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# Analysis of the Spanish scientific and technological output in the ICT sector

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This study presents a general view of the scientific and technological production in the ICT sector in Spain during the period 1990-2002 and its relative weight in the international production, as well as the identification of the main institutional actors and the performance patterns of the researchers in this scientific community through bibliometric techniques, with the aim of exploring the character of its outputs, both in terms of publications and patents. Indicators at macro-meso level are presented by: geographic regions, thematic areas at different aggregation levels, institutional sectors and research centres. Bibliometric indicators may help focus attention on the position and contribution of Spanish ICT science and technological capabilities.

## Introduction

The Information and Communication Technologies (ICT) sector is a rapidly developing area intensive in technological R&D&I and with immediate industrial effects. It is critically important for the competitiveness of all industrial sectors and is considered a source of economic growth. Being at the leading edge of the development and innovation in these technologies has always been an objective for governments. This technological sector has grown rapidly in recent years and has become the key element for the information industry and society. A reason for the relevance of the ICT area is its horizontal character, a fact that makes it a sector of high interdisciplinarity and difficult delimitation. It is, indeed, a scientific-technological field which comprises a complex network of scientific activities and research outputs, not only in forms of publications and patents.

The political interest of the sector is focused on promoting and reinforcing the Information Society and the New Economy, so it is considered as an area of high priority in the Research Plans at the European level reflected in the different EU-funded RTD Framework Programmes and of most advanced countries at national and regional levels. Policies relating to ICT in Spain from different Ministries, Agencies and trade

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organisations aim to the development of infrastructures and services in ICT areas, but also to facilitate the penetration of these technologies in all social and economic fields. Many of these policies are directed to encourage the development of small and medium-sized companies (SMEs), to foster innovation in SMEs, to increase the competitiveness of Spanish companies, to stimulate private investment on technological innovation and to favour the starting up of new technology-based firms. Spain, as a decentralised state with 17 autonomous communities (NUTS2 regions), has a very active regional Information Society and has implemented many programmes and initiatives to support the ICT sector (EC, 2004). As a consequence from market data and the significance of the sector for the economy and social impact, policy makers are expressing an increasing demand on indicators to measure the effect of these government's ICT policies in different countries and the sector has been included in the main world publications on Science & Technology Indicators (see for example, NSB, 2002; EC, 2003; OECD, 2003b; OECD, 2003c). In addition, periodically OECD and European Commission, through EUROSTAT and European Information Technology Observatory (EITO) provide data, statistics and indicators on ICT sector (OECD, 2000, 2002, 2004c, 2003a, 2004b; EITO, 2001).

Bibliometric studies that deal explicitly with ICT sector as a whole are rare. TIJSSEN & VAN WIJK (1998, 1999) published the first studies. There are also recent studies that use bibliometric tools to examine a specific field: in Computer Science (GUAN & MA, 2004) or Semiconductors (TSAY & MA, 2000, 2003). There are other general studies on innovative activity based on patents including ICT (HICKS et al., 2001). In the case of Spain, there are several innovation studies carried out by COTEC Foundation which considers ICT as a key technology for economic growth and development (COTEC, 2000, 2001–2003). Some regional studies on the sector are available because of the proliferation of Information Society Observatories to monitor Information Economy and priority attention to ICT in regional R&D Plans (see for example, IKEI, 2002; OBSERVATORIO DE LA SOCIEDAD DE LA INFORMACIÓN EN NAVARRA, 2003; GAPTEL, 2004).

The aim of the present study is to analyse the Spanish contribution to the expanding ICT sector, both in Science and in Technology, and to determine possible specialities in Spanish regions.

## Methods

Scientific output data were obtained from the specialised database INSPEC ONDISC (Information Service for the Physics and Engineering) in CD-ROM version, produced by the Institution of Electrical Engineers, with comprehensive coverage not only of "main stream" scientific journals, but also of national journals and conferences. INSPEC classifies the records into four thematic sections: Physics, Electrical

Engineering & Electronics, Computers & Control and Information Technology. The ICT sector was delimited by selecting publications covered by INSPEC under sections B (Electrical Engineering and Electronics), C (Computers and Control) and D (Information Technology). Those documents with a Spanish address during the years 1990-2002 were downloaded. The INSPEC thematic classification at first level codes (3 digits) was used to detect disciplines, as well as the "Treatment" field to show the nature of research or focus which authors have given to their papers.

In this study ICT sector has been divided in 3 thematic domains: Electrical Engineering & Electronics, Computers & Control and Telecommunications. Codes in INSPEC referred to Telecommunications are classified in B section (B62*), and together with the few Information Technology documents, have been re-assigned.

Technological output was obtained from the patent databases of the European Patent Office (EPO) and the Spanish Patent Office (OEPM). Patents requested or published during 1996-2000, with Spanish applicant or inventor, were retrieved. According to the criteria from OECD (2004a) and EUROSTAT (STRACK, 2003) to delimit the ICT sector, the following International Patent Classification (IPC) complete 3 digit codes were selected: G06, G11, H01, H03 and H04; some other four digit IPC codes were also included: B07C, B41J, B41K, G01 except G01T, G07, G08G, G08C, G09B, G09C, G09G, G10L, G02B6, G02F, G03G, G05B and G05F (WIPO, 2000). The distribution of IPC codes into the three thematic domains has followed the OECD criteria (2004a) and the widely accepted OST-INPI/FhG-ISI technology classification (SANZ MENÉNDEZ & ARIAS, 1998), recommended by the OECD manual about using patents as indicators of the technological innovation process (OECD, 1994) (see Table 1).

The items retrieved were transferred into a customised relational database with interconnected files of ICT research papers and patents. The names of the institutions to which the authors or inventors are affiliated were standardised by codifying the regions, institutional sector and research centre of the author (FERNÁNDEZ et al., 1993). Computer specific programs were developed to calculate the bibliometric indicators of science and technology at a regional level, by institutional sectors and specific research centres.

Input indicators related to science, technology and innovation at the regional level were used:

- % Gross Expenditure in R&D/Gross Domestic Product (%GERD/GDP), N. researchers (full time equivalent) relative to population, as a proxy to scientific effort.
- % Business Expenditure in R&D/GERD (%BERD/GERD), Innovation expenditures/GDP and Innovation intensity in High Technology Sectors, N. researchers in industry per population, as a proxy to technological commitment.

Table 1. International Patent Classification codes selected for ICT sector

| ICT Domains | IPC Codes | | | |
|---|---|---|---|---|
| Computers, Control & Instrumentation | B07C | G01L | G06C | G07C |
| | B41J | G01M | G06D | G07D |
| | B41K | G01N | G06E | G07F |
| | G01B | G01P | G06F | G07G |
| | G01C | G01R | G06G | G08G |
| | G01D | G01V | G06J | G09B |
| | G01F | G01W | G06K | G09G |
| | G01G | G02B | G06M | G10L |
| | G01H | G02F | G06N | G11C |
| | G01J | G05B | G06T | H03K |
| | G01K | G05F | G07B | H03L |
| Electrical Engineering & Electronics | G11B | H01H | H01T | H04N |
| | H01B | H01J | H03F | H04R |
| | H01C | H01L | H03G | H04S |
| | H01F | H01M | H03J | |
| | H01G | H01R | H04H | |
| Telecommunications | G01S | H01S | H03M | H04M |
| | G08C | H03B | H04B | H04Q |
| | G09C | H03C | H04J | |
| | H01P | H03D | H04K | |
| | H01Q | H03H | H04L | |

## Results and discussion

*ICT research activity and publication output of EU-15 countries*

Spain occupies the sixth position among European countries, producing 5% of the EU total output. The United Kingdom (24%), Germany (22%), France (15%), Italy (11%) and Netherlands (6%) are holding the first five positions (Figure 1). All EU-15 countries produce more conference papers than journal papers in similar percentages as Spain. This emphasises the importance of scientific meetings or professional events for this research community.

Table 2 shows the total ICT output by ICT thematic domains and countries. World total refers to global INSPEC data by domains in all document types and all countries. The Spanish output represents 1.5% of the world in Computers & Control, while in Telecommunications and Electrical Engineering & Electronics it is scarcely over 1%. This contribution is much lower than the Spanish share in global science through SCI (2.7%). A specialisation in domains of Germany and Sweden in Electrical Engineering & Electronics, of Austria in Computers, and Finland and Greece in Telecommunications is detected. In contrast, Netherlands, France and Spain show low percentages in Telecommunications.

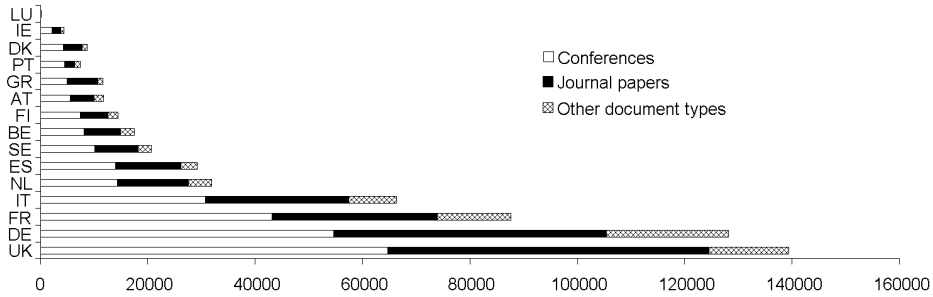


Figure 1. ICT production of EU-15 by document types (INSPEC 90-02)

Table 2. Output of international ICT research by domains in EU-15 (INSPEC 90-02)

| Countries | B | (%) | C | (%) | E | (%) | % B | % C | % E |
|---|---|---|---|---|---|---|---|---|---|
| UK | 67715 | (5.3) | 82828 | (6.7) | 14291 | (6.7) | 41.1 | 50.2 | 8.7 |
| Germany | 72988 | (5.7) | 66873 | (5.4) | 11440 | (5.4) | **48.2** | 44.2 | 7.6 |
| France | 49596 | (3.9) | 49420 | (4.0) | 6674 | (3.1) | 46.9 | 46.8 | 6.3 |
| Italy | 36661 | (2.8) | 37625 | (3.0) | 6600 | (3.1) | 45.3 | 46.5 | 8.2 |
| Netherlands | 16021 | (1.2) | 19363 | (1.6) | 2244 | (1.1) | 42.6 | 51.5 | 6.0 |
| Spain | 15976 | (1.2) | 18448 | (1.5) | 2354 | (1.1) | 43.4 | 50.2 | 6.4 |
| Sweden | 11820 | (0.9) | 10597 | (0.9) | 2223 | (1.0) | **48.0** | 43.0 | 9.0 |
| Belgium | 9878 | (0.8) | 9776 | (0.8) | 1786 | (0.8) | 46.1 | 45.6 | 8.3 |
| Finland | 7239 | (0.6) | 8738 | (0.7) | 2050 | (1.0) | 40.2 | 48.5 | **11.4** |
| Austria | 5600 | (0.4) | 7588 | (0.6) | 840 | (0.4) | 39.9 | **54.1** | 6.0 |
| Greece | 5741 | (0.4) | 7854 | (0.6) | 1535 | (0.7) | 37.9 | 51.9 | **10.1** |
| Portugal | 3468 | (0.3) | 4895 | (0.4) | 913 | (0.4) | 37.4 | 52.8 | 9.8 |
| Denmark | 3943 | (0.3) | 5164 | (0.4) | 1003 | (0.5) | 39.0 | 51.1 | 9.9 |
| Ireland | 2471 | (0.2) | 2365 | (0.2) | 466 | (0.2) | 46.6 | 44.6 | 8.8 |
| Luxembourg | 43 | (0.0) | 152 | (0.0) | 25 | (0.0) | 19.5 | 69.1 | 11.4 |
| World Total | 1287314 | | 1242588 | | 212344 | | | | |

B = Electrical Engineering & Electronics; C = Computers & Control; E = Telecommunications

### *Spanish ICT research output*

The ICT knowledge base of Spain obtained from INSPEC contains 29215 items from publication years 1990–2002, distributed mainly in presentations in scientific meetings (48%) and journal articles (42%). The growth rate in total ICT outcome in the period is 371%, corresponding to an emerging sector along the nineties. Both journal articles and meeting-abstracts present a similar distribution in time (Figure 2) but they will be analysed separately due to a possible different behaviour.

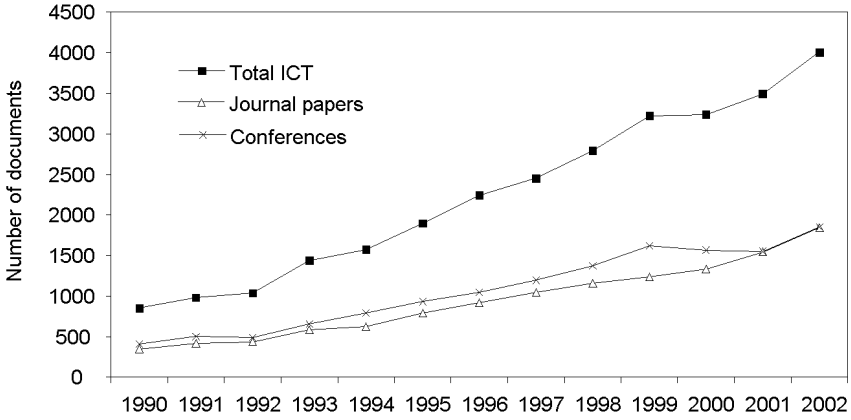


Figure 2. Spanish scientific production in ICT sector (INSPEC 1990–2002)

Items were analysed following the INSPEC "treatment terms" (Table 3). The ICT Spanish scientific community presents their theoretical-basic results mostly through articles in journal papers (61%) while Practical & Application research results appear preferentially in conferences (69%).

Table 3. Treatment types of Spanish ICT sector research

| | Journal papers | | Conferences | |
|---|---|---|---|---|
| INSPEC treatment types | N. | % | N. | % |
| Theoretical or Mathematical | 7503 | 61 | 7042 | 50 |
| Practical | 4229 | 34 | 7669 | 55 |
| Experimental | 3330 | 27 | 3073 | 22 |
| Application | 991 | 8 | 1967 | 14 |
| General or Review | 363 | 3 | 286 | 2 |
| New Development | 169 | 1 | 256 | 2 |
| Bibliographic | 136 | 1 | 20 | – |
| Economic or Commercial | 93 | 1 | 63 | – |
| Product Review | 29 | – | 6 | – |
| Non-classified | 28 | – | 5 | – |
| Total | 12276 | | 13975 | |

The 12276 journal papers were published in 1291 journals, 60% of which are covered by SCI Expanded. A high dispersion is observed, as 50% of documents are located in 90 journals, so a clear core of journals is not found. The 19 more productive journals that cover 25% of documents were analysed: ISI journals are in quartiles 1-2 according to Impact Factor, and according to their basic/applied character, mostly in levels 2 and 3 of Technological & Applied research (NOMA et al, 1986). The most frequently used journal is *Electronics Letters* that is the leader journal in citations, the second journal in papers and occupies the 81st position in citations per paper in the Engineering field (ISI, 2004). Three Spanish journals are included amongst the most productive (INSPEC covers 32 journals edited in Spain). The *Revista Española de Electrónica* occupies the second position, followed by *Journal of Applied Physics, Microwave & Optical Technology Letters* and *Applied Physics Letters,* with more than 200 items. HICKS et al. (2001) pointed out that *Applied Physics Letters*, *Journal of Applied Physics* and *Electronics Letters* were the most cited in the Semiconductors and Telecommunications areas.

On the other hand, the 13975 conference papers were analysed separately, considering the meetings as one of the main instruments of communication for professionals, very important for this research community. Output in congresses follows a very similar distribution as in journals: 50% of conference papers are grouped in 96 meetings. The most important conferences to the ICT sector researchers, all of them international conferences, are related to well known international institutions: the American Institute of Electrical and Electronics Engineers (IEEE) and its Societies (as the Industrial Electronics Society, the IEEE Signal Processing Society, the IEEE Circuits & Systems Society and European Microwave Association), as well as the British Institution of Electrical Engineers (IEE) that is the largest professional engineering society in Europe. These organisations are an essential reference for scientists in ICT technologies, as 29% of Spanish ICT conference papers were presented at meetings from these institutions.

The thematic distribution of scientific output by ICT domains shows differences between journal papers and conferences. Scientific meetings are the most important vehicle in Computers and Telecommunications while in Electrical Engineering & Electronics both document types present similar figures (Table 4), what suggests a more basic character of this latter domain.

Table 4. Spanish publications in ICT sector domains

| ICT domains | Journal papers | % | Conferences | % |
|---|---|---|---|---|
| Computers & Control | 6969 | 56.8 | 10281 | 73.6 |
| Electrical Engineering & Electronics | 7665 | 62.4 | 7664 | 54.8 |
| Telecommunications | 710 | 5.8 | 1503 | 10.8 |
| Total | 12276 | | 13975 | |

A thematic analysis following INSPEC first level codes (see Table 5) shows that the main discipline is Systems and Control theory (both in journal papers, 29%, and in conferences, 33%). In journal papers, General topics, Engineering mathematics and Materials science (23%), Computer applications (18%) and Numerical analysis and Theoretical computer topics (17%) follow. The dissemination through conference papers is centred mainly in Computer hardware-software (29%), its Applications (28%); and Communications (22%).

Due to the interdisciplinary character of ICT sector, a very high multiple-classification is observed: on average, each INSPEC document has 9 codes.

Table 5. Scientific disciplines by ICT thematic domains (INSPEC 1990–2002)

| ICT domains | Disciplines | Journal papers | Conferences | Total | % |
|---|---|---|---|---|---|
| Computers & Control | Systems and control theory | **3549** | **4654** | 8203 | 31.2 |
| | Computer applications | **2215** | **3929** | 6144 | 23.4 |
| | Computer hardware | 1538 | **4087** | 5625 | 21.4 |
| | Computer software | 1574 | **4050** | 5624 | 21.4 |
| | Numerical analysis and theoretical computer topics | **2088** | 2186 | 4274 | 16.3 |
| | Control technology | 768 | 2097 | 2865 | 10.9 |
| | General and management topics | 189 | 257 | 446 | 1.7 |
| | Applications of IT | 4 | 14 | 18 | 0.1 |
| | General & management aspects | 1 | 4 | 5 | – |
| Electrical Engineering & Electronics | General topics, engineering Mathematics and materials science | **2893** | 2412 | 5305 | 20.2 |
| | Communications | 1620 | **3076** | 4696 | 17.9 |
| | Components, electron devices and materials | 1514 | 1494 | 3008 | 11.5 |
| | Circuit theory and circuits | 1158 | 1745 | 2903 | 11.1 |
| | Instrumentation and special applications | 1339 | 1520 | 2859 | 10.9 |
| | Power systems and applications | 855 | 1688 | 2543 | 9.7 |
| | Optical materials and applications, electro-optics and optoelectronics | 1466 | 369 | 1835 | 7 |
| | Electromagnetic fields | 819 | 757 | 1576 | 6 |
| | Magnetic and superconducting materials and devices | 200 | 115 | 315 | 1.2 |
| Tele-comm. | Telecommunications | 708 | 1503 | 2211 | 8.4 |
| | Office automation – communications | 2 | – | 2 | – |
| Total | | 12276 | 13975 | 26251 | |

Therefore, besides the 3 thematic domains as a core, a set of other interrelated disciplines from INSPEC Physics section have been identified, amongst them: Optics and Condensed Matter Spectroscopy, Medical Physics and Biomedical Engineering. Similarly, TIJSSEN & VAN WIJK (1998) had found related areas to the ICT sector with strong orientation towards ICT applications, such as Optics and Applied Physics.

Spain shows an irregular distribution of ICT scientific activity amongst its regions (NUTS 2), the major share being concentrated in Madrid and Catalonia, followed by Andalusia and Valencia. These four regions produce more than 70% of the Spanish output. Congresses are specially concentrated in Madrid and Catalonia (24%) while Madrid publishes 26% of journal papers (Table 6). Taking into account the size of the regions by considering per capita output, two small regions, Cantabria and Navarra, emerge.

Growth rates were calculated comparing 1998 to 2002 output, as ICT publications at the beginning of the nineties were very scarce and could distort the calculations. Table 6 shows these trends per region. Andalusia and the Basque Country are those larger regions with a higher growth trend in journal papers, although Catalonia, Madrid and Valencia also show considerable growth rates.

Table 6. ICT Spanish publications by regions

| | Journal papers | | | Conferences | | | Total | ICT domains specialisation | | | N.docs/ $10^4$ inhabs. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Regions | N.docs. 90-02 | % | Δ 98-02 | N.docs. 90-02 | % | Δ 98-02 | | % B | % C | % E | |
| Madrid | 3207 | 26.1 | 53 | 3385 | 24.2 | 18 | 6592 | 47.5 | 44.2 | **8.3** | **11.9** |
| Catalonia | 2277 | 18.6 | 49 | 3375 | 24.2 | 22 | 5652 | 44.0 | 49.5 | 6.5 | 8.7 |
| Andalusia | 1670 | 13.6 | 79 | 1725 | 12.3 | 42 | 3395 | 42.6 | 53.6 | 3.8 | 4.5 |
| Valencia | 1410 | 11.5 | 47 | 1551 | 11.1 | 33 | 2961 | 40.3 | 52.3 | 7.4 | 6.8 |
| Galicia | 778 | 6.3 | 34 | 815 | 5.8 | 17 | 1593 | 45.5 | 47.2 | 7.3 | 5.8 |
| Basque Country | 479 | 3.9 | 60 | 397 | 2.8 | 3 | 876 | 30.4 | **65.0** | 4.6 | 4.2 |
| Aragon | 439 | 3.6 | 33 | 353 | 2.5 | 7 | 792 | 46.8 | 49.4 | 3.8 | 6.5 |
| Castile-Leon | 382 | 3.1 | 91 | 378 | 2.7 | –5 | 760 | 43.7 | 53.1 | 3.2 | 3.1 |
| Cantabria | 342 | 2.8 | –7 | 348 | 2.5 | –25 | 690 | **53.8** | 39.3 | 6.9 | **12.7** |
| Asturias | 247 | 2.0 | 74 | 390 | 2.8 | 19 | 637 | 50.0 | 48.1 | 1.9 | 5.9 |
| Canary Islands | 210 | 1.7 | 120 | 240 | 1.7 | 33 | 450 | 34.1 | 60.8 | 5.1 | 2.4 |
| Navarra | 207 | 1.7 | 160 | 164 | 1.2 | 23 | 371 | **54.2** | 36.5 | 9.3 | 6.5 |
| Murcia | 181 | 1.5 | 186 | 181 | 1.3 | 76 | 362 | 32.0 | 63.4 | 4.5 | 3.0 |
| Balearic Islands | 166 | 1.4 | 210 | 175 | 1.3 | 14 | 341 | 46.9 | 46.0 | 7.1 | 3.7 |
| Castile-La Mancha | 88 | 0.7 | 625 | 117 | 0.8 | 63 | 205 | 34.3 | 58.0 | 7.7 | 1.2 |
| Extremadura | 91 | 0.7 | 425 | 87 | 0.6 | 64 | 178 | 42.9 | 55.8 | 1.3 | 1.7 |
| La Rioja | 41 | 0.3 | –40 | 29 | 0.2 | – | 70 | 44.3 | 54.8 | 0.9 | 2.5 |
| Non-identified | 61 | 0.5 | – | 265 | 1.9 | – | 326 | – | – | – | – |
| **Total Spain** | **12276** | | | **13975** | | | **26251** | | | | |

B = Electrical Engineering & Electronics; C = Computers & Control; E = Telecommunications

A specialisation of Madrid in Telecommunications is observed; the Basque Country in Computers and Control; Navarra and Cantabria in Electrical Engineering & Electronics.

The first institutional sector originating the scientific output is very predominantly the public sector, being the main research actor the University (more than 86%), followed by the Spanish Council for Scientific Research (CSIC). In spite of ICT being a technological sector, the Industry participates in very low proportions in journal papers (2%) and is more involved in conferences (5%) (Table 7).

Table 7. Scientific production by institutional sectors

| Institutional sectors | Journal papers | % | Conferences | % |
|---|---|---|---|---|
| University | 10695 | 87.1 | 12073 | 86.4 |
| CSIC | 876 | 7.1 | 800 | 5.7 |
| Industry | 279 | 2.3 | 706 | 5.1 |
| Other Public Research Centres | 139 | 1.1 | 78 | 0.6 |
| Administration | 75 | 0.6 | 27 | 0.2 |
| Hospitals | 63 | 0.5 | 26 | 0.2 |
| Non-Profit Institutions | 35 | 0.3 | 77 | 0.6 |
| Other | 103 | 0.8 | 169 | 1.2 |

Table 8. Scientific production of Universities (more than 400 documents)

| Universities | Journal papers | % | Conference papers | % | Total |
|---|---|---|---|---|---|
| Univ. Politecn Catalonia | **1059** | 8.6 | **2109** | 15.1 | **3168** |
| Univ. Politecn Madrid | 794 | 6.5 | **1415** | 10.1 | **2209** |
| Univ. Politecn Valencia | 549 | 4.5 | **941** | 6.7 | **1490** |
| Univ. Granada | **559** | 4.6 | 365 | 2.6 | 924 |
| Univ. Sevilla | 441 | 3.6 | 479 | 3.4 | 920 |
| Univ. Complutense Madrid | 534 | 4.3 | 297 | 2.1 | 831 |
| Univ. Zaragoza | 412 | 3.4 | 339 | 2.4 | 751 |
| Univ. País Vasco | 391 | 3.2 | 324 | 2.3 | 715 |
| Univ. Vigo | 313 | 2.5 | 383 | 2.7 | 696 |
| Univ. Málaga | 246 | 2.0 | 406 | 2.9 | 652 |
| Univ. Cantabria | 316 | 2.6 | 331 | 2.4 | 647 |
| Univ. Oviedo | 242 | 2.0 | 389 | 2.8 | 631 |
| Univ. Valencia | 425 | 3.5 | 201 | 1.4 | 626 |
| Univ. Carlos III | 281 | 2.3 | 328 | 2.3 | 609 |
| Univ. Autónoma Barcelona | 305 | 2.5 | 288 | 2.1 | 593 |
| Univ. Valladolid | 231 | 1.9 | 310 | 2.2 | 541 |
| Univ. Santiago Compostela | 354 | 2.9 | 178 | 1.3 | 532 |
| Univ. Barcelona | 223 | 1.8 | 210 | 1.5 | 433 |
| Univ. Autónoma Madrid | 305 | 2.5 | 127 | 0.9 | 432 |

The most active universities are the three technical universities of Catalonia, Madrid and Valencia whose output is specially oriented towards conference papers. Granada

University, with a more basic character, has a high production of journal papers (Table 8).

Citations provide an indicator of the international influence of Spanish science, so an attempt was made to compare the visibility of the most active Spanish universities with those of the world as a whole. The international impact of the most active universities in ICT sector was analysed through the Essential Science Indicators (ISI, 2004) in the areas of Computer Science and Engineering. Table 9 shows the relationship between the number of papers and citations of the most productive Spanish universities in INSPEC sorted by rank order of citations per paper compared to the world. In the Engineering field, the three technical universities with more ICT INSPEC publications also show a high number of ISI publications, but they receive few citations per paper. In contrast, more basic universities of Barcelona, Oviedo and Complutense in Madrid show the highest impact per paper, and therefore better rank positions. In Computer Science, the University of Barcelona, although with a small number of papers, occupies the third position in the world in the rank order of citations per paper, a specially prominent position as to the influence of its papers. In general, technical universities are less visible than basic science ones.

Table 9. Most productive universities inside 1% percentil of cites

| | Papers | Citations | C/P | Rank order world Cit./paper |
|---|---|---|---|---|
| **Engineering** | | | | |
| Univ Barcelona | 368 | 2266 | **6.16** | 125 |
| Univ Oviedo | 414 | 2371 | **5.73** | 159 |
| Univ Complutense de Madrid | 662 | 3294 | **4.98** | 258 |
| Univ Valencia | 434 | 2077 | 4.79 | 284 |
| Univ Autonoma de Barcelona | 330 | 1516 | 4.59 | 312 |
| Univ Granada | 623 | 2621 | 4.21 | 384 |
| Univ Zaragoza | 485 | 1899 | 3.92 | 443 |
| Univ Pais Vasco | 296 | 1106 | 3.74 | 482 |
| Univ Politecn Cataluña | 946 | 3516 | 3.72 | 488 |
| Univ Santiago de Compostela | 388 | 1441 | 3.71 | 491 |
| Univ Malaga | 359 | 1109 | 3.09 | 626 |
| Univ Sevilla | 739 | 2127 | 2.88 | 679 |
| Univ Vigo | 281 | 802 | 2.85 | 687 |
| Univ Cantabria | 342 | 905 | 2.65 | 737 |
| Univ Politecn Madrid | 798 | 2046 | 2.56 | 752 |
| Univ Politecn Valencia | 541 | 1315 | 2.43 | 794 |
| **Computer Science** | | | | |
| Univ Barcelona | 32 | 913 | **28.53** | **3** |
| Univ Politecn Cataluña | 675 | 1484 | 2.20 | 218 |

Source: Essential Science Indicators (ISI), 1994–2004

*Spanish ICT technological output*

The Spanish ICT technological and innovative output was studied through 825 European (EPO) and 1511 Spanish patents (OEPM), which represent 18% of total national patents requested or published in the period 1996–2000. The number of Spanish patents nearly doubles that of European ones. A high number of patents have been applied firstly in the Spanish and later in the European Office (National and European via). The percentage of European patents having associated (by priority date) a Spanish patent is nearly 60%. This strong overlap does not allow the addition of both types of patents that, therefore, are analysed separately. A high percentage of patents in Computers, Control & Instrumentation in both databases is observed, while the number of patents in the other domains is much lower (Table 10).

The analysis of the regional origin of ICT patents shows a strong concentration in two regions: Madrid together with Catalonia are the most powerful regions as to number of patents from the Spanish and European databases, sharing more than 50% of total Spanish patents in the ICT sector. Navarra, a small region, occupies the 4$^{th}$ position as to European patents, very near to Valencia. When considering patents in relation to the population, the most active region is Navarra, followed by Madrid and Catalonia. Other authors have already described a high degree of concentration of the technological capabilities in few Spanish regions (SANZ & ARIAS, 1998). A specialisation of regions can be observed by thematic domains: Madrid in Telecommunications (in agreement with the innovation investments of Telecommunications services firms being 58% of the whole of Spain during 1998); Catalonia in Electrical Engineering & Electronics; and Madrid followed by Catalonia, Valencia, Andalusia, Basque Country and Navarra in Computers & Control (Table 11).

The industrial sector is responsible for the great majority of patents, followed by private individuals, of which some are working in enterprises. University and Public Research centres present reduced percentages (Table 12). The University has a much higher number of Spanish than European patents, partly due to the fact that they do not pay for Spanish patents while European ones are quite expensive. Most patenting universities are: Complutense in Madrid and the Polytechnics universities in Catalonia and Madrid.

Table 10. Patents by ICT domains (1996–2000)

| ICT domains | OEPM | % | EPO | % |
|---|---|---|---|---|
| Computers, Control & Instrumentation | 1137 | 75.2 | 515 | 62.4 |
| Electrical Engineering & Electronics | 386 | 25.5 | 231 | 28.0 |
| Telecommunications | 328 | 21.7 | 194 | 23.5 |
| Total | 1511 | | 825 | |

Most active patenting enterprises are presented in Table 13. Telefonica and Alcatel, devoted to Telecommunications business sector, are the most productive companies in Madrid, in agreement with the thematic specialisation shown in Table 11. Catalonia industries leaders in patents are in electric components for automobile sector, such as Lear. The small region of Navarra has 3 companies amongst the most productive of Spain: Azkoyen and Jofemar specialised in automatic vending machines; and Navarra de Componentes Electrónicos in electric and electronics materials business sector.

Table 11. ICT Spanish patents by regions (OEPM & EPO 1996–2000)

| | OEPM | | EPO | | ICT domains specialisation | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Regions | N. patents | % | N. patents | % | B | C | E | OEPM patents/ $10^5$ inhabs. | EPO patents/ $10^5$ inhabs. |
| **Madrid** | 548 | 36.3 | 170 | 20.6 | 159 | **427** | **197** | **9.9** | 3.1 |
| **Catalonia** | 331 | 21.9 | 172 | 20.9 | **218** | 261 | 49 | 5.1 | 2.6 |
| **Valencia** | 127 | 8.4 | 46 | 5.6 | 42 | 118 | 27 | 2.9 | 1.1 |
| Basque Country | 119 | 7.9 | 27 | 3.3 | 34 | 97 | 23 | 5.6 | 1.3 |
| Andalusia | 100 | 6.6 | 27 | 3.3 | 14 | 104 | 19 | 1.3 | 0.4 |
| Navarra | 68 | 4.5 | 42 | 5.1 | 16 | 91 | 8 | **11.9** | **7.4** |
| Aragon | 48 | 3.2 | 12 | 1.5 | 12 | 40 | 11 | 3.9 | 1.0 |
| Galicia | 39 | 2.6 | 14 | 1.7 | 16 | 31 | 9 | 1.4 | 0.5 |
| Castile-Leon | 28 | 1.9 | 5 | 0.6 | 9 | 25 | 2 | 1.1 | 0.2 |
| Asturias | 19 | 1.3 | 2 | 0.2 | 4 | 17 | – | 1.8 | 0.2 |
| Balearic Islands | 13 | 0.9 | 6 | 0.7 | 5 | 13 | 2 | 1.4 | 0.7 |
| Murcia | 12 | 0.8 | 1 | 0.1 | 2 | 10 | 1 | 1.0 | 0.1 |
| Castile-La Mancha | 11 | 0.7 | 5 | 0.6 | 3 | 12 | 1 | 0.6 | 0.3 |
| Canary Islands | 10 | 0.7 | 4 | 0.5 | 1 | 10 | 4 | 0.5 | 0.2 |
| Cantabria | 10 | 0.7 | 1 | 0.1 | - | 11 | – | 1.8 | 0.2 |
| Extremadura | 9 | 0.6 | – | – | 1 | 9 | – | 0.8 | – |
| La Rioja | 3 | 0.2 | – | – | – | 3 | – | 1.1 | – |
| No Spanish address of applicant | 16 | | 340 | | | | | | |
| **Total** | 1511 | | 825* | | | | | | |

B = Electrical Engineering & Electronics; C = Computers & Control; E = Telecommunications
* There are patents in collaboration because the European database EPO includes all applicants' addresses.

Table 12. Patents by institutional sectors (OEPM & EPO)

| Institutional sectors | OEPM | % | EPO | % |
|---|---|---|---|---|
| Industry | 697 | 46.1 | 354 | 42.9 |
| Private individuals | 468 | 31.0 | 130 | 15.8 |
| University | 240 | 15.9 | 33 | 4.0 |
| CSIC | 57 | 3.8 | 15 | 1.8 |
| Non-Profit Institutions | 18 | 1.2 | 2 | 0.2 |
| Administration | 7 | 0.5 | 2 | 0.2 |
| Other Public Research Centres | 6 | 0.4 | 1 | 0.1 |
| Hospitals | 2 | 0.1 | 1 | 0.1 |
| No Spanish address of applicant | 16 | | 340 | |
| Total | 1511 | | 825 | |

Table 13. Patents from Spanish enterprises (more than 10 patents)

| Industries | OEPM | EPO |
|---|---|---|
| Telefónica S.A., Madrid | 53 | 24 |
| Lear Corporation, Tarragona (Barcelona) | 17 | 51 |
| Azkoyen Industrial, S.A., Navarra | 23 | 21 |
| ALCATEL S.A., Madrid | 24 | 12 |
| Jofemar S.A., Navarra | 14 | 12 |
| Power Controls Ibérica S.L. Barcelona | 11 | 10 |
| Grupo Exide Europa, Madrid | 9 | 4 |
| Probitas Pharma, S.A., Barcelona | 7 | 5 |
| Fagor, S.A., Guipúzcoa | 7 | 4 |
| Navarra de Componentes Electrónicos S.A. | 7 | 3 |
| Patentes TALGO S.A., Madrid | 4 | 6 |
| Schneider Electric Esp. S.A., Barcelona | 5 | 5 |
| SEGA S.A., Madrid | 6 | 4 |

*Science versus Technology*

In general, scientific output is much higher than technological in all ICT domains. If we compare the total scientific and technological output (Figure 3), patents represent 33% of total in Telecommunications, 17% in Computers, while only 8% in Electrical & Electronics Engineering. In Computers and Telecommunications conferences are more frequent. Electrical & Electronic Engineering is more science oriented, while Computers and Telecommunications are more technology oriented, as shown by a higher percentage of patents and conferences.

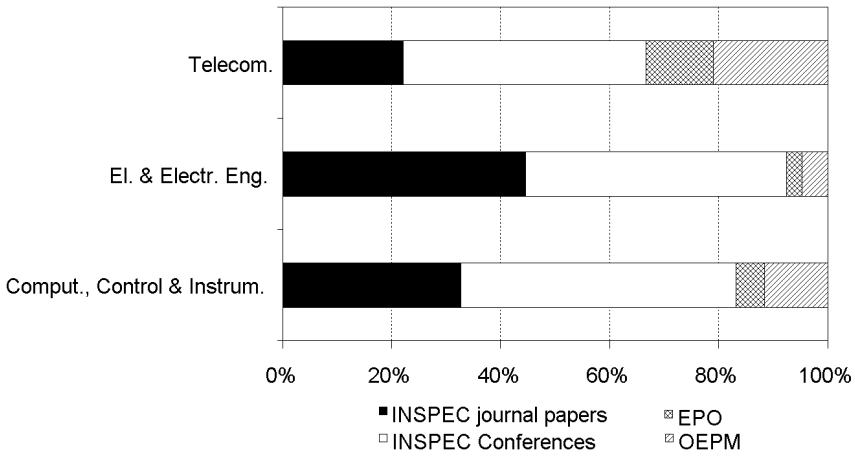


Figure 3. Science vs. Technology (1996–2000) in Spanish ICT

*Regional analysis for Science and Technology*

The scientific and technological capabilities of the Spanish regions in the ICT sector can be pointed out using the scientific and technological production related to the population, together with relative input socio-economic indicators (Table 14). Relative indicators allow the identification of small size regions with an important activity in ICT sector. Patents and INSPEC items are shown as average number of yearly documents or patents per inhabitants. The R+D intensity in regions is measured through input indicators: GERD/regional GDP, and researchers per population. The technological effort of regions is measured by Innovation intensity, the private involvement in R&D as the percentage of GERD financed by Industry and the researchers in enterprises, as innovation proxies. The effort indicators in highly technological sectors defined by OECD has been selected as proxies of competitiveness in Spanish regions.

Madrid and Catalonia, the two strongest regions in absolute figures, show high values in all indicators, both input and output. Catalonia presents a better relative position respect to Madrid due to the industrial percentage devoted to R&D expenditure (68.4% vs. 58.1%). Their scientific production per inhabitant presents very high values, and medium-high levels in patents, which correlate with over-average input indicators.

Table 14. Distribution of total output by Spanish regions

| | Output | | | Input | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| REGIONS | Docs.year/$10^6$ inhabs. | Patents OEPM year/$10^6$ inhabs. | Patents EPO year/$10^6$ inhabs. | R&D Intensity(GERD/%GDP) 2002 | R&D Intensity in HTS(GERD in HTS/ %GDP) 2000 | Researchers (FTE)/ $10^3$ inhabs. 2001 | Innovation Intensity (GEI/ %GDP) 2000 | Innovation Intensity in HTS (GEI in HTS/ %GDP) 2000 | % BERD/ GERD 2002 | Industry Researchers (FTE)/ $10^3$ inhabs 2000 |
| **Madrid** | **91.5** | **19.8** | **6.2** | **1.90** | **0.71** | **3.7** | **2.52** | **1.37** | **58.1** | **1.29** |
| **Catalonia** | **66.9** | **10.2** | **5.2** | **1.27** | **0.55** | **2.3** | **2.43** | **1.16** | **68.4** | **0.81** |
| Andalusia | 34.6 | 2.6 | 0.8 | 0.62 | 0.17 | 1.5 | 0.77 | 0.37 | 34.7 | 0.21 |
| Valencia | **52.3** | 5.8 | 2.2 | 0.81 | 0.20 | 1.5 | 1.36 | 0.36 | 32.4 | 0.40 |
| Galicia | 44.6 | 2.8 | 1.0 | 0.80 | 0.17 | 1.6 | 1.28 | 0.75 | 38.7 | 0.14 |
| **Basque Country** | 32.3 | **11.2** | 2.6 | **1.32** | **0.70** | **2.6** | **2.35** | **1.19** | **75.8** | **1.34** |
| **Aragon** | **50.0** | **7.8** | 2.0 | 0.75 | **0.34** | 1.7 | **2.57** | **1.66** | **62.8** | **0.55** |
| Castile-Leon | 23.8 | 2.2 | 0.4 | 0.81 | 0.22 | **2.0** | 1.13 | 0.54 | 53.2 | 0.23 |
| Cantabria | **97.7** | 3.6 | 0.4 | 0.54 | 0.06 | 1.3 | 1.51 | 0.54 | 42.0 | 0.07 |
| Asturias | 45.4 | 3.6 | 0.4 | 0.64 | 0.11 | **1.9** | 1.12 | 0.23 | 38.1 | 0.24 |
| Canary I. | 18.5 | 1.0 | 0.4 | 0.62 | 0.07 | 1.6 | 0.46 | 0.09 | 23.8 | 0.03 |
| **Navarra** | **50.0** | **23.8** | **14.8** | **1.11** | **0.54** | **3.0** | **1.69** | **0.76** | **68.9** | **0.72** |
| Murcia | 23.1 | 2.0 | 0.2 | 0.58 | 0.17 | 1.2 | 1.05 | 0.37 | 35.9 | 0.12 |
| Balearic Islands | 28.5 | 2.8 | 1.4 | 0.26 | 0.03 | 0.6 | 0.29 | 0.08 | 19.7 | 0.01 |
| Castile-La Mancha | 9.2 | 1.2 | 0.6 | 0.45 | 0.33 | 0.5 | 1.22 | 0.48 | 40.5 | 0.25 |
| Extremadura | 13.1 | 1.6 | 0.0 | 0.60 | 0.10 | 1.1 | 0.39 | 0.14 | 11.9 | 0.12 |
| Rioja | 19.2 | 2.2 | 0.0 | 0.57 | 0.23 | 1.5 | 1.52 | 0.61 | **59.7** | **0.22** |
| **SPAIN** | **48.4** | **7.2** | **4** | **1.03** | **0.38** | **1.9** | **1.67** | **0.80** | **54.6** | **0.52** |

Source: S&T Indicators based on R&D&I Statistics and Indicators in High Technology Sectors (HTS) from Instituto Nacional de Estadística (INE-Spanish Statistical Office).

Basque Country and Navarra present medium levels in absolute values of technological output. Considering these same indicators but normalised to population, Navarra emerges and stands out both in publications and patents, while the Basque

Country only in Spanish patents. As to input indicators, both Basque Country and Navarra reflect a very favourable situation, clearly over Spanish average. Moreover, the Basque Country has very positive innovation indicators, being the only region in Spain with over 50% of researchers in enterprises. Aragon enjoys a wealthy R&D&I position but despite its important industrial R&D&I investment, particularly in high technology sectors, Aragon doesn't show specially relevant values in patents, while its position as to ICT publications is positive. All indicators point to Basque Country, Navarra and Aragon being very industrialised regions. The rest of autonomous communities are much weaker in ICT.

## Conclusions

The ICT sector from the market point of view has grown very strongly in EU-15 along the nineties (from 15 to 25% annually), whilst it suffered a deceleration in 2001 (its growth rate was 3%), reflecting the crisis of the sector, but now the upward trend seems to have restarted. Nevertheless, the innovation in ICT technology is supporting the new economy and is influencing many industrial and services sectors (IKEI, 2002). Spain represents 6% of the EU market; it was considered in 2000 among OECD countries with low ICT intensity together with Germany (OECD, 2000) but in 2004 it improved to intermediate with regard to the development of its ICT sector, i.e. a state that is mainly importer of ICT goods, but that otherwise is substantial recipient of ICT sector inward investment with high levels of domestic value-added and that has significant independent production and export capabilities in selected ICT areas (EC, 2004).

In our study we have seen how Spain occupies the sixth position as to the number of publications from EU-15 countries in the ICT sector during the period 1990-2002, producing 5% of the EU total. Growth rates of the Spanish publications in ICT sector have been increasing, so the share of Spanish ICT output in the total Spanish publications has considerably grown, from 2.9% in 1990 to 13.7 in 2002. This was partly due to the scientific policies of the Spanish government in the recent years, in which ICT sector has been a top priority research area (CICYT, 1999). The specialised database used allowed us to consider both papers published in national and international academic journals and conference proceedings. The theoretical-basic research was published in journal articles while applied research preferentially in conference papers. Spain, as all EU countries, produces more conferences than journal papers on this topic. Meetings are more important for the industrial sector, as professional events are a way to keep in touch with professionals and customers, to observe new products and services from competing enterprises and so keeping watch over new technologies. On the other hand, publishing papers in international journals strengthens the impact of

research outputs and its development and is better connected to mainstream science than papers published in domestic journals and proceedings.

Three large thematic domains were considered in our study: Electrical Engineering & Electronics, Computers & Control and Telecommunications. All European countries including Spain show a strong output in Electrical Engineering & Electronics and Computers & Control research. These are the main domains of research activity in ICT sector. In Spain ICT meetings are more frequent in Computers & Control and Telecommunications, while in Electrical Engineering & Electronics both document types present similar figures. Spanish publications in Telecommunications are scarce.

As we have observed through our INSPEC data, the scientific output is originated very predominantly by the public sector (universities and research institutes), while only 3.6% of ICT papers are from the private sector in Spain. The Spanish science output is of good quality, considering that the citation impact of its publications is higher than the European average in Computers (1.45 vs. 1.35) and slightly below average in Telecommunications (2.39 vs. 2.53). But the low involvement of the private sector in ICT publications is a difficulty to the transfer of knowledge from the public to the private sector, as in order to be able to absorb it, firms need complementary investments and accumulated capabilities that can only be acquired through being active in research. TIJSSEN & VAN WIJK (1998, 1999) have described both EU and in particular Spanish science base as net exporters of scientific knowledge within the Triad in ICT, due to a much lower involvement of the private sector in EU than in USA or Japan.

Regarding patent activity in ICT sector, applications to the EPO continue an upward trend. An important increase of patent applications to the European Patent Office in the ICT sector is observed between 1991–2001. This is a sign of the growing importance of the ICT sector as well as its rising share in total patents of EU countries (from 6.8% to 15.5%) (STRACK, 2003). In 2000, the total number of ICT patents filed at the EPO amounted to the 38337, of which the EU accounted for 38.2%, significantly above the shares of the USA (29.5%) and Japan (23.5%) (OECD, 2004a). The most notable increases are observed for Finland and Sweden. Spain started the nineties with very low ICT-figures, but along the decade a significant increase in the share of EPO patents in Advanced Technological Subfields is observed, particularly in Audiovisual, Information Technologies and Semiconductors (EC, 2003).

A strong positive correlation is expected between the number of ICT patents and industry-financed R&D expenditure. Countries with a high level of industry-financed R&D expenditure (such as USA, Japan and Germany) also have large numbers of triadic patent families (OECD, 2004a). Spain is far below the EU countries with an average (1990–2001) R&D expenditure financed by industry per GDP of 0.46% versus 1.49% in OECD, 1.18% in EU, 1.9% in USA and 2.03% in Japan (OECD, 2003b).

Spain is much stronger in publications than in patents, in spite of ICT being a high technology sector. The total amount of patents is low, due to a not very active

innovation effort of the Spanish ICT industrial sector, responsible for the majority of the patents; neither are the Spanish universities, mostly technological universities which are responsible for 16% of Spanish and only 4% of EPO patents. Spin-offs are not frequent, showing the lack of facilities for knowledge transfer from the public to the private sector. The interface between Science and Technology, between the public and private sector, is very important considering the National Innovation System. In USA and Japan companies are strongly involved in scientific publications and, on the other hand, universities are also involved in patenting. The fact that in USA patents from the Higher Education sector are increasing very sharply has been considered as important to local innovation (HICKS et al., 2001).

Nevertheless there are some Spanish regions that do not agree to this general description, as regional differences are particularly strong in the ICT sector. Spanish ICT activity is concentrated in two powerful regions, Madrid and Catalonia, both considering scientific or technological output. The coexistence of high scientific and technological activity has been described as a high potential for spillovers (ZITT et al., 2003). When considering scientific or technological output in relation to the size of the regions, other smaller regions emerge: this is the case of Cantabria in relation to science, and Navarra and Basque Country as to patents. Particularly in Navarra the number of ICT patents in relation to its inhabitants is exceptionally high. The input indicators that measure the involvement of the regions in science, technology or innovation, particularly in High Tech, are clearly over-average in Madrid, Catalonia, Basque Country and Navarra, showing a good correlation with the scientific and technological output indicators. These same regions have been described as pertaining to the strongest scientific cluster (Madrid) or technological cluster (Catalonia, Basque Country, Navarra) in previous studies where all subject areas were considered (GÓMEZ et al., 2005). When analysing the percentage of Spanish expenditure on Innovation by regions over total innovative enterprises, Catalonia and Madrid are the clear leaders, in agreement with their highest concentration of firms and highest regional GDP.

Regional policies are important instruments to support the competitiveness of the ICT Innovation System, by fostering collaboration networks between the different actors involved in R&D&I activities, particularly SMEs. For example, the Basque Country has small ICT enterprises active in R&D and a series of infrastructures promoted both by the firms (through Associations) and the regional government (enhancing regional networks and technology parks or promoting training activities for science, technology and innovation) (IKEI, 2002). The so-called Technology-based Knowledge Intensive Business Services (TKIBS) include ICT-related consulting services that are strongly involved in implementing technologies from other economic sectors. In this sense, promoting TKIBS can be strategic for technology transfer, as they have a prominent role in the innovation process, specially in the diffusion phase, but moreover acting as innovation mediators to other industries.

Our results demonstrate that only in seven Spanish regions the percentage of private R&D expenditure is higher than that of public expenditure. In consequence, the Spanish government is making an effort to attain the objectives of the Lisbon Summit Conference through a general plan to enhance the economy. According to the government, a 0.1% increase in R&D investments originates a per capita increase in GDP of 0.3–0.4%. The Innovation System in Spain is still weak, it is strictly necessary for its competitiveness that the private sector invests more in R&D, to attain the Lisbon objectives in ten years.

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