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Aggregate convergence and sectoral specialization in innovation

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Abstract. Over the last 20 years OECD countries have converged in terms of their innovations, in parallel to the process of economic convergence and catching up in technology. However, this has not led to a similarity in the sectoral strengths of the majority of countries. Applying a measure of 'technological distance' between pairs of countries based on patents, it is shown that nations have increased their technological specialization (i.e. their sectoral differences) over the 1980s. An apparent paradox is pointed out, as countries converge by becoming more different and grow by becoming more specialized.

Key Words: Technology – Convergence – Specialization – Catching up

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1. Introduction

Technology contributes to the growth of national economies in two apparently contradictory ways. Firstly, technology is a powerful engine of 'disequilibrating' growth for countries able to develop innovation-based competitive advantages. Secondly, technology plays an 'equilibrating' role as the know how spreads from innovators to imitators allowing laggard countries to catch up. While the former role leads to diverging economic positions of individual countries, the latter contributes to a growing convergence of national performances.

For the relatively small group of advanced OECD countries, economic indicators show that over the past decades a strong convergence has taken place. Among the factors contributing to convergence in income levels, technology plays a prominent role. The first issue addressed in this paper is whether advanced countries have also converged in their endogenous technological capability. In other words, do indicators of technological intensity show the same pattern of growing similarity among advanced countries as we find for economic variables, or do they reveal strong persisting national differences? And how can patterns of convergence in technology be compared to patterns in economic indicators?

The issue of convergence has mainly been addressed in aggregate terms. However, we believe that it is crucial to consider also the sectoral composition of the technological activities carried out in each country. In fact, the second question here addressed is whether convergence has led to a growing similarity across nations also in their sectors of technological activity. Our hypothesis is that convergence in aggregate innovative levels is combined to a greater technological specialization and international division of labour.

In order to address such questions, after an overview of the relationship between technology and economic performance in section 2, this paper examines in section 3 the patterns shown in the past two decades by aggregate economic and technological indicators (including R&D and patent data). While a broad process of convergence can be found, significant differences among advanced countries do persist in technology, well beyond the reduced distance in terms of GDP per capita and other economic indicators.

In section 4 the sectoral structure of national technological activities, as measured by patents in the US, is considered and the profiles of major OECD countries are compared over two periods of time developing a measure of 'technological distance'. The results show that the partial technological convergence at the aggregate level is rooted in a greater differentiation at the sectoral level, as the degree of national sectoral specialization has generally increased and countries' innovative efforts have gone in diverging fields. Some conclusions are drawn, in section 5, on the link between convergence and specialization in economic and technological activities.

2. Technological factors in national economic performances

The issue of convergence and divergence among countries is a major theme in economic research, related to the problems of long term growth. Many studies have documented the growing economic convergence of a small number of countries, especially in the postwar period.[1] A variety of macroeconomic and international factors – including sustained global demand, expanding industrial capacity, open markets, etc. – have contributed to such an outcome. But a specific role has been played in this process by technology, with the growth of innovative activities and the diffusion of new products and processes incorporating innovations, leading to a rapid dissemination of technical advances and know how in different fields and countries. These forces can explain the international convergence in productivity (see Dollar and Wolff 1988). In a recent empirical analysis which has decomposed the factors contributing to economic convergence, Soete and Verspagen (1993a) have shown that technological change has been the 'driving force for convergence'.

In this way technology has become increasingly important. On the one hand, advanced countries have become more knowledge-intensive; on the other hand the

[1] See, most recently, Abramovitz (1986), Baumol (1989), Arrighi (1991), Maddison (1982, 1991), Dosi et al. (1992).

group of countries able to innovate at the frontier of technological opportunities has expanded. International competitiveness, productivity, and rates of growth are linked to the ability to innovate successfully, as illustrated by a large number of empirical analyses.[2]

Mastering technological innovation, however, is not a simple task. National success in innovation requires the combination of different factors, including high quality research, institutions supporting technical advance and adequate managerial skills. Such characteristics define the 'national system of innovation', an important concept for the study of how countries develop and use technology.[3] These factors are unevenly distributed across countries, resulting in substantial differences in the quantity, nature and trajectory of the innovations produced. Since innovation is becoming a key factor in competition among countries, national economic performances are affected by domestic capabilities. In order to keep its position in international competition, each country has to increase its effort to produce new technology and to adapt and diffuse innovations. Most countries have perceived this changing environment and have devoted a greater attention to science and technology, with a variety of institutional efforts to support technical advance.

One should stress here that patterns in the production of innovations can differ from patterns in the adoption and diffusion of technology. National differences in the efforts and ability to develop innovations on the one hand, and to spread and use them effectively are major factors leading to possible divergence among advanced countries. A key aspect is the ability of national economies to use their different technological resources, and to acquire the know how they do not produce from a variety of channels, including trade, patent cross-licensing, international cooperative research projects, and many other specific forms of technology transfer.

Therefore similar economic performances might result from different combinations in the countries' production and use of technology. But the question is to what extent economic convergence can be achieved and sustained without convergence also in innovative activities. We could expect that after some point further progress in economic convergence needs to be sustained by a parallel convergence in countries' ability to carry out research and produce innovations.

In the next section these issues will be explored comparing the patterns of convergence in economic variables, such as per capita GDP, and in indicators of technological intensity, such as R&D expenditure and patents. While this provides important evidence at the aggregate level, much less attention has been paid to the sectoral composition of innovations in each country. In fact, the convergence in terms of science and technology activities does not inform us about changes occurring in national sectoral strengths and weaknesses. Should we expect that the aggregate convergence is uniform across sectors, or should we expect that each nation is developing its strengths in selected fields? In other words, are countries becoming more similar also in the sectoral distribution of their technological activities, or on the contrary, the aggregate convergence has lead to an increasing specialization at the sectoral level? This issue has a crucial importance for our

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[2] See, among others, Hughes (1986) and Fagerberg (1988) for international competitiveness; Baumol et al. (1989) for productivity; and Fagerberg (1987) and Soete and Verspagen (1993b) for growth rates. An overview is provided in OECD (1992).

[3] On national systems of innovations see in particular Nelson (1993) and Lundvall (1992). See also Porter (1990).

understanding of international patterns of technological performance, since it shows whether advanced countries are becoming more complementary, leaving more room for international cooperation, or if, on the contrary, they are competing on the same technological fields.

3. Convergence in economic and technological activities

Four key indicators are used in this section in order to compare patterns of convergence in economic and technological performances over the past 20 years in 20 OECD countries.

Per capita GDP is the most important and widely used indicator of a country's economic growth, shown in Table 1. The coefficients of variation (standard deviation divided by the mean) of cross-country data have been calculated for the whole group of 20 countries and for the five most important countries (US, Japan, Germany, United Kingdom and France, which will be referred to as the G5 countries) for the years 1971, 1976, 1981, 1986 and 1990. Data from Table 1 confirm the widely available evidence on the convergence of income levels among the group of advanced countries: for 20 OECD countries the coefficient of variation falls from

Table 1. Gross domestic product per capita (US dollars, 1985 prices)

Countries	1971	rank	1976	rank	1981	rank	1986	rank	1990	rank
United States	13051	2	14115	2	15301	2	16928	1	18245	1
Switzerland	14358	1	14166	1	15615	1	16589	2	17889	2
Canada	10145	6	12316	3	13778	3	15195	3	16249	3
Germany	10324	5	11715	4	13049	4	14196	4	15597	4
Japan	7884	15	9089	15	10834	14	12486	10	15003	5
France	10009	7	11350	6	12572	5	13412	7	14841	6
Sweden	10406	3	11677	5	12181	6	13562	6	14363	7
Denmark	9896	9	11054	9	11545	10	13749	5	14258	8
Austria	8607	12	10296	11	11584	9	12536	9	14143	9
Finland	7994	14	9364	14	10814	15	12249	12	14006	10
Belgium	8923	11	10610	10	11510	11	12240	13	13962	11
Australia	10369	4	11310	7	12180	7	13261	8	13869	12
Italy	8184	13	9576	13	11252	13	12182	15	13641	13
The Netherlands	9927	8	11219	8	11666	8	12297	11	13401	14
United Kingdom	8996	10	9950	12	10450	16	12033	16	13400	15
Norway	7710	16	9040	16	11291	12	12217	14	12309	16
Spain	6379	17	7728	17	7752	17	8383	17	10035	17
Ireland	4982	18	5708	18	6821	18	7248	18	9116	18
Portugal	4170	20	4746	20	5530	20	5888	20	7103	19
Greece	4189	19	5130	19	5626	19	5962	19	6256	20
Avg. G20	8825		10008		11068		12131		13384	
Coeff. Var. G20	0.29		0.25		0.24		0.25		0.23	
Max/min	3.44		2.98		2.82		2.87		2.92	
Avg. G5	10053		11244		12441		13811		15417	
Coeff. Var. G5	0.17		0.15		0.14		0.13		0.10	
Max/min	1.66		1.55		1.46		1.41		1.36	

Source: CNR-ISRDS, elaboration from OECD data

Note: G5 includes: United States, Japan, Germany, France and United Kingdom

0.29 in 1971 to 0.23 in 1990 (with a small rise in 1986) and the ratio between the richest country (the US) and the poorest (Portugal or Greece) falls from 3.4 to less than 3. The coefficient of variation has also decreased in the G5 countries; this is mainly the result of the rapid catching up of Japan, which ranked 15th in 1971 and ranks 6th in 1990. For all countries the greatest increase of convergence in per capita income took place in the 1971-76 period, with the top four countries (US, Switzerland, Canada and Germany) moving very close and remaining so ever since.

The main indicator of a country's technological intensity is the share of GDP devoted to total Research and Development (R&D) expenditures. The last decades have seen the spread in most OECD countries of significant R&D activities with the establishment of R&D laboratories as institutions specifically designed to introduce innovations. R&D activities have a twofold aim: on the one hand, to produce innovations, on the other hand to imitate and adapt knowledge created elsewhere (see Cohen and Levinthal 1989).

Table 2 shows how this variable is distributed in the 20 OECD countries: in 1991 Japan, Switzerland, Sweden, the US and Germany devote a share close to 3% of GDP to total R&D activities, while the rest of the countries have values spreading from 2.4% (France) to 0.5% (Portugal and Greece). Convergence among the 20

Table 2. Total R&D expenditure as a percentage of GDP

Countries	1971	rank	1976	rank	1981	rank	1986	rank	1991	rank
Japan	1.71	7	1.80	6	2.13	6	2.56	5	2.88[n]	1
Switzerland	2.33	2	2.45	1	2.29	5	2.88	3	2.86[m]	2
Sweden	1.49	8	1.79[e]	7	2.30	4	2.89[i]	2	2.85[m]	3
United States	2.47[c]	1	2.30	2	2.45	1	2.91	1	2.82	4
Germany	2.20	3	2.16	4	2.43	2	2.73	4	2.81[n]	5
France	1.88	6	1.75	8	1.97	7	2.23	7	2.40[n]	6
United Kingdom	2.10[c]	4	2.17[e]	3	2.41	3	2.34	6	2.27[m]	7
The Netherlands	2.06	5	1.97	5	1.88	8	2.22	8	2.16[m]	8
Finland	0.87	14	0.91[e]	15	1.19	12	1.67	10	1.88[n]	9
Norway	1.10[b]	12	1.34[e]	9	1.29	10	1.62[i]	11	1.87	10
Belgium	1.41	9	1.33[e]	10	1.62[h]	9	1.68	9	1.69[n]	11
Denmark	0.96[b]	13	0.99	13	1.10	14	1.32	13	1.54[m]	12
Austria	0.61[b]	17	0.92[e]	14	1.17	13	1.31	14	1.50	13
Canada	1.36	10	1.04	11	1.23	11	1.46	12	1.43	14
Italy	0.85	15	0.77	17	0.87	16	1.13	16	1.35	15
Australia	1.22[d]	11	1.00	12	1.00	15	1.27	15	1.23[l]	16
Ireland	0.78	16	0.83[e]	16	0.73	17	0.89	17	0.88[n]	17
Spain	0.27	19	0.34	18	0.42	18	0.61	18	0.87	18
Portugal	0.38	18	0.27	19	0.35[g]	19	0.45	19	0.50[l]	19
Greece	0.10[a]	20	0.18[f]	20	0.21	20	0.33	20	0.47[m]	20
Avg. G20	1.31		1.32		1.45		1.72		1.81	
Coeff. Var. G20	0.53		0.52		0.50		0.47		0.43	
Max/min	24.70		13.61		11.67		8.82		6.13	
Avg. G5	2.07		2.04		2.28		2.55		2.64	
Coeff. Var. G5	0.13		0.11		0.08		0.10		0.09	
Max/min	1.44		1.31		1.24		1.30		1.27	

Source: CNR-ISRDS, elaboration from OECD data

[a] estimates; [b] 1970; [c] 1972; [d] 1973; [e] 1975; [f] 1979; [g] 1982; [h] 1983; [i] 1985; [l] 1988; [m] 1989; [n] 1990

Note: G5 includes: United States, Japan, Germany, France and United Kingdom

OECD countries has steadily increased also in this indicator, with the coefficient of variation falling from 0.53 in 1971 to 0.43 in 1990; a marked fall is also found in the ratio of the highest to the lowest value, from 25 to 6. It should again be noted the Japanese catching up, which was the 7th R&D intensive economy in 1971 and has become the leading country 20 years later. The US, on the contrary, fell from the 1st to the 4th position. Within the group of G5, the process of convergence has stopped during the 1980s since France and the UK have lagged behind Japan, the US and Germany.

Looking at the pattern of convergence of smaller groups of countries, a strong and sustained convergence is found for the top five countries in terms of R&D intensity (Japan, Switzerland, Sweden, the US and Germany), while France, the UK and the Netherlands, in spite of an early start at the top of the 'convergence club', since 1981 have diverged, falling behind the leading group. The remaining countries have generally increased their convergence, but remain at a great distance from the top countries. The aggregate evidence for the 20 OECD countries therefore conceals marked differences both in the level of national technological intensity and in the direction of the changes under way.

In Table 3 the R&D which is financed by and performed in industry (thus excluding government funded projects, including military R&D) is considered; this

Table 3. Industry financed R&D as a percentage of domestic product of industry

Countries	1971	rank	1976	rank	1981	rank	1986	rank	1990	rank
Japan	1.19	3	1.25	3	1.55	3	2.00	3	2.36	1
Sweden	1.13	5	1.57[f]	1	1.92	1	2.60[l]	1	2.35[o]	2
Germany	1.38	1	1.40[f]	2	1.76	2	2.12	2	2.12	3
United States	1.13	4	1.14	6	1.35	4	1.63	4	1.52	4
Finland	0.59	10	0.66[f]	10	0.83	9	1.24[l]	8	1.51[o]	5
Belgium	0.79[d]	8	1.19[h]	4	1.27	6	1.46	5	1.45	6
United Kingdom	1.05[c]	6	1.09[e]	7	1.29	5	1.41	6	1.41	7
The Netherlands	1.28	2	1.19	5	1.09	7	1.36	7	1.37[o]	8
France	0.85	7	0.92	8	1.06	8	1.21	9	1.30[o]	9
Norway	0.54[c]	11	0.68[f]	9	0.65	13	1.06[l]	10	1.09[o]	10
Denmark	0.60[b]	9	0.59	11	0.72	11	0.97	11	1.08[o]	11
Austria	0.36[b]	15	0.55[e]	12	0.75	10	0.81[l]	12	0.83	12
Canada	0.53	13	0.42	14	0.67	12	0.80	13	0.75[m]	13
Italy	0.53	12	0.45	13	0.52	14	0.55	14	0.73	14
Ireland	0.40	14	0.29[f]	15	0.36	15	0.54	15	0.68	15
Australia	0.25[d]	16	0.21[g]	16	0.20	17	0.47	16	0.51[o]	16
Spain	0.13[a]	17	0.21	17	0.21	16	0.36	17	0.42[o]	17
Portugal	0.10[a]	18	0.05[g]	18	0.12[i]	18	0.14	18	0.15[n]	18
Avg. G18	0.71		0.77		0.91		1.15		1.20	
Coeff. Var. G18	0.55		0.58		0.58		0.55		0.52	
Max/min	13.80		31.40		16.00		18.57		15.73	
Avg. G5	1.12		1.16		1.40		1.67		1.74	
Coeff. Var. G5	0.15		0.14		0.17		0.21		0.24	
Max/min	1.62		1.52		1.66		1.75		1.82	

Source: CNR-ISRDS, elaboration from OECD data
[a] estimates; [b] 1970; [c] 1972; [d] 1973; [e] 1975; [f] 1977; [g] 1978; [h] 1979; [i] 1982; [l] 1985; [m] 1987; [n] 1988; [o] 1989
Data for Switzerland and Greece are not available

Note: G5 includes: United States, Japan, Germany, France and United Kingdom

portion of R&D expenditure is more directly linked to economic growth than government funded R&D. The ranking of countries changes substantially: Japan, Sweden and Germany (and probably Switzerland, but data are not available) have a share greater than 2% of the Domestic Product of Industry, while the US follows with 1.5% and the remaining countries are widely scattered behind. Among the 18 countries considered here, evidence of convergence is much weaker than for previous variables. The coefficient of variation increases until 1981 and falls slightly only in the last decade; differences among countries remain extremely strong.

Within the group of G5 a marked process of divergence is found. Japan and Germany show a stable pattern of common growth, while the US increases its divergence: although the US ranks 4th both in 1971 and in 1990, its absolute distance from Japan and Germany has widened.[4] The other countries remain at a distance and show a little convergence only in the last period considered.

Table 4. External patents per unit of exports (Patent applications at foreign patent offices per million US $ of exports at 1985 prices).

Countries	1971	rank	1976	rank	1981	rank	1986	rank	1990	rank
Switzerland	1.06	1	0.67	1	0.58	1	0.57	1	0.57	1
Japan	0.40	5	0.27	5	0.30	5	0.37	5	0.44	2
United States	0.83	2	0.44	2	0.45	2	0.53	2	0.44	3
Finland	0.14	12	0.14	9	0.16	9	0.23	8	0.41	4
Sweden	0.42	4	0.32	3	0.40	3	0.40	3	0.38	5
Germany	0.53	3	0.32	4	0.36	4	0.37	4	0.36	6
France	0.31	6	0.20	6	0.20	6	0.24	7	0.26	7
United Kingdom	0.27	7	0.16	7	0.19	7	0.21	9	0.26	8
Australia	0.11	13	0.10	12	0.18	8	0.26	6	0.23	9
Denmark	0.20	9	0.14	10	0.15	10	0.20	10	0.21	10
The Netherlands	0.19	10	0.11	11	0.13	12	0.13	12	0.15	11
Austria	0.22	8	0.15	8	0.15	11	0.18	11	0.15	12
Italy	0.14	11	0.10	13	0.10	13	0.13	13	0.12	13
Norway	0.10	15	0.06	15	0.07	14	0.07	14	0.11	14
Canada	0.10	14	0.08	14	0.06	15	0.06	15	0.06	15
Belgium	0.08	16	0.04	17	0.04	17	0.05	16	0.05	16
Ireland	0.04	18	0.05	16	0.05	16	0.03	17	0.05	17
Spain	0.05	17	0.04	18	0.03	18	0.03	18	0.04	18
Greece	0.00	20	0.01	19	0.01	19	0.01	19	0.02	19
Portugal	0.01	19	0.00	20	0.00	20	0.01	20	0.00	20
Avg. G20	0.26		0.17		0.18		0.20		0.21	
Coeff. Var. G20	1.03		0.94		0.86		0.81		0.76	
Max/min[a]	23.65		19.11		16.97		19.41		13.26	
Avg. G5	0.61		0.50		0.69		0.89		1.17	
Coeff. Var. G5	0.48		0.46		0.48		0.44		0.34	
Max/min	0.30		3.64		3.19		2.71		2.17	

Source: CNR-ISRDS, elaboration from OECD data
[a] Excluding Greece and Portugal

Note: G5 includes: United States, Japan, Germany, France and United Kingdom

[4] The decline of the US technological leadership in many industries is addressed by a large literature: see Pianta (1988) and Scherer (1992).

The differentiated pace of convergence in business funded and total (including government funded) R&D shows that while governments of laggard OECD countries gave a high priority to the development, with public funds, of national scientific and technological capabilities, the business sector in most countries has been reluctant to move towards technology intensive productions.

The fourth indicator considered here is the number of patent applications extended abroad by national inventors, divided by a country's exports. Extended patents are an indicator of the production of innovations and are directly linked to their international diffusion. They need to be related to a measure, such as total exports, of the size and the international orientation of a national economy.[5] Table 4 presents such data, showing a strong and continuing process of convergence, evenly spread across all 20 OECD countries, with a slight slowdown in the 1980s, but with extremely high differences across countries even in 1990. This indicator also shows a remarkable convergence for the G5 group.

Many other indicators have been examined in order to describe the patterns of national convergence and divergence in technological activities (see Archibugi and Pianta 1992), but the three described above provide a good enough picture of the patterns that can be identified in three key areas: aggregate indicators of total national research efforts; the activity of firms in industrial innovation; and the evidence from output indicators.

Figures 1 and 2 summarize the evidence of convergence in economic and technological indicators for the 20 OECD countries and the G5 group, showing the values of the coefficient of variation from 1971 to 1990, calculated for the four variables discussed above. Countries differ in terms of per capita GDP much less than in terms of any technological indicator. They have converged more in terms of total R&D intensity than in terms of the R&D which is financed and performed by industry . More importantly, a significant divergence has taken place within the

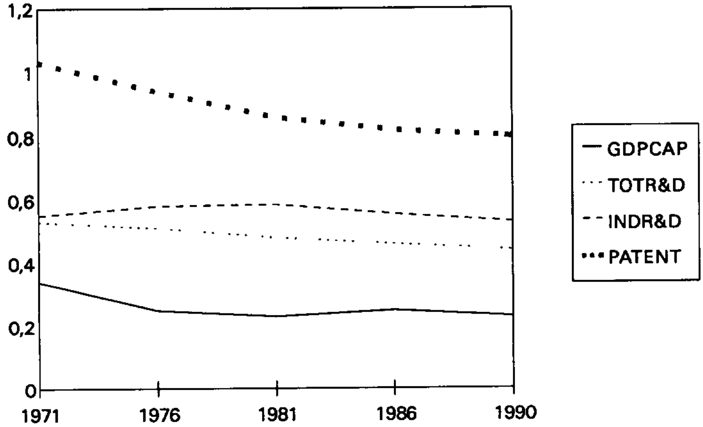

Fig. 1. Economic and technological indicators, coefficient of variation for 20 OECD countries

[5] The same analysis has been carried out also considering patents per capita, obtaining similar results. However, this indicator overestimates the innovative activity of small countries with a high international integration.

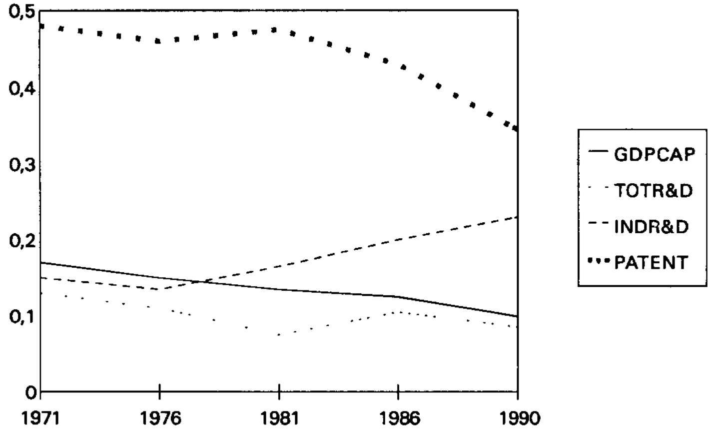

Fig. 2. Economic and technological indicators, coefficient of variation for 5 major countries

G5 group in terms of industrial R&D. Extremely high differences remain across OECD countries in terms of an output indicator such as international patenting per unit of exports, although, from a dynamic perspective, it has strongly converged for both the G20 and the G5 groups.

Over the past 20 years a small increase of convergence in per capita GDP can be found, and cross-country differences in industry R&D have not decreased significantly, while convergence is increasing for total R&D and, more rapidly, for patenting performances. While a general 'catching up' in technological activities has taken place in the group of OECD countries in the past two decades, very strong differences do persist in the ability to carry out research and to produce patented inventions. And one may wonder whether such continuing differences in technology have contributed to slow down in recent years the process of convergence in economic indicators.

The different intensities of technological activities in advanced countries point out the variety of patterns of growth which have been pursued in the last two decades, and the different roles played by technology. The next step in the analysis is to examine the sectoral pattern of technological activities behind the aggregate picture of moderate convergence.

4. Similarities and differences in countries' technological specialization

Several studies of national science and technology activities at the sectoral level have identified different models of specialization.[6] In order to explore the sectoral patterns that lie behind the aggregate picture described above, we need to ask whether the sectoral composition of national technological activities has become more or less similar across advanced countries.

[6] A description of national patterns of sectoral specialization, based on a variety of patent data and other indicators is provided in Casson (1991), Freeman et al. (1991) and Archibugi and Pianta (1992).

Patents granted in the US are taken as an indicator of countries' sectoral distribution of innovations. Although we are fully aware of the limitations of patenting as indicator of technology, they provide a solid base for international comparisons across fields: in fact, they are the only available indicator of technological activity offering a detailed break down by sectors for a large number of countries and for long time series (Archibugi 1992).

We focus here on patents taken out at the US patent office because the US is the largest and technologically most developed market of the world, and it is reasonable to assume that inventions with strong commercial expectations are patented in this country.

We have shown elsewhere that patenting at the US Patent Office is a reliable indicator of national technological specialization for all countries, but it is somehow less so for the US, as patenting activity in the domestic market has a sectoral distribution which is slightly different from that emerging in foreign markets (see Archibugi and Pianta 1992). Particular caution is therefore needed in interpreting the results for the US.

In order to address the question of how similar or different national specializations are, the sectoral distribution of technological activities has been compared, developing a measure of distance between pairs of countries. The distance among individual countries will be analyzed for the periods 1975-81 and 1982-88, using data on the sectoral distribution across 41 SIC classes of patents granted in the US.[7]

Since we intend to compare the composition and not the level of national inventions, countries' patents need to be standardized and their percentage distribution will be considered (countries' shares of total patents granted in the US in 1990 range from 53% for the US, to 0.5% for Spain. Other OECD countries with a lower number of patents have been excluded since they do not provide statistically reliable information).

The method we have used is an application of the chi square statistic. Firstly, the percent distribution of patents in 41 non residual SIC classes (see Appendix 1 for their listing) is considered for two countries; the square of the difference between these percentages is calculated for each class, and divided by the share the class holds in the world total patents; the sum of these weighted squared differences is the distance indicator used in our analysis. The formula used is the following:

$$D_{ab} = \left\{ \sum_{i=1}^{n} (p_{ia} - p_{ib})^2 / p_{iw} \right\} \Big/ D_{max} * 1000$$

where:

D_{ab} is the distance between country a and country b;
p_{ia} is the percentage of patents of country a in sector i;
p_{ib} is the percentage of patents of country b in sector i;
p_{iw} is the percentage of patents of the world total in sector i;
n is equal to 41 non-residual SIC classes.
D_{max} is the maximum value of the distance for a given world distribution in n classes.

The distance index between two countries is equal to zero when they have the same percent distribution of patents across classes, and it grows rapidly when one country

[7] Since the yearly number of patents is biased by fluctuations, we have grouped patenting for a fairly large number of years.

Table 5. Distance among the patterns of technological specialization of advanced countries.

Countries	Period	USA	Japan	Germany	France	United Kingdom	Italy	The Netherlands	Belgium	Denmark	Spain	Switzerland	Sweden	Canada
USA	1	–	22 33	17 40	8 95	12.25	37.00	28.82	46.71	36.13	68 51	56.40	31 85	14.19
	2	–	24 64	17 11	6 89	11.02	35.18	23.36	45 11	37.20	69.06	46.09	29.75	13.84
Japan	1	22.33	–	29.28	23.70	25.79	50.74	43 18	57 48	56.14	104.10	73.21	68 58	56.14
	2	24.64	–	37 93	25 61	30.18	60.86	35.26	85 40	79.02	104.38	76.13	64.80	79.02
Germany	1	17.40	29 28	–	9 62	9.51	13.36	54.04	31.20	42 27	45.05	27.89	43 58	31.89
	2	17.11	37 93	–	12 24	14.74	13.58	48.81	46.09	132.19	40.03	24.02	29 18	28.87
France	1	8.95	23.70	9.62	–	3.24	23.22	32.78	40 09	39.13	51.03	40.04	39 63	22.76
	2	6.89	25 61	12.24	–	5 09	26.53	25 47	41 04	40 85	55.71	35.78	33.78	21.85
United Kingdom	1	12.25	25 79	9.51	3 24	–	26.44	78.24	37.50	33 77	53.78	39.02	42.40	27.86
	2	11.02	30.18	14.74	5.09	–	24 37	37.15	33.43	35.33	56.52	32.14	38.55	28.65
Italy	1	37.00	50 74	13.36	23 22	26.44	–	65.36	42.30	44 93	40.49	29.08	63.98	45.67
	2	35.18	60 86	13.58	26 53	24.37	–	64.82	53 61	41 20	38.19	19.79	44.79	42.18
The Netherlands	1	28 82	43 18	54.04	32 78	78.24	65 36	–	85.78	75.04	105.82	82.71	79.91	46 56
	2	23.36	35.26	48.81	25.47	37.15	64.82	–	65 38	74 14	119.77	74.82	73.68	41.17
Belgium	1	46.71	57.48	31.20	40.09	37.50	42.30	85.78	–	64 95	84.88	47.47	86.04	68.43
	2	45 11	85.40	46.09	41 04	33.43	53.61	65.38	–	59.65	90.47	53.45	77.72	61.77
Denmark	1	36 13	56.14	42.27	39 13	33.77	44 93	75.04	64 95	–	57.73	53.34	41.58	41.24
	2	37.20	79.02	132.19	40.85	35.33	41 20	74.14	59 65	–	48.95	47 76	36.32	36.09
Spain	1	68 51	104.10	45.05	51 03	53.78	40.49	105 82	84.88	57 73	–	51 99	63.30	55.79
	2	69.06	104.38	40.03	55.71	56.52	38.19	119 77	90 47	48 95	–	60.10	42.30	56.86
Switzerland	1	56.40	73.21	27.89	40.04	39.02	29.08	82 71	47 47	53 34	51.99	–	76.81	79.79
	2	46 09	76.13	24 02	35.78	32.14	19.79	74.82	53.45	47.76	60.10	–	87.65	64.02
Sweden	1	31.85	68.58	43.58	39.63	42.40	63 98	79 91	86 04	41 58	63.30	76 81	–	20.94
	2	29.75	64.80	29.18	33.78	38.55	44 79	73 68	77 72	36 32	42.30	87 65	–	17.11
Canada	1	14.19	56 14	31 89	22.76	27.86	45.67	46.56	68.43	41.24	55.79	79.79	20.94	–
	2	13.84	79 02	28 87	21.85	28.65	42.18	41 17	61 77	36.09	56.86	64.02	17.11	–

Source CNR-ISRDS elaboration on CHI Research data
The distance indicator is based on the percent distribution across 41 SIC classes of patents granted in the US to individual countries. The index varies from 0 to 1000.
Distance values are divided by the maximum possible distance, calculated on the average of the five more extreme cases. Period 1. 1975–81, Period 2: 1982–88

is strong in fields where the other holds few or no patents. Since the propensity to patent (i.e. the number of patents for each unit of innovative activity) varies considerably across sectors (Scherer 1983), the method here employed compares the number of patents of each country in each class to the number of patents of another country in the same class.

Table 5 provides the distance indexes for 13 major OECD countries. The pattern of relative differences emerging from the matrix is fairly complex; the US has the closest similarities to France, the UK and Canada in both periods. Japan is closest to the US and France, but with higher distance indexes. Germany has a sectoral distribution of patents similar to France, the UK and Italy.

In turn, France and the UK are very close together and are similar to the US and Germany. Italy is close to Germany, followed at a distance by France, the UK and Switzerland. The remaining countries have very high distance indexes and tend to show closer similarities either to the US or the major European countries.

In interpreting such patterns of relative differences across countries the impact of countries' size of patenting activities is evident. The larger countries, including the US, Japan, France, the UK and Germany, appear rather close, as they distribute their patents across all sectors.[8] Strong differences emerge on the other hand for small countries, which concentrate their patents in few (and different) areas.

Smaller countries are very different from one another and tend to be closer to the larger country which shares the same sectoral specialization. Smaller countries, in other words, appear to have developed a technological specialization in selected, country-specific 'niches' (see Walsh 1988). Such a position allows small countries to compete in these fields at a world class level. Their niches, however, are very different, showing that small nations can be specialized in entirely different areas: it is not just their size to decide the nature of their sectoral strengths and weaknesses.

The impact of selected sectors on national specialization is also evident from the distance matrix of Table 5. The strong similarity between France and the UK, and to a lesser extent the US, is due to the common importance of military-related and state-supported areas (aircraft, guided missiles, ordnance) and of classes such as drugs and medicines and agricultural and other chemicals. Some of these fields are areas of technological specialization also for Germany, which on the other hand shares with Italy and Switzerland a relative concentration of its patenting in specialized industrial machinery and in some chemical classes.

Other types of links among national specializations can be identified. A relative importance of electronics-related fields appears to be at the root of the similarities shown by Japan, the US, France and the Netherlands. The US is also fairly close to Canada, which in turn shows a specialization profile similar to that of Sweden, with Denmark not too far apart; in these linkages the relative importance in all countries of natural resource and agriculture-related activities, as well as of specialized production in fields such as shipbuilding and engineering appears to be crucial.

The analysis of the changes over time in the distance indicators is of particular interest as it highlights the different paths of specialization shown by groups of countries. From the late 1970s to the mid-1980, the US, the UK and France have

[8] In previous research (Archibugi and Pianta, 1992) we have shown that the degree of specialization in technology is inversely related to the size of technological activities of each country.

further increased their already strong similarity. Germany, on the other hand moved away from this group, even though it remains close to it. Germany continues to be highly similar to Italy and is now closer to Switzerland and Sweden. In turn, Italy moved closer to the technological specialization of Switzerland and Sweden, while increasing its distance from most other countries.

Japan is the clearest case of a country developing a distinct profile of specialization in electronic and mechanic technologies, which is highly and increasingly different from all other countries. For the remaining countries (with the partial exception of The Netherlands) the general trend is towards a growing distance, suggesting that most countries develop a sectoral distribution of their patenting activities leading to a more distinct national profile, linked to their own economic and technological characteristics, rather than converging to a standard patenting profile for all advanced countries.

From this complex picture of relative similarities and differences a number of lessons can be drawn. First, we can argue that the convergence in terms of technological activities among the US, the UK and France on the one hand and among Germany, Switzerland, Sweden and Italy on the other hand, is rooted in two different and diverging patterns of sectoral specialization. Japan shows an additional distinct pattern of technological activities which has led to the fastest path of aggregate convergence emerging from OECD countries. All these three different patterns of sectoral specialization have been successful in leading most countries of these groups to converge at the top of the economic and technological performances of advanced countries.

Secondly, the ability of large countries to cover most technology fields with their innovative activities means that size (i.e. the aggregate volume of their resources devoted to innovation) is an important factor in this measure of similarity. This leads to a picture of a core made of the major countries, which are fairly close to one another, while smaller ones appear scattered around them, closer to one of the larger countries, and highly different from most of the other smaller ones.

Thirdly, while the analysis of individual countries has shown strong stability in national patterns of specialization in technology (see Cantwell 1989), in comparing the relative distance between countries some mobility can be found. The differentiated pattern of sectoral patenting and the combined shifts over time of all countries lead to an overall picture of fairly dynamic relative positions of individual countries. In other words, even within the constraints of the technological capabilities accumulated by each nation over time, countries do shift their relative positions, taking or missing the technological opportunities offered by the changing patterns of innovation.

5. Conclusions

In this paper we have examined the technological basis of the process of economic convergence among advanced countries, showing that a moderate convergence can be found for indicators of aggregate technological efforts. We are not alone in showing this 'technological' convergence (for an overview, see Soete and Verspagen 1993a). Our analysis for the restricted sample of OECD countries, however, indicates that 'technology gaps' remain much wider than 'economic gaps'. From a dynamic perspective, there is no evidence that convergence in technology is occurring at a higher pace than for levels of income and consistently across different indicators of innovative activities. A significant divergence has emerged in the industrial R&D of the G5 group, where the US, the UK and France have not been able to keep up with the growth of resources in Japan and Germany.

More importantly, we have related the problem of convergence at the aggregate level to the sectoral specialization of advanced countries, showing that diverging patterns of sectoral innovative activities can be identified even for the countries at the forefront of the 'convergence club'. This evidence supports the relevance of national systems of inovation for the understanding of how countries develop and use technology. The qualitative and institutional differences among countries highlighted by a new body of research (see, among others, Freeman and Lundvall 1988; Lundvall 1992; Nelson 1993) indicate the crucial role played by nation-specific factors and institutions in shaping both the patterns of technological change and countries' comparative advantages. The latter represent a major constraint also for the strategies of firms which have been increasing the internationalization of technology. Cross-border strategies of multinational firms however do not necessarily bring about a greater uniformity among countries in the production of innovations; rather, they are more likely to lead to an increasing diversity.

Complementing the qualitative analyses carried out so far on the national systems of innovation, this paper provides quantitative evidence on the similarities and differences among advanced countries in their economic and technological performances, at both the aggregate and the sectoral level. We have shown the evidence and the limitations of the process of convergence in technology and the different sectoral patterns of specialization which may sustain it. Each country appears to have further developed its comparative advantages in selected technological niches.

However, the increasing specialization in the production of innovations does not necessarily mean that national patterns in the adoption and diffusion of technology, as well as patterns of market demand, are equally diverging. In particular, the aggregate picture of the technological and economic performance of advanced countries provided in section 3 shows that a process of aggregate convergence is taking place. This apparent paradox is related to the ability of national economies to use their different technological resources, and to acquire the know how they do not produce from a variety of channels, including trade, patent licensing, international cooperative research projects, and many other specific forms of technology transfer.

An interesting case of widely differing national systems of innovation, national patterns of sectoral specialization in technology and moderate convergence is offered by EC countries (see Grupp 1992). One may even suggest that the diversity among them should be regarded as an advantage, since it may make it possible to develop technological capabilities in different fields. However, in terms of developing a distinct profile of technological specialization, Europe still appears as an aggregate of disparate countries, some of them rather similar (the UK and France, or to a lesser extent Germany and Italy), other more different (all the smaller ones), and neither a common specialization profile, nor a clear complementarity is evident. The pattern of growing technological distance among EC countries does not appear as a clear outcome of either a policy of European integration or of a market-driven process of greater intra-European division of labour.

However, the most serious problem for European countries remains the uncomplete process of convergence. In most indicators of technological activities dramatic lags persist for many countries which have shown strong economic convergence but little ability in research and innovation. Although effective use, adaption and diffusion of foreign-developed technology has helped the convergence in per capita incomes, one may wonder whether there is room left for additional progress without a serious increase in domestic innovative activities, reducing the large gaps that are still visible for many countries. It should be clear however that any expansion of national aggregate innovative efforts is likely to take in each country different directions at the sectoral level, as shown by the patterns of specializations discussed above.

In conclusion, the evidence on technological activities of advanced countries shows that in the last two decades economic convergence has been achieved with relatively little increase in technological efforts. In the 1980s the convergence process has slowed down, perhaps also as a consequence of strong persisting differences in countries' innovative activities. When we look beyond the aggregate picture, and consider the sectoral patterns of technological specialization, we are left with a baffling paradox: countries converge by becoming more different and grow by becoming more specialized.

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Appendix

List of SIC classes used for patent applications in the United States

1. Food and kindred products
2. Textile mill products
3. Industrial inorganic chemistry
4. Industrial organic chemistry
5. Plastic materials and synthetic resins
6. Agricultural and other chemicals
7. Soaps, detergents, cleaners, perfumes, cosmetics and toiletries
8. Paints, varnishes and allied chemicals
9. Miscellaneous chemical products
10. Drugs and medicines
11. Petroleum, natural gas, extraction and refining
12. Rubber and miscellaneous plastic products
13. Stone, clay, glass and concrete products
14. Primary ferrous products
15. Primary and secondary non-ferrous metals
16. Fabricated metal products
17. Engines and turbines
18. Farm and garden machinery and equipment
19. Construction, mining and material handling machinery and equipment
20. Metalworking machinery and equipment
21. Office computing and accounting machines
22. Special industrial machinery, except metalworking machinery
23. General industrial machinery and equipment
24. Refrigeration and service industry machinery
25. Miscellaneous machinery, except electrical
26. Electrical transmission and distribution equipment

27. Electrical industrial apparatus
28. Household appliances
29. Electrical lighting and wiring equipment
30. Miscellaneous electrical machinery, equipment and supplies
31. Radio and television receiving equipment except communication types
32. Electronic components and accessories and communication equipment
33. Motor vehicles and other transportation equipment, except aircraft
34. Guided missiles and space vehicles and parts
35. Ship and boat building and repairing
36. Railroad equipment
37. Motorcycles, bicycles and parts
38. Miscellaneous transportation equipment
39. Ordnance except missiles
40. Aircraft and parts
41. Professional and scientific instruments
42. Unclassified patents
43. Other industries