

The Evolution of Specialisation: Public Research in the Chemical and Pharmaceutical Industries

Preliminary and incomplete draft: Paper

Aldo Geuna

SPRU, University of Sussex

Communication to

European Meeting on Applied Evolutionary
Economics

7 - 9 June 1999, Grenoble, France

Organised by the Institute for Energy Politics and Economics
Organisé par l'Institut d'Economie et de Politique de l'Energie /
IEPE, BP 47, 38040 Grenoble Cedex 9, France

And the INRA-Unit of Sociology and Economics of Research and Development
Et l'unité Sociologie et Economie de la Recherche Développement de l'INRA
INRA/SERD, BP 47, 38040 Grenoble Cedex 9, France

First draft: November 1998

This draft: 13 May 1999

Author's address: SPRU, University of Sussex, Mantell Building, Brighton, BN1 9RF, UK. Tel. +44 1273 877139, Fax. +44 1273 685865, e-mail: a.geuna@sussex.ac.uk

I am very grateful to Anthony Arundel for the supply of the PACE data. Comments and suggestions made by Anthony Arundel, Stefano Brusoni, Ammon Salter and Ed Steinmueller are gratefully acknowledged, as well as the financial support of the Commission of the European Communities, TSER Programme.

Abstract:

This paper aims to contribute to the debate over the relationship between public scientific research and industrial innovation, analysing, in particular, the importance of distance in the process of knowledge transfer from public research to industrial innovation. It also examines the evolution of scientific specialisation of the four largest European countries (UK, Germany, France and Italy), the EU as a whole, the US and Japan in the chemical and pharmaceutical fields. Particular attention is devoted to examining whether the country scientific specialisation is similar in different typologies of research (Applied Technology & Engineering, Applied Research and Basic Research) and if it is stable over time. By so doing the concepts of knowledge integration and knowledge persistence are introduced. The former refers to the degree of similarity in the country scientific specialisation in the typologies of research, while the latter defines the stability in the publication profile of a country along time.

The results of the analysis show that the chemical and pharmaceutical sectors have completely different perceptions of and make different use of public research, and that the pharmaceutical sector relies upon international, and particularly North American, research much more than does the chemical sector. Furthermore, the country level analysis of specialisation patterns indicates that the US has a much more integrated and persistent specialisation profile in Medical Chemistry and Pharmacy & Pharmacology.

JEL Subject Classification: O3, L3, H4,

Keywords: Public research, knowledge integration, knowledge persistence, industrial innovation, localisation, publication profile.

1. Introduction

A wide agreement exists among scholars and practitioners on the contribution of public research –i.e. scientific research performed at public research institutes and universities-- to the process of industrial innovation and yet different and sometimes conflicting measures of the relevance of its contribution have been proposed. Given the complexity and non linearity of the innovation process, the quantitative or even qualitative measurement of rates of return to the investment in public research have proven difficult (Martin, Salter, and al., 1996; Smith and Barfield, 1996).(et)

This paper has a twofold purpose. On the one hand, it aims to contribute to the debate over the relationship between public scientific research and industrial innovation, analysing, in particular, the importance of distance in the process of knowledge transfer from public research to industrial innovation. On the other hand, given the importance played by publications and technical reports in the process of knowledge transfer, it examines the evolution of scientific specialisation of the four largest European countries (the UK, Germany, France and Italy), the EU as a whole, the US and Japan in the chemical and pharmaceutical fields.

On the basis of the results of the PACE survey (the PACE questionnaire surveyed the largest R&D performing industrial firms in the twelve EU countries in 1993) two main issues were analysed. First, the importance –of the knowledge produced by public research institutes and universities to the process of innovation in the chemical and pharmaceutical industries was examined. Second, given the fact that public research is valued, analysis was made of how the distance from the public research institute or university affects this perception and the use that is made of the research. The results of the analysis show that the two industrial sectors have completely different perceptions of and make different use of public research, and that the pharmaceutical sectors relies upon international, and particularly North American, research much more than does the chemical sector. However, both sectors consider publications and technical reports as the most important channels to source knowledge about the scientific and technological development at the frontier both nationally and internationally.

In this context, it becomes extremely important to examine the publication profile of different countries in the fields of Chemistry and Pharmacology & Pharmacy. The Science Citation Index database of the Institute for Scientific Information is used to analyse the publication output of the four largest European countries, the EU, Japan and the US in the period 1989-1996. Eleven scientific fields relevant to the chemical and pharmaceutical industries are identified. Each publication in these fields is classified in a typology of research using the CHI journal classification: applied technology, engineering and technological sciences, applied research, and basic research. On the basis of these data the Symmetric Relative Specialisation Indexes are calculated. Core positive and negative specialisation and the evolution of the country specialisation in the 8 year period are analysed. Particular attention is devoted to examining whether the country scientific specialisation is similar in different typologies of research and if it is stable over time. In the course of this examination the concepts of knowledge integration and knowledge persistence are introduced. The former refers to the degree of similarity in the country scientific specialisation in the typologies of research, while the latter defines the stability in the publication profile of a country over time.

The paper is organised into four sections. The next section, Section 2, studies the contribution of publicly funded scientific research to the innovative activity in the chemical and pharmaceutical industries. The country scientific publication output is analysed in Section 3 focusing on the country core scientific specialisation and on its evolution. Finally, Section 4 provides concluding observations.

2. The contribution of publicly funded research to industrial innovation

The contribution of publicly funded research to the process of innovation in the chemical and pharmaceutical industries in the EU countries can be examined on the basis of the results of the PACE survey (Arundel, van de Paal, and Soete, 1995). The PACE questionnaire surveyed the largest R&D performing industrial firms in twelve of the EU countries in 1993. The responses are from 414 large manufacturing firms incorporated in

9 EU countries (Belgium, Denmark, Germany, Ireland, Italy, Luxembourg, Netherlands, Spain and the UK). No answers were received from Portuguese firms, and no Greek firms satisfied the requirements for inclusion. A similar questionnaire was also carried out in France, however the results are not examined here.

Seven questions included in the questionnaire address issues of relevance here, such as: (a) the contribution of public research institutes and universities to innovative activity, (b) how the research carried out at public institutes and universities is accessed, and (c) the importance of government policies. The following analysis focuses on the answers from firms in the chemical and pharmaceutical sectors (2-digit ISEC codes 24 and the separate 2423) compared to all manufacturing firms. All the questions considered here (except one) are ordinal, the extreme scores, defined as the combined percentage of respondents giving a ‘very important’ or ‘extremely important’ answer to a question, are discussed.

Table 1: Importance to the innovative activity of different sources of technical knowledge

	Chemical	Pharmaceutical	All Sectors
Public research institutes and universities	29.2%	61.0%	37.6%
Technical analysis of competitors’ products	52.6%	41.0%	46.8%
Independent customers	45.8%	25.6%	40.2%
Independent suppliers	20.8%	23.7%	41.4%
Joint ventures	32.3%	42.5%	32.8%
Affiliated firms	41.1%	43.6%	42.4%

Source: Elaboration of PACE data

Table 1 shows the percentage of respondents rating ‘very important’ or ‘extremely important’ to their innovative activity the different sources of technical knowledge. Less than one-third of respondents in the chemical sector considered technical knowledge obtained from public research institutes and university as important to their innovative activity. This share is lower than in the case of all the sectors combined, indicating the low relevance (compared to other sources) of technical knowledge produced in public institutions to chemical firms. By contrast, more than sixty percent of respondents in the pharmaceutical sector classed public research institutions

and universities as a ‘very important’ or ‘extremely important’ source of technical knowledge. This is the highest share among the manufacturing sectors.

From both a theoretical and a policy perspective it is extremely important to understand whether the contribution to the innovative activity of firms of external sources of knowledge is affected by the location of the source of knowledge. In recent years, academic research has turned its attention once again to analysis of the localisation of research in general (Audretsch and Feldman, 1996; Feldman, 1993; Florida, 1997; Storper, 1997; Swann, Prevezer, and Stout, 1998) and in particular to the localisation of public research (Acts, Feldman, and Audretsch, 1992; Audretsch and Stephan, 1996; Audretsch and Stephan, 1998; Jaffe, 1989; Jaffe, Trajtenberg, and Henderson, 1993; Mansfield, 1995; Mansfield and Lee, 1996; Trajtenberg, Henderson, and Jaffe, 1997). The relevance (extreme scores) of the localisation of public research institutes and universities in four regions is summarised in Table 2.

Table 2: Importance of technical knowledge from public research institutes and universities, by regions

	Chemical	Pharmaceutical	All Sectors
Your country	48.4%	70.7%	50.3%
Other Europe	24.3%	63.3%	22.8%
North America	19.4%	67.5%	19.7%
Japan	7.6%	29.7%	6.2%

Source: Elaboration of PACE data.

The importance for the innovative process in the chemical sector of technical knowledge from public institutions in the four different regions is not significantly different from the case of all the sectors combined. About 50% of the respondents considered the knowledge from public research institutions and universities in their country important; about one quarter of the respondents also regarded as important the technical knowledge produced in public institutions in other European countries. The share decreases to a bit less than 20% for organisations in North America and about 7% for those in Japan.

The responses from the R&D managers in the pharmaceutical industry highlight the much higher propensity for technical knowledge produced abroad to be valued. About two-thirds of the respondents assigned importance to the knowledge produced in public research institutes and universities regardless of the localisation of the organisation (own country scored slightly higher than the other two regions). The international nature of the pharmaceutical sectors is also evident from the high share of respondents (about one third) rating as important the technological knowledge produced in public institutions in Japan. This is more than four times the share for all the sectors combined.

These results tend to confirm the view that firms consider the knowledge produced by public research institutes and universities as more important for their process of innovation if these organisation are located in the home country of the firm. This phenomenon is less significant for the more science intensive industrial sectors, such as pharmaceuticals.

Public research institutes and universities produce different types of research outputs; in the PACE questionnaire four classes were identified: (1) general knowledge, (2) specialised knowledge, (3) instrumentation and (4) prototypes. Table 3 shows the share of respondents considering these research outputs as ‘very important’ or ‘extremely important’. In Table 2 the responses from the chemical industry tended to be not significantly different from those of all sectors combined, while a systematically higher share of respondents from the pharmaceutical sector rated as important the research output of public institutions. Among the four outputs considered, specialised or applied knowledge ranks as the most important. New instrumentation and techniques ranks second for all the sectors combined, while general knowledge obtained from basic research results is more relevant in the case of the chemical and pharmaceutical sectors. Finally, early versions or prototypes of new designs are considered as an important output of public institutes and universities in only a few cases.

Table 3: Importance of research outputs of public research institutes and universities

	Chemical	Pharmaceutical	All Sectors
--	----------	----------------	-------------

General knowledge	35.1%	75.6%	30.3%
Specialised Knowledge	45.4%	82.9%	56.5%
Instrumentation	32.0%	53.7%	38.1%
Prototypes	15.6%	32.5%	21.8%

Source: Elaboration of PACE data.

Up to this point, the concern has been with the perception R&D managers have of the relative importance of public research. The data from the PACE questionnaire can also be used to develop a better understanding of ways to access the research carried out at public institutes and universities. The focus here is on the mechanisms that facilitate the transfer or spill over of knowledge to firms. First, the importance of six different ways to access the knowledge produced in public institutions is considered (Table 4), then whether these methods have been used and their region of origin are examined.

Consistent with the previous results respondents from the pharmaceutical industry rate all the different mechanisms of higher importance than in the case of all sectors combined. Publications, informal personal contact and conferences are considered the most important sources for learning about research conducted in public research institutes or universities. The responses from R&D managers in the chemical industry tend to be similar to those from all the industrial sectors combined, however, the hiring of trained scientists and engineers is classed as the second most important method for sourcing public research. This result is consistent with the historical importance given to PhD graduates in the chemical industry. Finally, top priority is generally given by European countries' governments to contract research and joint research (usually grouped under the title of university-industry research collaborations) however R&D managers of the largest R&D intensive firms in Europe ranked them as the least important. This result is even more evident in the chemical industry.

Table 4: Importance of methods for learning about public research

	Chemical	Pharmaceutical	All Sectors
Publications and technical report	58.3%	90.3%	58.4%
Conferences and meetings	44.3%	85.0%	43.9%
Hiring trained scientists and engineers	48.4%	65.9%	44.4%
Informal personal contacts	47.5%	87.8%	51.6%
Contract research done by the institute or	35.1%	51.2%	36.3%

university			
Joint research projects	34.4%	51.3%	39.5%

Source: Elaboration of PACE data

The above has highlighted the importance of technical knowledge from public research institutes and universities which is affected by the localisation of the organisation. Localisation also matters when the methods used to obtain the results of public research are analysed. Regardless of the methods used, respondents were less likely to obtain the results of research conducted by public research institutes or universities when it was produced away from their own country. While the proportion of respondents who gleaned information from publications, informal contacts and conferences decline proportionately with distance, in the case of hiring, contract research and joint research there was a crucial reduction in the move from the home country to another European country. This indicates that localisation is much more relevant for these methods of knowledge diffusion.

The same analysis was carried out for the chemical and pharmaceutical sectors. As in the previous case the pharmaceutical industry is characterised by a high degree of internationalisation of research, higher than that for all the sectors combined. Most importantly, about 90% of respondents obtained information from publications, informal contacts and conferences within their own country, other European countries and North America with only a very small percentage receiving information from Japan. An important difference is that in the case of contract research and joint research the home country had a significantly higher share, followed by other European countries and North America each with similar levels. Thus, whether a firm decided to have some form of R&D collaboration with a public research institute or a university outside its home country was not related to whether the organisation was located in Europe or North America.

In the chemical industry respondents obtained the results of research conducted by public research institutes or universities from all the different sources at levels similar to those for all the sectors combined. However, a few particularities are worth

mentioning. Chemical firms obtained information with the same frequency from conferences in their own country and in other European countries (about 88% of the respondents). In the case of publications, informal contacts and hiring the shares assigned to other European countries and North America are similar and lower than own country, respectively about 80% for publications, 65% for informal contacts and 33% for hiring. Although less than the pharmaceutical sector, the chemical sector seems to be characterised by the development of informal relationships with public research institutes and universities at the European and North American levels, but still with a preponderant role for the home country. Any more formal kind of research relationship, such as research contract and joint research, is still strongly affected by distance, with Japan playing a minor role. Finally, it is worth mentioning that R&D managers in the chemical sector considered hiring as the second most important method for learning about public research, however when asked about the methods they used hiring turned out to be much less relevant.

The PACE questionnaire contained two sets of questions analysing the effect of government policies. Of interest here is the relative importance in the ability to innovate of: (a) public support for research in universities and research institutes; and (b) programmes to encourage co-operation in R&D between firms or between firms and research institute (unfortunately the two types of R&D co-operation are considered together).

Table 5: Importance of government policies

	Chemical	Pharmaceutical	All Sectors
Public support for research in universities and research institutes	24.0%	66.7%	32.2%
Programmes for R&D co-operation	29.5%	37.5%	32.9%
Subsidies	26.0%	45.0%	36.8%
Procurement programmes	10.5%	22.2%	22.7%
Patents search services	14.6%	25.0%	13.4%
Technical assistance programmes	8.4%	8.3%	15.1%
Foreign technological information	9.5%	16.7%	13.4%

Source: Elaboration of PACE data

Table 5 shows the percentage of respondents rating as ‘very important’ or ‘extremely important’ the different government policies supporting their innovative activity. Public support for research in universities and research institutes and the programmes for R&D co-operation are considered to be among the three most important government policies. Almost one-third of respondents valued them as important (very or extremely) in supporting the ability to innovate. R&D managers of chemical firms considered government policies to be less important and, in particular, less than one quarter of them rated public support for research as important. Contrasting results were obtained in the case of the pharmaceutical sector. Slightly more than two-thirds of respondents considered public support for research in universities and research institutes as ‘very’ or ‘extremely’ important. This is more than twice the share for all sectors combined (it is also the highest share among the manufacturing sectors). Programmes for R&D co-operation were considered important by a slightly higher share of respondents in the pharmaceutical sector than in all the sectors combined.

Overall, the analysis of the responses to the PACE questionnaire concerning the contribution of research developed in public research institutes and universities to the process of innovation in the chemical and pharmaceutical sectors, allows the following main observations to be made. First, R&D managers of the largest R&D performing industrial firms in the EU chemical and pharmaceutical sectors assign different importance to the knowledge produced by public research institutes and universities. The responses from the chemical sector tended to be similar to those for all the sectors combined. The pharmaceutical sector assigns much higher importance to general knowledge produced in public research institutes and universities diffused via publications and technical reports and, consequently, rates public support for research in universities and research institutes of high importance. Second, although all respondents valued and obtained the results of research conducted by public research institutes or universities less the further away it was produced from their own country, the pharmaceutical sector showed a much higher degree of internationalisation of research. In particular, the research carried out in North America plays a crucial role in the pharmaceutical sector. Finally, the less structured or formal methods for learning about

public research, with publications on the top, were valued and used more often than the more formal kind of research relationships such as research contracts and joint research. Furthermore, the latter are strongly affected by distance being valued as important and being used mainly with organisations in the same country as the firm.

3. Country scientific specialisation patterns

Given the importance played by publications in the process of gathering knowledge for the innovation process, a better understanding of the characteristics and evolution of scientific publication output is required. This section examines the publication profile in chemistry of the fifteen EU countries (and of the four large ones separately) and compares it to those of the US and Japan. Particular attention is devoted to examining whether the country scientific specialisation is similar in different typologies of research and if it is stable over time.

Table 6: Country's world share of publications in chemical literature, by years

	1989	1990	1991	1992	1993	1994	1995	1996
EU15	31.3	31.7	32.4	33.8	34.3	34.4	34.4	34.2
France	5.2	5.1	5.4	5.5	5.8	5.8	6.0	5.8
Germany	7.8	8.0	8.1	8.4	8.3	8.3	7.8	7.8
Italy	3.6	3.5	3.6	4.0	3.7	3.7	3.8	3.7
UK	6.4	6.4	6.5	6.5	6.6	6.7	6.9	6.8
US	25.7	25.2	25.9	25.6	25.4	24.9	24.0	24.2
Japan	11.9	12.0	11.9	12.3	12.0	12.1	12.3	12.5

Source: Elaboration of SCI data
Only articles included; authors fractional count.

The Science Citation Index (SCI) database of the Institute for Scientific Information (ISI) can be used to analyse the publication output of a country in chemistry. Table 6 illustrates the country's world share of total papers in chemical literature as calculated from the SCI database. The publications from researchers located in the 15 EU countries, account for about one-third of the total. Although shares of the four largest European countries have remained virtually unchanged between 1989 and 1996, the total share of the EU has increased indicating a raised publication output of the smaller European countries.

On the basis of the ISI classification of journals in scientific fields, 11 scientific fields relevant for chemistry were identified. They are: General Chemistry (C1),¹ Analytical Chemistry (C2), Applied Chemistry (C3), Crystallography (C4), Inorganic and Nuclear Chemistry (C5), Medical Chemistry (C6), Organic Chemistry (C7), Physical Chemistry (C8), Polymer Science (C9), Pharmacology & Pharmacy (C10), and Chemical Engineering (C11). Second, all the journals in these fields were classified in one of the four levels of the CHI journals classification: Applied Technology (L1), Engineering & Technological Sciences (L2), Applied Research (L3), and Basic Research (L4). Finally, publication output in the various classes was calculated for the EU, the 4 largest EU countries, US and Japan in the period 1989-1996, using a four dimensional matrix with 2,464 cells.

In order to work with a set of manageable statistics the following analysis will focus on only the three sub-periods 1989-1990, 1991-1993 and 1994-1996 (the data were aggregated for each period). It was decided to keep as much detail as possible because with the increase in the level of aggregation the information available decreases. For example, at the country level all fields combined, all journal levels combined (Table 6), there seem to have been very few changes. . However, as will be shown below, as soon as the level of detail increases many modifications come to the fore.

Table 7: World share of publications in chemical literature by scientific field

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
1989-1990	16.2	9.5	2.5	4.4	7.1	1.1	11.3	15.7	7.2	19.6	5.4
1991-1993	15.9	9.8	2.7	4.2	6.5	1.4	9.8	17.6	8.0	18.8	5.4
1994-1996	15.1	9.2	2.5	4.0	6.3	1.5	10.3	19.0	8.4	18.2	5.6

Source: elaboration of SCI data.

As a first step, the world production of publications in chemistry is examined in relation to the sub-fields and to the journal classification to set the background for the analysis. The eleven fields can be subdivided into three classes with different publication

¹ The ISI classifies in this field all the journals that cannot be classified in other fields.

levels (Table 7). First, General Chemistry (C1), Physical Chemistry (C8) and, Pharmacology & Pharmacy (C10) have shares higher than 15%. Second, Analytical Chemistry (C2), Organic Chemistry (C7) and Polymer Science (C9) have values around 10%. Finally, the remaining sub-fields have shares around 5% or less. In the period considered, the share of almost all the fields decreased or remained unchanged, with the exception of Polymer Science and Physical Chemistry both of which increased by about 21%.

Table 8: World share of publications in chemical literature by journal type

	Applied Technology	Engineering & Technological Sciences	Applied Research	Basic Research
1989-1990	2.8	9.7	42.5	45.1
1991-1993	2.5	9.9	45.0	42.5
1994-1996	2.3	10.2	45.1	42.4

Applied Research and Basic Research journals each account for about 40% of publications (Table 8). In the eight years being considered there has been an increase in the number of articles published in journals with a more applied character while in the journals classified in the Basic Research class there was a reduction in the number of publications. The other two classes of journals accounted for a small percentage of publications thus, in the following analysis they will be considered together as the area of Applied Technology & Engineering.

Given this background, the scientific publication output of a country can be studied in terms of scientific specialisation. In particular, the relative specialisation of a country and its evolution during the period 1989-1996 is examined. The aim of the analysis is twofold. First, the country scientific specialisation in research typologies and fields is analysed. Secondly, and most importantly, the statistical results are used to underline the existence of different levels of knowledge integration and knowledge persistence. The former is represented by the different degrees of similarity in the country scientific specialisation in the three typologies of research, while the latter is measured by the stability in the publication profile of a country over time.

3.1 Specialisation in a research typology

To develop a comparative analysis of the changes in scientific research output in chemistry the relative specialisation of a country was studied. The symmetric Relative Specialisation Index (RSI) was calculated on the basis of data from the SCI database for six countries and the EU, eleven scientific fields and three research areas between 1989 and 1996 (Balassa, 1965; Soete, 1981).

Table 9 in Appendix I presents the relative specialisation in a research typology as measured by the CHI journal classification. As stated above, Applied Technology and Engineering & Technological Sciences are considered together (Applied Technology & Engineering). The fifteen EU countries together have seen their specialisation changing during the eight years. At the beginning of the period the EU had a positive specialisation in Applied Technology & Engineering, and a slightly negative one in Applied Research and Basic Research. Over the years the specialisation in the EU has become positive in Basic Research and negative in Applied Technology & Engineering. However, the specialisation index for the EU as a whole is generally very low.

The four large EU countries considered have higher specialisation indexes. The UK is positively specialised in Applied Technology & Engineering, and negatively in Applied Research; it moved from having a negative specialisation in Basic Research at the beginning of the period to having a positive one. France has a positive specialisation in Basic Research and an important negative specialisation in Applied Technology & Engineering. Germany started out with a positive specialisation in Basic Research, and Applied Technology & Engineering and a negative specialisation in Applied Research. By the end of the period the positive specialisation in Applied Technology and Engineering had become a negative. Finally, Italy had a minor positive specialisation in Applied Research and moved from a negative to a positive specialisation in Basic Research, and from a positive to a negative in Applied Technology & Engineering.

The US started out with a significant specialisation in Applied Technology & Engineering that held throughout the period, together with a negative (although

decreasing) specialisation in Basic Research. Also the US witnessed a change from a positive Applied Research specialisation to a slightly negative one. Japan increased its specialisation in Applied Research, maintained a negative specialisation in Applied Technology & Engineering, and moved from a fairly positive specialisation in Basic Research to a negative one.

In general, most of the relative specialisation indexes calculated on the basis of the CHI journal classification, have low values, indicating a homogenous distribution in the various research typologies. However, both the UK and the US have a recognisably important positive specialisation in Applied Technology & Engineering, while France and Japan has a negative one in the same area of research. Finally, all countries are present in similar ways in both Applied and Basic Research, although the EU, and especially the four largest EU countries, have an increased specialisation in Basic Research.

Tables 10-12 in Appendix I present the symmetric RSI calculated from the SCI database for eleven chemistry fields. In order to analyse these tables it was decided to focus on the top two positive and negative scientific specialisation for each country in each typology of research (CHI journal classification), and on the most important changes in the country scientific specialisation.

3.2 Core Scientific Specialisation

First the publications in journals classified in Applied Technology & Engineering are examined. The fifteen EU countries together tend to have a positive specialisation in Applied Chemistry and Pharmacology & Pharmacy, and a negative in General Chemistry and Polymer Science (Table 10). The UK has a positive specialisation in the same chemistry fields, while it has also a significant negative specialisation in Applied Chemistry. France is positively specialised in Crystallography and Physical Chemistry and, like the UK, it has a negative specialisation in General Chemistry and Analytical Chemistry. Germany has a positive specialisation in Applied Chemistry and Crystallography, and a negative one in Medical Chemistry and Polymer Science. The case of the Italy is peculiar in that it has a positive specialisation throughout the period

only in Pharmacology & Pharmacy (it shows a positive specialisation in Physical Chemistry in most of the period), while it is negatively specialised in General Chemistry and Crystallography. The US has a positive relative specialisation in General Chemistry and Analytical Chemistry (Medical Chemistry and Polymer Science also have high values) and a negative in Crystallography and Physical Chemistry. Finally, Crystallography and Chemical Engineering are the only two fields of positive specialisation for Japan, while in General Chemistry and Medical Chemistry it has very negative RSI.

When journals in Applied Research are analysed the EU was seen to specialise in Crystallography and Organic Chemistry (Table 11). These are also the fields with higher specialisation for France and the UK, while in Germany General Chemistry is substituting for Organic Chemistry (Inorganic & Nuclear Chemistry was also a field of specialisation in all but the last years), and in Italy Medical Chemistry substitutes for Crystallography. The fifteen EU countries have negative values for the specialisation indexes of Applied Chemistry and Inorganic & Nuclear Chemistry. With the exclusion of Germany the other three large EU countries have a negative specialisation in Inorganic & Nuclear Chemistry (Italy has also an important negative RSI in Applied Chemistry). France and the UK have significant negative RSI in General Chemistry, while Germany has a negative specialisation in Applied Chemistry and Organic Chemistry. The US has a positive specialisation in Medical Chemistry and Pharmacology & Pharmacy, and it is negatively specialised in Analytical Chemistry and Inorganic & Nuclear Chemistry. Finally, Japan is specialised in Polymer Science and Pharmacology & Pharmacy, and has negative RSI for Applied Chemistry and Crystallography.

The six countries and the EU become characterised by a very diversified set of RSI when only journals focused on Basic Research are included (Table 12). The EU is specialised in Analytical Chemistry (although decreasingly so) and Inorganic & Nuclear Chemistry. France has positive RSI in Organic Chemistry and Physical Chemistry, it had also a considerable positive RSI in Crystallography except for the last years. Inorganic & Nuclear Chemistry and Crystallography are the fields of higher specialisation for

Germany. Italy has an extremely high specialisation index in Analytical Chemistry and a high RSI in Organic Chemistry. The UK tends to be particularly specialised in Medical Chemistry and Crystallography. The US is specialised in Medical Chemistry and Pharmacology & Pharmacy (as in the case of Applied Research), while Japan has high RSI in General Chemistry and Pharmacology & Pharmacy. These last two scientific fields are also those with higher negative specialisation for the fifteen EU countries. France and the UK also have the same fields of negative specialisation, together with a considerable but reducing negative specialisation in Analytical Chemistry. Italy is the only country among the four large EU countries where the negative specialisation in Physical Chemistry is more important than that in Pharmacology & Pharmacy, while Germany has an important negative RSI in Medical Chemistry. Crystallography and General Chemistry are the two scientific fields of negative specialisation for the US, while Japan shows a negative RSI in Analytical Chemistry and Inorganic & Nuclear Chemistry.

Table 13: Positive and negative specialisation by typology of research and country

	Applied Technology & Engineering		Applied Research		Basic Research	
	<i>Positive</i>	<i>Negative</i>	<i>Positive</i>	<i>Negative</i>	<i>Positive</i>	<i>Negative</i>
EU15	C3 C10	C1 C9	C4 C7	C3 C5	C2 C5	C1 C10
France	C4 C8	C1 C2	C4 C7	C1 C5	C7 C8 [C4]	C1 C10 [C2]
Germany	C3 C4 [C5]	C6 C9	C1 C4	C3 C7	C4 C5	C6 C10
Italy	C8 C10 [C6]	C1 C4	C6 C7	C3 C5	C2 C7	C1 C8
UK	C3 C10	C1 C2	C4 C7	C1 C5	C4 C6	C1 C10 [C2]
US	C1 C2	C4 C8	C6 C10	C2 C5	C6 C10	C1 C4
Japan	C4 C11	C1 C6	C9 C10	C3 C4	C1 C10	C2 C5

Table 13 presents a summary of the relative specialisation of the EU and the six countries under consideration. The first observation that can be made is that there is some degree of overlap between the positive specialisation in Applied Research and that in Basic Research, while the area of Applied Technology and Engineering differs from the other two areas of research. Only France and Germany have any specialisation in Crystallography and Physical Chemistry in the three areas of research (see Tables 10-12). Secondly, if the field of General Chemistry (C1), that includes all the journals that cannot be classified in other fields –i.e. journals of general focus –is excluded from the analysis, negative specialisation differs across the three areas of research. Thirdly, all the countries

except France are characterised by having some fields in which they have strong positive and negative specialisation depending on the research area considered. For example, the EU has positive specialisation in Pharmacology & Pharmacy, in Applied Technology and Engineering, but negative in Basic Research. Finally, the US is the only country with a complete overlap of the positive specialisation in Applied and Basic Research, while the EU is the only region with no overlap. These observations underline the fact that the US and France are characterised by a much clearer profile in terms of both positive and negative specialisation and in the area of research.

If knowledge integration is defined as the presence of positive specialisation in the same scientific fields in the three typologies of research, it can be stated that the US has a much higher degree of knowledge integration than the EU. Indeed, the US has a positive specialisation in Medical Chemistry and Pharmacology & Pharmacy in all three research typologies.

3.3. Stability of specialisation patterns

In the 8 year period under examination the specialisation of the EU and the six countries considered has changed, in some cases in a substantial way. Significant changes of the symmetric RSI (larger than 0.2) are examined here (Table 14). In the Applied Technology & Engineering area the most important changes occurred in Analytical Chemistry and Medical Chemistry. The EU, France, Germany and Italy witnessed an important decrease in negative specialisation in Analytical Chemistry; and in particular, Germany and Italy moved to a positive specialisation. The negative specialisation in Medical Chemistry in the UK increased during the period, while Germany, Italy and Japan saw a decrease in their negative specialisation (Italy became positively specialised in this field). Finally, France moved from a negative to a positive specialisation in Polymer Science.

Table 14: Most important changes in country specialisation

	Applied Technology and Engineering	Applied Research	Basic Research
EU15	C2+	C5- C7-	C6-
France	C2+ C9+	C5- C7-	C6+

Germany	C2+ C6+	C3- C4- C7+	C2- C6-
Italy	C2+ C6+	C3+ C4+	C6-
UK	C6-	C7-	C2+
US		C7+	
Japan	C6+	C1-	

Important changes also occurred in the area of Applied Research. The EU and France increased their negative specialisation in Inorganic & Nuclear Chemistry, while Germany switched from a positive to a negative specialisation. France, the UK and the fifteen EU countries together saw a significant decrease in their specialisation in Organic Chemistry, while Germany reduced its negative specialisation. The US witnessed only minor changes; only in Organic Chemistry was the switch from a very negative to a positive specialisation. This is the most important change that occurred in all the countries considered. Italy decreased quite significantly its negative specialisation in Applied Chemistry and became positively specialised in Crystallography. Finally, Germany increased its negative specialisation in Applied Chemistry and Japan turned its positive specialisation in General Chemistry into a negative specialisation.

Only six significant changes in specialisation happened in the area of Basic Research. First, Germany amplified its negative specialisation in Applied Chemistry, while the UK moved from a negative RSI to a positive one. Second, the EU moved from a positive to a negative specialisation in Medical Chemistry. This was despite the fact that France reduced its negative specialisation in this field and was mainly driven by the significant increase in the negative specialisation of Germany and by the shift from a very positive to a negative specialisation of Italy..

Overall, Germany with seven major changes and Italy and France with five were the countries that changed their specialisation in the most significant way. The US with one change and Japan with two are instead the countries with more evident stability in their publication profile. Second, Medical Chemistry and Analytical Chemistry are the scientific fields that witnessed the most frequent changes. Third, Basic Research is the area with the highest degree of stability. From seventy-seven possible cases for change (11 fields by 7 countries) in only 8 cases was there a switch from a positive to a negative

specialisation, or viceversa. This indicates that whenever a country has a specialisation in a scientific field in the area of Basic Research one can expect a high persistency in that specialisation.

To verify the stability of specialisation patterns in Basic Research the Pearson correlation coefficient was calculated for each country at the start and at the end of the period considered (Pavitt, 1989). The specialisation of the six countries analysed is positively correlated in the two periods, while no significant correlation was found for the EU. Japan and the US, with a Pearson coefficient higher than 0.9 and a significance level of 1%, are the two countries with the highest persistence in scientific specialisation.

These results are further confirmed by regressing the symmetric specialisation index in 1996 on the 1989 value (Cantwell, 1989; Dalum, Laursen, and Villumsen, 1998). From the countries considered only the US, Japan and the UK have β coefficients with a significance level higher than 5%, respectively 1.04 (1%), 0.95 (2%) and 0.44 (4%). The US with both $\beta > 1$ and $\beta/R > 1$ became more specialised in sectors where it was already specialised, and less specialised where initially specialisation was low. Japan with both $\beta \sim 1$ and $\beta/R \sim 1$ showed a high stability in its specialisation patterns. The four large European countries saw an increase in the dispersion of their scientific specialisation.

Three important observations can be made from the analysis of country relative scientific specialisation in chemistry. First, although the publication output of the countries considered has a sufficiently homogeneous distribution in the various research typologies, the US tends to be specialised towards the more applied type of research, while the EU, especially the four largest EU countries, increased its specialisation in basic research. Second, when the chemistry sub-fields are examined the US is the country with the highest level of knowledge integration being positively specialised in Medical Chemistry and Pharmacology & Pharmacy in all the three research typologies. Finally, the US also shows a very high degree of stability in its specialisation patterns while the EU countries have witnessed an increase in the dispersion of their specialisation. In

particular, the US has increased its specialisation in the fields where its strengths are highest such as Medical Chemistry and Pharmacology & Pharmacy.

4. Conclusions

The results of the analysis carried out in this paper highlight that there are significant differences in the degree of importance assigned by industrialists to university and publicly funded research, and that localisation matters both in this regard and in relation to the channels through which the results of it are obtained. For example, about two-thirds of the respondents from the pharmaceutical sector considered technical knowledge obtained from public research institutes and university as important to their innovative activity, while this was the case for less than one-third of respondents in the chemical sector. In each case, publications and technical reports are the most important (and most often used) methods for learning about public research.

This paper has provided the first detailed analysis of the characteristics and evolution of the scientific publication output in chemistry of the four largest European countries, the EU, the US and Japan during the period 1989-1996. Analysis of the relationships between core positive and negative scientific specialisation, and the typology of research (applied technology & engineering, applied research and basic research) has shown that the countries considered have different degrees of knowledge integration and knowledge persistence.

Preliminary results indicate that of the countries analysed the US has a much clearer specialisation profile, both in terms of positive and negative specialisation and in the area of research, indicating a much higher degree of knowledge integration than in the EU. Also, the evolution of country scientific specialisation in the 8 year period was analysed and this showed that the US has the most stable publication profile; compared to the other countries it has the highest level of knowledge persistence. In general, when a country has a specialisation in a scientific field in the area of basic research one can expect high persistency in that specialisation.

Finally, the results of the PACE questionnaire indicating that public research carried out in North America was valued and used extensively by the largest R&D firms in the pharmaceutical sector in the EU, are consistent with the fact that the US has a persistent specialisation in Medical Chemistry and Pharmacy & Pharmacology both in applied and in basic research. This conclusion points to a direction for further research that will aim to test the existence of a correlation between knowledge integration and knowledge persistence in certain scientific fields and technological and economic performances of firms and countries.

References

- Acts, Z.J., M.P. Feldman, and D.B. Audretsch. 1992. Real Effects of Academic Research. *American Economic Review*, 82: 363-367.
- Arundel, A., G. van de Paal, and L. Soete. 1995. *Innovation Strategies of Europe's Largest Industrial Firms*. PACE Report prepared for the SPRINT Programme of the European Commission.
- Audretsch, D.B. and M. Feldman. 1996. R&D Spillovers and the Geography of Innovation and Production. *American Economic Review*, 86: 630-642.
- Audretsch, D.B. and P.E. Stephan. 1996. Company-Scientist Localisation Links: The Case of Biotechnology. *American Economic Review*, 86: 641-652.
- Audretsch, D.B. and P.E. Stephan. 1998. How and Why Does Knowledge Spill Over? The Case of Biotechnology. Presented at the 1998 Annual Meeting of the American Economic Association.
- Balassa, B. 1965. Trade Liberalization and 'Revealed' Comparative Advantage. *The Manchester School of Economic and Social Studies*, 32: 99-123.
- Cantwell, J. 1989. *Technological Innovation and Multinational Corporations*. Oxford: Basil Blackwell Ltd.
- Dalum, B., K. Laursen, and G. Villumsen. 1998. Structural Change in OECD Export Specialisation Patterns: De-specialisation and 'Stickiness'. *International Review of Applied Economics*, 12: 447-467.
- Feldman, M.P. 1993. An Examination of the Geography of Innovation. *Industrial and Corporate Change*, 2: 451-470.
- Florida, R. 1997. The Globalisation of R&D: Results of a Survey of Foreign-Affiliated R&D Laboratories in the USA. *Research Policy*, 26: 85-103.
- Jaffe, A. 1989. Real Effects of Academic Research. *American Economic Review*, 79: 957-970.
- Jaffe, A., M. Trajtenberg, and R. Handerson. 1993. Geographic Localization of Knowledge Spillovers as Evidenced by Patents Citations. *Quarterly Journal of Economics*, 63: 577-598.

- Mansfield, E. 1995. Academic Research Underlying Industrial Innovations: Sources, Characteristics, and Finance. *The Review of Economics and Statistics*, 77: 55-65.
- Mansfield, E. and J-Y Lee. 1996. The Modern University: Contributor to Industrial Innovation and Recipient of Industrial R&D Support. *Research Policy*, 25: 1047-1058.
- Martin, B., A. Salter, and et al. 1996. *The Relationship between Publicly Funded Basic Research and Economic Performance*. Brighton: SPRU, University of Sussex.
- Pavitt, K. 1989. International Patterns of Technological Accumulation. In *Strategies in Global Competition*, ed. N. Hood and J.E. Vahlne. London: Croom Helm.
- Smith, B.L.R. and C.E. Barfield. 1996. Contributions of Research and Technological Advance. In *Technology, R&D, and the Economy*, ed. B.L.R. Smith and C.E. Barfield. Washington, D.C.: The Brookings Institution and American Enterprise Institute.
- Soete, L.L.G. 1981. A General Test of the Technological Gap Trade Theory. *Weltwirtschaftliches Archiv*, 117: 638-666.
- Storper, M. 1997. *The Regional World*. New York: The Guilford Press.
- Swann, G.M.P., M. Prevezer, and D. Stout, eds. 1998. *The Dynamics of Industrial Clustering*. Oxford: Oxford University Press.
- Trajtenberg, M., R. Henderson, and A. Jaffe. 1997. University versus corporate Patents: A Window on the Basicness of Invention. *Economics of Innovation and New Technology*, 5: 19-50.

Appendix I: Relative Specialisation Index

Table 9: Relative specialisation based on CHI journals classification, by countries and years

Year	Country	L1+L2	L3	L4
P1	EU15	0.034	-0.004	-0.006
P2	EU15	-0.003	0.001	0.000
P3	EU15	-0.015	-0.004	0.009
P1	UK	0.117	-0.035	-0.005
P2	UK	0.106	-0.032	-0.002
P3	UK	0.080	-0.043	0.018
P1	FRANCE	-0.084	-0.003	0.024
P2	FRANCE	-0.145	0.003	0.033
P3	FRANCE	-0.119	-0.019	0.049
P1	GERMANY	0.089	-0.083	0.043
P2	GERMANY	0.000	-0.040	0.039
P3	GERMANY	-0.050	-0.047	0.058
P1	ITALY	0.018	0.009	-0.014
P2	ITALY	-0.026	0.006	0.001
P3	ITALY	-0.079	0.012	0.009
P1	USA	0.139	0.042	-0.095
P2	USA	0.126	0.006	-0.051
P3	USA	0.113	-0.001	-0.038
P1	JAPAN	-0.123	0.029	0.002
P2	JAPAN	-0.130	0.032	-0.002
P3	JAPAN	-0.118	0.035	-0.008

P1 = 1989 - 1990

P2 = 1991 - 1993

P3 = 1994 - 1996

L1+ L2 = Applied Technology &
Engineering

L3 = Applied Research

L4 = Basic Research

Source: Elaboration SCI data. Only articles included; authors fractional count.

Only articles included; authors fractional count; journals assigned to a field in a fractional way on the basis of ISI classification scheme.

C1 = GENERAL CHEMISTRY.
 C2 = ANALYTICAL CHEMISTRY.
 C3 = APPLIED CHEMISTRY
 C4 = CRYSTALLOGRAPHY
 C5 = INORGANIC & NUCLEAR CHEMISTRY
 C6 = MEDICAL CHEMISTRY
 C7 = ORGANIC CHEMISTRY
 C8 = PHYSICAL CHEMISTRY
 C9 = POLYMER SCIENCE
 C10 = PHARMACOLOGY & PHARMACY
 C11 = CHEMICAL ENGINEERING

P1 = 1989 - 1990
 P2 = 1991 - 1993
 P3 = 1994 - 1996

L1 + L2 = Applied Technology & Engineering

Table 10: Relative specialisation based on eleven chemistry fields, by countries and years (CHI L1+L2).

Year	Country	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
P1	EU15	-0.397	-0.329	0.112	0.004	#N/A	-0.090	#N/A	0.020	-0.230	0.133	-0.091
P2	EU15	-0.219	-0.098	0.103	-0.023	#N/A	-0.091	#N/A	0.015	-0.252	0.121	-0.062
P3	EU15	-0.227	-0.046	0.077	-0.011	#N/A	-0.109	#N/A	0.000	-0.169	0.109	-0.048
P1	FRANCE	-0.469	-0.721	-0.333	0.179	#N/A	0.069	#N/A	0.330	-0.180	0.149	-0.136
P2	FRANCE	-0.453	-0.288	-0.220	0.150	#N/A	0.191	#N/A	0.275	-0.091	0.086	-0.048
P3	FRANCE	-0.312	-0.201	-0.155	0.091	#N/A	0.105	#N/A	0.225	0.035	0.061	-0.020
P1	GERMANY	-0.230	-0.310	0.264	0.182	#N/A	-0.574	#N/A	-0.129	-0.334	-0.220	0.094
P2	GERMANY	-0.274	-0.036	0.247	0.205	#N/A	-0.557	#N/A	-0.069	-0.337	-0.134	0.014
P3	GERMANY	-0.295	0.073	0.233	0.318	#N/A	-0.304	#N/A	-0.178	-0.301	-0.123	-0.055
P1	ITALY	-0.650	-0.289	-0.297	-0.370	#N/A	-0.195	#N/A	0.023	-0.208	0.348	-0.339
P2	ITALY	-0.610	0.040	-0.262	-0.528	#N/A	-0.006	#N/A	-0.013	-0.433	0.368	-0.281
P3	ITALY	-0.473	0.128	-0.207	-0.418	#N/A	0.291	#N/A	0.070	-0.283	0.294	-0.192
P1	UK	-0.457	-0.296	0.250	-0.048	#N/A	-0.125	#N/A	-0.239	-0.239	0.202	-0.197
P2	UK	-0.113	-0.285	0.209	-0.117	#N/A	-0.172	#N/A	-0.220	-0.348	0.183	-0.086
P3	UK	-0.313	-0.421	0.197	-0.125	#N/A	-0.601	#N/A	-0.260	-0.237	0.218	-0.063
P1	USA	0.316	0.277	-0.124	-0.354	#N/A	0.121	#N/A	-0.270	0.160	0.000	0.015
P2	USA	0.265	0.115	-0.093	-0.196	#N/A	0.148	#N/A	-0.245	0.128	0.022	-0.009
P3	USA	0.238	0.131	-0.056	-0.358	#N/A	0.120	#N/A	-0.308	0.113	0.048	-0.017
P1	JAPAN	-0.641	-0.393	-0.177	0.452	#N/A	-0.745	#N/A	-0.114	-0.341	-0.288	0.079
P2	JAPAN	-0.595	-0.015	-0.289	0.411	#N/A	-0.454	#N/A	-0.183	-0.343	-0.230	0.052
P3	JAPAN	-0.660	-0.304	-0.229	0.460	#N/A	-0.177	#N/A	-0.059	-0.422	-0.269	0.068

Source: Elaboration SCI data.

Table 11: Relative specialisation based on eleven chemistry fields, by countries and years (CHI L3)

Year	Country	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
P1	EU15	-0.040	-0.017	-0.186	0.190	-0.030	0.018	0.293	0.010	-0.029	0.047	-0.130
P2	EU15	0.023	0.013	-0.199	0.231	-0.126	-0.020	0.209	0.014	-0.041	0.028	-0.149
P3	EU15	0.030	0.032	-0.041	0.206	-0.343	-0.007	0.088	0.028	-0.074	0.007	-0.097
P1	FRANCE	-0.363	-0.090	-0.320	0.382	-0.401	0.204	0.527	0.180	0.066	-0.028	-0.058
P2	FRANCE	-0.344	-0.055	-0.380	0.441	-0.521	0.125	0.425	0.172	0.045	-0.043	-0.072
P3	FRANCE	-0.315	-0.105	-0.140	0.273	-0.660	0.107	0.145	0.154	0.011	-0.010	-0.007
P1	GERMANY	0.316	-0.083	-0.171	0.119	0.408	-0.230	-0.522	0.012	0.113	-0.128	-0.340
P2	GERMANY	0.423	0.008	-0.464	0.223	0.262	-0.307	-0.378	0.001	0.050	-0.173	-0.419
P3	GERMANY	0.434	0.019	-0.406	0.235	-0.084	-0.346	-0.249	0.068	-0.014	-0.209	-0.360
P1	ITALY	-0.166	-0.066	-0.612	-0.291	-0.388	0.193	0.394	-0.105	-0.110	0.186	-0.183
P2	ITALY	-0.208	-0.083	-0.393	-0.208	-0.468	0.212	0.195	-0.099	-0.122	0.205	-0.257
P3	ITALY	-0.195	0.014	-0.013	0.047	-0.455	0.345	0.223	-0.103	-0.146	0.133	-0.198
P1	UK	-0.270	-0.158	0.101	0.431	-0.405	0.142	0.517	-0.095	-0.103	0.175	-0.145
P2	UK	-0.237	-0.164	0.070	0.392	-0.438	0.048	0.383	-0.090	-0.052	0.174	-0.072
P3	UK	-0.209	-0.129	0.094	0.370	-0.479	0.045	0.142	-0.096	-0.101	0.180	-0.130
P1	USA	0.041	-0.117	0.030	-0.106	-0.452	0.271	-0.564	-0.010	-0.096	0.088	0.020
P2	USA	0.047	-0.123	0.036	-0.157	-0.387	0.263	-0.398	-0.067	-0.068	0.106	-0.031
P3	USA	0.061	-0.161	0.098	-0.046	-0.388	0.273	0.120	-0.102	-0.103	0.135	-0.073
P1	JAPAN	0.182	-0.068	-0.423	-0.264	-0.146	-0.320	-0.232	-0.143	0.097	0.073	-0.097
P2	JAPAN	0.044	-0.129	-0.413	-0.354	-0.292	-0.243	-0.124	-0.065	0.087	0.116	-0.250
P3	JAPAN	-0.044	-0.126	-0.282	-0.374	-0.323	-0.279	-0.364	-0.002	0.084	0.084	-0.112

Source: Elaboration SCI data.

Only articles included; authors fractional count; journals assigned to a field in a fractional way on the basis of ISI classification scheme.

C1 = GENERAL CHEMISTRY.
 C2 = ANALYTICAL CHEMISTRY.
 C3 = APPLIED CHEMISTRY
 C4 = CRYSTALLOGRAPHY
 C5 = INORGANIC & NUCLEAR CHEMISTRY
 C6 = MEDICAL CHEMISTRY
 C7 = ORGANIC CHEMISTRY
 C8 = PHYSICAL CHEMISTRY
 C9 = POLYMER SCIENCE
 C10 = PHARMACOLOGY & PHARMACY
 C11 = CHEMICAL ENGINEERING

P1 = 1989 - 1990
 P2 = 1991 - 1993
 P3 = 1994 - 1996

L3 = Applied Research

Table 12: Relative specialisation based on eleven chemistry fields, by countries and years (CHI Level 4)

Year	Country	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
P1	EU15	-0.101	0.215	#N/A	0.081	0.093	0.224	0.019	0.050	#N/A	-0.197	#N/A
P2	EU15	-0.123	0.096	-1.000	0.089	0.113	-0.015	0.033	0.037	#N/A	-0.171	#N/A
P3	EU15	-0.146	0.078	0.132	0.094	0.109	-0.103	0.042	0.024	#N/A	-0.127	#N/A
P1	FRANCE	-0.186	-0.235	#N/A	0.150	-0.035	-0.517	0.147	0.043	#N/A	-0.218	#N/A
P2	FRANCE	-0.235	-0.323	-1.000	0.132	0.013	-0.059	0.157	0.063	#N/A	-0.193	#N/A
P3	FRANCE	-0.164	-0.093	0.080	-0.003	-0.038	-0.057	0.133	0.062	#N/A	-0.151	#N/A
P1	GERMANY	-0.060	-0.024	#N/A	0.018	0.229	-0.035	-0.143	0.125	#N/A	-0.525	#N/A
P2	GERMANY	-0.050	0.007	-1.000	0.071	0.272	-0.430	-0.099	-0.015	#N/A	-0.457	#N/A
P3	GERMANY	-0.132	-0.233	-0.064	0.158	0.297	-0.513	-0.029	-0.062	#N/A	-0.404	#N/A
P1	ITALY	-0.197	0.640	#N/A	0.089	0.131	0.485	0.062	-0.047	#N/A	-0.043	#N/A
P2	ITALY	-0.247	0.601	-1.000	0.129	0.123	0.029	0.119	-0.075	#N/A	-0.018	#N/A
P3	ITALY	-0.202	0.485	0.464	-0.082	0.062	-0.054	0.139	-0.071	#N/A	0.061	#N/A
P1	UK	-0.129	-0.336	#N/A	0.121	0.141	0.419	0.048	-0.012	#N/A	-0.156	#N/A
P2	UK	-0.156	-0.337	-1.000	0.161	0.121	0.339	0.002	0.068	#N/A	-0.153	#N/A
P3	UK	-0.115	0.021	0.171	0.212	0.118	0.240	-0.058	0.036	#N/A	-0.123	#N/A
P1	USA	-0.163	0.182	#N/A	-0.134	-0.032	0.205	0.046	0.089	#N/A	0.269	#N/A
P2	USA	-0.147	0.219	0.624	-0.162	-0.094	0.364	0.070	0.097	#N/A	0.194	#N/A
P3	USA	-0.119	0.156	-0.478	-0.175	-0.074	0.348	0.041	0.067	#N/A	0.215	#N/A
P1	JAPAN	0.189	-0.467	#N/A	-0.167	-0.518	-0.163	0.068	-0.178	#N/A	0.023	#N/A
P2	JAPAN	0.169	-0.446	-1.000	-0.088	-0.433	-0.327	0.068	-0.185	#N/A	0.103	#N/A
P3	JAPAN	0.165	-0.514	0.323	-0.360	-0.375	-0.022	0.089	-0.127	#N/A	0.126	#N/A

Source: Elaboration SCI data.

Only articles included; authors fractional count; journals assigned to a field in a fractional way on the basis of ISI classification scheme.

C1 = GENERAL CHEMISTRY.
 C2 = ANALYTICAL CHEMISTRY.
 C3 = APPLIED CHEMISTRY
 C4 = CRYSTALLOGRAPHY
 C5 = INORGANIC & NUCLEAR CHEMISTRY
 C6 = MEDICAL CHEMISTRY
 C7 = ORGANIC CHEMISTRY
 C8 = PHYSICAL CHEMISTRY
 C9 = POLYMER SCIENCE
 C10 = PHARMACOLOGY & PHARMACY
 C11 = CHEMICAL ENGINEERING

P1 = 1989 - 1990

P2 = 1991 - 1993

P3 = 1994 - 1996

L4 = Basic Research

