● ABSTRACT

*International collaborative behaviour among scientists is investigated by examining international co-authorship patterns for a number of scientific fields using the 1973* Science Citation Index. *Three major findings emerge: (1) the more basic the field, the greater the proportion of international co-authorships; (2) the larger the national scientific enterprise, the smaller the proportion of international co-authorship; (3) international co-authorships occur along clearly discernible geographic lines, suggesting that extra-scientific factors (for example, geography, politics, language) play a strong role in determining who collaborates with whom in the international scientific community.*

# International Research Collaboration

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**International collaboration in research** can take many forms: the sharing of unique data sources, correspondence by mail, exchanges of ideas at conferences, visits to foreign laboratories, and the exchange of papers are all common examples of collaborative activity. The most obvious form of international collaboration — and the most easily measured — is collaboration in the writing of research findings. In this paper, international co-authorship patterns in nine scientific fields are examined. In particular, the investigation will look at collaborative patterns from three distinct viewpoints: (1) the impact of the 'hardness' or 'softness' of a

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discipline on international collaborative behaviour; (2) the role played by the size of the national scientific effort in determining the degree of international scientific collaboration; and (3) the geographic patterns of international research collaboration.

## The Data Base

The international collaboration data are taken from the 1973 *Science Citation Index* (*SCI*). The *SCI* covers approximately 2,400 journals in all fields of science. These journals have been assigned by Computer Horizons, Inc., to more than 100 separate subfields. The subfield assignments were made by investigating individual journal citation patterns, examining the stated objectives of journals, and conferring with experts. In general, journals assigned to the same subfield reference each other more heavily than they do journals outside the subfield. Articles appearing in these journals are then classified as belonging to the subfield of the journal. For example, articles appearing in 22 microbiology journals are categorized as microbiology articles. Publications in multidisciplinary journals are fractionally assigned to the subfields which constitute the journal.

In order to make an analysis of these publications tractable in this paper, the more than 100 subfields have been aggregated into nine fields of science: clinical medicine, biomedical research (for example, biochemistry, molecular biology, virology), biology (including agriculture), chemistry, physics, earth/space science, engineering/technology, mathematics, and psychology.

The determination of the nationality of authors is based on their institutional affiliations. This method of identifying the nationality of authors is not foolproof. For example, a scientist visiting a foreign laboratory may specify that laboratory as his institutional affiliation. Or scientists working at international research facilities (such as CERN) may be assigned to the wrong country. However, after making a detailed investigation of the nationality of scientists publishing in three physics journals over a period of one year, we have found that the impact of these misassignments is small when dealing with a sizeable data base.

An international institutional co-authorship exists between two countries if the authors of a paper report affiliations with institutions in both countries. International institutional co-authorship

counts were tabulated for the following countries and regions: USSR, USA, Japan, UK, East Germany, the rest of East Europe, West Germany, France, New Zealand, Australia, Canada, Italy, Sweden, the rest of Western Europe, South Africa, the rest of Africa, India, the rest of Asia and the Pacific,[1] Israel, the rest of the Near East and North Africa, and South and Central America. Because the regional data were comprised of international co-authorship figures for aggregates of countries, estimates were made of the international co-authorship level for a surrogate average major research producer for each region. These estimates take into account the fact that aggregated international coauthorship figures underestimate the international collaborative activity of the individual countries which constitute the aggregate.[2]

## International Collaboration Across Fields

Using international institutional co-authorships as an indicator of international research collaboration, we investigated the level of international scientific collaboration for the nine scientific fields mentioned earlier. Recognizing that our results could be coloured by linguistic, cultural, and political factors, we restricted our analysis to the Western countries in our data set. These are: the US, the UK, West Germany, France, Italy, Canada, Australia, New Zealand, South Africa, Israel, and Sweden. In this way we established a data base which rested on a fairly homogeneous sociocultural group comprising most of the world's leading scientific countries. Field differences in collaborative behaviour can then be ascribed to factors other than those which are linguistic, cultural, or political.

The results of our analysis of international institutional co-authorships for the eleven Western countries are given in Table 1. This table shows the proportion of all the papers produced by these countries in a given field which are co-authored with other countries in the data set. International institutional co-authorships occur most heavily in the earth/space sciences (4.45%), followed closely by physics (4.23%). The field with the fewest international institutional co-authorships is engineering/technology (1.46%).

A quick perusal of Table 1 enables us to make an obvious generalization of our results: Predominantly basic fields (that is, earth/space science, physics, mathematics, and biomedical research) have higher levels of international collaboration than predominant-

ly applied or clinical fields (that is, biology [including agricultural research], psychology, clinical medicine, and engineering/technology). Chemistry straddles the middle ground.[3]

The findings reported here confirm rigorously what sociologists and historians of science have noted for quite some time. A number of explanations of these results can be gleaned from the sociological and historical literature. Storer has stated that basic research is oriented toward an international community since it involves universal truths of universal interest. Applied science, which tends to be directed toward local problems, takes on nationalistic characteristics since countries see it as a national asset and exploit it as such.[4] Crane reaches similar conclusions.[5] One would thus anticipate that research oriented toward the international community would be characterized by greater levels of international collaboration than research oriented toward the domestic establishment.

The results of a survey of Irish scientists have led Herzog to hypothesize that the level of international scientific collaboration is a consequence of the reward orientation of scientists.[6] Basic researchers in high consensus disciplines (specifically, physics and geology) have an international orientation, since it is from the international research community that they achieve recognition. On

**TABLE 1**
**Percent of Papers Which Have International Institutional Co-authorships for Nine Fields of Science**

| | Number of Internationally Co-authored Papers | Total Number of Papers | % |
|---|---|---|---|
| Earth/Space Science | 423 | 9,508 | 4.45 |
| Physics | 979 | 23,131 | 4.23 |
| Mathematics | 271 | 7,230 | 3.75 |
| Biomedical Research | 796 | 30,304 | 2.63 |
| Chemistry | 511 | 25,233 | 2.03 |
| Biology | 330 | 19,703 | 1.68 |
| Psychology | 118 | 7,139 | 1.66 |
| Clinical Medicine | 979 | 60,696 | 1.61 |
| Engineering/Technology | 310 | 21,227 | 1.46 |

the other hand, applied researchers (specifically, dairy and animal scientists) who work in economically relevant fields find problems, information, and recognition at home.

In a historical study of collaboration, Beaver and Rosen have concluded that collaboration on published research arose in the eighteenth and nineteenth centuries as a response to the professionalization (and hence stratification) of science.[7] Their findings can be extended into the arena of twentieth-century international science, where, on the world level, stratification is more highly developed in the basic disciplines than in the applied disciplines.

Miles explains the high level of collaboration in the earth and space sciences more as a consequence of the unique nature of these disciplines than as a reflection of their position on a basic-to-applied scale.[8] In discussing oceanography and atmospheric and space science, Miles observes that the physical areas under investigation are vast and require the coordination of individuals and resources on a broad international scale. He nonetheless feels that the norm of internationalism as an element in the social system of science also plays a role in encouraging the international pursuit of research in oceanography and space science.

The role of government support of international scientific activities should not be ignored. Relatively large quantities of basic research conducted at the international level are supported by governments. For example, the Division of International Programs of the US National Science Foundation supports nearly a thousand basic researchers a year for the purpose of engaging in international cooperative research activities. In the biomedical area the Fogarty International Center of the US National Institutes of Health coordinates NIH's international research activities and conducts biomedical exchange programmes.

There is no comparable support of applied disciplines. Research in the very applied sciences which is supported (for example, by the US Agency for International Development) is either not truly collaborative or else is so technological in content that it does not lend itself to publication in professional journals. Clearly, the availability of funds for international collaboration in the most basic disciplines helps to assure a significant degree of international collaboration in these areas.

While the different explanations for the internationality of fundamental science presented here do not overlap fully, neither are they contradictory. It would seem that Storer's observations con-

cerning the universal character of basic research underlies them all. Even Miles' explanation of the internationality of large scale research in oceanography and the atmospheric and space sciences can be linked ultimately to Storer's observation: unless grandiose and expensive research projects have a broad, supranational appeal they will not secure financial support from a multiplicity of governments and from the international scientific community.

## National Scientific Size and International Collaboration

The impact of the size of a national scientific effort on national scientific research patterns has never been carefully investigated. Price has shown how scientific size is well correlated with a number of socioeconomic variables.[9] Elaborating on some of Price's work, Frame has demonstrated empirically that the relationship between research output, national economic size, and affluence is fundamentally different for developed and underdeveloped countries.[10]

In spite of the dearth of confirmatory findings, it is apparent that national scientific size has a bearing on patterns of national research production. Large scientific establishments are dependent to a substantial degree on the presence of abundant quantities of manpower and other material resources. These material resources create a climate favourable for the fostering of intellectual resources. The migration of talent (that is, a 'brain drain') from resource-poor to resource-rich countries provides evidence of this phenomenon. Thus we find that high levels of material and intellectual resources often go hand-in-hand.

It can be anticipated that the size of a nation's scientific effort will have an impact upon the degree to which scientist in the country engage in international collaboration. Faced with resource restrictions at home, scientists in a resource-poor country find themselves looking outside their national borders for additional material and intellectual resources. Scientists in large, resource-rich establishments can often meet their research needs domestically.

The co-authorship data favour the acceptance of this hypothesis. Table 2, which ranks countries and regions by scientific size, shows that as countries decrease in scientific size, the proportion of theory papers which are internationally co-authored increases. This is a general tendency and not a hard and fast rule. The largest research

**TABLE 2**
**The Percentage of International Institutional Co-authorships for 21 Countries and Regions**

| Country | Number of Publications | Co-authorships (%) |
|---|---|---|
| USA | 111,711 | 4.4 |
| UK | 26,551 | 7.8 |
| USSR | 24,584 | 1.2 |
| West Germany | 17,164 | 7.5 |
| France | 15,775 | 7.2 |
| Japan | 14,553 | 3.3 |
| Canada | 13,190 | 10.4 |
| India | 7,086 | 4.6 |
| Australia | 5,467 | 7.4 |
| Italy | 4,985 | 11.5 |
| Sweden | 4,467 | 12.2 |
| Israel | 2,834 | 13.2 |
| West Europe (n = 6) | 2,530* | 14.0* |
| East Germany | 2,255 | 5.8 |
| East Europe (n = 4) | 1,887* | 8.0* |
| South Africa | 1,300 | 7.2 |
| New Zealand | 1,200 | 7.5 |
| South America (n = 5) | 469* | 21.6* |
| Mideast (n = 3) | 343* | 23.3* |
| Asia (n = 6) | 139* | 30.5* |
| Black Africa (n = 8) | 110* | 29.8* |

*Estimates for an average major regional producer

producers (those above Australia in the list) generally have international co-authorships occurring in the range of 4 to 8 percent of their scientific papers. The Soviet Union and Japan fall conspicuously below this range. This no doubt is partially explained by the linguistic and cultural isolation of these countries. In the Soviet Union, political factors contribute further to the isolation of Russian scientists.

The data in Table 2 are for all fields of science. In looking at individual fields of research we find that Japanese scientists approach average levels of co-authorships in mathematics, clinical medicine, and biomedical research. Soviet co-authorship levels remain substantially below average for all fields of science.

The Canadian co-authorship level is noticeably higher than average for the large countries. The majority of these co-authorships are with the US, reflecting the strong interaction between American and Canadian science which is a consequence of the cultural and political heritage and geographic propinquity of these countries.

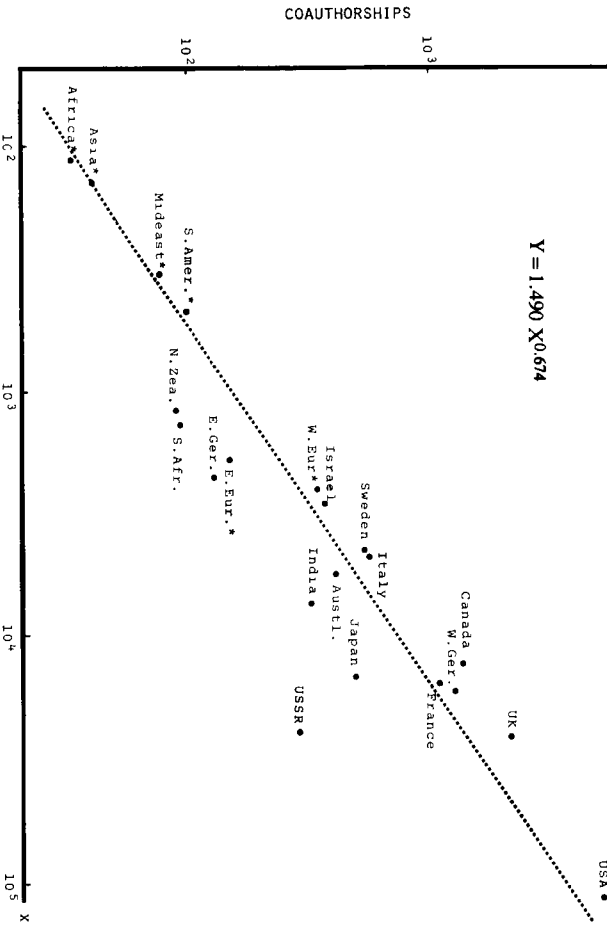
The data in Table 2 suggest that scientifically middle-sized countries (for example, Italy, Sweden, and Israel) internationally co-author between 7 and 14 percent of their papers. East Germany falls below this range, perhaps for political reasons. In no individual field do East German scientists internationally co-author papers to the same extent as in other countries of comparable size.

The smallest countries, which in general are also the underdeveloped countries, heavily engage in international collaboration. The average major national producer of scientific research in South America internationally co-authors an estimated 21.6 percent of its papers. For the Middle East this figure is 23.3%; for Black Africa it is 29.8 percent; and for Asia, it is 30.5 percent. It should be noted that a significant number of the authors publishing in the Middle East, Black Africa, and Asia may not be indigenous to these regions, but rather may be guest scientists from the West. It is possible that a relatively large fraction of international co-authorships for these regions is accounted for by the guest scientist collaborating with colleagues back home.

In Figure 1 the relationship between international co-authorships and national scientific size is portrayed on logarithmic scales. This figure demonstrates the existence of a log-linear relationship between international co-authorship and size. Expressed in exponential terms, the relationship is

$$Y = 1.490\ X^{0.674}$$

**FIGURE 1**
**The Relationship between National Levels of International Co-authorships and National Scientific Size**




*Estimate for average major producers in region

The exponential value of 0.674 specifies the rate at which the proportion of international co-authorships (Y) decreases for increases in national scientific size (X). The graph clearly shows that the larger a country's research effort is, the smaller the proportion of international co-authorships associated with the country.

In Figure 1, the positions of the points for the different countries in relation to the regression line indicate the degree to which the international co-authorship levels are above or below expectation. Because Soviet levels of international co-authorships were consistently low and anomalous for all fields, Soviet data were not included in the calculation of the regression coefficients. As was stated earlier, the paucity of Soviet international co-authorships reflects the isolation of Soviet science from the international scientific community. This isolation has also been demonstrated using citation indicators. A number of studies have shown that Soviet scientists receive far fewer citations than one would expect, knowing the USSR's national research size;[11] this indicates a low usage of Soviet scientific research. The Russians themselves are not ignorant of their position in world science. As the Soviet writers Nalimov and Mulchenko put it, 'foreign scientists do not personally know many of our scientists, and this results in their not paying sufficient attention to our publications and not reacting to them opportunely'.[12]

The data for Figure 1 are based on aggregate statistics for all fields of science. It would be interesting to determine whether the basic exponential relationship between international co-authorships and national scientific size holds across all scientific fields. In Table 3 it is seen that the exponential coefficients for the different fields fall into two groups. In one group the coefficients range from 0.76 to 0.84. This group is made up of physics, mathematics, and earth/space science. The nearer the exponential value gets to 1.0, the more linear is the relationship and the more homogeneous is the proportion of co-authorships for different sizes of national scientific establishments. In the second group, the coefficients range from 0.60 to 0.65, indicating a stronger deviation from linearity than for the first group. The fields that are associated with the second group are chemistry, engineering/technology, biology, clinical medicine, biomedical research, and psychology. These two groups closely correspond to the basic research/applied research dichotomy noted earlier. Thus we find that in the applied disciplines there is a sharper drop in interna-

tional collaboration than in the basic disciplines, as countries increase in research size. That is, larger countries appear to be substantially more self-sufficient in the applied disciplines than are small countries. While this high level of self-sufficiency can also be noted in the basic disciplines, it is not as pronounced. These findings are consonant with the observations that: (1) scientists in the smaller countries, because of their limited resources, direct themselves strongly to the international scientific community for research opportunities; and (2) for the larger countries, basic research has a stronger international orientation than applied research.

## Extra-Scientific Factors in International Collaboration

A common image of scientific activity is that it transcends national boundaries. It is often believed that on the world level science somehow remains aloof from the tugs and pulls of international political, social, and economic forces. The view that science is supranational is further enhanced by the observation that modern communications advances have led to a 'shrinking' of the globe, and that this has considerably reduced the effects of geography on colouring scientific activity. We live in what has been picturesquely

**TABLE 3**
**International Co-authorships vs. Publications for Different Scientific Areas**

Co-authorships = m (Publications)[a]

| | *m* | *a* |
|---|---|---|
| Physics | 0.40 | 0.84 |
| Mathematics | 0.46 | 0.78 |
| Chemistry | 0.80 | 0.64 |
| Earth/Space | 0.60 | 0.76 |
| Engineering/Technology | 0.58 | 0.65 |
| Biology | 0.97 | 0.60 |
| Clinical Medicine | 0.93 | 0.63 |
| Biomedical Research | 0.94 | 0.64 |
| Psychology | 0.51 | 0.60 |

titled a 'Global Village', or on 'Spaceship Earth'. If, in fact, science *is* supranational in the sense depicted here, we would expect to find that the collaborative behaviour of scientists would occur independently of extra-scientific factors, such as geography and politics.

The possible effect of geography and sociopolitical factors on collaboration was investigated by performing a non-metric multidimensional scaling (MDS) analysis on the cross-country co-authorship matrix for all scientific fields lumped together.[13] The co-authorship values in the table are taken to be collaboration 'proximity' measures between countries. The MDS procedure yields a 'map' in which pairs of countries with a high volume of collaboration and a similar pattern of collaboration are placed close together, and dissimilar pairs with a low volume, far apart.

The results reported here are for a four-dimensional MDS configuration.[14] Diagonal values in the cross-country collaboration matrix have been ignored. In order to see how countries grouped together according to their co-authorship behaviour, the rotated MDS coordinates of the countries and regions considered in the study were subjected to a cluster analysis. Four easily interpreted clusters emerged after the eleventh stage of a hierarchical clustering

**TABLE 4**
**Clustering of Countries According To Similar Co-authorship Patterns**

*Group 1*
Canada
France
Italy
United Kingdom
United States
West Europe
West Germany

*Group 2*
East Europe
USSR

*Group 3*
Australia
New Zealand

*Group 4*
Asia
India
Japan

*Ungrouped*
Black Africa
Israel
Latin America
Middle East
South Africa
Sweden

procedure. A number of countries failed to fit into any of these clusters. The grouping of countries according to clusters is given in Table 4.

The clusters clearly reflect the effects of geography, and of political, social, and economic factors, on international co-authorships. The countries of Western Europe and North America — the so-called Western powers — are brought together in Cluster 1. These countries have much in common. Economically, they are the most advanced countries in the world. Politically, they tend to be liberal democracies. Socially, their populations are Caucasian, they share a common history, and they speak Germanic- and Latin-based tongues.

Cluster 2 is comprised of the Soviet bloc countries in Eastern Europe. Cluster 2 countries also have much in common. They are geographically continuous to one another. They share a common history distinct from that of Western Europe. Politically and economically, they are communist states with centralized economies, and they operate largely under Soviet hegemony. Linguistically, most of the Eastern European populations speak Slavic tongues, with Hungary and Rumania being obvious exceptions.

Cluster 3 is made up of the countries of Oceania: Australia and New Zealand. The links between these two countries are obvious. The most noteworthy feature about Cluster 3 is that it exists apart from Cluster 1 (the Western powers). Both Australia and New Zealand have such strong political, social, linguistic, and economic ties to the Western countries that one might have guessed that they would have fit comfortably into Cluster 1. The element of geography would appear to play a strong role in determining international co-authorship behaviour in the Antipodes.

Finally, in Cluster 4 we find the countries of Asia. The political, economic, social, and linguistic backgrounds of these countries are mixed. Nevertheless, they generally have more in common with each other than with countries from other regions (for example, their populations are largely Mongoloid, their economies are agricultural, they have rice cultures, and many of them share world outlooks rooted in Buddhism or Hinduism). Japan's appearance in Cluster 4 would appear to be anomalous if one believed that science was fully supranational. If international co-authorships were grounded on purely scientific considerations, then Japanese scientists — coming from a sophisticated scientific environment —

should be directing their collaborative efforts primarily toward scientists from the most advanced countries. Yet we see from the MDS results that Japanese co-authorship behaviour is largely oriented toward an Asian pattern.

As Table 4 shows, a number of countries did not fall into any of the four clusters. Both sociopolitical and geographic factors can be used to explain individual cases. Israel and South Africa, which possess good scientific capabilities in a number of areas, physically lie outside the belt of the world's major research producers. Furthermore, they both exist in rather hostile political environments. The underdeveloped regions — Latin America, Black Africa, and the Middle East — lie far from the scientific mainstream in both a geographic and intellectual sense. Sweden is the only state whose appearance on this list of ungrouped countries seems anomalous.

The co-authorship data we have presented in this paper have been international. If we examine domestic institutional co-authorship data as well we find that in all the world's major scientific countries substantially more institutional co-authorships occur domestically than internationally. This by itself is a telling argument against the view that science has approached a state of pure supranationality. Scientists collaborate heavily with colleagues at domestic institutions for a number of reasons of convenience which are unrelated to purely scientific motivations: they speak the same language; visits to one another are not usually financially prohibitive; they can speak to each other cheaply over a telephone; and so on.

These interpretations of the MDS results are meant to be suggestive and not conclusive. Limitations in the analytic abilities of the authors, in the data, as well as in the MDS and cluster analysis procedures, all preclude the making of firm conclusions. The broadest conclusion which can be drawn is that while we may live on Spaceship Earth, we must recognize that it is a very large spaceship indeed. Conditions are varied throughout the spaceship, and not all compartments of the spaceship can be accessed with equal facility.

## Summary

The institutional co-authorship data demonstrate that international scientific activity does not occur unfettered, oblivious to national

borders. We suggest that the degree to which international collaboration on scientific papers occurs is related to a number of factors closely tied to the nationality of scientists. The size of a national research effort, and a number of non-science factors — including geographic locale, and linguistic, cultural, and political factors — all contribute to determining how much international collaboration occurs, and who will collaborate with whom. Furthermore, there are very clear field-to-field variations in levels of international collaborations: in general, predominantly basic disciplines are characterized by higher levels of international collaboration than predominantly applied disciplines.

## • *NOTES*

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1. Because scientists in the People's Republic of China virtually ceased publishing journal articles after the Cultural Revolution, the data for Asia and the Pacific do not reflect the research activity of this large country.

2. The degree to which the regional aggregation of the co-authorship data leads to the underestimation of co-authorship levels for individual countries can be approximately estimated by looking at the effects of aggregation on the countries for which we have disaggregated data. When these countries were placed into regions with which they had much in common, their international collaboration levels typically declined by roughly a fifth. Hence, in estimating co-authorship levels of surrogate countries from the different regions, we increased the known regional figures by 25 percent. We then divided the adjusted international co-authorship total for each region by the number of major research producers in the region, where this number was defined as the smallest number of countries which together account for at least 80 percent of the published research in the region. The quotient of this division, after being multiplied by 0.8, is an estimate of the number of international co-authorships associated with the works of a typical major research producer of the region.

3. In recognition of the fact that the sizes of national research efforts may affect the levels of international collaboration, we created an index which took a size-independent view of collaboration. That is, acknowledging that large countries represent large co-authorship targets — and that this fact might affect our results — we examined international co-authorship patterns after factoring out the effects of

national research size. The results were essentially the same as those reported in Table 1.

4. Norman W. Storer, 'The Internationality of Science and the Nationality of Scientists', *International Social Science Journal*, Vol. 22 (1970), 89-104.

5. Diana Crane, 'Transnational Networks in Basic Science', in Robert O. Keohane and Joseph S. Nye (eds), *Transnational Relations and World Politics* (Cambridge, Mass.: Harvard University Press, 1972), 235-51.

6. Arnold J. Herzog, 'Social and Cognitive Factors Influencing the International Transfer of Scientific Knowledge', paper presented to The First International Conference on Social Studies of Science, Ithaca, NY, 4-6 November 1976.

7. Donald deB. Beaver and Richard Rosen, 'Studies in Scientific Collaboration. Part I. The Professional Origins of Scientific Co-authorship', *Scientometrics*, Vol. 1 (1978), 65-84; 'Part II. Scientific Co-authorship, Research Productivity and Visibility in the French Scientific Elite, 1799-1830', ibid. (1979), 133-49.

8. Edward Miles, 'Transnationalism in Space', in Keohane and Nye, op. cit. note 5, 252-75.

9. Derek de Solla Price, 'Measuring the Size of Science', *Proceedings of the Israel Academy of Science and Humanities*, Vol. 4 (1969), 98-111.

10. J. Davidson Frame, 'National Economic Resources and the Production of Research in Lesser Developed Countries', *Social Studies of Science*, Vol. 9 (1979), 233-46.

11. V. Nalimov and Z. Mulchenko (trans. Foreign Technology Division, USAF Systems Command), *Measurement of Science: Study of the Development of Science as an Information Process* (Dayton, Ohio: Foreign Technology Division, Wright Patterson AFB, 1971); Francis Narin and Mark P. Carpenter, 'National Publication and Citation Comparisons', *Journal of the American Society for Information Sciences*, Vol. 26 (1975), 80-93; J. Davidson Frame and Francis Narin, 'The International Distribution of Biomedical Publications', *Federation Proceedings*, Vol. 36 (1977), 1790-95.

12. Nalimov and Mulchenko, op. cit. note 11, 168.

13. The programme used in the multidimensional scaling was Bell Laboratory's M-D SCAL.

14. The stress value associated with the four-dimensional configuration is 0.439, using a Stress 2 formula. This value is two to three times greater than what we would have obtained had we employed a Stress 1 formula. See J. B. Kruskal and M. Wish, *Multidimensional Scaling* (New York: Sage Publications, 1978), 54. In examining stress values, we found that they decreased almost linearly as we increased the dimensions in the MDS procedure and that there was no natural 'elbow' in these values when plotted against dimensions. In the end we settled on a four dimensional configuration on two grounds: (1) the number of dimensions should not exceed one-fourth the number of variables, which in our case imposed an upward limit of five dimensions on us (Kruskal and Wish, ibid., 34); and (2) a factor analysis performed on the data yielded a four-dimensional configuration.

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