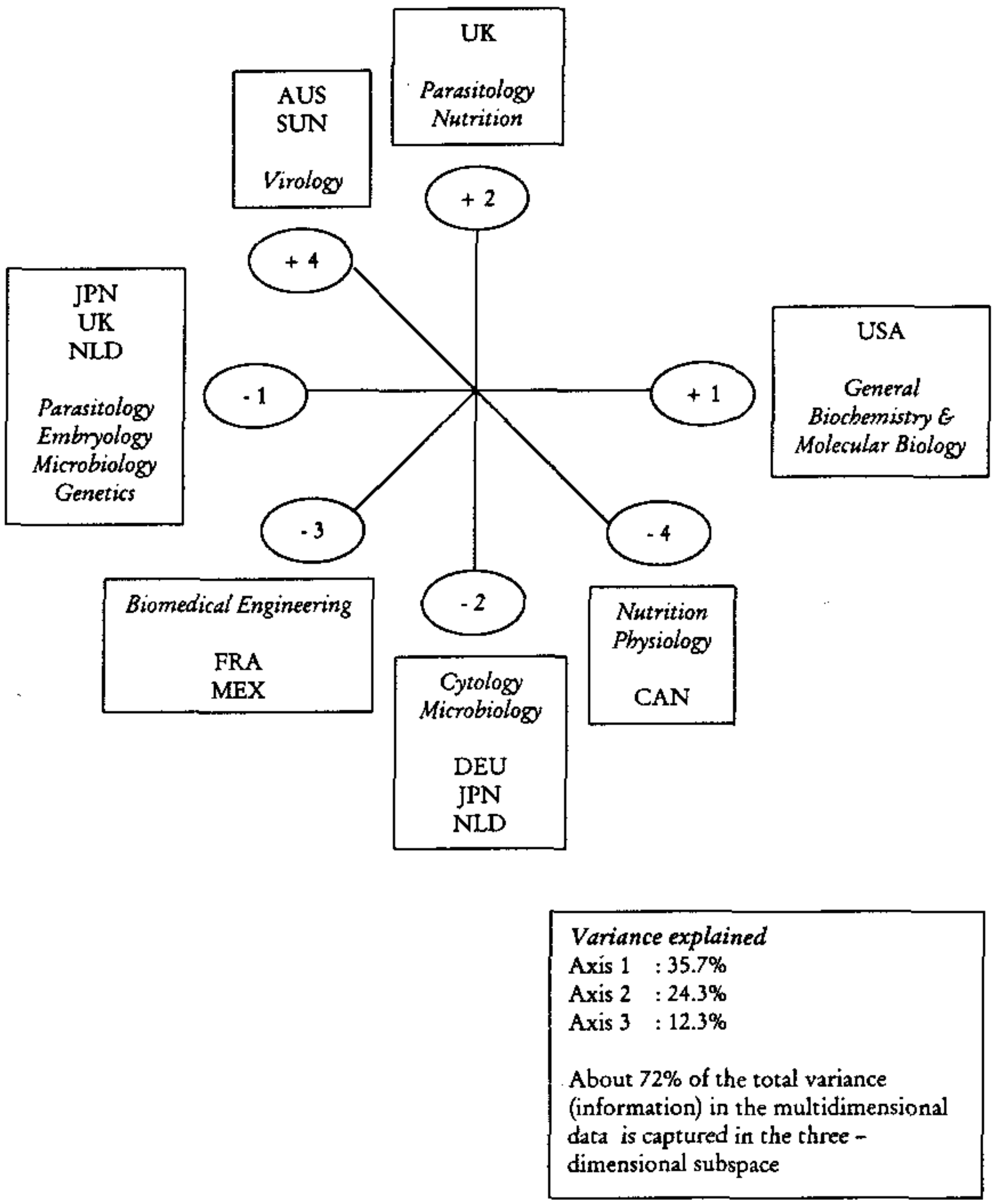


Fig. 12.8: Summary of correspondence analysis

13 Transnational Links in Engineering and Technology

This chapter analyzes the patterns of India's research output and transnational cooperation in different subfields of *Engineering & Technology* during the five - year period: 1990 - 1994.

1. General & Miscellaneous Engineering (*GEN*)
2. Aerospace Technology (*AER*)
3. Chemical Engineering (*CHEM*)
4. Civil Engineering (including Construction Engineering)(*CIV*)
5. Electrical and Electronics Engineering (*ELE*)
6. Mechanical Engineering (*MECH*)
7. Metals and Metallurgy (*MET*)
8. Nuclear Technology (*NUCL*)
9. Telecommunication Engineering (*TELE*)

General Overview of the Data

During this period, India had published 4316 articles (*Articles, Reviews, Notes* and *Letters*) in the *SCI* - covered journals in *Engineering & Technology*. Of these, 482 (11%) articles were internationally coauthored, indicating a total of 538 cooperation links, spanning over 44 countries. Only 17 countries had more than five cooperation links; the names of these countries are given in Table 13.1.

Table 13.1
India's Cooperation Links with Major Partners in *Engineering & Technology*

Country	*No. of Links*	%	*Country*	*No. of Links*	%	*Country*	*No. of Links*	%
USA	182	34.76	BGD	13	2.42	ROM	7	1.30
CAN	52	9.67	FRA	13	2.42	SAU	7	1.30
DEU	52	9.67	ITA	13	2.42	SWE	7	1.30
UKD	48	8.92	MEX	12	2.23	EGY	6	1.12
JPN	18	3.35	AUS	11	2.04	SGP	6	1.12
CHE	14	2.60	NLD	8	1.49	27 other countries	64	11.90

The distribution of cooperation links among these countries is highly skewed. USA alone accounts for more than one third of all cooperation links in this field. Canada and Germany, occupying the second rank are far behind, each accounting for less than 10% of all cooperation links.

Inter - Field Differences in Transnational Cooperation

Figure 13.1 depicts the distribution of articles, internationally coauthored articles (*ICOA*) and transnational cooperation links (*COP*) in different subfields of *Engineering & Technology*.

It can be easily seen that the proportions of articles and *ICOA*'s / *COP*'s do not always match with each other. For instance, *Chemical Engineering* accounts for 19.32% of all articles, but it accounts for only 14.52% of all *ICOA*'s and 14.13% of all *COP*'s. This means that *Chemical Engineering* attracts less transnational cooperation than *Engineering & Technology* as a whole. *Civil Engineering* accounts for 4.05% of all articles, but it accounts for 8.81% of all *ICOA*'s and 8.18% of all *COP*'s. This means that *Civil Engineering* attracts more (than average) transnational cooperation.

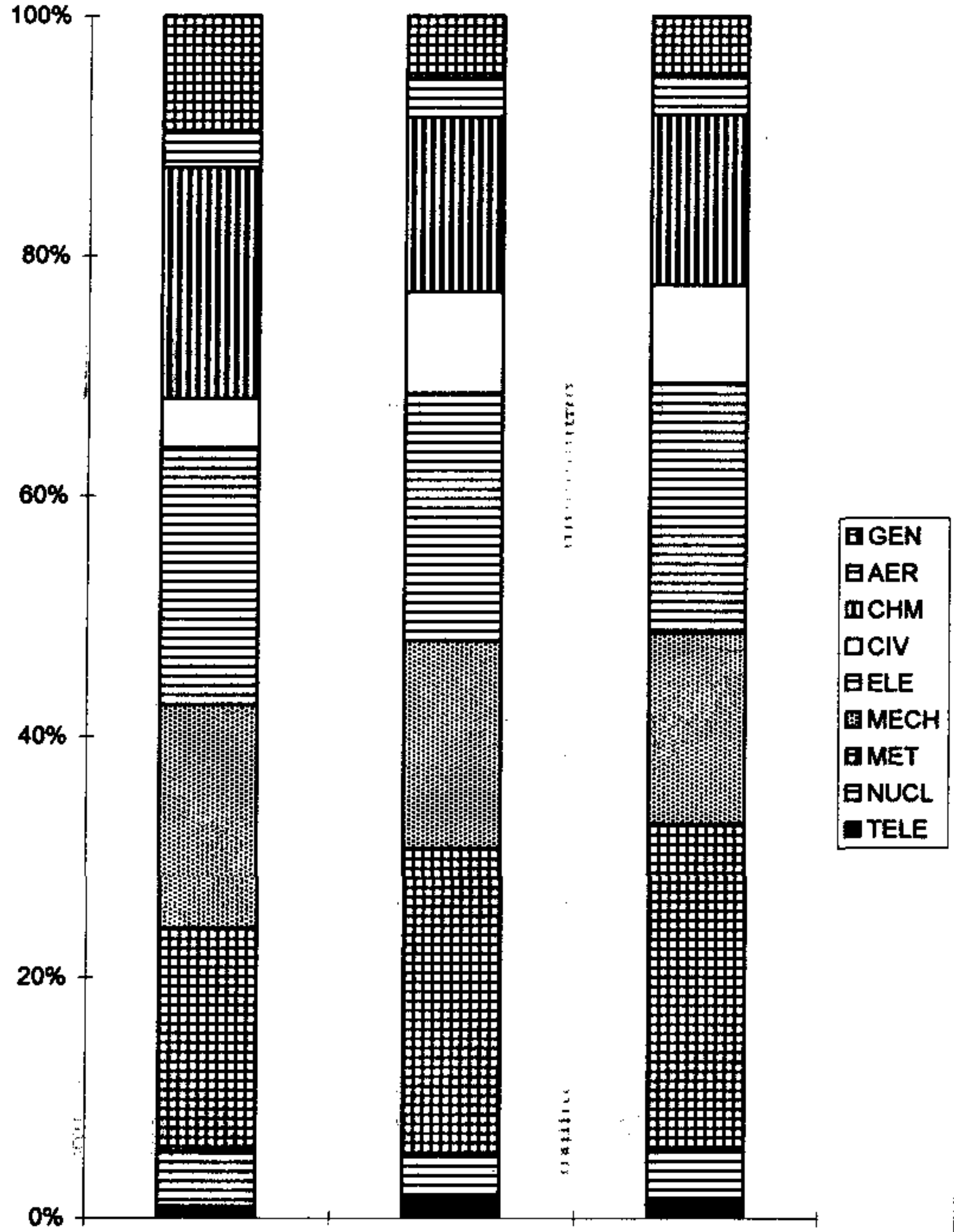


Fig. 13.1: Distribution of articles, internationally coauthored artilces (ICOA) and cooperation links (COP) in different subfields of Engineering & Technology

We have computed the following indices for assessing inter - field and inter - country differences in transnational cooperation.

(i.) Internationalization Index *(INI)*

(ii.) Cooperation Index *(COI)*

(iii.) Cooperation Extensiveness Index *(CEI)*

(iv.) Affinity Index *(AFI)*

These indices are defined in Chapter 4. Table 13.2 presents the data on the output of articles, internationally coauthored articles *(ICOA)* and cooperation links *(COP)* and associated indicators for different subfields of *Engineering & Technology*.

Table 13.2
Publication Output and Cooperative Links in Different Subfields of *Engineering & Technology* (1990 - 1994)

Subfield	*No. of Articles*	*ICOA*	*No. of Links*	*Internationalization Index INI %*	*Cooperation Index COI %*	*Cooperation Extensiveness Index CEI*
Gen & Misc Engg	417	25	27	5.99	6.47	1.08
Aerospace	129	16	17	12.4	13.18	1.06
Chemical Engg	834	70	76	8.39	9.11	1.09
Civil Engg	175	41	44	23.43	25.14	1.07
Electrical & Electronics	921	99	111	10.75	12.05	1.12
Mechanical Engg	802	83	85	10.35	10.60	1.02
Metals & Metallurgy	800	123	145	15.37	18.12	1.18
Nuclear Technology	197	17	21	8.63	10.66	1.23
Telecommunication	41	8	9	19.51	21.95	1.12
Total	4316	482	538	11.03	12.49	1.12

Civil Engineering is the most internationalizational subfield. About one fourth of all articles in this subfield are internationally coauthored. *Aerospace Engineering*, *Metals & Metallurgy* and *Telecommunication* have above average values of *Internationalization Index*.

Electrical & Electronics Engineering and *Mechanical Engineering* have about average values of *Internationalization Index*. The values of *COI* also reveal a similar trend. *Nuclear Technology* has less than average level of internationalization, but involves relatively more frequent multilateral cooperation than the other subfields of *Engineering & Technology*.

Inter – Country Differences in Transnational Cooperation

Inter – country differences in transnational cooperation were assessed by computing the *Affinity Index* (*AFI*).

Figure 13.2 depicts India's affinities towards its eleven partners, which had at least ten cooperation links in *Engineering & Technology*. USA occupies the most important position in India's transnational cooperation in this field. About 35% of India's transnational links are with USA. Canada and Germany occupy the second position, each accounting for about 10% of all transnational links. Japan, a world leader in Technology, accounts for only 3% of India's transnational links.

Figure 13.3 depicts India's affinities for each of its four most important partners (USA, Canada, Germany and UK) in nine subfields. Figure 13.4 represents India's affinities towards its eleven significant partners (USA, Canada, Germany, UK, Japan, Switzerland, Bangladesh, France, Italy, Mexico and Australia) separately for each subfield. These figures are self – explanatory and any elaboration would be redundant.

Country	*Subfields of*	
	Highest affinity	*Lowest affinity*
USA	Chemical Engineering	Nuclear Technology
Canada	General Engineering	Nuclear Technology, Telecommunication
Germany	Nuclear Technology	Civil Engineering, Electrical & Electronics Mechanical Engineering
UK	Civil Engineering Electrical & Electronics	Nuclear Technology, Telecommunication
Japan	Telecommunication	Civil Engineering
Switzerland	Nuclear Technology	Aerospace, Mechanical Engineering Telecommunication

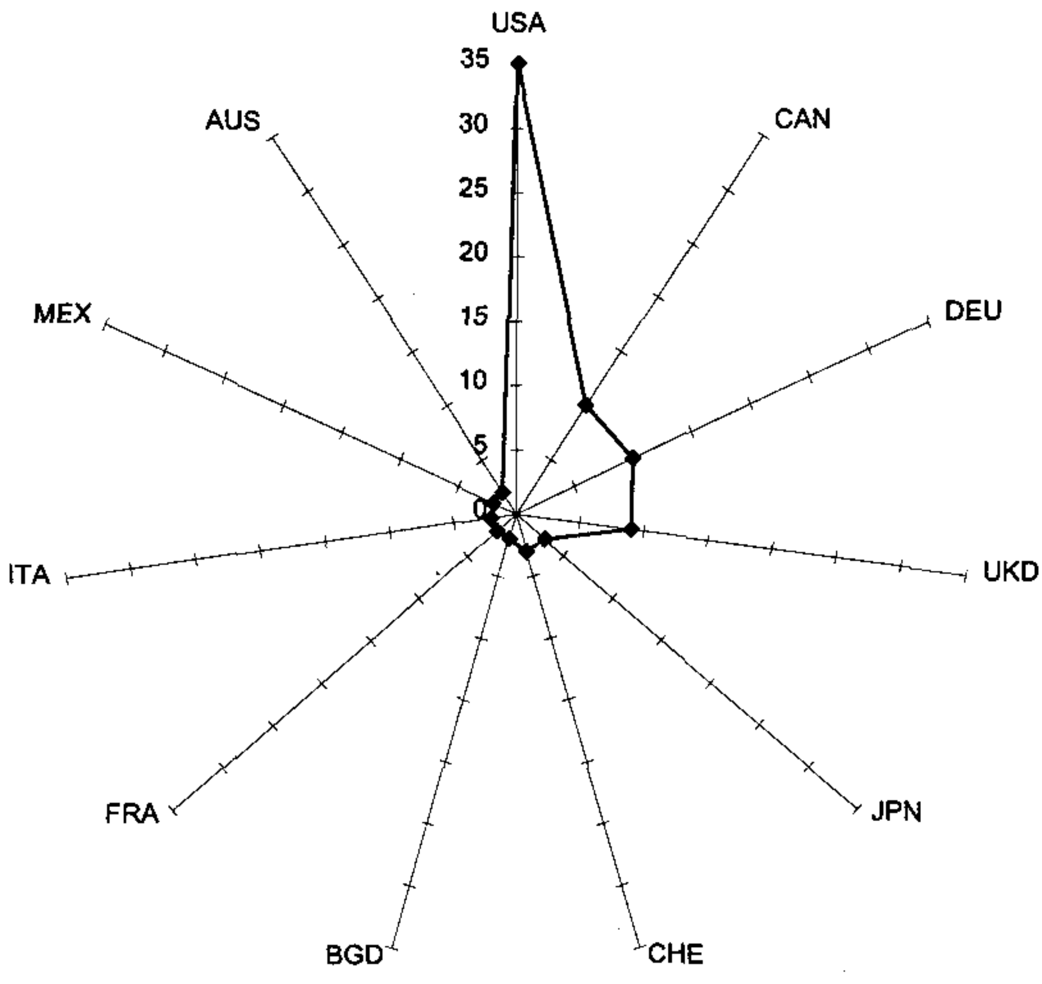


Fig. 13.2: India's linkages in Engineering and Technology (1990-1994)
(Affinity Index)

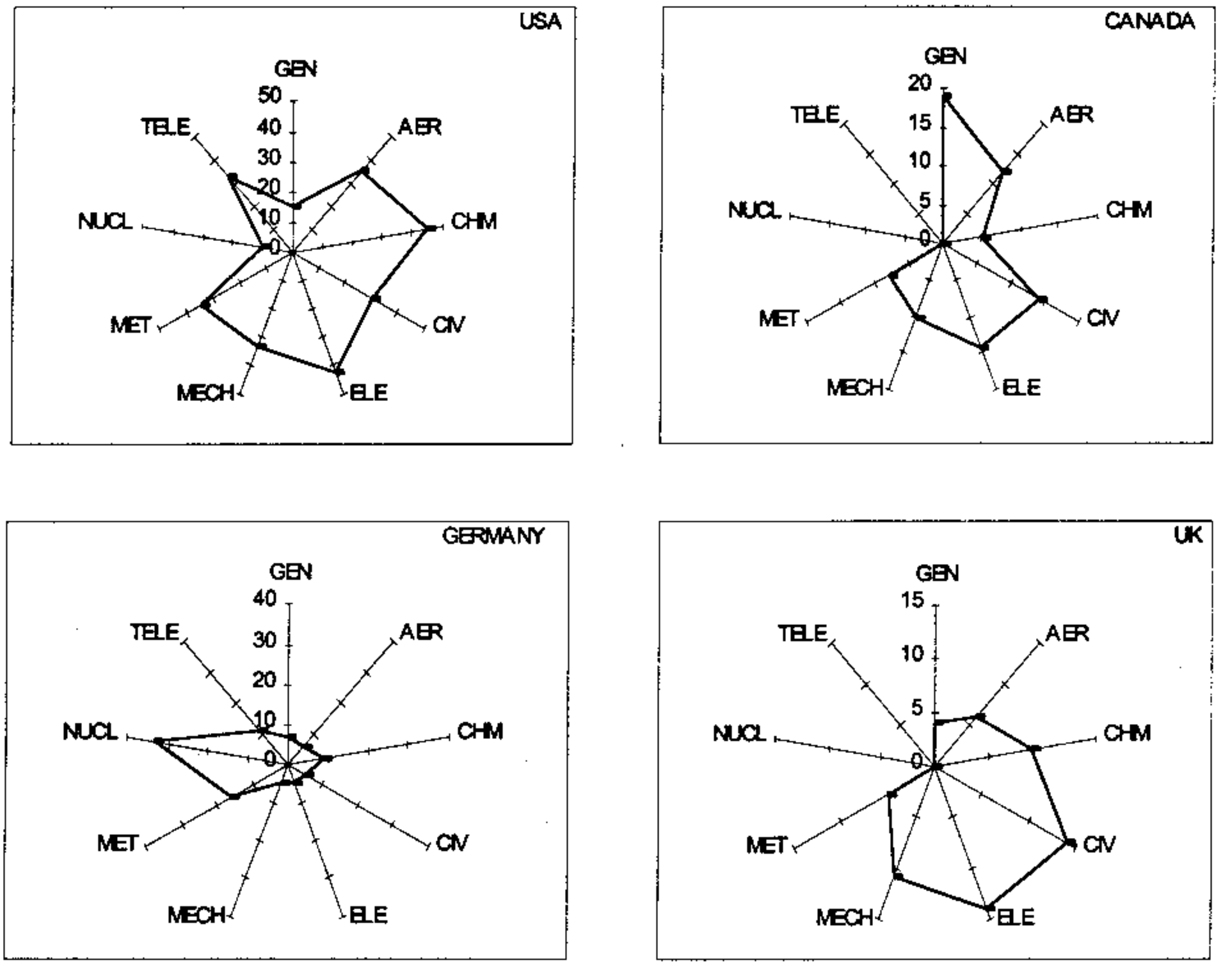


Fig. 13.3: India's affinities towards major cooperating countries in different subfields of Engineering & Technology (1990-1994)
(Affinity Index)

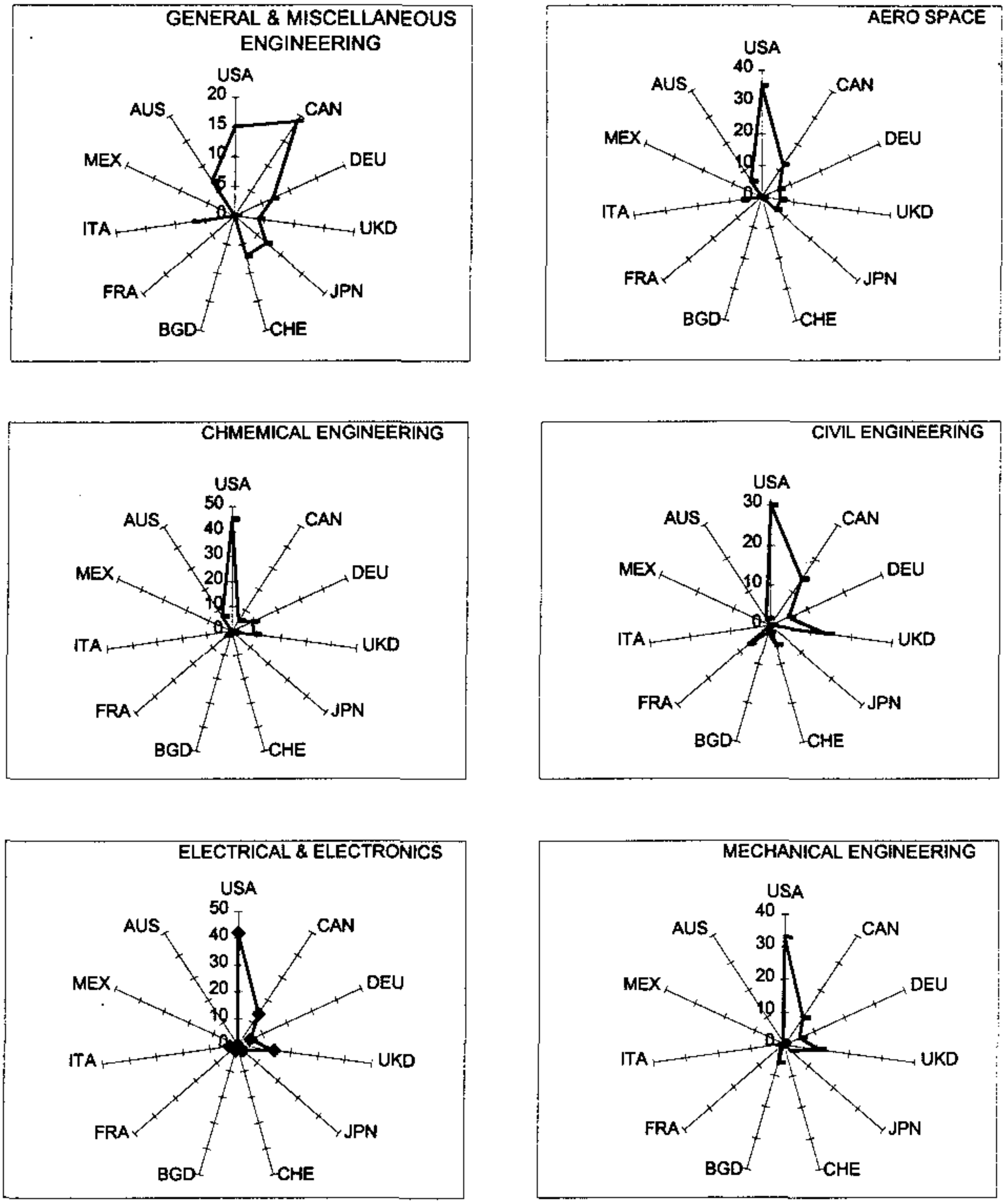


Fig. 13.4: India's linkages in different subfields of Engineering & Technology (1990-1994)
(Affinity Index)

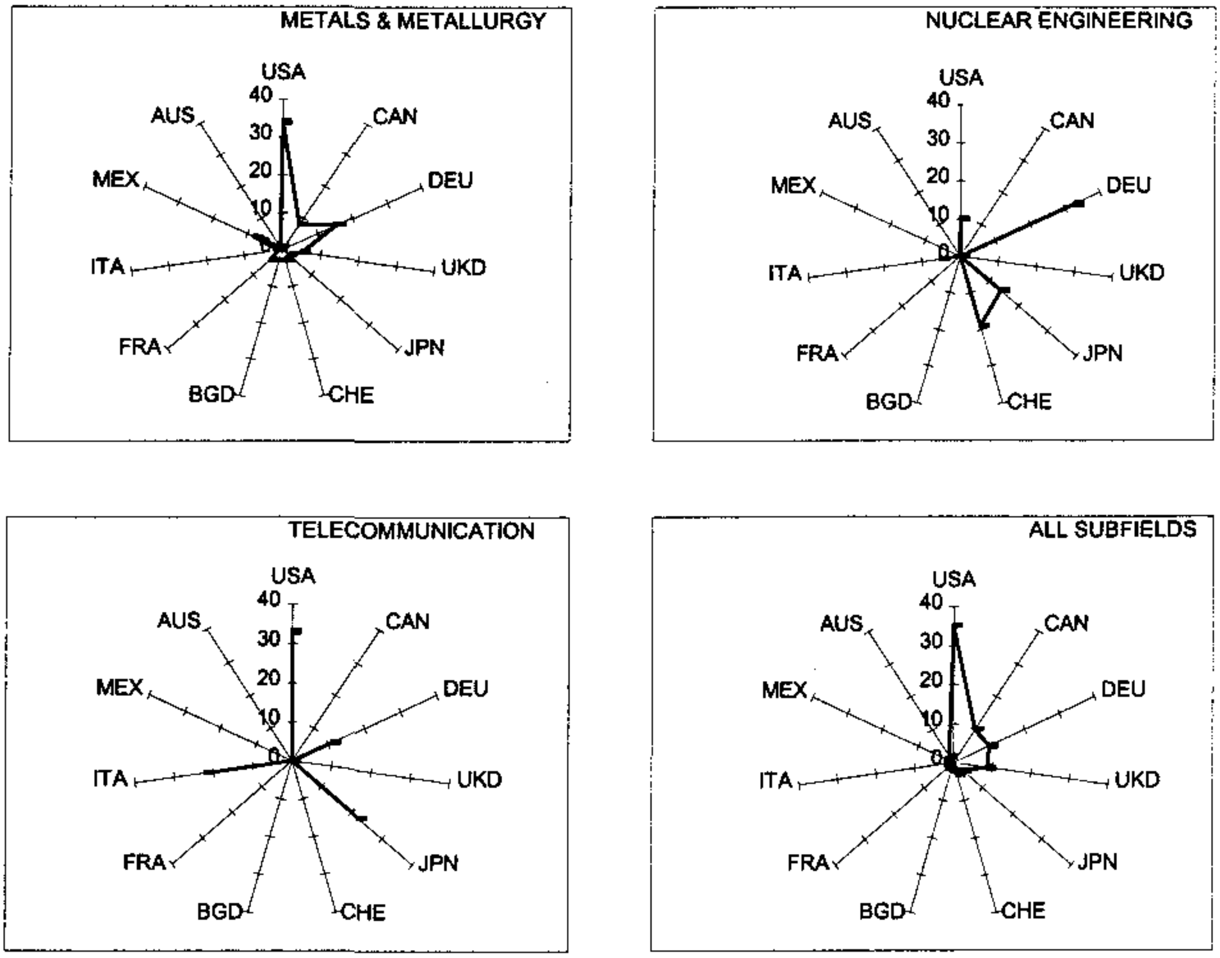


Fig. 13.4 (Contd.): India's linkages in different subfields of Engineering & Technology (1990-1994)
(Affinity Index)

Structure of Transnational Cooperation

The foregoing country - by - country and field - by - field analyses of India's transnational cooperation links are quite enlightening, but they are also time - consuming. They provide unidimensional views of the data, which are essentially multidimensional.

The multidimensional structure of India's relationships with its eleven significant partners in nine subfields was analyzed through Correspondence Analysis, using the computer program SimCA. Correspondence Analysis shows how India's significant partners are placed relative to each other and different research areas of *Engineering & Technology.*

Eigen values computed by the program indicate that the total variance ($\Sigma\lambda i$ = .454876) is quite large, implying wide variations in the amplitudes of cooperation profiles of India's significant partners. The first three factorial axes account for about 80% of the total variance in the multidimensional data. Of these, the first two factorial axes account for 68.2% of the total variance, whereas the third factorial axis accounts for 12.2% of the total variance. The remaining axes, indicating successively smaller amounts of variance, represent information of a random nature that does not have any bearing on the structure of the multidimensional data. Thus, the two - dimensional map, spanned by the first two factorial axes, represents the most essential features of the multidimensional data. The third factorial axis provides complementary information for further elaboration and interpretation of the data. All research fields and all countries (except Canada) are quite well represented in the three - dimensional subspace.

The results of Correspondence Analysis are presented in Tables 13.3 and 13.4.

Figure 13.5 presents the two - dimensional factorial map spanned by ϕ_1 and ϕ_2 axes, summing up 68.2% of the total variance.

Table 13.3
Contributions of explicative points to the composition of the first three factorial axes (Absolute contribution)*

Cloud	*Explicative points with positive coordinates*	*Explicative points with negative coordinates*
	Axis 1 (λ_1 = 0.183481, τ_1 = 40.34%)	
Subfields	Electrical and Electronics (154)	Nuclear Technology (542)
Countries	USA (89) UK (122)	Germany (259) Japan (105) Switzerland (302)
	Axis 2 (λ_2 = 0.126896, τ_2 = 27.90%)	
Subfields	Telecommunication (199) General and Miscellaneous Engineering (170)	Metals (471)
Countries	Italy (256) Japan (189)	Mexico (362)
	Axis 3 (λ_3 = 0.055434, τ_3 = 12.19%)	
Subfields	Telecommunication (299)	Chemical Engineering (272) Civil Engineering (165)
Countries	Japan (103) Italy (141)	Australia (361)

Note: Values are in permills (%)

Table 13.4
Contributions of the explained points to the eccentricities of the first three factorial axes (Relative *contribution, permill*)

Cloud	*Explained points with positive coordinates*	*Explained points with negative coordinates*
	Axis 1 (λ_1 = 0.183481, τ_1 = 40.34%)	
Subfields	Electrical and Electronics (652) Metallurgy (460)	Nuclear Technology (808)
Countries	USA (688) UK (760)	Germany (878) Japan (392) Switzerland (756)
	Axis 2 (λ_2 = 0.126896, τ_2 = 27.90%)	
Subfields	Aerospace (587) Telecommunication (448) General and Miscellaneous Engineering (470)	Metals (695)
Countries	Japan (486) Italy (669)	France (496) Mexico (657)
	Axis 3 (λ_3 = 0.055434, τ_3 = 12.19%)	
Subfields	Telecommunication (295)	Chemical Engineering (396) Civil Engineering (345)
Countries	–	Australia (485)

Note: Values are in permills (‰)

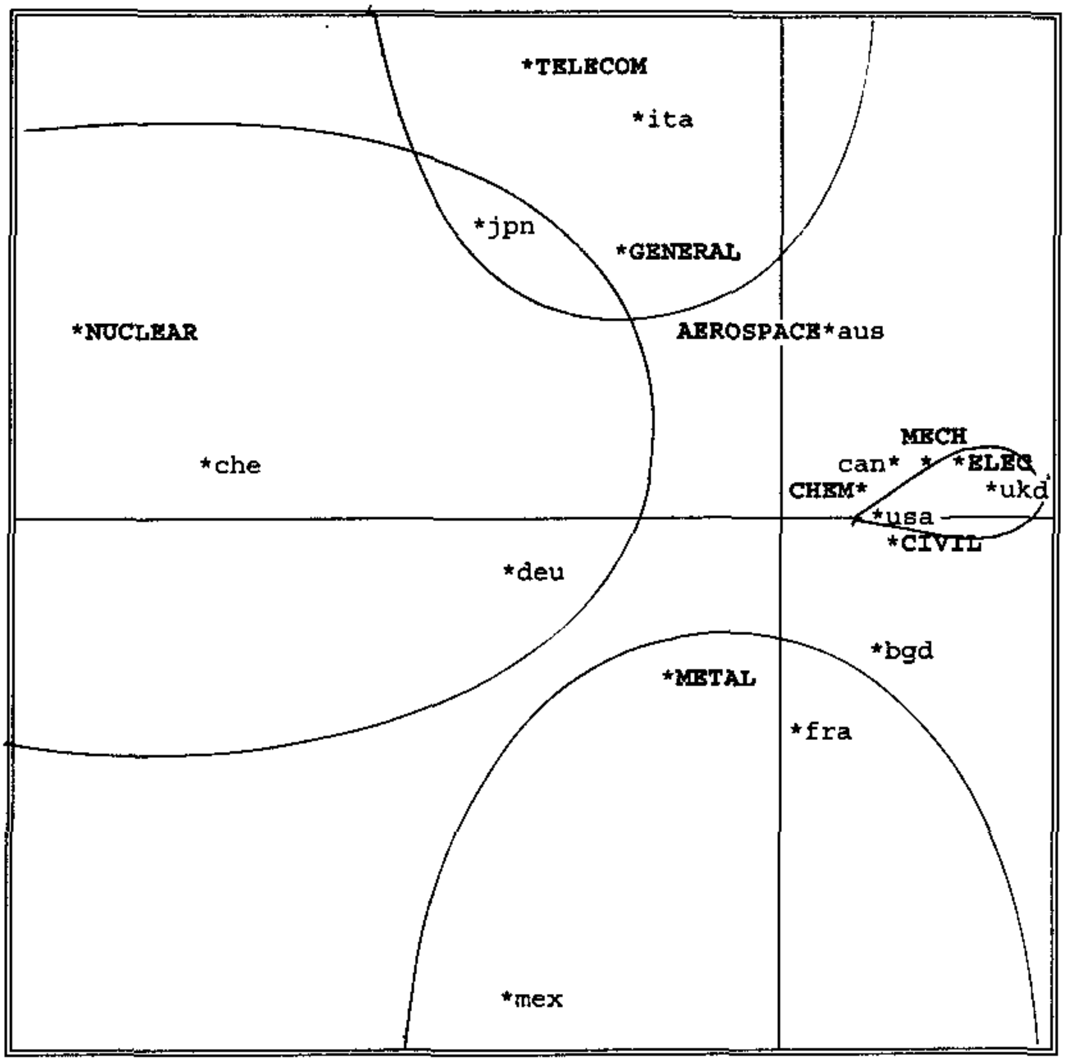


Fig. 13.5: Correspondence Analysis of transnational cooperation in Engineering & Technology subfields

Notes:
Horizontal axis is dimension 1 with inertia = 0.1835 (40.3%)
Vertical axis is dimension 2 with inertia = 0.1269 (27.9%)
68.2% of total inertia is represented in the above map

Factor ϕ_1: The first factorial axis, accounting for 40.3% of the total variance, constitutes the most important element of the multivariate structure of relationships between countries and subfields of *Engineering & Technology*.

On the cloud of subfields, this axis is characterized by the opposition between *Electrical & Electronics Engineering* which is projected with positive coordinate and *Nuclear Technology* which is projected with negative coordinate.

On the country cloud, this axis is characterized by the opposition between USA and UK on the one hand and Germany, Japan and Switzerland on the other. USA and UK are projected on this axis with positive coordinates; these countries are therefore correlated to *Electrical and Electronics Engineering*. Japan, Germany and Switzerland are projected on this axis with negative coordinates and are therefore correlated to *Nuclear Technology*.

Factor ϕ_2: This axis, accounting for 27.9% of the total variance, constitutes the second most important element of the multivariate structure of relationships between countries and subfields of *Engineering & Technology*.

On the cloud of subfields, this axis is characterized by the opposition between *Telecommunication* and *General Engineering* on the one hand and *Metals & Metallurgy* on the other. *Telecommunication* and *General Engineering* are projected on this axis with positive coordinates, whereas *Metals & Metallurgy* is projected with negative coordinate.

On the country cloud, the axis is characterized by the opposition between Italy and Japan on the one hand and France and Mexico on the other. Italy and Japan are projected on this axis with positive coordinates and are therefore correlated to *Telecommunication* and *General Engineering*. France and Mexico, which are projected with negative coordinates are correlated to *Metals & Metallurgy*.

Factor ϕ_3: This factorial axis accounts for 12.2% of the total variance. Figure 13.6 depicts two – dimensional factorial map spanned by ϕ_1 and ϕ_3 axes.

On the cloud of subfields, this axis is characterized by the opposition between *Telecommunication* on the one hand and *Chemical Engineering* and *Civil Engineering* on the other. These two subfields are projected on this axis with negative coordinates, whereas *Telecommunication* is projected on this axis with positive coordinate.

On the country cloud, this factorial axis does not exhibit polarity. Australia is projected on this axis with negative coordinate, and is therefore correlated to *Chemical Engineering* and *Civil Engineering*. These two subfields are prominent in the mutual cooperation between India and Australia.

The results of Correspondence Analysis are summarized in Figure 13.7.

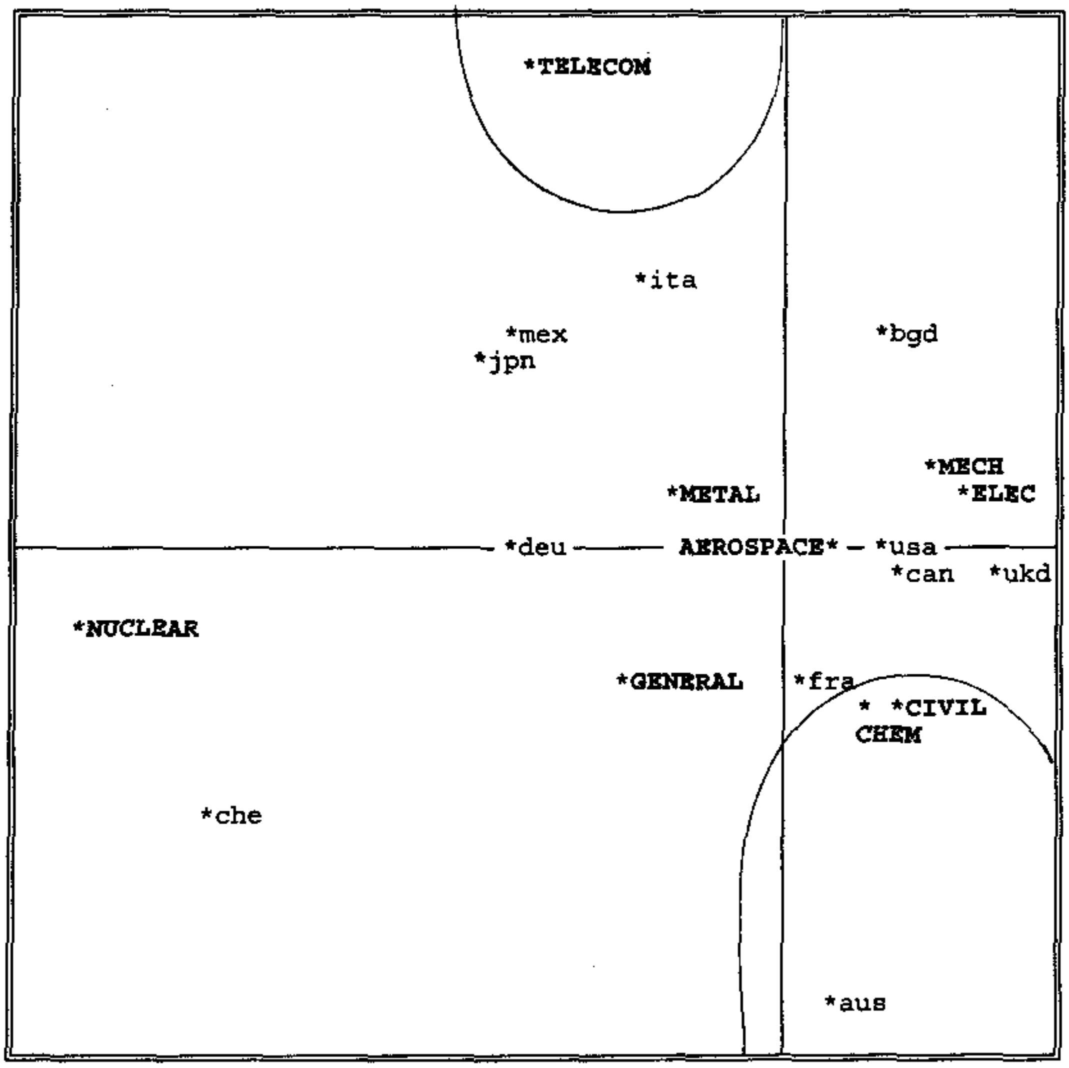


Fig. 13.6: Correspondence Analysis of transnational cooperation in Engineering & Technology subfields

Notes:
Horizontal axis is dimension 1 with inertia = 0.1835 (40.3%)
Vertical axis is dimension 3 with inertia = 0.0554 (12.2%)

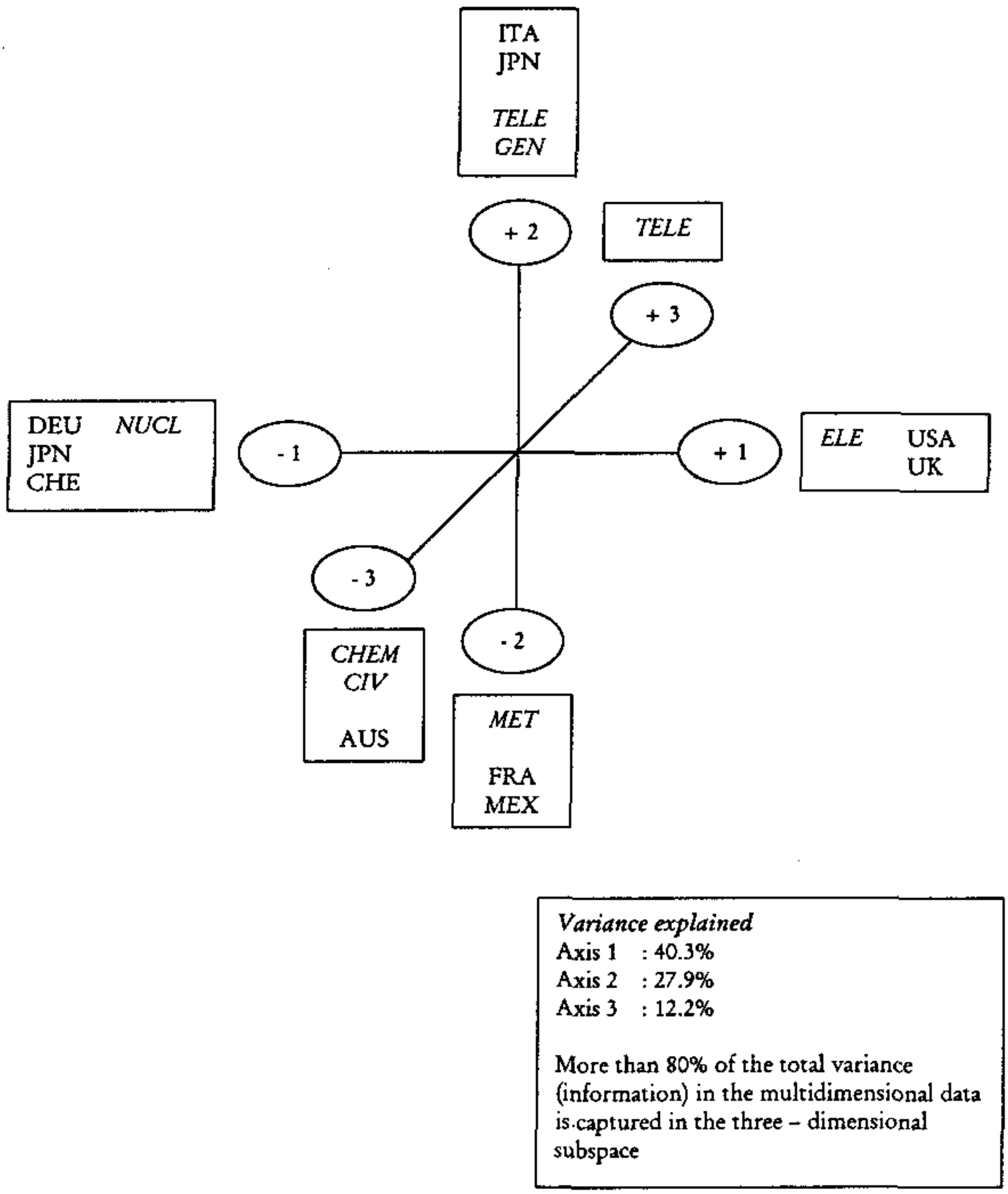


Fig. 13.7: Summary of correspondence analysis

14 Transnational Links in Materials Science

India had contributed 1950 articles (*Articles*, *Reviews*, *Notes* and *Letters*) in the mainstream literature in eight different subfields of *Materials Science*. Of these, 192 articles (9.85%) were internationally coauthored, indicating a total of 207 cooperation links, spanning over 23 countries:

1. General Materials Science (*GEN*)
2. Biomaterials (*BIO*)
3. Ceramics (*CER*)
4. Characterization of Materials (*CHA*)
5. Coatings & Films (*CTG*)
6. Composites (*CMP*)
7. Papers & Pulp (*PAP*)
8. Fibres & Textiles (*FIB*)

The distribution of cooperation links among the countries is highly skewed. USA alone accounts for about 38% of all cooperation links in this field; UK, which ranks second is far behind, accounting for 16% of all links. Only eight countries had more than five cooperation links. The names of these countries are given in Table 14.1.

Inter – Field Differences in Transnational Cooperation

Figure 14.1 depicts the distribution of articles, internationally coauthored articles (ICOA) and transnational cooperation links in different subfields of *Materials Science*. It can be

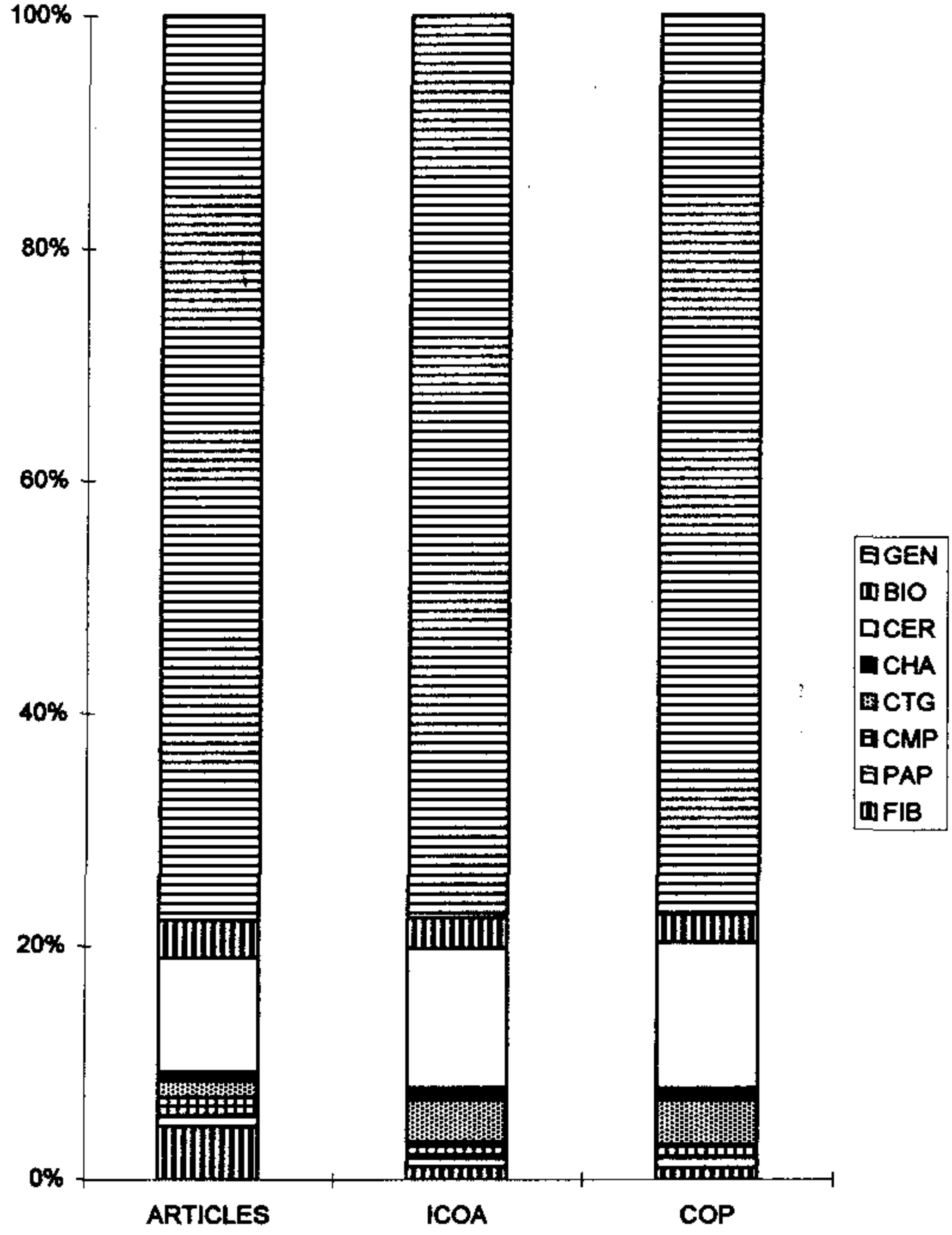


Fig. 14.1: Distribution of articles, internationally coauthored articles (ICOA) and cooperation links (COP) in different subfields of Materials Science

easily seen that the proportions of articles and *ICOA*'s / *COP*'s do not always match with each other. For example, *Biomaterials* attracts less transnational cooperation than expected on the basis of publication output. *Ceramics* and *Coatings & Films* attract relatively more cooperation than expected on the basis of publication output. *Fibres*, *Textiles* and *Leather* hardly attract any transnational cooperation.

Table 14.1
India's Cooperation Links with Major Partners in *Materials Science*

Country	*No. of Links*	%	*Country*	*No. of Links*	%	*Country*	*No. of Links*	%
USA	78	37.68	DEU	16	7.73	ITA	9	4.35
UKD	33	15.94	CAN	13	6.28	ESP	7	3.38
FRA	20	9.66	JPN	10	4.83	Other 15 countries	19	11.29

Inter - field differences, however, can be assessed more systematically through the following relational indicators:

(i.) Internationalization Index (*INI*)

(ii.) Cooperation Index (*COI*)

(iii.) Cooperation Extensiveness Index (*CEI*)

These indices are defined in Chapter 4. Table 14.2 presents the data on the output of articles, internationally coauthored articles (*ICOA*) and transnational cooperation links (*COP*) and associated indicators: *INI*, *COI* and *CEI*.

The values of *INI* and *COI* reveal more or less similar trends, implying that cooperation links are mostly bilateral. This is also confirmed from the values of *CEI*, which range between 1.00 and 1.14. *Coatings & Films* is the most internationalized area of *Materials Science*, followed by *Characterization of Materials* and *Ceramics*, whereas *Paper & Pulp* is the least internationalized area. *Coatings & Films* and *Ceramics* have higher than average values of *CEI*; these subfields have greater tendency towards multilateral cooperation than the other subfields of *Materials Science*.

Table 14.2
Publication Output and Cooperation Links in *Materials Science* subfields (1990-1994)

Subfield	*No. of Articles*	*ICOA*	*No. of Links*	*Internationalization Index INI %*	*Cooperation Index COI %*	*Cooperation Extensiveness Index CEI*
General Materials Science	1517	149	160	9.82	10.61	1.07
Biomaterials	63	5	5	7.94	7.94	1.00
Ceramics	191	23	26	12.04	13.61	1.13
Characterization	15	2	2	-	-	-
Coatings & Films	28	7	8	25.00	28.57	1.14
Composites	29	2	2	-	-	-
Paper & Pulp	19	2	2	-	-	-
Fibers & Textiles	88	2	2	-	-	-
Total	1950	192	207	10.37	10.61	1.08

Note: Indices are computed only when the number of links ≥ 5

Inter - Country Differences in Transnational Cooperation

Inter - country variations in transnational cooperation were assessed by computing the *Affinity Index*. Figure 14.2 depicts India's affinities towards its six major partners in *Materials Science* (all subfields combined). Figure 14.2 also represents India's affinities towards its six significant partners separately for two subfields (*General Materials Science* and *Ceramics*). Affinity Indices for other subfields were not computed since they had only a few links. This figure is self - explanatory and needs no elaboration.

Structure of Transnational Cooperation

The structure of India's cooperation links with its six major partners (USA, UK, France, Germany, Canada and Japan) in eight subfields of *Materials Science* was analyzed through Correspondence Analysis, using the computer program SimCA. The results of Correspondence Analysis are presented in Tables 14.3 and 14.4. Correspondence analysis shows how India's major partners are placed relative to each other and different research areas of *Materials Science*.

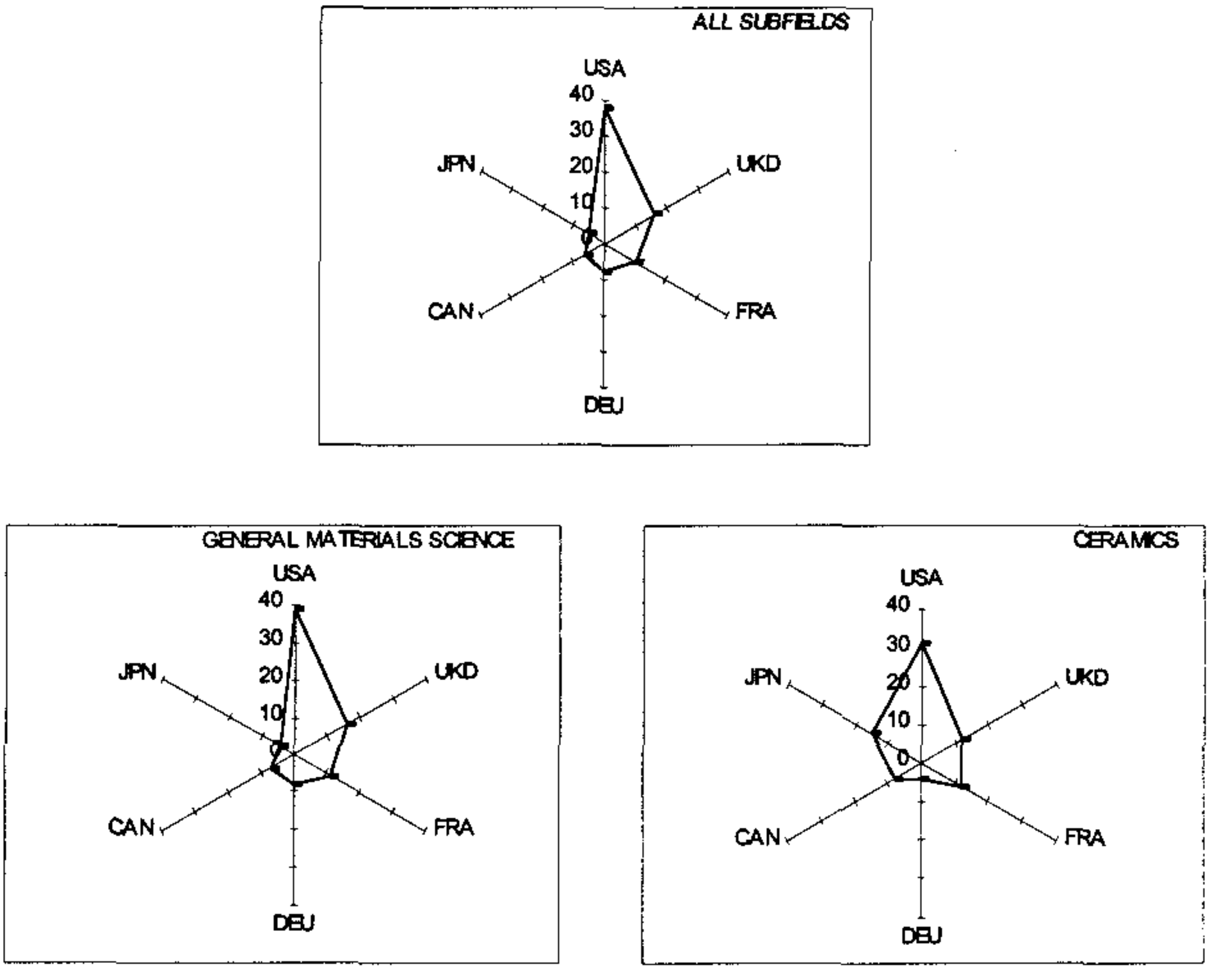


Fig. 14.2: India's linkages in different subfields of Materials Science (1990-1994)
(Affinity Index)

Table 14.3
Contributions of explicative points to the composition of the first three factorial axes (Absolute contribution)*

Cloud	*Explicative points with positive coordinates*	*Explicative points with negative coordinates*
	Axis 1 (λ_1 = 0.091177, τ_1 = 51.49%)	
Subfields	—	Characterization (275) Composites (275) Paper & Pulp (275)
Countries	—	Germany (731)
	Axis 2 (λ_2 = 0.059822, τ_2 = 33.78%)	
Subfields	Biomaterials (218) Coatings & Films (276)	Ceramics (482)
Countries	UK (350)	Japan (498)

Note: Values are in permills (‰)

Table 14.4
Contributions of the explained points to the eccentricities of the first three factorial axes (Relative contribution)*

Cloud	*Explained points with positive coordinates*	*Explained points with negative coordinates*
	Axis 1 (λ_1 = 0.091177, τ_1 = 51.49%)	
Subfields	—	Characterization (967) Composites (967) Paper & Pulp (967)
Countries	UK (286)	Germany (956)
	Axis 2 (λ_2 = 0.059822, τ_2 = 33.78%)	
Subfields	Biomaterials (729) Coatings & Films (610)	Ceramics (610)
Countries	UK (573)	Japan (673) Canada (373) France (346)

Note: Values are in permills (‰)

Eigen values issued from the Correspondence Analysis indicate that the total variance ($\Sigma\lambda i = 0.177079$) is sufficiently large, implying variations in the amplitudes of cooperation profiles of these countries. The first two factorial axes, ϕ_1 and ϕ_2, account for 85.3% of the total variance. Thus the two - dimensional factorial map, spanned by ϕ_1 and ϕ_2 axes, represents the main features of the multidimensional data.

Figure 14.4 presents the two - dimensional factorial map spanned by the first two axes, summing up 85% of the total variance.

Factor ϕ_1: The first factorial axis, accounting for 51.5% of the total variance, represents the most important features of the data. This is a unipolar factor characterized by three subfields: *Characterization of Materials*, *Composites* and *Paper & Pulp*, which are projected with negative coordinates. On the country cloud, this factor is characterized by Germany, which is projected with negative coordinate. This means, that India collaborates with Germany mainly in these three subfields. The remaining five countries (USA, UK, France, Italy and Spain) do not emphasize these subfields in their cooperation with India.

Factor ϕ_2: The second factorial axis accounts for 33.8% of the total variance.

On the cloud of subfields, this axis is characterized by the opposition between *Biomaterials* and *Coatings & Films* on the one hand and *Ceramics* on the other. *Biomaterials* and *Coatings & Films* are projected with positive coordinates, whereas *Ceramics* is projected with negative coordinate.

On the country cloud, this axis is characterized by the opposition between UK (projected on this axis with positive coordinate) and Japan (projected with negative coordinate). This implies that India cooperates with UK mainly in *Biomaterials* and *Coatings & Films*, and with Japan in *Ceramics*.

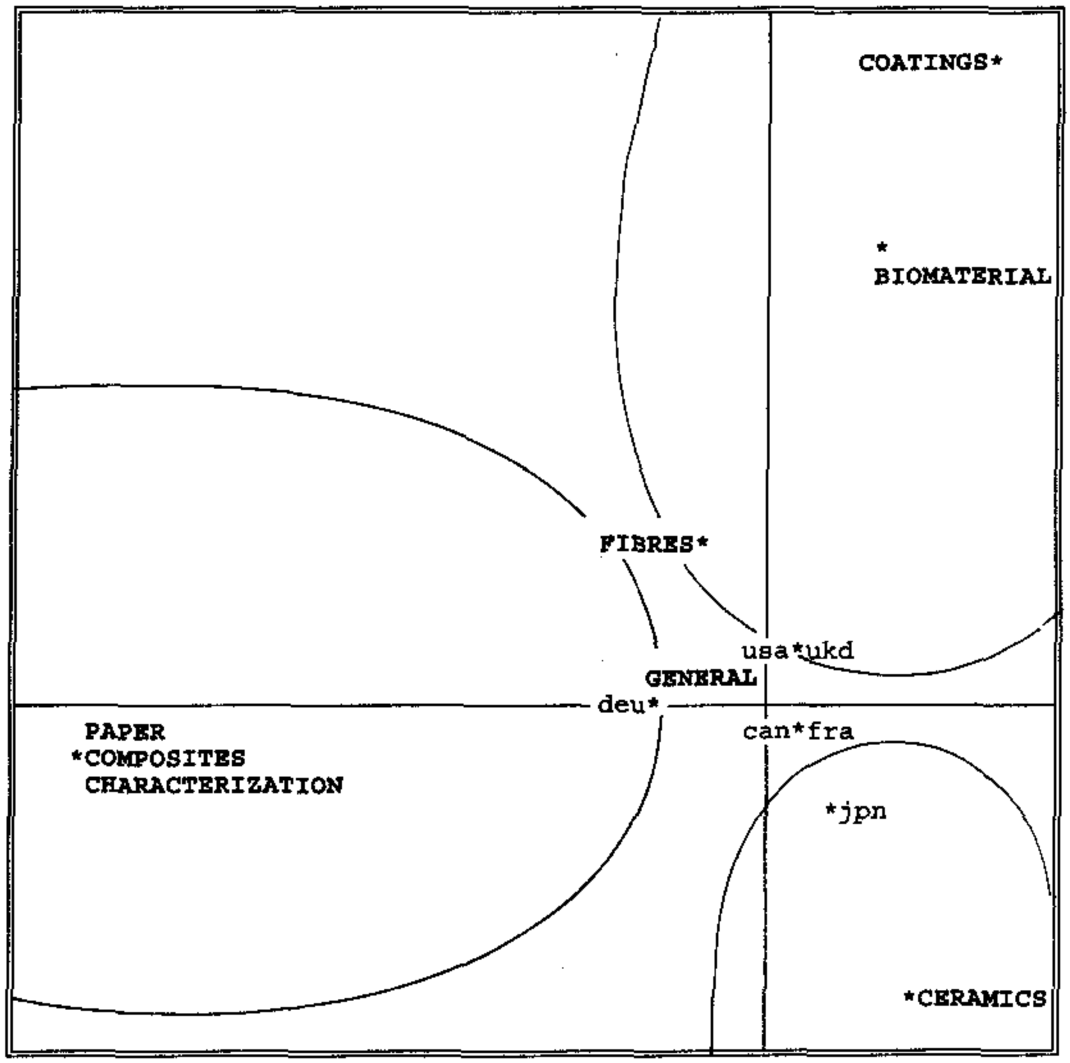


Fig. 14.4: Correspondence Analysis of transnational cooperation in Materials Science subfields

Notes:
Horizontal axis is dimension 1 with inertia = 0.0912 (51.5%)
Vertical axis is dimension 2 with inertia = 0.0598 (33.8%)

The remaining countries, viz. USA, France and Canada have more or less average profiles. Similarly, *Fibres & General Materials* also have more or less average profiles.

Thus the set of six countries can be classified into the following four typology categories:

Typology Group	*Countries*	*Subfields of Prominence*
Type 1	UK	Coatings & Films Biomaterials
Type 2	Japan	Ceramics
Type 3	Germany	Composites Characterization Paper & Pulp
Type 4	USA, Canada, France	Average Profile

15 Transnational Links in Computer Science

During the five - year period: 1990 - 1994, India had published 410 articles in *Computer Science* journals, covered in the *Science Citation Index*. Of these, 84 articles (20.5%) were internationally coauthored, indicating 105 cooperation links, spanning over 19 countries. The articles are classified into the following nine subfields:

1. Artificial Intelligence (*AI*)
2. Cybernetics (*CYB*)
3. Computer Hardware (*HARD*)
4. Information Systems (*INF*)
5. Computer Applications (*APP*)
6. Computer Software (*SOFT*)
7. Robotics (*ROBOT*)
8. Computer Theory (*THEO*)
9. Miscellaneous (*MISC*)

Table 15.1 presents the data on India's cooperation links with its significant partner countries. The distribution of links among the cooperating countries is highly skewed. USA alone accounts for about 47% of all cooperation links in this field. Canada and Switzerland rank second, but they are far behind USA, each accounting for only 11.4% of all cooperation links.

Table 15.1
India's Cooperation Links with Major Partners in *Computer Science*

Country	*No. of Links*	%	*Country*	*No. of Links*	%	*Country*	*No. of Links*	%
USA	49	46.67	DEU	4	3.81	NLD	3	2.86
CAN	12	11.43	DNK	3	2.86	Other 8 countries	8	7.62
CHE	12	11.43	JPN	3	2.86			
FRA	6	5.71	UKD	3	2.86			

Inter – Field Differences in Transnational Cooperation

Figure 15.1 indicates the distribution of articles, internationally coauthored articles (*ICOA*) and transnational cooperation links (*COP*) in different subfields. It can be easily seen that the proportions of articles, internationally coauthored articles (*ICOA*) and cooperation links (*COP*) do not match with each other, which means that different *Computer Science* subfields do not attract the same amount of international cooperation. For example, *Artificial Intelligence* accounts for 14.4% of all articles, but it accounts for only 10.7% of all internationally coauthored articles (*ICOA*) and 9.5% of cooperation links (*COP*). On the other hand, *Computer Theory*, which accounts for 8.1% of all articles, accounts for 11.9% of all internationally coauthored articles (*ICOA*) and 15.2% of all cooperation links (*COP*). This means that cooperation links in this subfield are not only relatively more frequent, they also tend to be multilateral.

However, inter – field differences in transnational cooperation can be visualized better through the following relational indicators:

(i.) Internationalization Index (*INI*)
(ii.) Cooperation Index (*COI*)
(iii.) Cooperation Extensiveness Index (*CEI*)

These indicators are defined in Chapter 4.

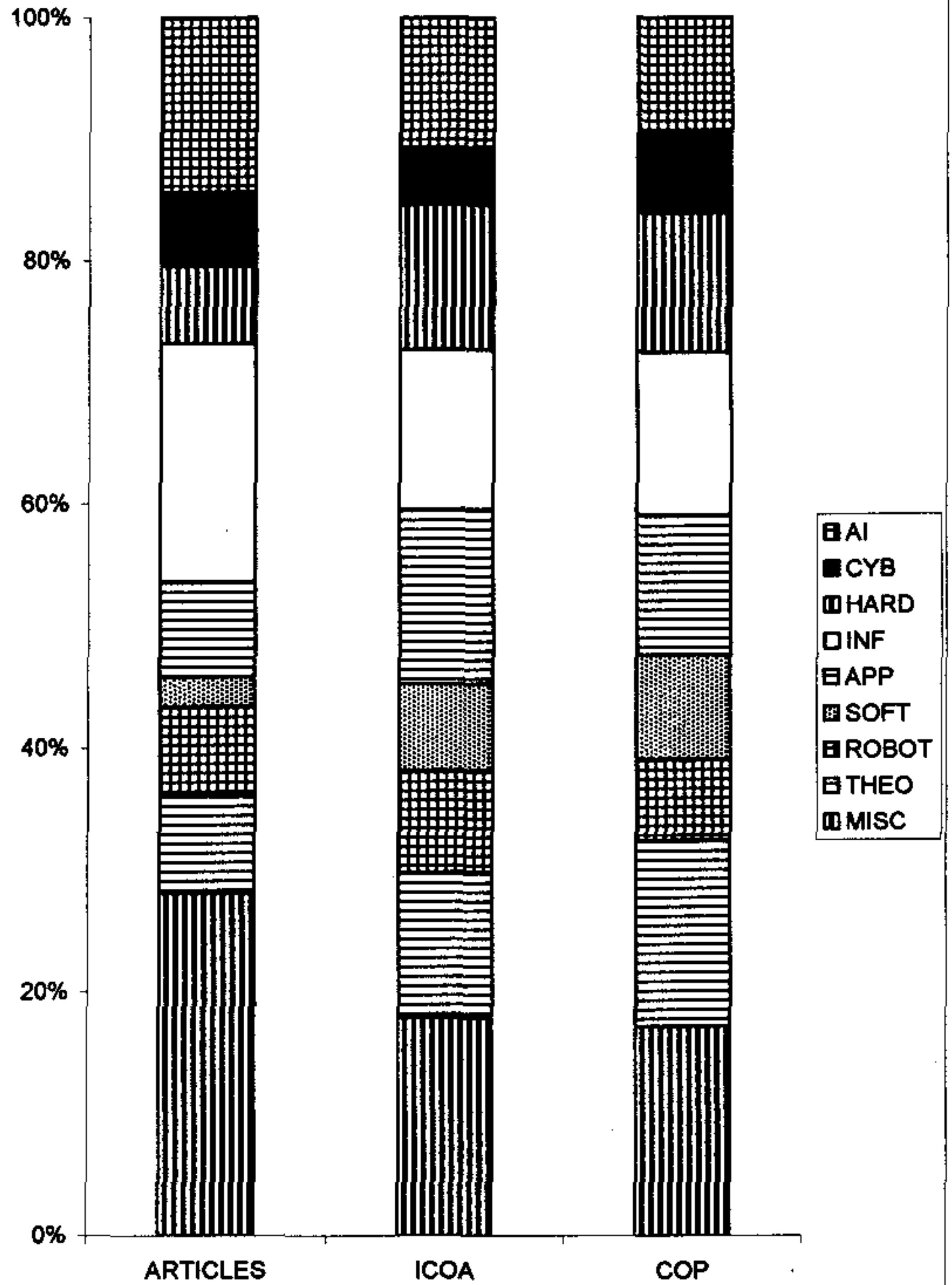


Fig. 15.1: Distribution of articles, internationally coauthored articles (ICOA) and cooperation links (COP) in different subfields of Computer Science

Table 15.2 presents the data on the output of articles, *Internationally Coauthored Articles (ICOA)*, *Cooperation Links (COP)* and associated indicators, viz. *Internationalization Index (INI)*, *Cooperation Index (COI)* and *Cooperation Extensiveness Index (CEI)* for different subfields of *Computer Science.*

Computer Software is the most internationalized subfield. Sixty percent of articles in this area are internationally coauthored. This subfield has also the highest value of *COI* (90%). *Information Systems* does not attract much international cooperation. It is one of the least internationalized area of *Computer Science* - only 13.75% of articles in this subfield are internationally coauthored, much below the average for the entire field (20.49%). The values of *CEI* indicate that *Computer Software* and *Cybernetics* involve more multilateral cooperation than other subfields of *Computer Science.*

Table 15.2
Publication Output and Cooperation Links in *Computers Science* (1990 - 1994)

Subfield	*No. of Articles*	*ICOA*	*No. of Links*	*Internationalization Index INI %*	*Cooperation Index COI %*	*Cooperation Extensiveness Index CEI*
Artificial Intelligence	59	9	10	15.25	16.95	1.11
Cybernetics	25	4	7	16.00	24.00	1.50
Hardware & Architecture	26	10	12	38.46	46.15	1.20
Information Systems	80	11	14	13.75	16.25	1.18
Computer Applications	32	12	12	37.50	37.50	1.00
Software & Graphics	10	6	9	60.00	90.00	1.50
Robotics & Control	30	7	7	23.33	23.33	1.00
Theory & Methodology	33	10	16	30.30	30.30	1.00
Miscellaneous	115	15	18	13.04	15.65	1.20
Total	410	84	105	20.49	23.66	1.15

Inter - Country Differences in Transnational Cooperation

Inter - Country differences in transnational cooperation were assessed by computing the *Affinity Index (AFI)*. Figure 15.2 depicts India's affinities towards its nine significant partner countries (USA, Canada, Switzerland, France, Germany, Denmark, Japan, UK and Netherlands).

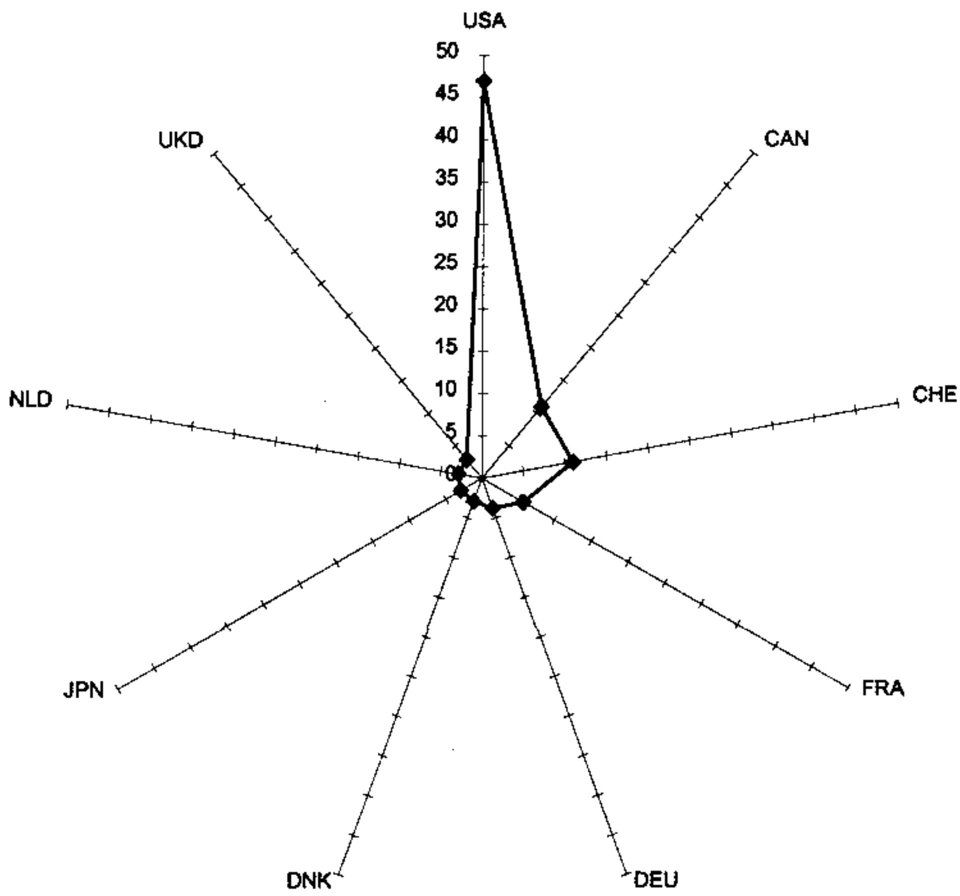


Fig. 15.2: India's linkages in Computer Science (1990-1994)
(Affinity Index)

USA occupies the most important position in India's transnational cooperation in *Computer Science*. About 47% of all internationally coauthored articles involve cooperation with USA.

Canada and Switzerland each occupy the second rank - about 11.5% of all internationally coauthored articles of India in this field involve cooperation with each of these two countries.

India does not have much cooperation with UK and Japan (less than 3% cooperation links with each of these countries), though these countries are quite advanced in *Computer Science*.

Figure 15.3 depicts India's affinities towards its four major partners USA (49 *COP's*), Canada (12 *COP's*), Switzerland (12 *COP's*) and France (6 *COP's*) in different subfields of *Computer Science*.

Figure 15.4 depicts India affinities towards these four countries separately for the following subfields: *Artificial Intelligence*, *Computer Hardware*, *Information Systems*, *Computer Applications*, *Computer Theory* and *Miscellaneous*.

These figures are self – explanatory and any elaboration would be redundant.

The main trends are summarized below:

Country	*Subfields of*	
	Highest affinity	*Lowest affinity*
USA	Artificial Intelligence, Computer Hardware	Computer Theory
Canada	Robotics	Computer Software, Computer Applications Information Systems
Switzerland	Computer Software	Artificial Intelligence, Information Systems Computer Applications, Robotics
France	Computer Applications	Computer Hardware, Computer Software Information Systems, Robotics

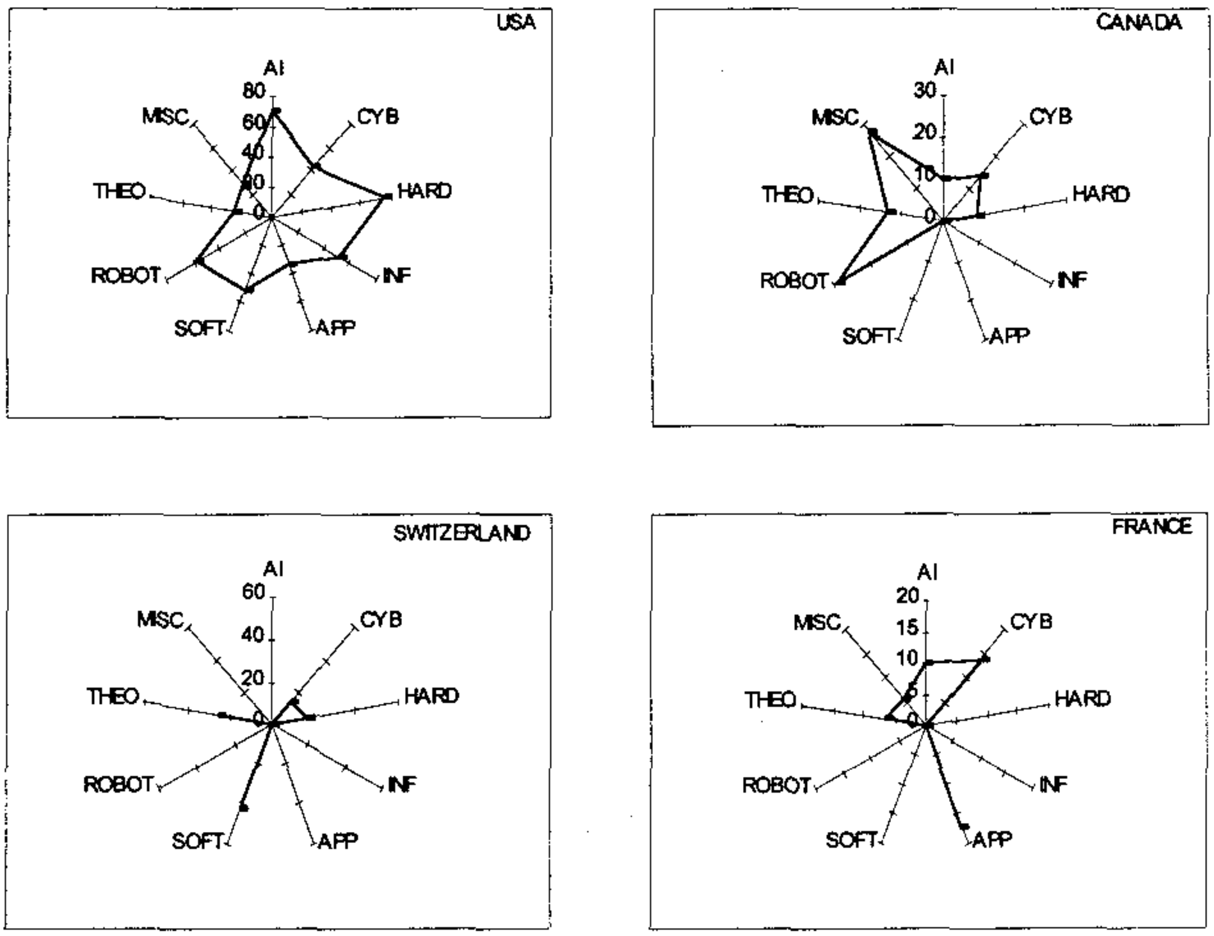


Fig. 15.3: India's affinities towards major cooperating countries in different subfields of Computer Science (1990 -1994)
(Affinity Index)

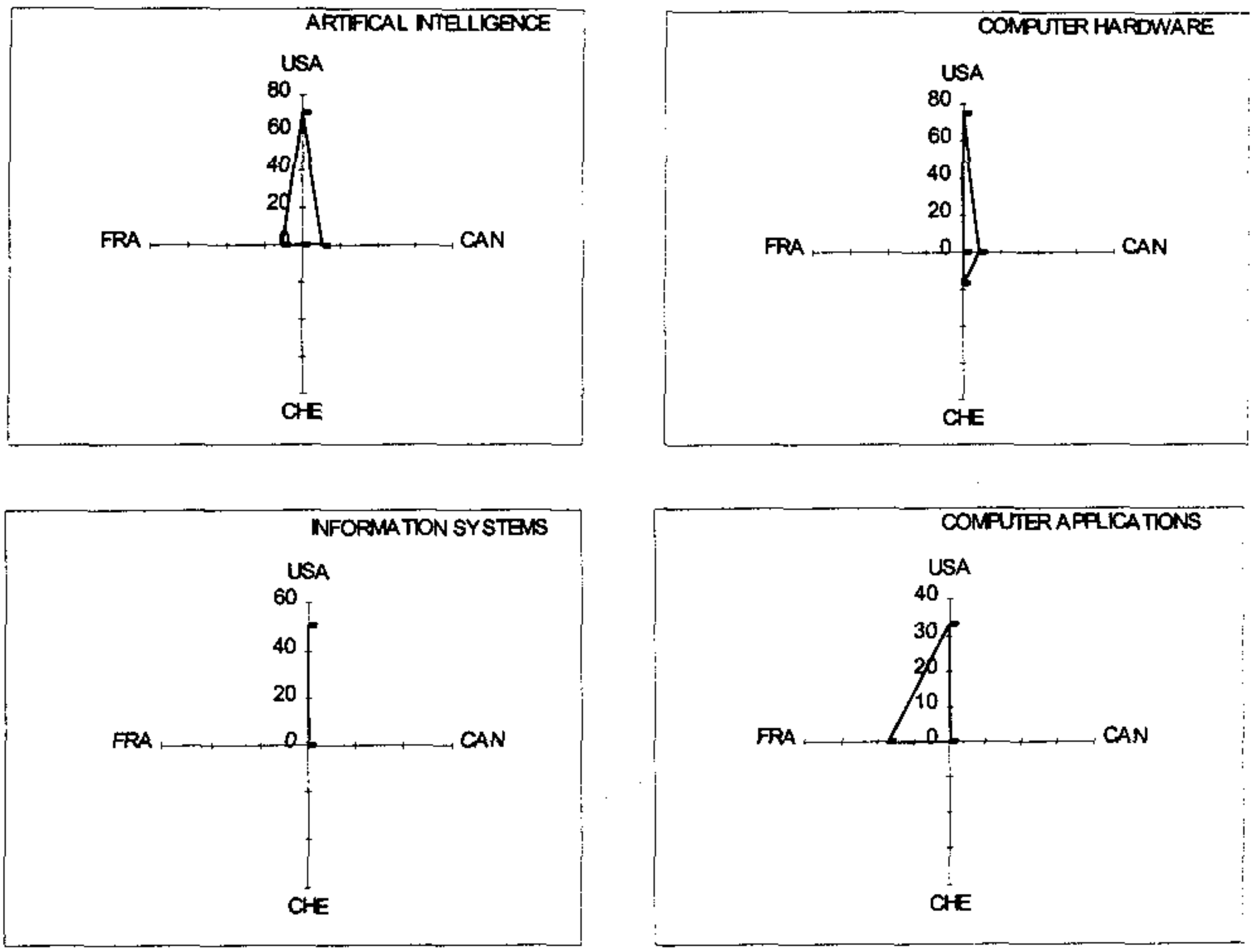
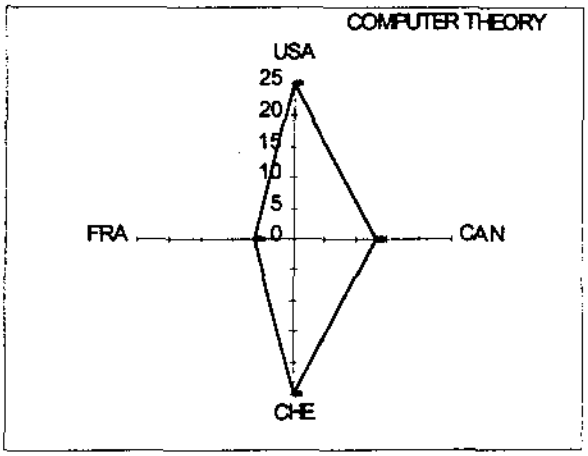
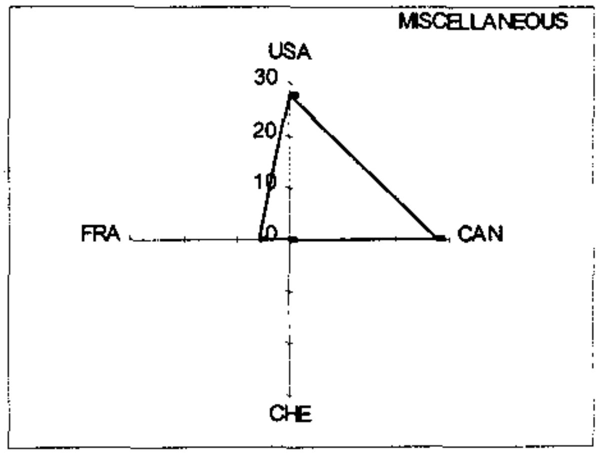


Fig. 15.4: India's linkages in different subfields of Computer Science (1990-94)
(Affinity Index)





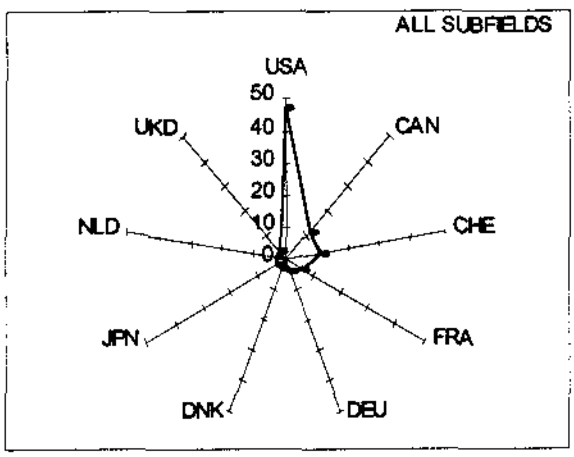


Fig. 15.4 (Contd.): India's linkages in different subfields of Computer Science (1990-1994)
(Affinity Index)

Structure of Transnational Cooperation

The structure of relationships between India's major partners in *Computer Science* (USA, Canada, Switzerland and France) and nine subfields was analyzed through Correspondence Analysis, using the Computer Program SimCA. The results are presented in Tables 15.3 and 15.4.

Eigen values obtained from Correspondence Analysis indicate that the total inertia ($\Sigma\lambda i$ = 0.519365) is quite large, implying large variations in the amplitudes of cooperation profiles.

Figure 15.5 presents the two - dimensional factorial map spanned by ϕ_1 and ϕ_2 axes, summing up 79% of the total variance (information) in the multidimensional data. Thus, the two - dimensional factorial map ($\phi_1 - \phi_2$) reveals the main features of the data.

Factor ϕ_1: The first factorial axis, indicating 49.3% of the total variance, constitutes the *most important element of the multidimensional* data.

On the cloud of subfields, this factor mirrors the polarity between *Computer Software* and *Computer Theory* on the one hand and *Robotics* and *Miscellaneous* on the other. The latter two subfields are projected on this axis with negative coordinates, whereas the former two subfields are projected with positive coordinates.

On the country cloud, this factor mirrors the polarity between Canada and Switzerland. Canada is projected with negative coordinate and is therefore correlated to *Robotics* and *Miscellaneous*, which means that Canada has strong preference for collaboration with India in these two subfields. Switzerland is projected on this axis with positive coordinate and is therefore correlated to *Computer Software* and *Computer Theory*, which means that Switzerland prefers to collaborate with India in these two subfields.

Factor ϕ_2: This axis indicates 29.6% of the total variance and is the second most important element of the multidimensional structure.

Table 15.3
Contributions of explicative points to the composition of the first four factorial axes (Absolute contribution, permill)

Cloud	*Explicative points with positive coordinates*	*Explicative points with negative coordinates*
	Axis 1 (λ_1 = .255873, τ_1 = 49.27%)	
Subfields	Computer Software (454) Computer Theory (102)	Robotics (70) Miscellaneous (262)
Countries	Switzerland (698)	Canada (231)
	Axis 2 (λ_2 = .15376, τ_2 = 29.91%)	
Subfields	Computer Theory (146) Miscellaneous (289)	Artificial Intelligence (84) Information Systems (232) Computer Applications (189)
Countries	Canada (604)	USA (104))
	Axis 3 (λ_3 = .0109731, τ_3 = 21.13%)	
Subfields	Artificial Intelligence (141) Information Systems (159) Robotics (343)	Cybernetics (88) Computer Applications (453)
Countries	USA (122)	France (835)

Table 15.4
***Contributions of the explained points to the eccentricities of the first four factorial axes (Relative* contribution, permill)**

Cloud	*Explained points with positive coordinates*	*Explained points with negative coordinates*
	Axis 1 (λ_1 = .255873, τ_1 = 49.27%)	
Subfields	Computer Software (994) Computer Theory (455)	Robotics (526) Miscellaneous (601)
Countries	Switzerland (892)	Canada (385)
	Axis 2 (λ_2= .15376, τ_2 = 29.91%)	
Subfields	Computer Theory (394) Miscellaneous (398)	Artificial Intelligence (518) Information Systems (657) Computer Applications (326)
Countries	Canada (606)	USA (713)
	Axis 3 (λ_3 = .0109731, τ_3 = 21.13%)	
Subfields	Artificial Intelligence (592) Information Systems (323) Robotics (343)	Cybernetics (945) Computer Applications (555)
Countries	USA (250)	France (820)

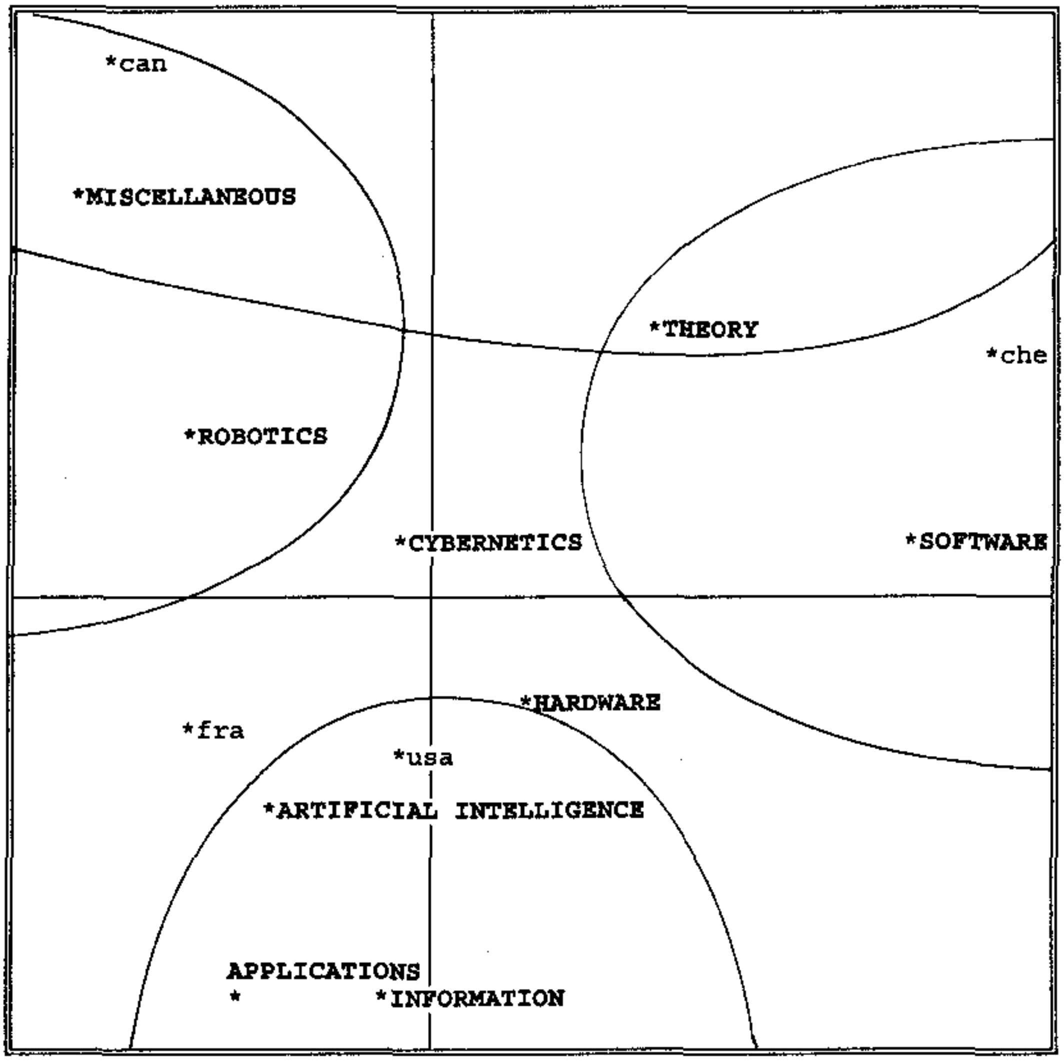


Fig. 15.5: Correspondence Analysis of transnational cooperation in Computer Science subfields

Notes:
Horizontal axis is dimension 1 with inertia = 0.2559 (49.3%)
Vertical axis is dimension 2 with inertia = 0.1538 (29.6%)
78.9% of total inertia is represented in the above map.

On the cloud of subfields this axis mirrors the polarity between *Computer Theory* and *Miscellaneous* on the one hand and *Artificial Intelligence*, *Computer Applications* and *Information Systems* on the other. The former two subfields are projected on this axis with positive coordinates, whereas the latter three subfields are projected with negative coordinates.

On the country cloud, this axis mirrors the polarity between Canada and USA. Canada is projected with positive coordinate and is therefore correlated to *Computer Theory* and *Miscellaneous*. Thus, Canada has strong preference for cooperation with India in these two subfields. USA is projected with negative coordinate and is therefore correlated to *Artificial Intelligence*, *Information Systems* and *Computer Applications*. Thus, USA prefers to collaborate with India in these three areas.

Factor ϕ_3: This axis accounts for 21.1% of the total variance in the multidimensional data. Figure 15.6 presents the scatter plot of countries and subfields in the two – dimensional factorial map spanned by ϕ_1 and ϕ_3 axes.

On the cloud of subfields, this factor mirrors the polarity between *Computer Hardware*, *Information Systems* and *Robotics* on the one hand and *Cybernetics* and *Computer Applications* on the other. The latter two subfields are projected on this axis with negative coordinates, whereas the former three subfields are projected with positive coordinates.

On the country cloud this axis does not have polarity; it is dominated by France, which is projected on this axis with negative coordinate and is therefore correlated to *Computer Applications* and *Cybernetics*. Thus, France has strong preference for cooperation with India in these two subfields.

The results of Correspondence Analysis are summarized in Figure 15.7.

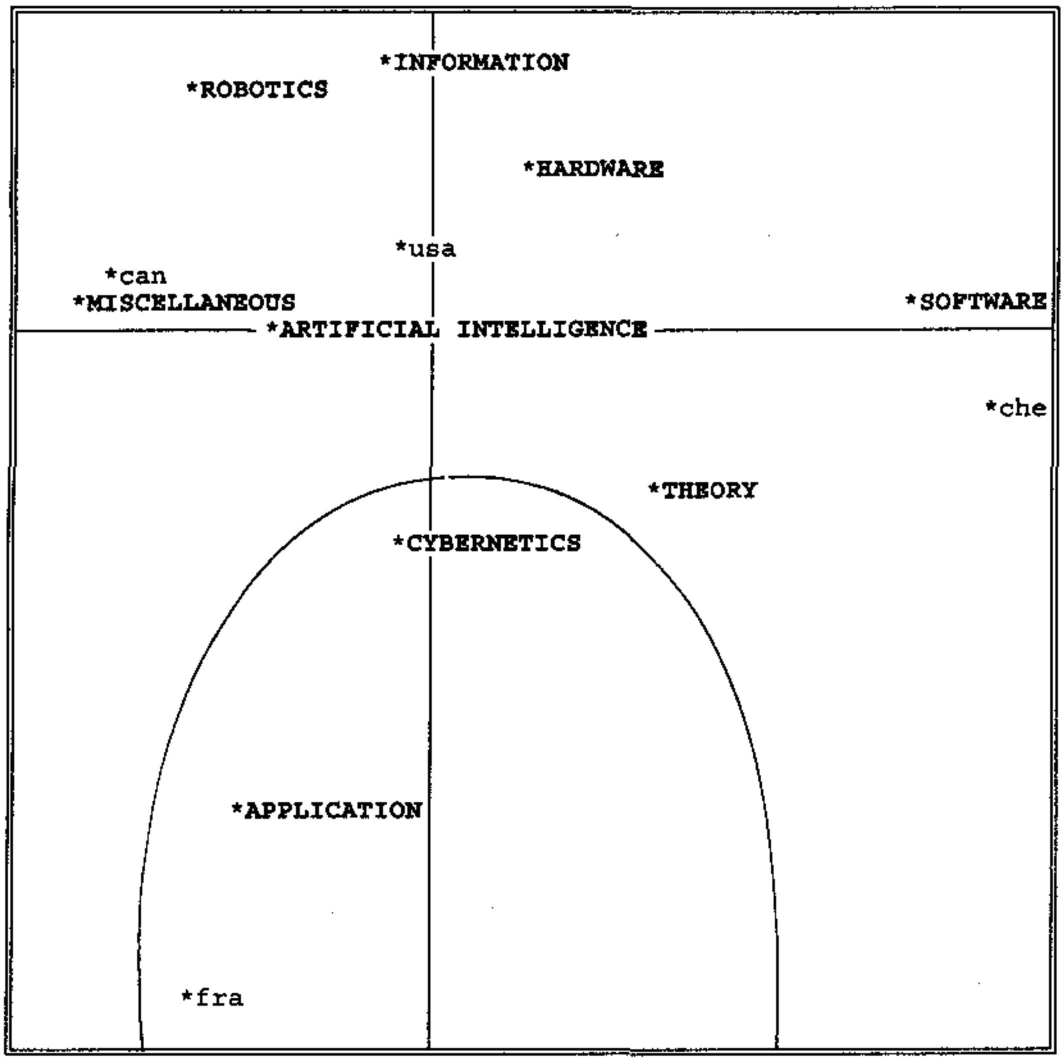
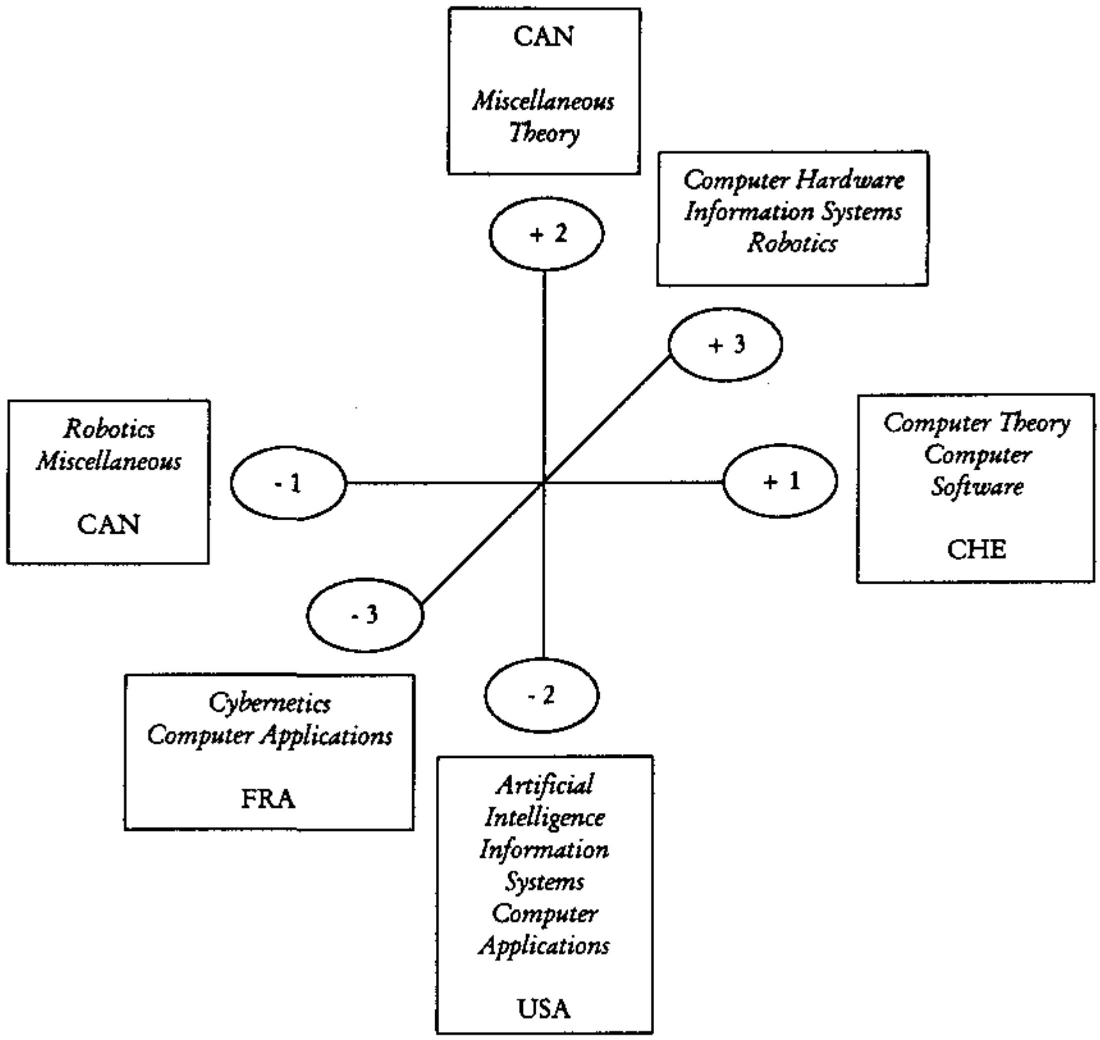


Fig. 15.6: Correspondence Analysis of transnational cooperation in Computer Science subfields

Notes:
Horizontal axis is dimension 1 with inertia = 0.2559 (49.3%)
Vertical axis is dimension 3 with inertia = 0.1097 (21.1%)
70.4% of total inertia is represented in the above map



Variance explained
Axis 1 : 49.2%
Axis 2 : 29.8%
Axis 3 : 21.1%

All the variance (information) in the multidimensional data is captured in the three - dimensional subspace

Fig. 15.7: Summary of correspondence analysis

Appendices

Appendix 1

ISO standard country codes

AFG	Afghanistan	BHU	Bhutan	COK	Cook Island
AFI	Afars & Iss	BIG	Bissau Guinea	COL	Colombia
AGO	Angola	BLZ	Belize	CRI	Costa Rica
ALB	Albania	BMU	Bermuda	CSK	Czechoslovakia
ANT	Neth Antillas	BOL	Bolivia	CUB	Cuba
ARE	United Arab Emir	BPW	Bophuthatswana	CYP	Cyprus
ARG	Argentina	BRA	Brazil	DDR	German DR
ASM	American Samoa	BRB	Barbados	DEU	Germany FR
ATA	Antarctica	BRN	Brunei	DNA	Dominican Rep
AUS	Australia	BUR	Burma	DNK	Denmark
AUT	Austria	BWA	Botswana	DZA	Algeria
BDI	Burundi	CAF	Central Africa	ECU	Ecuador
BEL	Belgium	CAN	Canada	EGY	Egypt
BEN	Benin	CHE	Switzerland	EQG	Equat Guinea
BEU	Belau	CHL	Chile	ESP	Spain
BGD	Bangladesh	CIK	Ciskei	ETH	Ethiopia
BGR	Bulgaria	CIV	Ivory Coast	FIN	Finland
BHR	Bahrain	CMR	Cameroon	FJI	Fiji
BHS	Bahamas	COG	Congo PR	FRA	France

GAB	Gabon	LKA	Sri Lanka	PRC	PR China
GHA	Ghana	LSO	Lesotho	PRK	North Korea
GIB	Gibralter	LUX	Luxembourg	PRT	Portugal
GIN	Guinea	MAR	Morocco	PRY	Paraguay
GLP	Guadeloupe	MAU	Mauritania	PYF	French Polynesia
GRC	Greece	MCO	Monaco	QAT	Qatar
GRL	Greenland	MDG	Malagasy Rep	REU	Reunion
GTM	Guatemala	MEX	Mexico	ROM	Romania
GUF	*French Guyana*	MIC	*Micronesia*	RWA	Rwanda
GUY	Guyana	MIL	Marshall Islands	SAU	Saudi Arabia
HKG	Hong Kong	MLI	Mali	SDN	Sudan
HND	Honduras	MLT	Malta	SGA	Senegambia
HTI	Haiti	MNG	Mongol PR	SGP	Singapore
HUN	Hungary	MOZ	Mozambique	SIK	Sikkim
HVO	Upper Volta	MTQ	Martinique	SLB	Solomon Isl
IDN	Indonesia	MUS	Mauritius	SLE	Sierra Leone
IND	India	MWI	Malawi	SLV	El Salvador
IRL	Ireland	MYS	Malaysia	SMR	San Marino
IRN	Iran	NAM	Namibia	SOM	Somalia
IRQ	*Iraq*	NCL	*New Caledonia*	SSA	Spanish Sahara
ISL	Iceland	NGA	Nigeria	SUN	USSR
ISR	Israel	NGR	Niger	SUR	Surinam
ITA	Italy	NIC	Nicaragua	SWE	Sweden
JAM	Jamaica	NIU	Niue	SWZ	Swaziland
JOR	Jordan	NLD	Netherlands	SYC	Seychelles
JPN	Japan	NOR	Norway	SYR	Syria
KEN	Kenya	NPL	Nepal	TCD	Chad
KIR	Kiribati	NZL	New Zealand	TGO	Togo
KOR	South Korea	OMN	Oman	THA	Thailand
KWT	Kuwait	PAK	Pakistan	TON	Tonga
LAO	Laos	PAN	Panama	TRK	Transkei
LBN	Lebanon	PER	Peru	TTO	Trinidad & Tobago
LBR	Liberia	PHL	Philippines	TUN	Tunisia
LBY	Libya	PNG	Papua New Guinea	TUR	Turkey
LIE	Liechtenstein	POL	Poland	TWN	Taiwan

TZA	Tanzania	VND	Venda	YUG	Yugoslavia
UGA	Uganda	VNM	Vietnam	ZAF	South African R
UKD	UK	VUT	Vanuatu	ZAR	Zaire
URY	Uruguay	WIA	W Indian Assoc	ZMB	Zambia
USA	USA	WSM	Western Samoa	ZWE	Zimbabwe
VAT	Vatican	YEM	Yemen Arab Rep		
VEN	Venezuela	YMD	Yemen PDR		

Appendix 2

Classification system

Science

1. Mathematics (*MAT*)
2. Physics (*PHY*)
3. Chemistry (*CHM*)
4. Biology (*BIO*)
5. Earth & Atmospheric Sciences (*EAS*)
6. Food & Agriculture Research (*AGR*)
7. Clinical Medicine (*CLI*)
8. Biomedical Research (*BIM*)
9. Engineering and Technology (*ENT*)
10. Computer Science (*COM*)
11. Materials Science (*MTS*)

Mathematics

1. General Mathematics (*GEN*)
2. Applied Mathematics (*APP*)
3. Interdisciplinary Mathematics (*IND*)
4. Probability and Statistics (*STAT*)
5. Operations Research & Management Science (*OR/MS*)

Physics

1. General Physics (*GEN*)

2. Acoustics (*ACU*)
3. Applied Physics (*APP*)
4. Astronomy/Astrophysics (*AST*)
5. Chemical Physics (Atomic, Molecular and Chemical Physics) (*CHM*)
6. Crystallography (*CRY*)
7. Fluids & Plasmas (*FLU*)
8. Mathematical Physics (*MAT*)
9. Microscopy (*MIC*)
10. Nuclear and Particle Physics (*NUC*)
11. Optics (*OPT*)
12. Solid State Physics (*SOL*)
13. Spectroscopy (*SPC*)

Chemistry

1. General Chemistry (*GEN*)
2. Analytical Chemistry (*ANA*)
3. Applied Chemistry (*APP*)
4. Electrochemistry (*ELE*)
5. Inorganic Chemistry (*INO*)
6. Organic Chemistry (*ORG*)
7. Physical Chemistry (*PHY*)
8. Polymer Chemistry (*POL*)

Biology

1. General Biology (*GNB*)
2. Botany (*BOT*)
3. Ecology (*ECO*)
4. Entomology (*ENT*)
5. Marine Biology & Hydrobiology (*HYD*)
6. Miscellaneous Biology (*MIB*)
7. General Zoology (*ZOO*)
8. Miscellaneous Zoology (*MIZ*).

Earth & Atmospheric Sciences

1. Earth & Planetary Sciences (*EPS*)
2. Environmental Sciences (*ENV*)
3. Geology (*GEO*)
4. Metereology and Atmospheric Sciences (*MET*)
5. Oceanography & Limnology (*OCN*)
6. Remote Sensing (*REM*)

Food & Agriculture Research

1. General Agriculture (*GENAG*)
2. Agricultural Economics & Policy (*ECON*)
3. Dairy & Animal Sciences (*DAIRY*)
4. Agricultural Soil Science (*SOIL*)
5. Forestry (*FORES*)
6. Horticulture (*HORT*)
7. Food Science & Technology (*FOOD*)

Clinical Medicine

1. General & Internal Medicine (*INM*)
2. Addictive Diseases (*ADD*)
3. Allergy (*ALL*)
4. Anesthesiology (*ANE*)
5. Arthritis & Rheumatism (*ART*)
6. Cardiovascular System (*CAR*)
7. Dentistry (*DEN*)
8. Dermatology & Venereal Diseases (*DER*)
9. Endocrinology (*END*)
10. Fertility (*FER*)
11. Gastroenterology (*GAS*)
12. Geriatrics (*GER*)
13. Hematology (*HEM*)
14. Hygiene & Public Health (*HYG*)
15. Immunology (*IMM*)
16. Miscellaneous Clinical Medicine (*MCM*)
17. Nephrology (*NEP*)
18. Neurology & Neurosurgery (*NEU*)
19. Obsteretics & Gynaecology (*GYN*)
20. Oncology (*ONC*)
21. Ophthalmology (*OPT*)
22. Orthopaedics (*ORP*)
23. Otorhinolaryngology (*OTO*)
24. Pathology (*PAT*)
25. Pediatrics (*PED*)
26. Pharmacology & Pharmacy (*PHA*)
27. Psychiatry (*PSY*)
28. Radiology & Nuclear Medicine (*RAD*)
29. Respiratory System (*RES*)
30. Surgery (*SUR*)

31. Tropical Medicine (*TRO*)
32. Urology (*URO*)
33. Veterinary Medicine (*VET*)

Biomedical Research

1. General Biomedical Research (*GEN*)
2. Anatomy & Morphology (*ANA*)
3. Biochemistry & Molecular Biology (*BMB*)
4. Biomedical Engineering (*BEG*)
5. Biophysics (*BPH*)
6. Cell Biology, Cytology and Histology (*CYT*)
7. Embryology (*EMB*)
8. Genetics & Heredity (*G&H*)
9. Microbiology (*MIC*)
10. Nutrition & Dietetics (*NUT*)
11. Parasitology (*PAR*)
12. Physiology (*PHY*)
13. Virology (*VIR*)

Engineering & Technology

1. General & Miscellaneous Engineering (*GEN*)
2. Aerospace Technology (*AER*)
3. Chemical Engineering (*CHEM*)
4. Civil Engineering (including Construction Engineering)(*CIV*)
5. Electrical and Electronics Engineering (*ELE*)
6. Mechanical Engineering (*MECH*)
7. Metals and Metallurgy (*MET*)
8. Nuclear Technology (*NUCL*)
9. Telecommunication Engineering (*TELE*)

Materials Science

1. General Materials Science (*GEN*)
2. Biomaterials (*BIO*)
3. Ceramics (*CER*)
4. Characterization of Materials (*CHA*)
5. Coatings & Films (*CTG*)
6. Composites (*CMP*)
7. Papers & Pulp (*PAP*)
8. Fibres & Textiles (*FIB*)

Computer Science

1. Artificial Intelligence (*AI*)
2. Cybernetics (*CYB*)
3. Computer Hardware (*HARD*)
4. Information Systems (*INF*)
5. Computer Applications (*APP*)
6. Computer Software (*SOFT*)
7. Robotics (*ROBOT*)
8. Computer Theory (*THEO*)
9. Miscellaneous (*MISC*)