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SPECIALIZATION AND SIZE OF SCIENTIFIC ACTIVITIES: A BIBLIOMETRIC ANALYSIS OF ADVANCED COUNTRIES

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The relationship between the size of national scientific activities of advanced countries and the degree of specialization by fields of science is examined using bibliometric indicators of the number of papers and of paper citations. A negative relation between the amount of scientific activity and the degree of scientific specialization has emerged, with Japan and, to a lesser extent Italy, showing a specialization degree higher than expected. Countries with established scientific traditions (such as the US, the UK, the Netherlands, and Switzerland) have a lower than expected specialization degree, suggesting a more diversified range of research activities. Over time, however, most countries have reduced their scientific specialization, a pattern which is in contrast with recent research on patents and technological specialization.

Introduction

This paper presents an analysis of the patterns of national specialization by field of science in advanced countries. While several international comparisons have been made concerning the quantity and quality of scientific output either at the aggregate level or on specific disciplines,[1] less attention has been devoted to the distribution of countries' scientific activity across fields. To what extent are the scientific efforts of advanced countries spread over different research areas, or concentrated in few sectors? The answer, obviously, depends also on the scope of national research activities, but what specific relation can be identified between a country's size and the degree of specialization of its scientific base? These two key questions are addressed in this paper.

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Similar issues have already been investigated for a variety of technological and economic indicators. In a previous study on patent statistics,[2] we found that in the production of technological knowledge large countries tend to have a more even distribution of patented inventions in all sectors, while small countries concentrate their production of technology in a few areas where they can achieve economies of scale in industrial R & D and innovation, creating selected niches of international excellence. We have also found that for the majority of countries an increasing technological specialization has occurred during the 1980s.

Such patterns can be found also for economic variables describing a country's production and trade activities. Smaller countries tend to have higher levels of specialization, and over the last decades a pattern of increasing specialization in trade has been documented for the majority of advanced countries as a consequence of greater economic integration and growing international trade.

Similar patterns could also be expected in the production of scientific knowledge: for small and medium sized countries it would be difficult to cover all the scientific disciplines uniformly. Since scientific knowledge is highly diversified, it would not be surprising if the scientific community of a small country focused its activity in a selected number of fields without covering others.

While the differences between productive and scientific specializations seem to be greater than the similarities, a more thorough comparison of the patterns of specialization in science and technology is required. This largely depends upon the lack of a clear-cut distinction between activities labelled "scientific" or "technological", in spite of the theoretical and empirical efforts made to discriminate between them.[3]

In this paper, we will make an 'institutional' distinction between science and technology: we will call "scientific" those activities carried out in institutions designed to the improvement of knowledge and producing non proprietary results. Conversely, we will define as "technological" those activities which are intended to generate new or better products and processes linked to competitive assessment and proprietary in nature. While "scientific" activities as defined above are primarily promoted and financed by governments, universities and other public institutions, the majority of technological activities are carried out by business firms.

The existence of a relationship, if any, between the scientific size of a country and its distribution of scientific output across fields is particularly relevant to science policy. The priorities given by the public funding authorities are one of the key elements in shaping the scientific specialization of a country. Identifying the nature of the relation between the number of fields covered by the scientific community of a country and the quantity and quality of the results achieved in each of them represents information of importance in guiding policy making.

Various reviews of the science policies implemented in advanced countries[4] have shown that substantially different strategies are followed. While some governments give priority to those fields where their country was lagging behind, others prefer to concentrate their efforts in those sectors where levels of excellence have already been achieved. Over time, the former countries are therefore expected to reduce their specialization, and the latter to increase it.

Methodology and databases employed

As indicators of scientific production, we have considered data on articles published in scientific journals. Bibliometric data offer several advantages for our purposes. They are highly disaggregated by areas of research and neither data on R & D expenditure nor the number of researchers provide the same detailed information as to "what is going on" in specific scientific fields in each country. Bibliometric data also provide direct information on the output of the scientific community of each country. Together with the number of papers, we have also considered the number of citations received by papers, as an indicator of the impact of a country's scientific production.

The variables on the number of scientific papers and the number of citations they received are drawn from two databases, developed by CHI Research and based on the Science Citation Index of the Institute for Scientific Information:

(1) The first database refers to publications (articles, notes and reviews) appeared between 1973 and 1984 in a fixed set of about 2100 journals defined in 1973. We have subdivided the 12-year time series into two 6-year periods.

(2) The second database refers to publications appearing between 1981 and 1986 in a set of 3081 journals defined in 1981. These data will be first analyzed as a single 6-year period; in the study of the changes over time of the degree of national specialization this series will then be split into two subperiods, 1981-83 and 1984-86.

These databases account for a large share of the world's scientific literature, and include a very high share of the most cited publications, although they still cover only a subset of the world's production of scientific papers. It should be borne in mind also that they include a disproportionate share of English-language journals and a very strong representation of biomedical sciences.

The percent distribution among countries of world papers in the two databases is shown in Table 1, together with the average number of citations per paper. These data provide an overview of the relative importance of the countries considered and, more importantly, of their changes over time.

The US accounts for 37% of all papers and 52% of the citations included in the first database in both the 1973-78 and the 1979-84 periods. In the second database, the US shares fall slightly to 36% and 51%. EEC countries show a remarkably stable pattern, with 26% of all papers and 25% of citations in all periods; within the EEC the largest contribution comes from the UK, whose share of papers and citations falls from 9.1% and 10.7% in 1973-78 to about 8.3% in the 1981-86 database.[5] Germany and France show a slight fall in the share of papers (to 6% and 4.8% in 1981-86) and an increase in their citations; Italy, starting from a 1.8% share of papers and a 1.3% share of citations in 1973-78, increases to 2.3% and 1.8% in 1981-86. Japan expands its share of world papers from 5.6% in 1973-78 to 7.2% in 1981-86, and its citations grow from 4.2% to 5.8%. The remaining OECD countries have a generally stable pattern.

Significant differences emerge in the average number of citations per paper.[6] The US has the most cited papers in all periods, followed closely by Switzerland (especially in the latest data), Sweden, Denmark, the UK, and the Netherlands. The EEC aggregate is further behind, but over time it moves closer to the world average; a similar convergence can be found also for Japan, which starts from an even lower average number of citations per paper.

Output indicators of scientific activity, such as the number of papers and paper citations need to be related to an input indicator which may express the size of national scientific communities. We will use here the number of researchers and scientists employed in the non-business sector (i.e. higher education, government and non-profit institutions) in full time equivalent units. The number of researchers seems to be a more stable and reliable indicator of the dimension of a country's scientific effort than R & D expenditure, the latter being strongly influenced by economic factors such as wage levels, GDP growth, etc. We consider the number of researchers employed in the non-business sector because the production of scientific papers is their main output, while researchers employed in business firms tend to be extensively involved in applied, development and engineering work, while publishing in academic journals has a lower priority.

Table 1
Papers and citations of advanced countries.
Percent distribution across countries of the number of papers and paper citations and average number of citations per paper,
A. 1973-84 database: 1973-78 and 1979-84,
B. 1981-86 database: 1981-86

	A. Data from the 1973-84 database						B. 1981-86 database		
	1973-78 data			1979-84 data			1981-86 data		
Countries	Papers, %	Citat., %	Average cit.per paper	Papers, %	Citat., %	Average cit.per paper	Papers, %	Citat., %	Average cit.per paper
United States	37.17	52.62	11.83	37.05	51.60	4.32	35.85	50.59	4.97
Japan	5.60	4.21	6.28	7.14	5.70	2.48	7.26	5.85	2.84
EEC	26.54	24.72	7.78	26.00	24.76	2.95	26.32	25.57	3.42
FR Germany	6.42	5.22	6.79	6.18	5.85	2.93	6.07	5.84	3.39
France	5.49	3.92	5.96	5.14	4.27	2.58	4.84	4.31	3.14
Un. Kingdom	9.10	10.67	9.79	8.26	8.99	3.38	8.30	8.24	3.92
Italy	1.82	1.27	5.83	2.08	1.57	2.34	2.31	1.75	2.66
Netherlands	1.35	1.57	9.69	1.55	1.75	3.51	1.72	1.92	3.93
Belgium	0.82	0.73	7.55	0.81	0.78	2.97	0.87	0.85	3.43
Denmark	0.80	0.99	10.37	0.86	0.97	3.49	0.84	0.92	3.89
Spain	0.38	0.18	3.92	0.68	0.36	1.64	0.89	0.47	1.88
Ireland	0.19	0.09	4.07	0.18	0.10	1.76	0.17	0.11	2.19
Portugal	0.04	0.02	4.96	0.05	0.03	1.68	0.06	0.03	1.89
Greece	0.14	0.06	3.73	0.21	0.09	1.38	0.18	0.08	1.63
Switzerland	1.38	1.57	9.51	1.34	1.76	4.06	1.29	1.78	4.86
Sweden	1.58	2.17	11.50	1.65	1.93	3.63	1.68	1.99	4.17
Austria	0.58	0.29	4.15	0.55	0.34	1.91	0.55	0.35	2.26
Canada	4.30	4.31	8.37	4.20	4.05	3.00	4.14	4.00	3.40
Australia	1.76	0.63	2.97	2.01	1.87	2.89	2.14	2.02	3.32
Others	21.10	9.50	3.76	20.07	7.98	1.50	20.81	7.87	1.33
World	100	100	8.35	100	100	3.10	100	100	3.52

Source: CNR-ISRDS elaboration on CHI Research data.

Table 2 reports the number of researchers in OECD countries, calculating the averages for the three periods considered, 1973-78, 1979-84 and 1981-86.

Table 2
Number of researchers and scientists.
Researchers, scientists and engineers (University graduates) full time equivalents, averages 1973-78, 1979-84, 1981-86

Countries	1973-78		1979-84		1981-86	
United States	163183		185483		193667	
Japan	101564		118819		124814	
EEC	168675		212798		224838	
FR Germany	42966		47661	e	48976	f
France	35568		51493		55360	
Un. Kingdom	35116	i	37703	j	38566	k
Italy	23599		34667		38586	
Netherlands	9810	b	12453	e	12840	f
Belgium	6297	b	6280	j	6430	k
Denmark	3641		4541		4930	
Spain	5809	a	10788		11398	
Ireland	2047	b	2302		2439	
Portugal	1656	c	2326		2581	
Greece	2167	i	2584	d	2734	f
Switzerland	5455		5770	d	6044	k
Sweden	6617	b	6997	e	8048	f
Austria	3306	b	3826	e	4038	
Canada	25862		27502		29177	
Australia	18491	c	20771	e	22588	g

Source: CNR-ISRDS elaboration on OECD data, *Main Science & Technology Indicators*, April 1990.
Note: Average values are calculated on data for at least four years within each period, or on two symmetrical values. When only one datum is available the following have been used:
a. 1974, b. 1975, c. 1976, d. 1979, e. 1981, f. 1983 g. 1984 h. 1985.
Missing data were replaced with estimates from linear regression for the following years:
i. 1975, j. 1981, k. 1983.
Data for Japan are adjusted; data for the UK are rough estimates.

The degree of specialization

In order to explore to patterns of specialization of the scientific activities of advanced countries we have developed a measure of the dispersion across fields of the publications and citations of each country. We have broken down data on papers and citations of each country into 96 scientific subfields (reported in the *Appendix*).

Following a method already applied in our study on patenting,[7] the percent distribution of the number of papers and citations across 96 subfields of science[8] for each country was calculated and compared with the world sectoral distribution of scientific activity. Chi square values were calculated for each country,[9] in order to measure how different the national pattern of specialization in scientific subfields was from the aggregate distribution of papers and citations. Chi square values were calculated for papers and citations for the two subperiods of both databases, and are shown in Table 3. They allow an assessment to be made of the national degree of specialization, its changes over time, and a comparison between the patterns shown by paper counts and paper citations.

Table 3
The degree of scientific specialization.
Chi square values by country, papers and citations,
A. 1973-84 database: 1973-78 and 1979-84, B. 1981-86 database: 1981-83 and 1984-86

Countries	A. Data from the 1973-84 database				B. Data from the 1981-86 database			
	papers 1973-78	citations 1973-78	papers 1979-84	citations 1979-84	papers 1981-83	citations 1981-83	papers 1984-86	citations 1984-86
USA	10.26	3.15	9.47	3.76	8.27	4.03	7.03	4.22
Japan	54.80	61.11	40.45	53.11	38.86	50.75	36.34	48.62
EEC	5.37	5.11	5.08	5.19	3.82	4.21	3.54	4.38
FR Germany	20.29	29.68	18.44	33.05	13.76	21.92	13.23	25.21
France	34.73	24.69	20.92	17.79	15.04	18.04	14.62	15.37
Un. Kingdom	16.41	11.78	16.84	13.78	12.00	10.29	11.97	10.75
Italy	52.38	43.06	38.12	37.66	33.71	38.68	30.92	34.88
Netherlands	19.20	19.92	19.76	18.37	14.20	14.10	14.26	20.02
Belgium	23.97	19.94	23.11	23.62	37.69	22.27	23.59	23.94
Denmark	73.24	50.51	75.88	51.42	61.50	39.43	71.75	46.05
Spain	107.30	50.55	64.93	51.08	90.31	72.93	75.20	83.00
Ireland	160.54	116.66	120.53	140.61	121.26	131.00	73.03	81.08
Portugal	93.54	140.89	68.62	114.17	90.85	326.42	77.23	157.09
Greece	64.37	94.30	50.80	75.21	63.61	107.22	54.59	91.50
Switzerland	41.33	35.57	30.90	32.11	38.14	46.03	30.61	46.39
Sweden	57.71	41.26	70.25	40.58	63.50	41.95	56.15	47.17
Austria	85.65	62.91	69.85	51.20	49.85	38.65	44.66	34.50
Canada	25.59	27.39	30.85	26.82	18.74	22.23	18.99	22.27
Australia	34.75	30.29	34.60	31.17	32.10	38.72	35.14	38.90

Source: CNR-Isrds elaboration on CHI Research data.

The national degrees of specialization differ widely for all the variables considered, and the countries' rank is frequently different for the number of papers and citations. The EEC aggregate presents the lowest chi square values measured for the number of papers in all periods, while the US has the lowest values for paper citations in all periods. While the EEC spreads its scientific publications across subfields more evenly than the US, the EEC papers with the greatest impact are not distributed as widely as those of the US. However, this result may be due to the over-representation in the database of US (and generally English language) journals, which have higher citation rates.

The UK is the European country with the lowest chi square values, and a distribution of scientific activities fairly dispersed and closer to the world total in the database. Germany and France follow, with the former showing a lower degree of specialization in papers, and the latter in paper citations in all periods. The Netherlands, Canada and Belgium have a less stable position, and in some cases show a lower chi square value than Germany or France.

Among the largest countries, Japan presents a high level of specialization in both databases and in papers as well as in citations. Italy, Switzerland, Sweden and Denmark have a high degree of specialization, concentrating their scientific efforts in selected subfields. Even higher, but statistically less reliable, are the chi square values of Spain, Greece, Portugal and Ireland.

An obvious explanatory variable of such a pattern is the size of national scientific communities, whose influence will be explored in a later section, after looking at the changes over time and at the comparison between papers and citations.

Specialization over time: a fall for papers, a rise for citations

Over time, the degree of specialization of national scientific activity measured by paper counts falls in almost all countries. In the first database, comparing the two periods 1973-78 and 1979-84, we find that France, Switzerland, Italy and Japan are the main OECD countries with an increasingly uniform distribution across fields of scientific activities of both papers and citations, resulting in lower chi square values for both variables. Several other countries show the same falling specialization over time for paper counts only (the US, Germany and Belgium), or for citations only (the Netherlands, Canada and Sweden). The UK and Denmark are the only countries showing an opposite pattern of growing specialization over time in both paper counts and citations.

Looking at the second database, between 1981-83 and 1984-86 the falling specialization shown by the number of publications is even more evident, and only the Netherlands, Denmark, Canada and Australia concentrate on fewer sectors their scientific activities. On the other hand, citation data show a general pattern of increasing sectoral specialization, with the exception of France, Italy, Japan and Austria, among the main OECD countries. As already pointed out, this result for citation data is strongly affected by the shorter time span in which more recent papers could be cited; as more citations cumulate over the years, this pattern may change.

These data suggest that countries tend to develop their scientific activities, as measured by the number of papers, more in the areas of their relative weakness than in those of their greater strength. In this way they come closer to the distribution of scientific activities by subfields of science shown by the total of world publications.

Comparing papers and citations

A comparison of the chi square values for paper counts and citations provides additional information on the nature of scientific activity. In the first period, 1973-78, the chi square values measuring the degree of specialization for papers are generally higher than those for citations. Only Japan, Germany and the Netherlands, among the major OECD countries, show an opposite pattern. In other words, in most countries papers with the greatest impact, as measured by the cumulation of citations over a fairly long period of time, are more evenly distributed across fields of science than all papers.

In the 1979-84 period Japan and Germany maintain their greater specialization in citations than in paper counts and, among major OECD countries, Switzerland and Belgium follow the same pattern.

In the new database built on the 1981 journal set the picture is reversed. However, the short time span in which the papers appearing in this period could be cited, and the relatively low numbers of total citations received suggest particular caution in interpreting these results. In the period 1981-83 France, Italy, Switzerland and Canada join the countries with a greater degree of specialization in citations than in papers. In the last period, 1984-86, only the US, the UK, Denmark, Sweden and Austria show for citations a more even distribution across subfields than for papers.

From the chi square values it would appear that for most countries the research with the greatest impact on scientific literature, as measured by the number of citations, shows a growing degree of specialization also relative to the distribution of the number of publications. But this pattern may well be the result of the decreasing number of citations which are available for the more recent periods considered. No conclusive evidence on the relative degrees of specialization between paper counts and paper citations is therefore available.

These trends in the sectoral specialization shown by countries in papers and citations are related to some basic characteristics of scientific activity, such as the non-proprietary nature of scientific knowledge, and the availability of state-of-the-art knowledge published by international scientific journals. Both factors make it possible for a country to be active and publish in a variety of fields, without the need to concentrate resources and efforts in a few areas only. The open nature of scientific inquiry makes it possible to learn rapidly from other scientists' results, thus offering the possibility of addressing other fields of science.

However, when a smaller number of citations is available (as in the case of papers published more recently, and of countries with lower citation rates) a growing degree of specialization has been found, as the subfields of greater strength of national scientific activity are likely to emerge more rapidly and selectively in the citation patterns of the scientific literature.

The relationship between specialization and size of scientific activity

The national degree of specialization across fields, measured by the chi square values (Table 3), can now be related to the size of countries' scientific communities, as measured by the number of researchers and scientists employed in the non-business sector (reported in Table 2). The relationship will be explored for the two subperiods of the first database (1973-78 and 1979-84) and for the whole 1981-86 period covered by the second database.

Figures 1, 2, and 3 show the relationship between degree of specialization and size of the national scientific base, transforming the two variables in their natural logarithm. A negative relation is evident in all graphs, and the linear regression line is drawn in order to illustrate the average pattern among all countries considered.

Figure 1 shows that for the number of scientific papers some countries, including Japan, Italy, Spain, Sweden and Denmark, have a specialization degree higher than the one expected on the basis of the size of their scientific community. The US, the UK, the Netherlands, Belgium and Switzerland show on the other hand the broadest distribution of their efforts across fields of science. The EEC aggregate shows the greatest diversification among areas of research. While the EEC countries have a comparable number of researchers to the US, they have on the whole a considerably lower specialization degree, resulting also from the diversity of national activities and positions of the twelve countries of the Community.

Over time, the distribution of countries becomes slightly more uniform, suggesting, as we have already seen, a broader diversification of the areas of scientific research in most OECD countries.

Looking at the data for paper citations, reported in Fig. 2, the countries showing a higher degree of specialization than that expected from their scientific size are Japan, Germany and Italy, while the US, the UK, the Netherlands, Belgium and Switzerland have a wide distribution of their scientific efforts. In citations, the EEC aggregate becomes more specialized than the US.

Again, over time the pattern is shifting slightly towards a more even distribution of national degrees of specialization relative to changes in the size of the countries' activity.

For the second database, data for papers and paper citations in 1981-86 are shown together in Fig. 3. The relative position of most countries is confirmed, with Japan, Italy, Australia and Spain showing the highest degree of specialization relative to their size, and the US, the UK, Canada, the Netherlands, Belgium and Switzerland showing the broadest distribution of their scientific activity. The average distribution of papers is more uniform than that of paper citations, as pointed out above.

On Y axis: Logarithm of the specialization index. CHI squares of the percent distribution of papers by subfields of science, 1973-78, 1979-84.

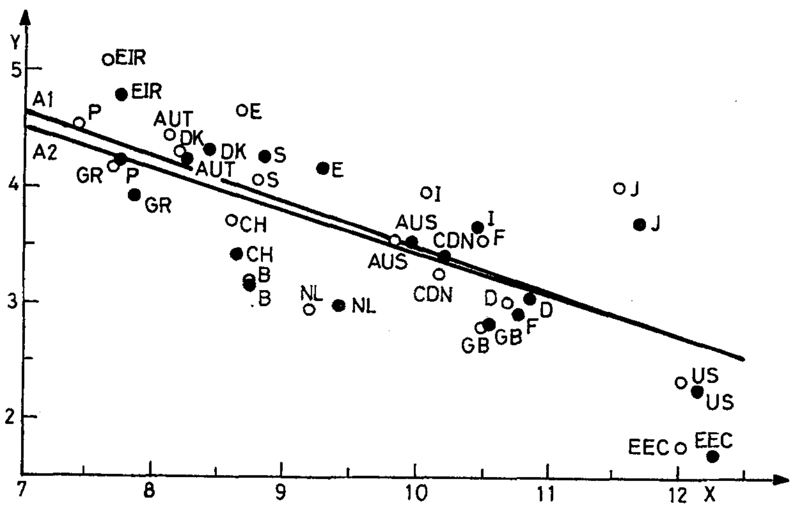

Fig. 1. Specialization and size of scientific activity.
Number of researchers and scientists and CHI squares of the distribution of the number of papers by subfields of science, 1973-78, 1979-84.

On X axis: Size of national scientific activity. Logarithm of the number of researchers and scientists (non-business sector). Average 1973-78, 1979-84.
o normal = calculated on the number of papers, 1973-78,
• **bold** = calculated on the number of papers, 1979-84.
Legend: AUS = Australia, AUT = Austria, B = Belgium, CDN = Canada, DK = Denmark, F = France, D = West Germany, GR = Greece, EIR = Ireland, I = Italy, J = Japan, NL = Netherlands, E = Spain, S = Sweden, CH = Switzerland, GB = United Kingdom, US = United States, EEC = European Community
A1: Number of papers, 1973-78,
A2: Number of papers, 1979-84.

On Y axis:
Logarithm of the specialization index.
CHI squares of the percent distribution of paper citations by subfields of science, 1973-78, 1979-84.

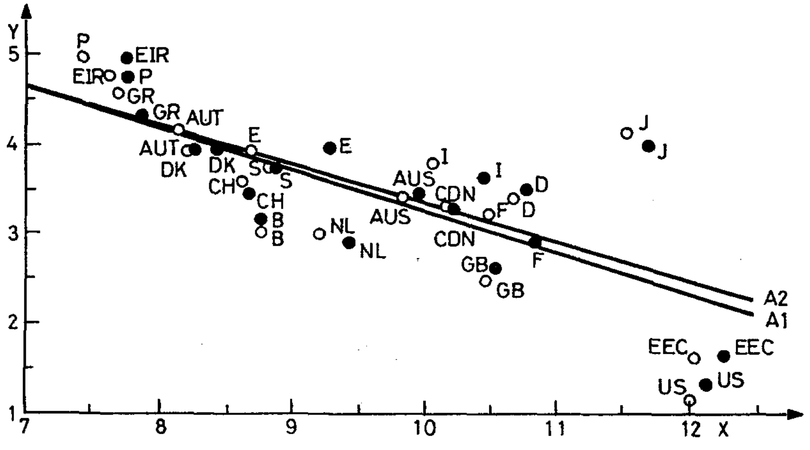

Fig. 2. Specialization and size of scientific activity.
Number of researchers and scientists and CHI squares of the distribution of the number of paper citations by subfields of science, 1973-78, 1979-84.

On X axis: Size of national scientific activity. Logarithm of the number of researchers and scientists (non-business sector). Average 1973-78, 1979-84.
o normal = calculated on the number of paper citations, 1973-78,
• **bold** = calculated on the number of paper citations, 1979-84.
Legend: see Fig. 1.
A1: Number of paper citations, 1973-78,
A2: Number of paper citations, 1979-84.

On Y axis:
Logarithm of the specialization index.
CHI squares of the percent distribution of papers and citations by subfields of science.

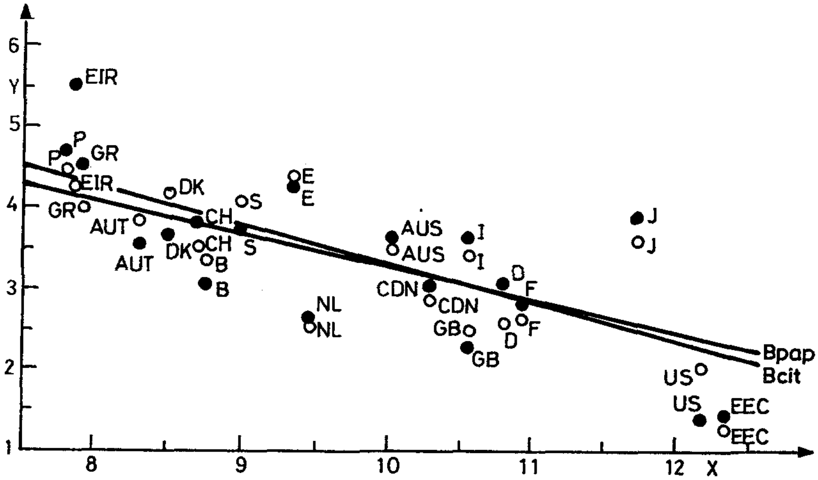

Fig. 3. Specialization and size of scientific activity.
Number of researchers and scientists and CHI squares of the distribution of the number of papers and paper citations by subfields of science, 1981-86.

On X axis: Size of national scientific activity. Logarithm of the number of researchers and scientists (non-business sector). Average 1981-86.
o normal = calculated on the number of papers, 1981-86,
• **bold** = calculated on the number of paper citations, 1981-86.
Legend: see Fig. 1.

BPAP: Number of papers, 1981-86,
BCIT: Number of paper citations, 1981-86.

Concluding remarks

The degree of specialization of advanced countries and the size of their scientific communities in the non-business sector have an inverse relation: the size of a country has an influence on the distribution of its research activities across subfields of science. This relationship is, however, very loose, and significant anomalies have been found. Japan and, to a lesser extent, Italy, show a substantially higher degree of specialization relative to the size of their scientific base. Conversely, several other countries, in particular those with established scientific traditions such as the US, the UK, the Netherlands, Switzerland and Belgium, show a lower degree of specialization than expected.

Our previous research on patenting[10] has revealed the existence of a significant negative relation between the degree of specialization in technological activities and countries' size.[11] Also in technology countries such as Japan and Italy show a higher specialization degree than expected, relative to the distribution of advanced countries, while the US, France, the UK and other countries display an opposite pattern.

A more detailed comparison of the specialization emerging from science and technology indicators is developed elsewhere;[12] suffice it to note here that if we compare the ranks of all countries in the chi square values calculated for different science and technology indicators, we find a wide variety of relative positions. Some countries have a higher degree of specialization in scientific papers than in patents (France, Japan, Sweden, Canada), others (including the UK, Germany, Belgium, Switzerland, the Netherlands and, lately also Italy) show a higher specialization in patents than in publications relative to distribution of advanced countries. However, a more detailed analysis of the patterns of specialization emerging from science and technology indicators should take into account the policies of governments and firms in each country, in order to explain institutional differences and specific positions of individual countries.

Although some caution is required when interpreting our results over time, a tendency towards a decreasing degree of scientific specialization, measured on the number of publications, is evident in the majority of countries. This suggests that it is easier to expand a country's scientific activity in fields of relative weakness rather than in the areas of national strength.

While it is commonly argued that science and technology are experiencing a similar process of internationalization, these diverging trends in scientific and technological specialization point to the different nature and logic of development of science and technology. The increasing international activities of national scientific communities may have accelerated the acquistion of knowledge in the areas of greater national weakness, resulting in a smoother pattern of specialization for the majority of countries. Conversely, the internationalization of technology, mainly through the competitive mechanisms of the world market, seems to produce an increasing concentration of technological activities in the areas of existing national advantage, leading to an increased degree of specialization.

The extent to which these trends are the outcome of deliberate policies is open to speculation. It should be noted, however, that trends in technological specialization can be largely explained by the operation of firms in the international market, while trends in scientific specialization are related to the activity of research institutions where the public sector plays a much larger role.

Ultimately, the divergent trends of scientific and technological specialization are related to a basic difference in the nature of science and technology: the latter is proprietary in nature, and its payoffs are linked to competitive assessment; agents active in technological research are forced to achieve results which can keep pace with those of their competitors. Their efforts are understandably concentrated in the sectors of greater experience, exploiting accumulated skills and know how, without paying new entry costs. The acquisition and diffusion of scientific knowledge, on the contrary, is one of the leading aims of any scientific community. The non proprietary and non localized nature of scientific knowledge lead to the free exchange of communication among world researchers through international journals, conferences and other forms of information flows; this makes it possible, and convenient, to fill the gaps in the fields of major weakness of national scientific communities.

The policy implications of these patterns are still to be explored. In both science and technology government policies play an important role, and can be effective in directing research efforts towards areas of greater national priority. However the impact of national institutional settings on the dynamics of specialization and the success or failure of policies favouring or opposing these trends can only be assessed in specific case studies.

Notes and references

1. See, among others, the overviews offered by the reports of the US National Science Board, *Science and Engineering Indicators*, Washington D.C., 1987, and of the OECD, *Science and Technology Outlook 1988*, Paris, 1988.

2. D. ARCHIBUGI, M. PIANTA, Specialization and size of technological activities in industrial countries: the analysis of patent data. In: M. PERLMAN (Ed.), *Entrepreneurship., Technological Innovation and Economic Growth: International Perspectives,* University of Michigan Press, Ann Arbor (forthcoming).
3. Among an extensive literature on the relationship between science and technology, see N. ROSENBERG, How exogenous is science? In: *Inside the Black Box,* Cambridge University Press, Cambridge, 1982; D. DE SOLLA PRICE, The science/technology relationship, the craft of experimental science, and policy for the improvement of high technology innovations, *Research Policy,* 13, (1984); D. ARCHIBUGI, Paradigms and revolutions: from science to technology?, Paper presented at the EASST 4th annual meeting, Strasbourg, October 1986. An empirical study of this relationship is in: F. NARIN, E. NOMA, Is technology becoming science?, *Scientometrics,* 7 (1985) 369.
4. A recent survey of national cases can be found in: B. MARTIN, J. IRVINE, *Research Foresight. Priority-Setting in Science,* Pinter, London, 1989.
5. The relative decline of British scientific output has been the subject of a long standing debate, which has raised questions also on the significance of the database used here. See, B. MARTIN, J. IRVINE, F. NARIN, C. STERRITT, The continuing decline of British science, *Nature,* 330 (12 November 1987) 123; L. LEYDERSDORFF, Problems with the 'measurement' of national scientific performance, *Science and Public Policy,* 15 (1988) 149; T. BRAUN, W. GLÄNZEL, A. SCHUBERT, Assessing assessments of British science: some facts and figures to accept or decline, *Scientometrics* 15 (1989) 165; J. IRVINE, B. MARTIN, International comparisons of scientific performances revisited, *Scientometrics,* 15 (1989) 369.
6. Here we use the total number of citations received by the papers over the period considered, and obviously older papers have a greater probability of being cited than recent ones. Summing together the citations received by papers of different years may combine data which are not entirely comparable, but for our descriptive purposes this variable offers a valuable overview of the relative position of different countries.
   A possible distortion, however, may be introduced in the average number of citations. For the countries where the average impact of their papers, measured by the number of citations received, has rapidly changed over time, this indicator may underestimate the change. However, we have found a generally stable pattern, and for our purposes an aggregate picture for an extended period of time is a fairly satisfactory indicator of the impact of a country's papers in the world scientific literature.
7. See note 2.
8. The 96 subfields considered, listed in the *Appendix*, are basically those provided by the disaggregation of the CHI Research database; a few classes with the lowest number of papers have been combined together. These subfields provide a detailed picture of the distribution of a country's scientific activities within the areas of Clinical Medicine, Biomedical Research, Biology, Chemistry, Physics, Earth and Space Sciences, Engineering and Technology, Mathematics.
9. The chi square statistic is calculated as the sum of the squares of the differences between a country's share of its papers in a subfield and the share of the world total in that subfield. The index in equal to zero when the country's sectoral distribution is the same as the world's and no national specialization can be found. The higher the index, the greater the degree of national specialization in a few subfields of scientific activity. In our calculations, the percent values have been multiplied by 100.
10. See note 2.
11. Also for patenting, the degree of specialization is based on the chi square value calculated on the percent distribution by subfields of a country's patents, compared to the world's distribution. The indicator for the size of a country's technological activities is cumulative R & D expenditure. For further details see the paper referred to in note 2.
12. A more detailed analysis of the patterns shown by science and technology can be found in: D. ARCHIBUGI, M. PIANTA, *The European Technological Specialization*, EEC Final Report, December 1990.

Appendix

Fields and subfields of science in the CHI Research database

List of the 8 fields of science

9991	Clinical medicine
9992	Biomedical research
9993	Biology
9994	Chemistry
9995	Physics
9996	Earth and space
9997	Engineering & techn
9999	Mathematics

List of the 96 subfields of science

10 Genrl & inter. med	640 Hygiene & publ hlth	2700 Polymers
100 Allergy	660 Misc clinical med	2800 Physical chemistry
120 Anesthesiology	700 Physiology	3000 Chemical physics
140 Cancer	720 Anatomy & morphology	3100 Solid state physics
160 Cardiovascular systm	730 Embryology	3200 Fluids & plasmas
180 Dentistry	740 Genetics & heredity	3300 Applied physics
200 Dermat & venerl dis	760 Nutrition & dietet	3400 Acoustics
220 Endocrinology	800 Biochem & Molec biol	3500 Optics
230 Fertility	810 Biophysics	3600 General physics
240 Gastroenterology	820 Cell biol cyt & hist	3610 Nucl & particle phys
260 Geriatrics	840 Microbiology	3650 Miscellaneous phys
280 Hematology	860 Virology	4130 Astronomy & astrophys
300 Immunology	870 Parasitology	4300 Meteorol & atmos sci
320 Obstetrics & gynecol	910 Biomedical enginrng	4500 Geology
340 Neurol & neurosurg	920 Microscopy	4EEG Earth, env. & geog.
360 Ophthalmology	950 Misc biomedical res	4900 Oceanography & limno
380 Orthopedics	990 Genrl biomedical res	5100 Chemical engineering
390 Arthritis & rheumat	1000 General biology	5200 Mechanical engineer
400 Otorhinolaryngology	1100 General zoology	5300 Civil engineering
420 Pathology	1160 Entomology	5400 Electr eng & elctron
440 Pediatrics	1190 Miscellaneous zool	57MG Misc. & gen. eng.
460 Pharmacology	1200 Marine bio & hydrobi	5900 Metals & metallurgy
470 Pharmacy	1300 Botany	6100 Materials science
480 Psychiatry	1400 Ecology	6300 Nuclear technology
500 Radiology & nucl med	1500 Agricult & food sci	6400 Aerospace technology
520 Respiratory system	1600 Dairy & animal sci	6500 Computers
540 Surgery	1700 Miscellaneous biol	6700 Library & info sci
560 Tropical medicine	2100 Analytical chemistry	6800 Op res & managmt sci
580 Urology	2200 Organic chemistry	8100 Probablty & statist
590 Nephrology	2300 Inorganic & nucl chm	8300 Applied mathematics
600 Veterinary medicine	2400 Applied chemistry	8400 General mathematics
620 Addictive diseases	2500 General chemistry	8500 Misc mathematics