Specialization and size of technological activities in industrial countries: The analysis of patent data

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The determinants and direction of the technological specialization of advanced countries are investigated in this paper using patent counts and citations as technology indicators.

During the 1980s, international patenting increased more rapidly than the resources devoted to R&D, indicating a globalization of technology markets, paralleled by a growing degree of sectoral specialization of countries' innovative activities.

A clear-cut inverse relationship between countries' technological size (measured by cumulative R&D expenditure) and degree of specialization has been found. Only large countries can afford to spread their activities across most technological fields, while small and medium-sized countries are to some extent forced to specialize in more narrow niches.

Some methodological aspects in the use of patenting as an internationally comparable indicator are also discussed. Considerable differences emerged between patent specialization profiles in the internal and in external markets. Firms tend to protect their internal market through patenting also in fields where they do not excel at the international level, leading to a smoother specialization profile.

1. Introduction

Several studies in recent years have addressed the pattern of specialization of industrial countries. For variables such as productivity, production, trade and patents, [1] the international sectoral distribution across industries or technologies has came under scrutiny in an attempt to identify the areas of strength and weakness of each country. Analyses over time have revealed evidence of a growing specialization for many countries and sectors, but conclusive evidence is lacking on the direction taken by this process; a key question is whether industrial countries are expanding their productive and technological activities in the same fields or in different areas, and what impact this has on their overall specialization pattern.

At the same time, a growing convergence among industrial countries has been documented at the aggregate level, in terms of production, productivity, and resources devoted to technology (see, for example, [15] and [16]). Reconciling the evidence of convergence at the aggregate level with the signs of specialization at the sectoral level is an additional issue to be addressed.

The implications of these processes are important for national technology policy. As technological knowledge becomes more diversified and highly specific to firms, industries and countries, to what extent should a country try to cover all fields, or should it concentrate its efforts in few areas where it is more specialized? (Pavitt [19] and Cantwell [4] have already examined cross-country differences in technological accumulation). In

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[1] See among others, a study on productivity by Dollar and Wolff [6]; trade data are examined in Dollar and Wolff [7]; for patenting, see Soete [23]; and Patel and Pavitt [17]. See also Gerstenberger [11].

more specific terms, what is the trade-off between the extent of a country's presence in all sectors of technological activity and its ability to be internationally competitive in each of them?

In such a context, this paper focuses on the sectoral specialization of technological activities in advanced countries, as described by patent indicators. Using a variety of databases, we will focus on two issues:

(1) The profiles of sectoral specialization in the technological activity of advanced countries; i.e. the distribution across sectors of their patented inventions compared to those of other countries;

(2) The regularities in the patterns of specialization across countries in relation to the size of their technological activities.

In section 2, the trends of the resources, devoted to Science and Technology (S&T) will be documented. While R&D expenditure has increased substantially, patents in external markets are growing at a faster rate, suggesting a globalization of the firms' strategy to appropriate the results of their technological efforts.

Our research has also some implications in assessing the value of patenting as an internationally comparable technology indicator. Patenting in the US is widely used as a basis for international comparisons, but we will show that considerable differences exist among the specialization profiles resulting from domestic and foreign patenting. In section 3 patent data in the US, at the European Patent Office and in other countries will be considered, broken down according to two different sectoral classifications (IPC and SIC).

In section 4 we will examine the degree of specialization of advanced countries, testing how different a country's sectoral distribution of technological activities is from that resulting from the world total. A measure of the degree of specialization shown by countries will be introduced, and its relation to the size of national technological activities will be explored in section 5.

Throughout this paper, countries will be the unit of analysis, and the technological specialization will refer to all activities performed by firms located within national borders. The presence of foreign-owned firms and of affiliates in other countries is not considered in our data. Obviously, the cross-border technological activities of multinational firms are of great importance in shaping the patterns of specialization, and will be taken into account in the interpretation of the results, considering also the specific work by other research teams (see, for example, [5] and [18]) which provide a useful complement to our analysis.

However, the use of national data does have some relevance. First, it is widely accepted that "national systems of innovation" have emerged, with individual countries being characterized by a specific pattern of technological accumulation, industrial structure and innovative resources, as well as by a unique set of institutions supporting and regulating technological change (the analysis of the national systems of innovation has been developed by Freeman, Nelson, Lundvall, and others; see the essays in [8] and [10]). The technological strengths of a country represent a key influence for the locational choices by large firms in their R&D strategy; national patterns of sectoral specialization are both the result and a determinant of the technological strategies of multinational firms.

Second, while capital and firms are highly mobile across borders, many factors contributing to innovative activities, including labour, are much more country specific and can be measured by national indicators. Furthermore, it is at the national level that major technology policy decisions are made, shaping the conditions for the activities of firms.

2. The appropriability of innovations in international markets

Resources devoted to Science and Technology (S&T) increased strongly in the 1980s. Internationally comparable data on the total amount of resources devoted to S&T are not yet available. However, a proxy of the S&T effort is represented by the resources devoted to formal R&D. Column 2 of table 1 shows that in the 1979–88 period R&D resources increased considerably in almost all OECD countries. R&D expenditure has always grown faster than industrial production (see column 1).

The greater the resources devoted by each country to S&T, the more we can expect that it would try to appropriate the benefits in several markets, and patents are one of the methods used by firms to protect their innovations. Domestic patent applications (i.e., patent applications of residents in their own country; see column 3 of table 1) increased over the same period at a very slow rate, and in eight countries out of eighteen a decline actually occurred. On the contrary, a rapid growth can be found in the number of external patents (column 5 of table 1), i.e., the total number of applications filed by national firms and inventors in other countries. [2] One possible explanation is that in domestic markets patents with a more uncertain business impact have decreased, while patent applications have been extended abroad in a greater number of countries. This pattern is consistent with the findings of a research which has shown that, although the number of patents granted in selected countries has declined, the money spent on renewal fees has not. [3]

[2] A single patent application could therefore be counted more than once if it is extended in more than one country.

[3] Cf. Schankerman and Pakes [21, p. 1071]: "Part of the decline in the patenting per unit of inventive input may reflect a shift away from 'more patents' to 'higher quality'."

In parallel, as shown in column 4 of table 1, the number of foreign patents (i.e., patent applications filed by foreign applicants in a given country) has significantly increased in all OECD countries. The efforts to appropriate the benefits of innovations represent a definite factor contributing to the rapid globalization of technology among advanced countries.

The ratios of external to domestic patents for 1979 and 1988 are reported in columns 6 and 7 of table 1. This index reflects the propensity to protect innovations in foreign markets, and shows that all countries have increased the international dimension of their technological activities. Two different factors have contributed to this: (a) a rise in the average number of countries in which each patent extended abroad is registered; and (b) an increase in the number of patents which are extended abroad. However, our databases do not allow the relative importance of these two factors to be separated.

Table 1
Patterns of industrial production, R&D and patents in OECD countries

Countries	Average annual rates of change (percent)					Ratio of external patents to domestic patents	
	industrial production 1979–88 (1)	R&D expend. 1979–88 (2)	domestic patents 1979–88 (3)	foreign patents 1979–88 (4)	external patents 1979–88 (5)	1979 (6)	1988 (7)
USA	2.66 [a]	5.30	2.44	6.30	7.50	1.73	2.67
Japan	3.84 [a]	8.15 [a]	8.30	3.85	11.53	0.25	0.33
Germany	1.70	3.58	0.54	4 87	6.79	2.28	3.93
France	1.82	4 86	1.16	5 95	7 64	2.41	4.22
Un. Kingdom	1.44 [a]	2.43 [c]	0.64	5.49	8.34	1.37	2.65
Italy	1.95	9.43	−11.59 [f]	10.01	8.50	1.97	n.a.
Netherlands	1 50	3.83 [a]	2.00	10.17	6.91	5.18	7.90
Belgium	2.08	4.40 [a]	−1.05	10.15	6.38	3.65	7.00
Denmark	1.49	7.18 [a]	3.28	7.24	13.47	2.74	6.38
Spain	2.19 [f]	10 11	−0.31	11.77	5.06	0.92	1.48
Ireland	0.94 [d]	6.06	9.34 [a]	3.38	14.12	0.81	1.29
Portugal	0.94 [d]	6.76 [b]	−6.19	5.33	29.86	0.10	1.94
Greece	0.93 [a]	10.30 [d]	−0.18	27.88	8.96	0.07	0.15
Switzerland	2.21 [g]	4.75 [d]	−2 21	9 87	3.38	4 60	7.58
Sweden	1.98	7.71 [a]	−2 39	10 12	8.56	2.51	6.52
Austria	1.82	3.95 [e]	−0.75	13.51	7.44	1.66	3.39
Canada	2.39 [d]	5.60	6.28	2.88	8.31	2.83	3.35
Australia	3.37 [a]	6.08 [b]	3 26	5.31	17.36	0.70	2.22

[a] 1979–87, [b] 1978–86, [c] 1978–87, [d] 1979–86, [e] 1981–88, [f] 1980–88. [g] For Switzerland, data for industrial production are not available; data for Swiss GDP have been used.

(1), (2) Industrial production and R&D data are transformed in real terms using OECD GDP deflators; (3) Patent applications by residents of the country; (4) Patent applications by foreigners in the country; (5) Patent applications by residents extended in other countries.

Source: Elaboration on OECD data, Main Science & Technology Indicators, April 1990.

While the trend towards the internationalization of patenting is generalized, there are still significant cross-country differences in national levels, as shown by the ratio of domestic to extended patents. In 1988, the ratio was particularly high for small and medium-sized countries, such as the Netherlands (7.9), Switzerland (7.6), Belgium (7.0) and Denmark (6.4). Countries with a small internal market are to some extent forced to appropriate the results of their innovative effort in foreign markets. Larger countries, on the contrary, have a weaker propensity to extend their patented inventions abroad.

The US and the United Kingdom have a lower ratio than the other more advanced countries (2.7 for both). It should also be noted that this index is very low for Japan. This result is partially an institutional artifact, since the Japanese patent system does not allow the different technical aspects of an invention to be included in the same application, thus inducing inventors to multiply the number of their domestic applications. This result also indicates that, in spite of the fast growth of Japanese patents abroad (shown in column 5 of table 1), this country still has a vast technological potential.

In spite of international differences in patenting, a general trend towards a globalization of firms' strategies for appropriability is evident. The aggregate analysis performed in this section does not, however, indicate the direction of the innovative strategies pursued by firms and governments in each country. The increase in the resources devoted to S&T and the higher propensity to appropriate the results in international markets could be related either to growing competition or to a growing division of labour among advanced countries. The next section addresses this question and identifies national patterns of technological specialization.

3. The profiles of technological specialization from patent data

In spite of a number of drawbacks identified in the literature, patent data offer the most detailed indicator for studying the patterns of technological specialization at the sectoral level (for a survey of the use of patents as a technology indicator see [3,20,22]).

Two different sets of data have been considered. The first includes patents granted in the US, patent applications and patents granted in France and in the Federal Republic of Germany and patent applications to the European Patent Office. The data refer to 11 countries, cover the periods 1981–87 or 1982–87 and are disaggregated by 32 technology-based International Patent Classes (IPC; the classes are listed in Appendix B). Number of patents, percent distribution across sectors, and the index of Technological Revealed Comparative Advantage [4] for each country have been analyzed elsewhere (see [2]), providing a detailed picture of the pattern of specialization resulting from each database.

Patents registered in the US have been used as the sole source of data by most studies on patenting. [5] The comparison across four patent institutions offers a much needed test of how reliable US patenting is, and how stable the national patterns of specialization are in different databases.

The second set of data we used includes the number of patents granted and frontpage patent citations in the United States. The technical importance of patents varies widely, and the absolute number of patents registered does not provide entirely reliable information as to the significance and impact of patented innovations. For this reason, the number of citations each patent has received from later patents has been considered as a parallel indicator of the impact a country's inventions have on international patenting activity. Data on patent citations are readily available for the US and refer to the list of citations on the frontpage of the patent prepared by the US Patent Office examiner. This external assessment of the link of a new patent to previous ones assures a fairly stan-

[4] The technological revealed comparative advantage index (TRCA, or specialization index) has often been applied to patenting. It is equal to the ratio of the share of patents registered in a given patent office by country i in the class j to the overall share of country i in total patents. It is above (below) 1 if there is a comparative advantage (disadvantage). If, for example, the share of Italian patents registered at the European Patent Office in the class Agriculture is equal to 4 percent, and the Italian total share is equal to 3 percent, the index, i.e. the ratio among these two shares, would be equal to 1.33. A discussion of this index is provided in [12] and [9].

[5] See, among others, those performed by CHI Research, by the Science Policy Research Unit of the University of Sussex, and by the Department of Economics of the University of Reading.

dard approach to the use of citations; this is much more reliable than the use of the citations listed by each inventor, which may overstate the importance of previous patents registered by the same inventor or firm, and ignore other inventors' patents.

The data refer to 16 countries, cover the period 1975–88 and are disaggregated by the 43 classes of the Standard Industrial Classification (SIC; the classes are listed in Appendix C). [6] Again, the number of patents and citations, the percent distribution across sectors and the index of Technological Revealed Comparative Advantage have been investigated elsewhere (see [2]).

Citation data offer an indication of the impact of a country's patents in each sector, providing additional information as to the nature of national technological activities. Citations are cumulated over the years considered; this means that citations referring to patents of different age have been combined. When national characteristics or sectoral patterns affect the speed of patent citation, especially for more recent patents, this indicator should be used with particular caution.

The profiles of technological specialization for the more advanced countries are presented and discussed in a separate report [2], while in the Appendixes B and C the specialization profiles of the United States resulting from the two sets of data considered are presented. The data for the US are reported as an example of the data available for all countries, but they are of particular interest as for the first time they allow a comparison between the spezialization profiles based on patenting in the domestic and in foreign markets. [7]

3.1. The consistency of countries' specialization profiles

A test of the coherence of national specialization profiles in different patent institutions and of

[6] This database, acquired from CHI Research, is described in detail by Narin and Olivastro [14].

[7] Residual classes, i.e. the class Others for the IPC classification, and the classes Unclassified and Other industries for the SIC classification, will be excluded from the subsequent elaborations (correlation coefficients across the vectors of the TRCAs indexes in this section, and the calculation of the degree of specialization in the next section).

Table 2
Correlation coefficients between profiles of patent specialization in different countries

(Correlation coefficients between indexes of technological specialization of advanced countries by IPC classes on patents in the US versus other patenting institutions)

	Correlation coefficients				
	USgr–FRap	USgr–FRgr	USgr–WGap	USgr–WGgr	USgr–EPOap
USA	0.057 *	−0.017 *	0.262 *	0.179 *	0.046 *
Japan	0.796	0.760	0.962	0.950	0.924
West Germany	0.366	0.502	0.378	0.342	0.489
France	0.125 *	0.285 *	0.561	0 816	0.755
United Kingdom	0.075 *	0.256 *	0.455	0.528	0.535
Italy	0.815	0.835	0.763	0.778	0.753
Netherlands	0.671	0.661	0.487	0.789	0.858
Belgium	0.563	0.681	0.500	0.735	0.554
Switzerland	0.766	0.795	0.314 *	0.612	0.787
Sweden	0.907	0.920	0.847	0.881	0 967
Canada	0.189 *	0.303 *	0.546	0.500	n.a.

USgr – Specialization index of patents granted in the USA, 1981–87
FRap – Specialization index of patent applications in France, 1981–87
FRgr – Specialization index of patents granted in France, 1981–87
WGap – Specialization index of patent applications in West Germany, 1982–87
WGgr – Specialization index of patents granted in West Germany, 1982–87
EPOap – Specialization index of patent applications in the European Patent Office, 1982–87.
Correlation coefficients across 31 IPC classes. The residual class "Others" has been excluded. (See Appendix B for the list of classes)
n.a.–not available.
All coefficients are statistically significant at the 5% level, except the coefficients marked with an asterisk (*).
Source: CNR–ISRDS, elaboration on WIPO and EPO data, annual reports, various years.

its consistency in domestic and foreign markets is shown in table 2, with the correlation coefficients between the indexes of specialization calculated on US patents and those based on data from the other patenting institutions.

In general, for all countries (except the US), the specialization profiles based on patents in the US and at the EPO are closely correlated; also patents in the US and in Germany show a high correlation, with a greater similarity for patents granted than for applications.

Special attention should be devoted to those countries – the US, France and Germany – whose domestic patent data were considered. The US specialization profile measured on patents granted in the US shows no correlation with the profiles emerging from the patenting activity of US inventors abroad. A similar picture emerges for France, whose domestic specialization profile is significantly correlated only to that emerging from EPO patents. Germany, on the other hand, shows a consistent specialization profile in its domestic patenting, in patents registered in France and at the EPO, with low correlations (little more than 0.3) only with US data. [8]

The conclusions which can be drawn from this effort to measure specialization profiles in different patenting institutions is that domestic patenting is an unreliable indicator of a country's specialization, as it is distorted by a large number of inventions of lesser significance, which are not extended abroad, and are aimed only at protecting the domestic market from foreign competition. Such characteristics of domestic patenting result in a much less clear pattern of sectoral specialization; the areas of a country's international strength can be hardly identified within the vast and more uniform domestic patenting activity.

This has a particular relevance for the analysis of US technological specialization. The specialization profile of the United States based on US

[8] The full matrix of the correlation coefficients across the vectors of the specializations indexes measured for each country in different patent institutions can be found in a progress report, available on request.

Table 3
Correlation coefficients across technological specialization profiles for patents granted and patent citations in the US, 1975–81 and 1982–86

(Correlation coefficients between indexes of technological specialization of advanced countries by SIC classes)

Countries	Correlation coefficients between.			
	patents 1975–81 and citations 1975–81	patents 1982–88 and citations 1982–88	patents 1975–81 and patents 1982–88	citations 1975–81 and citations 1982–88
USA	0.95	0 93	0.88	0.86
Japan	0.95	0.93	0.93	0 91
West Germany	0.92	0.90	0.86	0.84
United Kingdom	0.88	0.88	0.78	0.56
France	0 91	0.87	0.79	0 77
Canada	0.92	0.88	0.85	0.70
Italy	0 95	0.91	0.89	0.81
Netherlands	0.96	0 78	0.87	0.47
Switzerland	0.98	0 95	0.95	0.93
Sweden	0.94	0 82	0.84	0 81
Belgium	0.91	0 94	0.74	0.80
Spain	0.86	0 69	0.74	0.59
Denmark	0 87	0.91	0 77	0 75
Ireland	0 91	0.74	0 10 *	0 08 *
Portugal	0.30 *	0.28 *	−0.14 *	−0.12 *
Greece	0.66	0.41	0.05 *	−0.19 *

Correlation coefficients across 41 SIC classes. The residual classes "Other Industries" and "Unclassified" have been excluded. (See Appendix C for the list of classes.)
All coefficients are statistically significant at the 5% level, except the coefficients marked with an asterisk (*).
Source: Elaborations on CHI Research data, supplied to ISRDS–CNR.

domestic patenting described by previous studies (see, for example, [17] and [23]), does not therefore appear as an accurate description of the areas of technological strength and weakness of the US in international markets, as the tables in Appendixes B and C clearly show.

3.2. Patents and patent citations in the US

Information on the impact patents have on later inventions can be obtained from the second set of data, on patents and patent citations in the US for two periods, 1975–81 and 1982–88. A test of the stability of the specialization profiles emerging from these four variables is provided in table 3, which shows the correlation coefficients between the vectors of the TRCA indexes for patents and citations in both periods, and the correlations between the distributions of each variable in the two periods.

A rather high stability over time of the specialization profiles can be found for all countries, except the UK and France, confirming the importance of the cumulative nature of technological knowledge. Only the smaller patenting countries (Ireland, Portugal and Greece) show a more erratic pattern.

A very close relation between patents and citations is found. Since the number of citations received by each country reflects the number of patents granted, this result is not surprising: as indicators of technological specialization both patent counts and patent citations provide similar pictures of countries' performance. But the relation between the two indicators falls over time, as is shown by the generalized fall (except for France, Belgium and Denmark) of the correlation coefficients. This suggests that besides a growing sectoral specialization as measured by patent counts, there may be an even faster process of qualitative specialization, as measured by patent citations. However, as the number of citations to more recent patents falls in the later period, this result should be considered with caution.

4. The degree of specialization of industrial countries

From the evidence summarized in the previous section, we can now address the more general question of the degree of specialization shown by the countries considered. The measure which has been used for each country on the main patent databases described above is the chi square statistic; a country's percent distribution of patents across sectors was compared with the sectoral distribution of the world's patents, thus providing a measure of how different national profiles are from the world sectoral profile on all patents, a simple definition of a country's technological specialization. [9] The results are shown in table 4. Using chi square values as an index of technological specialization allows us to examine the changes over time in the position of individual countries, and to compare their degree of specialization as measured by different indicators.

Taking into account the less differentiated nature of domestic patenting activity, it is not surprising that the US shows the lowest degree of specialization in the data based on US patents and that the EEC countries on aggregate have the lowest specialization at the European Patent Office, the patent institution which is the main vehicle of appropriability within the EEC internal market.

For the majority of countries, again excluding the three smallest patenting countries, the degree of specialization appears fairly consistent in all the databases considered. For patents in the US in the 1980s, even comparing two very different sectoral classifications such as the SIC and the IPC (columns 2 and 5 of table 4) the ranking of countries is very similar, with a rank correlation coefficient of 0.96.

The comparison between patents in the US and patents at the EPO shows greater differences, with rank correlation coefficients of 0.84 between EPO

[9] Chi square values have been calculated for each country on the vector containing the percent distribution of its patents (or patent citations) in the classes considered. The expected values with which the country shares have been compared are the values of the percent distribution of the world total. The percentages of the vectors were multiplied by 100. The chi square value of country i is defined as:

$$\chi_i^2 = \Sigma_j (AS_{ij} - ES_j)^2 / ES_j$$

where AS_{ij} is the actual share of patents (or patent citations) of country i in the class j, and ES_j is the expected share, i.e., the share of the world total. If the sectoral distibution of a country is identical to the percent distribution of the total for all countries, the value of chi square will be equal to 0.

Table 4
The technological specialization of advanced countries – chi square values [a]

(Chi squares of the percent distributions by sectors of patent data for advanced countries: A Patents and citations in the US by 41 SIC classes, 1975–81 and 1982–88; B. Patents granted in the US 1981–87 and patent applications at the EPO 1982–87 by 31 IPC classes)

Countries	A. Chi squares by 41 SIC classes [c]				B Chi squares by 31 IPC classes [b]	
	pat. gr. in the US 1975–81 (1)	pat gr in the US 1982–88 (2)	pat. cit in the US 1975–81 (3)	pat cit. in the US 1982–88 (4)	pat gr. in the US 1981–87 (5)	pat. appl at the EPO 1982–87 (6)
US	0 94	1.31	1.05	2.06	1.61	7.86
Japan	13.46	14.68	12.96	14.96	20.98	18 94
EEC	3.84	4.50	5.76	6.90	4.49	3.47
W Germany	8 16	10.05	13.51	15.39	9 39	3.63
France	4.00	3 86	4 01	3 83	8 46	10.89
Un Kingdom	5.91	6.85	10.43	17.91	5.97	5.22
Italy	21.85	24 53	25.55	25.21	26 92	34.12
Netherlands	23.06	20 46	27 52	22 48	21 72	23.19
Belgium	30.72	38.84	56.02	110.56	28.89	38.29
Denmark	24.63	31.88	41.06	62.40	n.a	n a.
Spain	46.88	53.52	88.73	101.09	n.a.	n a.
Ireland	77 99	22.42	84 78	50.58	n.a.	n.a
Portugal	139 81	212 25	289 36	299 57	n a.	n.a.
Greece	96.13	89 96	153.46	290 15	n.a.	n.a.
Canada	12.38	14.09	16 56	13 41	18 63	n a.
Switzerland	36.16	34 39	39.54	56 12	41.41	24.98
Sweden	24.72	24 74	23.70	23.15	32.80	43.05

[a] The chi square values are used as measures of the distance between the sectoral percent distributions of patents (by SIC or IPC classes) of the world and those of each country

[b] The EEC data by IPC classes include only the seven major countries. W Germany, France, Italy, Netherlands, Belgium, Sweden, United Kingdom.

[c] Residual classes (i e., "Other Industries" and "Unclassified" for the SIC classification and "Others" for the IPC classification) have been excluded (See Appendices B and C for the list of classes.)

n.a.–not available.

and US patents when based on the same IPC classification (columns 6 and 5), and of 0.83 when based on different classifications (the IPC for the EPO and the SIC for the US; columns 6 and 2). These results show that, as expected, differences in the Patent Office database used are more important than the differences in the types of sectoral classification employed.

Over time these indicators of technological specialization show a general increase in the values for both patents and citations; only France and the Netherlands experience a fall in their degree of specialization, while Canada, Sweden and Italy have a rising specialization for patents and a (moderately) falling one for citations. The three smallest countries have again less clear patterns, due to the small number of patents registered.

Comparing the results of patent counts and of patent citations, the increase in the degree of specialization based on citations is faster, suggesting a significant differentiation of the technological fields with greater impact.

5. The relation between size and specialization

A key issue in the exploration of the dynamics of technological specialization of advanced countries is the analysis of the relationship between the size of the technology base and the degree of specialization. The existence of regularities in this relationship can highlight the possible "paths of specialization" followed by countries as they expand their S&T activities and search for technology-based competitive advantages in international markets.

The results of the previous sections make a cross-country study of this relationship possible;

as indicator of the technology base we will use the cumulative R&D expenditure at constant prices (see Appendix A for method) and as indicator of the level of a country's specialization we will use the chi square values shown in table 4.

We have plotted in figs 1, 2, and 3 the position of each country (except Portugal, which has erratic values) on a logarithmic scale against these two variables. Table 5 reports the estimates of the regression equations. The variety of the databases considered allows us to assess the stability of the distribution (1) across two different classifications; (2) across two different patent institutions; (3) over time; (4) between indicators of simple count (the number of patents) and of impact (citations).

All figures show a consistent inverse relationship between the size of the technology base and the degree of specialization. While in the previous section, we have already discussed international differences in the absolute levels of specialization we can here compare the position of individual countries to the overall distribution.

Figure 1 shows, for the period 1981–88, the patterns of specialization emerging from US and EPO patents, disaggregated by technology-based IPC classes. The distribution of the two sets of data is similar, with the notable exception of countries where the "domestic market effect" emerges (the US has the lowest specialization degree in the domestic market, and the EEC and Germany have a similarly low index at the EPO). The relatively high degree of specialization shown by the US in the European market should also be related to the relatively low propensity of American inventors to extend abroad their patents (column 7 of table 1); it is likely that the US patents actually extended abroad reflect the sectors of more significant US strength.

Japan has a considerably higher specialization degree than what would be expected from the size of its S&T activities. Also Italy and, to a lesser extent, Sweden have quite high specialization levels, while the UK and France appear to spread their technological activities across a broader range of sectors.

Figure 2 shows the same relationship for patents granted in the US according to the SIC classes for two periods, 1975–81 and 1982–88. Over time, a general upward shift is clearly visible. The countries' relative positions are confirmed, with the US, the UK and France showing degrees of specialization below the expected ones, while Japan, Italy, Switzerland and Spain present higher levels of specialization.

Table 5

The relationship between technological dimension and specialization. Estimates of the equations presented in figs 1–3

$\ln(Y)$ = logarithm of the index of technological specialization – chi square of the percent distributions of patents or citations,

$\ln(X)$ = logarithm of the indicator of technological dimension – cumulative R&D expenditure, 1975–81, 1982–88

EPO Patent applications at European Patent Office, IPC classes, 1982–87 (fig. 1)
Y = specialization index calculated on patent applications at EPO
X = R&D expenditure, 1982–88
$\ln(Y) = 7\,643 - 0.44 \ln(X)$
t value of the coeff. (9 d.f.) = 2.632
Adjusted $R^2 = 0\,397$

US. Patents granted in USA, IPC classes, 1981–87 (fig 1)
Y = specialization index calculated on patents granted in USA, 1981–87
X = R&D expenditure, 1982–88
$\ln(Y) = 9\,475 - 0.615 \ln(X)$
t value of the coeff. (10 d f.) = 4 428
Adjusted $R^2 = 0.65$

PAT1 Patents granted in USA, SIC classes, 1975–81 (fig. 2)
Y = specialization index calculated on patents granted in USA, 1975–81
X = R&D expenditure, 1975–81
$\ln(Y) = 8.516 - 0.575 \ln(X)$
t value of the coeff. (14 d.f.) = 7.348
Adjusted $R^2 = 0\,791$

PAT2 Patents granted in USA, SIC classes, 1982–88 (fig. 2)
Y = specialization index calculated on patents granted in USA, 1982–88
X = R&D expenditure, 1982–88
$\ln(Y) = 7.806 - 0.483 \ln(X)$
t value of the coeff. (14 d.f.) = 4.993
Adjusted $R^2 = 0.631$

CIT1 Patent citations in USA, SIC classes, 1975–81 (fig. 3)
Y = specialization index calculated on patent citations in USA, 1975–81
X = R&D expenditure, 1975–81
$\ln(Y) = 9\,141 - 0.61 \ln(X)$
t value of the coeff. (14 d.f.) = 7 365
Adjusted $R^2 = 0.792$

CIT2 Patent Citations in USA, SIC classes, 1982–88 (fig. 3)
Y = specialization index calculated on patent citations in USA, 1982–88
X = R&D expenditure, 1982–88
$\ln(Y) = 9\,478 - 0.602 \ln(X)$
t value of the coeff. (14 d f.) = 5.73
Adjusted $R^2 = 0\,695$

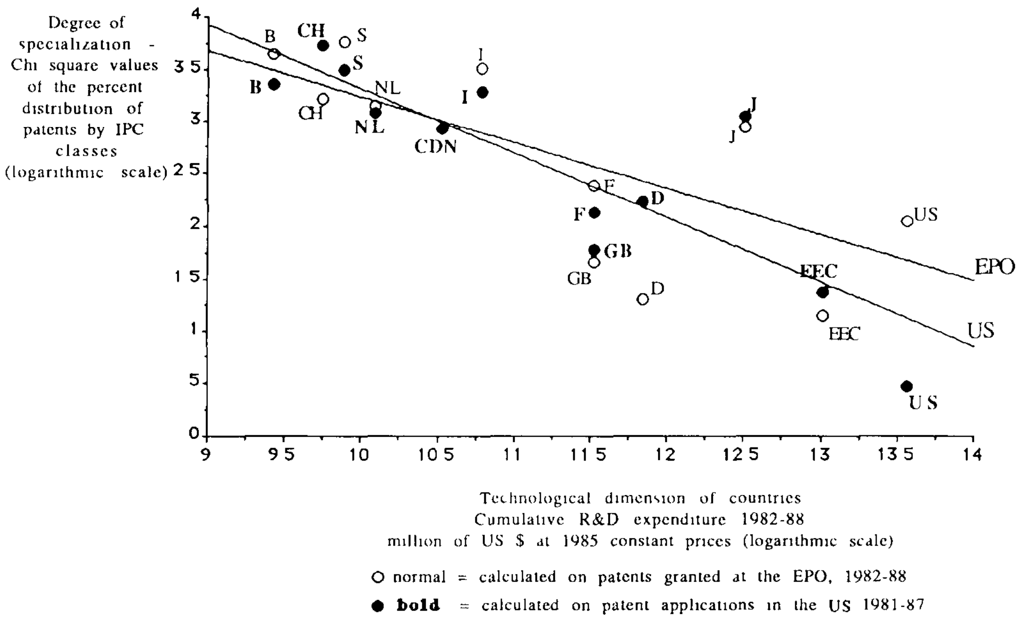

Fig. 1. Degree of specialization and size of technological activity. Chi square values of the distribution by IPC classes of patents in the US and at the EPO, and cumulative R&D expenditure, 1982–88. ●, US: patents granted in the US, 1981–87; ○, EPO: patent applications at the EPO, 1982–88. B = Belgium; CDN = Canada; F = France; D = FR Germany; I = Italy; J = Japan; NL = Netherlands; S = Sweden; CH = Switzerland; GB = United Kingdom; US = United States; EEC = European Community.

Figure 3 presents data on patent citations in the US for the same periods. The upward shift of the regression line from the first to the second period is even more evident than for patent counts. For countries such as the US, the UK and Belgium the specialization degree has increased

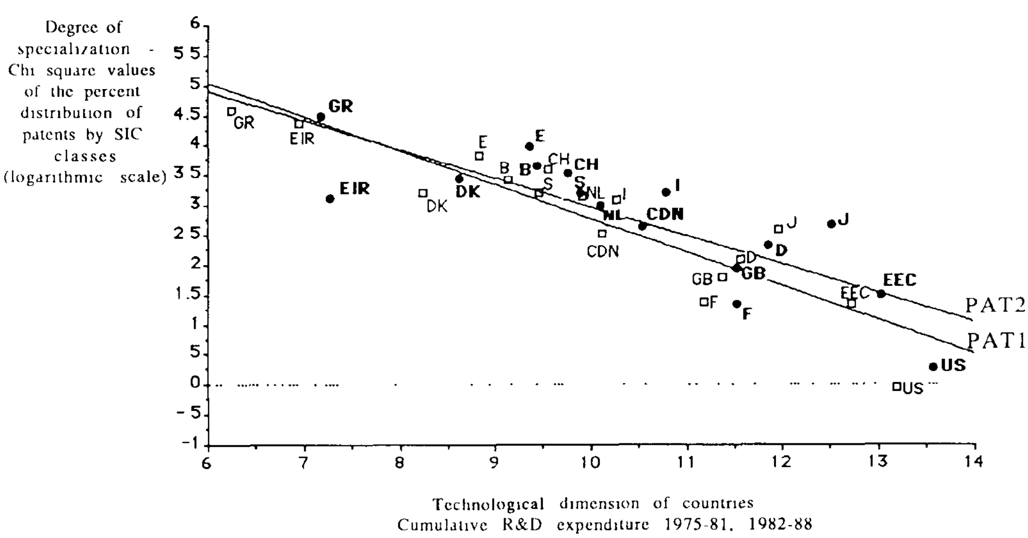

Fig. 2. Degree of specialization and size of technological activity. Chi square values of the distribution by SIC classes of patents in the US and cumulative R&D expenditure, 1975–81, 1982–88. □, PAT1: Patents granted, 1975–81; ●, PAT2: Patents granted, 1982–88. B = Belgium; CDN = Canada; DK = Denmark; F = France; D = FR 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.

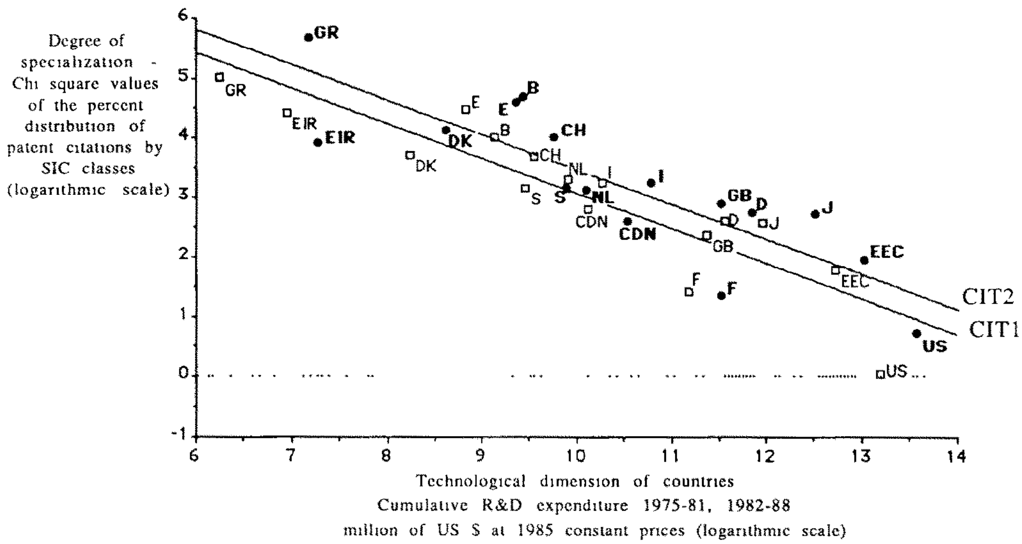

Fig. 3. Degree of specialization and size of technological activity. Chi square values of the distribution by SIC classes of patent citations in the US and cumulative R&D expenditure, 1975–81, 1982–88. □, CIT1: Citations 1975–81; ● CIT2: Citations 1982–88. B = Belgium; CDN = Canada; DK = Denmark; F = France; D = FR 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.

sharply, while France, Canada and the Netherlands are the only countries showing a slight reduction. However, as already pointed out, the pattern shown by citations in the second period may be affected by the different sectoral citation speeds of national data.

A few regularities can be identified from these data. Countries devoting smaller resources to R&D tend to be more specialized, and the degree of specialization is higher in terms of impact of their technological activities than for the simple count of patent data. The degree of specialization increases over time and appears fairly stable when measured in different patent institutions, and according to various sectoral classifications.

6. Concluding remarks

This paper presents some fresh evidence on the patterns of technological specialization of the most advanced countries and discusses some methodological issues in the use of patenting as an internationally comparable technology indicator.

Over the last decade, a rapid growth of international patent activity has occurred, while domestic patenting has been stagnant. Patenting abroad, as a tool for appropriating returns from innovative activities and for protecting technological advantage, appears to be of increasing importance in the internationalization of economic activity, also for establishing selected, technology-based competitive advantages in the various markets relevant to a country's (and a firm's) operations.

Significant differences have emerged between the specialization profiles measured by patents in the domestic and international markets. The major sectors of strength of a country's technology emerge in all databases, but each patenting market has specific characteristics. While the US patent system has often been employed for international comparisons, our findings suggest that US specialization measured on patents granted in the US is not an adequate description of the country's international strengths.

Countries' profile of specialization on both patent counts and citations are highly correlated, but the latter shows for almost all countries a higher and faster growing specialization degree. This suggests that the indicator of the impact of technological activities is more unevenly distributed across sectors and countries than a quantitative indicator such as patent counts.

These patterns can be seen as the result of a combination of factors, including:

(i) the heritage of technological knowledge accumulated in the past, which identifies the basic strengths and weaknesses of the national system of innovation;

(ii) increased international competition, which leads firms and countries to expand their technology-based advantages and building on their already existing strengths;

(iii) the impact of specific government technology policies, which are an essential requirement for international strength in sectors where public procurement plays a crucial role.

We have suggested that the total amount of resources devoted by each country to S&T is inversely related to the degree of specialization across technological fields. Only large countries can afford to distribute their innovations more uniformly across technologies. Small countries, on the contrary, are to some extent forced to specialize in selected niches, which suggests that they are more dependent on international technology flows and cooperation than large ones. The same pattern has long been shown for international trade, and it is confirmed here for technological innovation.

In some countries, however, the degree of specialization is substantially higher than what would be expected from the general pattern highlighted above. The most notable case is Japan, and, to a lesser extent, Italy. Conversely, the UK and France have a comparatively low level of specialization. These differences may be viewed as the outcome of diverging technological strategies followed by firms and governments due to substantial differences in terms of national technological accumulation, international competitive advantages and domestic technology policy.

The evidence presented in this paper raises new questions on the possible link between the pattern of technological specialization and the rate of growth of technological activities; countries with higher specialization levels have generally shown faster growth of the resources devoted to S&T. A parallel link could be explored between the degree of specialization and economic performance; countries with strong technological priorities seem to experience a robust economic performance. These issues need to be addressed in future research.

Appendix A – Additional information on data sources and methods

In tables 2 and 3 the correlation coefficients are calculated between the indexes of Technological Revealed Comparative Advantage, described in note 4.

In table 3 the source of data is CHI Research-Computer Horizons, Inc., Technological Activity and Impact Indicators Database, 13 June 1989, supplied to ISRDS–CNR.

In table 5 the regression equations are calculated on the following number of countries:

EPO: 10 countries (data are not available for Canada)
US: 11 countries
PAT1, PAT2, CIT1, CIT2: 15 countries (Portugal is excluded)

Obviously, the EEC aggregate is always excluded from the calculation of the regression equation, and it is shown in the figures in order to point out the relative position of the EEC.

In figs 1, 2 and 3, data on cumulative R&D expenditure are expressed in million of US dollars at 1985 constant prices. National currencies have been converted using the Purchasing Power Parities provided by the OECD, Main Science and Technology Indicators, April 1990. Missing values for individual years have been replaced by the estimates obtained from the regression equation calculated on the available values.

Appendix B – USA: Profile of technological specialization
Specialization indexes based on patent data; International Patent Classes

Nr	IPC	USA patents granted 198–87	France patent applic. 1981–87	France patents granted 1981–87	W. Germ. patent applic. 1982–87	W. Germ. patents granted 1982–87	Europ. pat. Off applic. 1982–87
US% excl	nation. patent	–	24.46%	27.81%	22.07%	28.87%	–
US% incl.	nation. patent	56.13%	10.79%	17.79%	6.48%	13.71%	26.12%
1	Agriculture	1.24	0.45	0.64	0.49	0.68	0.66
2	Foodstuffs	1.07	0.99	0.97	0.88	0.85	1.14
3	Footw. clothing	1 22	0.64	0.67	0.86	0.78	0.54
4	Health	1.26	1.24	1.15	1.26	1.14	1.17
5	Medical	0.89	1.21	1.08	1.14	1.09	1.34
6	Separ. & mix.	1.05	1.03	1.06	1.10	1.03	1.06
7	Machin. tools	0.92	0.72	0.71	0.79	0.75	0.67
8	Hand tools	1.03	0.90	0.91	1.02	1.07	0.85
9	Printing	0.89	0.74	1.02	0.70	1.35	1.01
10	Transport	0.94	0.42	0.54	0.76	0.67	0.58
11	Machinery	1.08	0.97	0.86	0.98	1.10	0.74
12	Inor. chemic.	0.99	1.22	1.26	1.21	1.10	1.16
13	Org. chemic.	0.94	0.98	1.02	1.12	1 11	1.03
14	Org. compounds	1.03	1.53	1.49	1.40	1.41	1.44
15	Paint, petrol	1.10	1.67	1.40	1.51	1.28	1.32
16	Bio-chemistry	0.95	1.18	1.00	1.15	1.12	1.33
17	Metallurgy	0.91	1.53	1.32	1.26	1.02	1 08
18	Textiles	0.63	0.52	0.58	0.73	0.62	0.61
19	Paper	0.89	1.00	0.90	0.89	1.04	1.07
20	Building	1.13	0.43	0.42	0.56	0.51	0.30
21	Mining	1.37	1.55	1.26	1.72	1.49	1.58
22	Engines	0.78	0.82	0.87	0.85	0.81	0.74
23	Engineering	0.97	0.83	0.91	1.01	0.92	0.87
24	Light. & heat.	1.09	0.74	0.77	0.79	0.81	0.65
25	Weapons	1.17	0.58	0.45	1.04	0.79	0.47
26	Optics photo	0.87	1.18	1.24	0.86	0.97	1 15
27	Computing	1.03	1.27	1.26	1.07	1.21	1.52
28	Inform. instr.	0.85	1.06	1.11	0.68	0.90	1.01
29	Nuclear physics	0.95	1.65	1.27	1.59	1.19	1.19
30	Electricity	1.02	1.41	1.23	1.33	1.08	1.07
31	Electron. telec.	0.95	1.61	1.17	1.26	1 05	0.96
32	Others	1.12	1.13	0.51	0.79	0.00	0.77
	Average value	1.00	1.00	1.00	1.00	1.00	1.00

Source: Archibugi and Pianta [2], elaboration on WIPO and EPO data.

Appendix C – USA: Profile of technological specialization
Specialization indexes based on patent data and patent citations in the USA; Standard Industrial Classes

SIC classes	Pat. ind. 1975–81	Pat. ind. 1982–88	Cit. ind. 1975–81	Cit. ind. 1982–88
% of all patents	62.09%	54.89%	65.05%	57.19%
1 Food, kindred products	1.07	1.14	1 07	1 19
2 Textile mill products	0.90	0.91	0.93	0.93
3 Inorganic chemicals	0.96	1.06	0.98	1.15
4 Organic chemicals	0.88	0 95	0.85	0.97
5 Plastic matrls, synth res	0.91	1.02	0.88	1.02
6 Agricultural chemicals	0.82	0.86	0 83	0.91
7 Soaps, detergents, clnrs	1 02	1.07	1.04	1.03
8 Paints, allied chemicals	1.00	1.06	1 00	1.09
9 Misc chemical products	1.12	1.10	1.13	1.12
10 Drugs & medicines	0.82	0.91	0.84	0.97
11 Petrol, nat gas extr, ref	1.33	1.45	1.32	1.49
12 Rubber, misc plast prods	1.02	1.04	1.01	1.04
13 Stone, clay, glass, concr	0.99	1.00	0.98	1 04
14 Primary ferrous prods	0.77	0.81	0.77	0.86
15 Prim, sec non-ferr prods	0.85	0.86	0.91	0 94
16 Fabricated metal prods	1.12	1.13	1.12	1.13
17 Engines & turbines	0.89	0.79	0.84	0.65
18 Farm, garden mach & equip	1.13	1.17	1.13	1.23
19 Cnstr, mng, metal hand eqp	1.04	1.09	1.03	1.12
20 Metal working mach, equip	0.94	0.95	0.97	0.95
21 Office comput, acctg mach	1.01	0 88	1.05	0.92
22 Spec ind mach (exc m wrk)	0.86	0.83	0.84	0.83
23 Genrl indust mach, equip	0.97	0.93	0.96	0.92
24 Refrig, servc indust mach	1.05	1.09	1.06	1.15
25 Misc Mach (exc electric)	0.91	0.89	0.79	0.69
26 Electr trans, distr equip	1.06	1.02	1.06	1.05
27 Electr indust apparatus	0.90	0 88	0.91	0.89
28 Household appliances	0.99	0.92	1.00	0.95
29 Electr lightng, wirng eqp	1.11	1.14	1.12	1 16
30 Misc elec mach, eqp, suppl	0.96	1.01	1.00	1.06
31 Radio, TV receiving equip	0.85	0.80	0 86	0 81
32 Elect cmp, acc, comm equip	1.04	1.00	1.06	1 04
33 Motor veh, motor veh eqp	0.93	0.74	0.85	0.60
34 Guid mssls, spce veh, prts	1.23	1.24	1.18	1.30
35 Ship, boat bldng & repair	1.04	1.06	1.06	1.20
36 Railroad equipment	0.98	0.97	0.93	0.91
37 Motorcycles, bicy & parts	0 87	0 73	0.78	0.56
38 Misc transportation eqp	1.10	1.02	1.00	0.81
39 Ordnance (exc missiles)	1.15	1.08	1.13	1.17
40 Aircraft & parts	0.89	0.79	0 80	0 60
41 Prof, scien instruments	0.99	0.98	0.99	0 98
42 Unclassified patents	1.14	1.02	1.20	1.29
43 Other industries	1.15	1.20	1.12	1.17
Average value	1 00	1.00	1.00	1.00

Source: Archibugi and Pianta [2], elaboration on CHI Research data.

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