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Science–technology flows in Spanish regions An analysis of scientific citations in patents

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Abstract

Many regions of the European Union with a high degree of autonomy have elected very clearly to stimulate scientific research and technological development (R&D) as a specific means of promoting economic growth and the welfare of their citizens. In Spain, several autonomous regions have organised their efforts in science and technology by means of the adoption of regional R&D plans. In some cases, particular concern is taken to link the scope of scientific research with that of technology, but even in these few cases, it is acknowledged that little is known of the mechanisms by which the results of scientific research are translated into technological development, and how this latter in turn influences the objectives of scientific research. Our aim in this article is to study in greater depth the relationship between science and technological development in the various regions of Spain. The methodology that we apply to investigate the links between science and technology is based on an analysis of scientific citations in patent documents (non-patent citation (NPC)). The results obtained from this study provide some relevant data on the interconnection between the scientific and technological systems from a regional perspective.

Keywords: Science–technology flows; Scientific citations; Patents; NPC methodology regional R&D planning

1. Introduction

In Spain, as in other developed countries, it is a customary practice to produce regional planning documents for research and technological development (R&D), and these generally serve to complement national and supranational development plans, by providing additional resources. Apart from the National R&D Plan and the European Framework Program, a variety of regional plans are also formulated and developed in Spain; however, the processes for formulating these regional plans do not always take account of the need for equilibrium between the scientific and technological aspects of the local system of innovation. In some cases, it is clear that particular care has been taken to link the scientific and technological fields, but little is known of the ways in which scientific output is translated into technological development, and how this, in turn, influences scientific research activity.

In this paper, we undertake an in-depth study of the links between science and technology in the autonomous regions of Spain. We compare three types of region: the less developed regions (with per capita GDP less than 75% of the European Union average, namely "objective no. 1" regions); regions with a per capita GDP of approximately 90% of the European average; and finally, the autonomous community of Madrid, which is the only one of the 17 Spanish

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regions which is in full convergence with European economic levels. Our main aim is to provide an objective analysis which may serve as the basis for a debate on the design and planning of regional policies for science and technology, and thus clarify whether or not the stimulation of scientific research is the best approach to adopt, or whether the balance should be tilted more towards technological aspects favouring innovations for the productive systems of the region; a third and possibly still more effective and beneficial approach may be to seek some kind of equilibrium between basic science and applied technology. Specifically, our foremost objective is to respond to the following questions: on which type of knowledge, scientific or technological, is industrial innovation most fundamentally based? Which sectors of industry and commerce are the most dynamic in their employment of scientific knowledge? Which are the scientific fields most closely related to the needs of industry? Are there significant differences between sectors of industry in their relationship with science? Secondly, we set out to explore whether these differences exist between the three types of region previously defined.

There are two novel features to this study: in the first place, it constitutes one of the first attempts to identify, by means of indicators and quantitative techniques, the interrelationships between science and technology in the regions of Spain; the second novel aspect is the application on a regional scale of NPC methodology, which to date has normally been used only in national analyses, generally for industrialised countries.

The paper is structured in the following way: in the next section, we present a theoretical framework to establish the relationship between science and technology, and its measurement; thereafter, an analysis is made of the spatial scope of the subject under study, in which we discuss the situation of the main economic indicators, of scientific research and technological development at the regional level. Subsequently, we formulate the initial working hypotheses, and describe the methodology employed and the results obtained. Finally, we draw certain conclusions that may serve as a useful basis, in conjunction with other instruments of diagnosis, for future thinking on the design of policies for research and technological development at the regional level.

2. Theoretical framework

One of the principal reasons why economists have devoted such considerable effort to the study of science and scientific policy is its effect on economic growth, and, more specifically, on technological development as the intermediate step between science and economic growth. Various lines of research have been opened, utilising different methodologies, to examine the relationships between scientific knowledge and the development of innovations (Mansfield, 1991, 1998; Nelson and Wolff, 1997). Other authors have identified the scientific antecedents of technological innovation with a view to explaining science–technology flows (Narin et al., 1997; Meyer, 2000a,b,c; Tijssen, 2001), or have examined the contribution of universities to the processes of innovation in companies (Meyer-Krahmer and Schmoch, 1998; Mansfield and Lee, 1996; Beise and Stahl, 1999; Schartinger et al., 2002).

In regional contexts, the application of a descriptive methodology based on the analysis of specific areas, such as high technology complexes (Markusen et al., 1986; Saxenian, 1994; Sternberg and Tamásy, 1999; Wever and Stam, 1999), regional systems of innovation (Cooke et al., 1998; Braczyk et al., 1998) or others who propose an econometric methodology to identify the externalities or real effects of scientific research (Varga, 1998; Anselin et al., 1997, 2000), have demonstrated that the generation of scientific knowledge is also important on scales smaller than the national. The proliferation of such literature, consistently stressing the importance of physical proximity for the two-way flow of knowledge and for the development and fostering of innovation, underpinned by the high degree of autonomy enjoyed by many European regions, thereby permitting the formulation and development of specific R&D programmes in those regions, serves to demonstrate that the study of scientific activity is not only relevant at national or supranational level, but also in the regional context.

The idea that basic scientific research drives technological development, and consequently has direct repercussions on economic growth, originally derived from a hypothesis of linearity in the process of innovation that arose from the visible success of the application of science in the industrial and commercial development of certain high technology activities in the USA after World War II (Malecki, 1997, p. 52). However, the technological impulse that this linear model suggests or assumes is insufficient to explain the mutual transfer of knowledge between science and technology. The appearance—sometimes voluntary, sometimes imposed—of numerous institutions (associations of companies, universities, research institutes and others providing an interface to allow the integration of science and technology) organised systematically, has replaced the old linear model.

Modern theories of innovation, based on an evolutionary approach put forward in the pioneering work of Nelson and Winter (1982),[1] adopt a more sociological perspective with regard to the process of innovation, whereby knowledge, as a resource, and interactive learning are regarded as fundamental aspects of the process (Lundvall and Borrás, 1997; Lundvall and Johnson, 1994). New organisational forms have appeared among the institutional spheres—higher education, industry and government—that demonstrate the importance of knowledge and the flow of learning in the processes of economic growth and social transformation: these include the national/regional system for promoting innovation (Nelson, 1993; Lundvall, 1992; Braczyk et al., 1998), research systems in transition (Cozzens et al., 1990; Ziman, 1994), the triple helix model (Etzkowitz and Leydesdorff, 1997, 2000; Leydesdorff, 2000), etc.

In these approaches, the relationship between science and technology is not presented in terms of unidirectional linearity: on the contrary, the flows are at least two-way (often multi-way in networks) and the interaction is continuous. In this new context, basic scientific research makes a dual contribution to technological progress: through direct factors (generation of useful knowledge); and indirect factors (problem-solving capacity, building of networks, etc.). More specifically, the following mechanisms for science–technology transmission and interconnection have been suggested (Martin et al., 1996; Lundvall and Borrás, 1997; Pavit, 1998; Salter and Martin, 2001): (1) increases in the stock of valuable knowledge; (2) the development of new methodologies and techniques; (3) the creation of scientific instrumentation; (4) the training of scientists and engineers; (5) the formation of networks and stimulation of social interaction; and (6) the direct transfer of technology to appropriate companies, based on the knowledge accumulated in the universities. Nevertheless, it is a generally-accepted notion that the principal contribution of scientific research as a whole is through the provision of key personnel to the stock of human resources: scientists capable of generating scientific output, exchanging knowledge by means of international networks and resolving technological problems. But even under this new perspective, the classic justification and legitimisation for scientific research remains valid: it makes inestimable contributions to human society and culture, as well as to other fields, such as military defence, public and individual health, protection of the natural environment, etc. However, it increasingly appears that the future legitimisation of scientific research will rest more fundamentally on it being an inexhaustible source of new knowledge on which economic development can be based (Etzkowitz and Leydesdorff, 2000).

But how does a regional focus fit into this debate? The modern theories of innovation based on evolutionary propositions have added new and solid reasons to the need for a deeper investigation of the spatial aspects of innovation. It has been argued that the social determinants of innovation (political, economic and industrial institutions, etc.) show profound differences between regions, an approach that illustrates the essential role of regional economies as the building blocks of an increasingly globalised world (Storper, 1995, 1997). Moreover, various authors have stated that the economy based on knowledge, on the capabilities of the labour force and on the presence of highly-competitive firms operates more effectively on the local or regional scale than on the national (Krugman, 1992, 1995; Porter, 1990; Cooke, 1997). This type of reasoning has led many regional economists and geographers to bring the theory of

[1] The common characteristic of the new theories of innovation and of technological change is the perception of innovation as a complex process that involves elements of uncertainty and of accumulation (Dosi et al., 1988, p. 222). Most authors concur in acknowledging the work of Dosi et al. (1988) as the point of departure for these new ideas. The solid contributions of Freeman (1990, 1994) are also recognised as valuable for presenting the defining characteristics of innovation. The work of the group of Danish economists of the University of Aalborg, under the leadership of B.A. Lundvall, on the learning economy has provided a firm theoretical framework to explain innovation from the evolutionary perspective, defining it as a process of learning that generates knowledge cumulatively and in which institutions play an essential role.

innovation, which has no specific spatial dimension, into convergence with regional studies.

Various lines of study have been opened, the most notable exponents of which are the authors with close links to the "Groupement de Recherche Européen sur Les Milieux Innovateur (GREMI)" (European Grouping for Research on the Innovative Local Environment) (Aydalot and Keeble, 1988; Camagni, 1991; Maillat, 1991, 1998; Ratti et al., 1997), the analysts of the high technology industrial districts (Markusen et al., 1986; Saxenian, 1994) and the Californian School of Economic Geography (Storper, 1992, 1993, 1995, 1997). The output of these tendencies is the development of concepts such as: the learning region (Asheim, 1996; Simmie, 1997; Morgan, 1997); structural competitivity (Cooke and Schienstock, 2000); regional innovative capacity (Lawson, 1999; Lawson and Lorenz, 1999); the regional system of innovation (Cooke et al., 1998; Braczyk et al., 1998); technological enclaves and districts (Castells and Hall, 1994; Storper, 1995, 1997; Paci and Usai, 2000); and others. All this literature has a point of convergence: the importance of the environmental and institutional factors that come together in a particular territorial framework to foster certain kinds of *collective learning* that constitute a favourable climate for increased activity aimed at innovation and the stimulation of competitivity. In general, the factors of geographical proximity, accessibility, physical concentration and the presence of favourable externalities together exert a powerful influence on the flow of knowledge (i.e. learning) that is the fundamental basis of technological change and the process of innovation. This interaction is very often found to happen within a regional context. All the theoretical arguments previously expounded would, however, yield no practical gains if there did not exist the climate necessary for the organs of government with decision-making power in regional policies to set in motion the appropriate measures of consultation and planning to promote and strengthen scientific research, technological development and innovation; and fortunately, these are conditions that do exist in many European regions, including some Spanish regions.

3. The spatial context

To be logically consistent with the objectives of this study and with the hypotheses that we wish to test, we have classified the 17 autonomous regions of our national territory into groups according to their respective levels of economic development. On this basis, we have grouped together for the purposes of

Table 1
Indicators of R&D activity in 1998: regional differences in Spain

	Objective no. 1	Catalonia	Madrid	Basque Country	Rest	Spain
R&D: basic data						
R&D expenditure as % of national GDP	0.64	1.19	1.77	1.37	0.65	0.99
R&D expenditure (Spain = 100)	32.20	22.81	30.89	8.79	5.32	100
R&D personnel (Spain = 100)	37.05	20.62	29.13	7.51	5.69	100
No. of researchers (Spain = 100)	41.81	19.03	26.18	6.90	6.08	100
R&D in the private sector						
R&D expenditure as % of national GDP	0.22	0.76	0.94	1.10	0.35	0.52
R&D expenditure (Spain = 100)	21.50	27.98	31.59	13.52	5.40	100
Company R&D expenditure as % of total R&D cost	34.79	63.94	53.30	80.21	52.96	52.11
No. of researchers (Spain = 100)	21.50	27.98	31.59	13.52	5.40	100
R&D in universities						
R&D expenditure as % of national GDP	0.32	0.31	0.32	0.24	0.22	0.30
R&D expenditure (Spain = 100)	51.68	19.44	18.03	5.00	5.85	100
University R&D expenditure as % of total R&D cost	48.97	26.00	17.81	17.38	33.58	30.51
No. of researchers (Spain = 100)	54.03	17.37	15.39	6.18	7.03	100

Source: National Statistics Institute (INE) and authors' own data.

this study those regions with per capita GDP below 75% of the European Union average, the so-called “objective no. 1” regions (Andalusia, Asturias, Canary Islands, Cantabria, Castille and León, Castille-La Mancha, Community of Valencia, Extremadura, Galicia and Murcia); we then consider separately the industrial regions of Catalonia and the Basque Country, two autonomous communities with similar levels of economic development (per capita GDP of around 90% of the European Union average); and finally, the autonomous community of Madrid, the only Spanish region in full economic convergence with Europe.

The following tables identify the basic regional profile of R&D activity. It may be observed from Table 1 that the “objective no. 1” regions show weakness in all the principal indicators: their combined contribution to the total R&D activity undertaken in Spain represents only 32.2% (10 autonomous communities provide practically the same R&D resources as the autonomous community of Madrid); the level of combined technological effort (R&D expenditure as percentage of national GDP) of these regions is lower than the Spanish average and much lower than the other more developed regions; it may also be appreciated that the companies of these regions only

Table 2
Regional distribution of expenditure on innovation, by sector[a] (Spain = 100)

Technology sector	Objective no. 1	Catalonia	Madrid	Basque Country	Rest
I. Electrical engineering					
1. Electrical machinery and apparatus, electrical energy	20.17	36.65	22.73	13.67	6.78
2. Audio-visual technology 3. Telecommunications 5. Semiconductors	8.93	12.56	71.90	3.50	3.10
4. Information technology	6.65	81.13	10.89	0.89	0.45
II. Instruments					
6. Optics 7. Analysis, measurement, control technology 8. Medical technology	38.50	16.64	31.59	12.69	0.58
III. Chemistry, pharmaceuticals					
9. Organic fine chemistry 10. Macromolecular chemistry, polymers 16. Chemical engineering	36.76	39.38	11.58	6.00	6.27
11. Pharmaceuticals, cosmetics	9.21	62.13	25.25	2.29	1.12
13. Materials, metallurgy	60.53	7.83	5.50	15.81	10.32
14. Agriculture, food chemistry	58.08	28.82	4.16	4.00	4.95
15. Chemical and petrol industry, basic materials chemistry	18.22	40.76	38.51	2.50	0.00
IV. Process engineering, machinery					
17. Surface technology, coating	17.88	22.21	9.26	47.84	2.81
18. Materials processing, textiles, paper	23.64	35.06	30.28	4.38	6.64
V. Mechanical engineering, machinery					
21. Machine tools	15.62	26.52	17.92	19.24	20.70
24. Handling, printing	28.04	28.70	33.79	3.15	6.32
26. Transport	27.11	29.59	5.32	11.84	26.14
28. Space technology, weapons	8.26	0.02	64.75	26.29	0.68
29. Consumer goods and equipment	59.14	16.53	16.07	4.17	4.08
30. Civil engineering, building, mining	62.42	7.73	17.20	8.61	4.04
Total	30.46	27.77	20.93	11.19	9.65

Source: National Statistics Institute and authors’ own data.
[a] French–German classification of OST–ISI–INPI.

Table 3
Number of patents by technology sector and autonomous community (1998–2001)[a]

Technology sector	Regional distribution of total no. of patents					Coefficients of specialisation[b]			
	Objective no. 1	Madrid	Catalonia	Basque Country	Total	Objetive no. 1	Madrid	Catalonia	Basque Country
I. Electrical engineering									
1. Electrical machinery and apparatus, electrical energy	3.16	5.65	15.11	9.78	9.31	0.34	0.61	1.62	1.05
2. Audio-visual technology	1.58	5.65	3.36	0.00	3.17	0.50	1.78	1.06	0.00
3. Telecommunications	0.40	15.32	1.20	6.52	4.95	0.08	3.10	0.24	1.32
4. Information technology	0.40	1.61	0.00	1.09	0.59	0.67	2.72	0.00	1.83
5. Semiconductors	0.79	0.00	0.24	0.00	0.30	2.66	0.00	0.81	0.00
II. Instruments									
6. Optics	0.00	0.40	0.72	0.00	0.40	0.00	1.02	1.82	0.00
7. Analysis, measurement, control technology	5.93	10.48	3.36	4.35	5.84	1.01	1.79	0.57	0.74
8. Medical technology	4.35	4.44	3.36	1.09	3.66	1.19	1.21	0.92	0.30
III. Chemistry, pharmaceuticals									
9. Organic fine chemistry	0.79	5.24	9.59	5.43	5.94	0.13	0.88	1.61	0.91
10. Macromolecular chemistry, polymers	0.79	2.02	0.24	0.00	0.79	1.00	2.55	0.30	0.00
11. Pharmaceuticals, cosmetics	3.16	3.23	5.52	0.00	3.86	0.82	0.84	1.43	0.00
12. Biotechnology	1.19	3.63	1.20	2.17	1.88	0.63	1.93	0.64	1.16
13. Materials, metallurgy	2.37	2.42	1.68	6.52	2.48	0.96	0.98	0.68	2.63
14. Agriculture, food chemistry	5.93	2.42	3.60	0.00	3.56	1.66	0.68	1.01	0.00
15. Chemical and petrol industry, basic materials chemistry	1.58	2.02	1.44	1.09	1.58	1.00	1.27	0.91	0.69
IV. Process engineering, special equipments									
16. Chemical engineering	4.35	1.61	2.40	2.17	2.67	1.63	0.60	0.90	0.81
17. Surface technology, coating	1.98	0.81	1.92	1.09	1.58	1.25	0.51	1.21	0.69
18. Materials processing, textiles, paper	4.35	2.82	6.00	2.17	4.46	0.98	0.63	1.35	0.49
19. Thermal processes and apparatus	3.16	0.81	0.72	4.35	1.68	1.88	0.48	0.43	2.58
20. Environmental technology	1.19	1.61	2.16	0.00	1.58	0.75	1.02	1.36	0.00
V. Mechanical engineering, machinery									
21. Machine tools	2.77	1.61	2.64	9.78	3.07	0.90	0.53	0.86	3.19
22. Engines, pumps and turbines	1.98	0.40	1.68	2.17	1.49	1.33	0.27	1.13	1.46
23. Mechanical elements	1.98	0.40	2.88	3.26	2.08	0.95	0.19	1.38	1.57
24. Handling, printing	8.70	3.63	10.55	9.78	8.32	1.05	0.44	1.27	1.18
25. Agriculture and food processing, machinery and apparatus	8.30	2.82	2.64	5.43	4.36	1.91	0.65	0.61	1.25
26. Transport	3.56	5.24	4.08	4.35	4.26	0.84	1.23	0.96	1.02
27. Nuclear engineering	0.00	0.40	0.00	0.00	0.10	0.00	4.07	0.00	0.00
28. Space technology, weapons	0.40	1.21	0.00	0.00	0.40	1.00	3.05	0.00	0.00
29. Consumer goods and equipment	11.46	5.24	6.24	9.78	7.62	1.50	0.69	0.82	1.28
30. Civil engineering, building, mining	13.44	6.85	5.52	7.61	8.02	1.68	0.85	0.69	0.95
Total	100	100	100	100	100	1.00	1.00	1.00	1.00
Total no. of Patents	253	248	417	92	1010	–	–	–	–

Source: OEPM and authors' own data.

[a] French–German classification of OST–ISI–INPI. Domestic patents (NLP) applied during 1998–2001 in the Spanish Office of Patents and Trade Marks (OEPM).

[b] $(S_{ij}/R_j)/(\sum S_i/\sum R_j)$. S_{ij}: patents in sector i of region j. R_j: patents in region j.

Table 4
High technology indicators by region 1999[a]

Region	Companies (%)		Value added (%)		No. of persons occupied (%)		No. of persons occupied/no. of companies		VAB/no. of persons occupied
	HT	MHT	HT	MHT	HT	MHT	HT	MHT	HT + MHT
Objective no. 1	31.46	41.46	17.27	33.19	18.93	35.02	41.85	25.77	93.16
Catalonia	38.57	30.68	35.67	34.70	32.44	28.92	58.49	28.76	118.42
Madrid	21.76	11.03	39.96	13.32	40.98	13.57	130.97	37.52	102.03
Basque Country	4.33	8.44	4.12	12.81	4.89	10.70	78.57	38.71	114.64
Rest	3.89	8.39	2.98	5.98	2.76	11.80	49.21	42.89	–
Total Spain	100	100	100	100	100	100	69.53	30.51	100

Source: INE and authors' own data.
[a] HT: high technology; MHT: medium-high technology (according to the OECD classification).

participate to a very limited extent in the combined R&D-related activities that are undertaken. A very different panorama from the deficiencies presented by the private sector is reflected by the resources destined to higher education (universities), where the principal indicators present the "objective no. 1" regions in a more favourable light. This situation is the consequence of a relatively uniform government policy towards the less developed Spanish regions aimed at balancing the total expenditure by allocating proportionately more public resources to the universities.

If we look in more detail at the differences between sectors for the regions selected, the technological specialisation data (Table 2)[2] show that companies' expenditure of innovation follows a similar pattern to that of total R&D resources. Analysed by technology sector, it is evident that the "objective no. 1" regions concentrate their expenditure on industrial activities of "low technological intensity", apart from a few exceptions. These regions concentrate more than 50% of innovation expenditure in sectors like metallurgy, agriculture and food chemistry, consumer goods and equipment, and civil engineering, whereas other sectors in which technological competition is stronger (pharmaceuticals, audio-visual technology, telecommunications, etc.), barely account for 10% of the total.

In Table 3, the relative importance and the coefficients of specialisation have been calculated and shown alongside the "results" of the process of innovation, in terms of the number of patents issued. These data confirm that, in the "objective no. 1" regions, the sectors of certain relative relevance (those accounting for more than 5% of the total patents issued in the whole of Spain) can be classified as of medium-low technological intensity (handling and printing, agricultural and food processing, consumer goods and civil engineering); it is precisely in those sectors that these less-developed regions are more specialised (with coefficients greater than unity).

Lastly, it is well known that the most intensive flows between science and technology occur in sectors where the use of technology is more intensive (activities characterised by strong competition and rapid changes). Table 4 illustrates the principal indicators of high technology activity by region. It is clear from these data that in high technology sectors, 10 "objective no. 1" regions account for 31.46% of total companies and only 17.27% of total value added, in respect of Spain as a whole. If we consider sectors classified as employing medium-high technology, these figures look slightly better, but it may still be observed that the sectors of high and medium-high technology in the "objective no. 1" regions are characterised by a notably lower corporate dimension than the remaining Spanish regions and by a level of productivity (in terms of value added per person occupied) which is lower than the regional average.

[2] The patents have been classified in accordance with a sufficient criterion to distinguish between five technological areas and thirty sub-fields based on the International Classification of Patents (IPC). This classification has been produced jointly by the FhG-ISI, the French Office of Patents (INPI), and the Observatory of Sciences and Techniques (OST).

4. Hypotheses

The situation of strong competition within the same sector is now in itself an incentive for the development of innovative activities: high technology industries are necessarily more innovative (Malecki, 1997, p. 23). The latter seek to take full advantage of access to up-to-date scientific knowledge, particularly in those sectors in which technological advance is more rapid and in which the support of scientific literature is necessary because the inventions that are continually being made are not immediately available (Schmoch, 1993). These statements lead us to think that, in terms of science–technology flows generally, there must be significant differences between the less and the more advanced regions; such discrepancies will ultimately be conditioned by the degree of specialisation in sectors of high technology. As demonstrated in the preceding section of this paper, "objective no. 1" regions present a very unfavourable profile in respect of high technology sectors: fewer companies, of smaller size and with a lower productivity than the other regions of intermediate or high economic development. These initial premises lead us to formulate the following hypotheses.

H1. Significant interregional differences exist in the science–technology linkages between the less developed (objective no. 1) regions and those of intermediate development (Catalonia, the Basque Country).

H2. Significant interregional differences exist in the science–technology linkages between the less developed (objective no. 1) regions and the most developed region (Madrid).

This type of comparison may be subject to certain kinds of potential bias. In general, there exist substantial inter-sector differences in the number and type of scientific citations in the patent documents that are directly related to the different patterns of innovation or propensities to seek patents presented by each sector (Bell and Pavitt, 1993). In order to avoid the distortions introduced by sector differences, these hypotheses will be tested by taking account of the degree of technological complexity of the sector. Furthermore, in diverse spatial contexts (countries), it has been shown that science–technology relationships are specific: chemical patents cite scientific articles in chemical journals; medical patents cite articles on biomedicine, etc. (Klevorick et al., 1995; Godin, 1996; Hicks and Katz, 1997; Narin et al., 1997). In principle, it may be imagined that the level of regional development might alter this relationship, to the extent that those regions more specialised in a particular sector would be more knowledgeable of the scientific advances affecting the technological development of their activities. To allow for this situation, the first and second hypotheses will also be tested, by taking into account not only the technological complexity of the sector, but also the scientific field of the citation.

In the "objective no. 1" regions there exists a technological specialisation by sector in activities of intermediate or low complexity (above all in materials and metallurgy, agriculture and food chemistry, and civil engineering, building and mining). Unlike in the sectors of high technological competition, in these activities, technological development arises more from knowledge of the technology itself (i.e. on previous inventions) than from the use of scientific literature. This idea leads us to formulate the following hypotheses.

H3. There exist significant differences in knowledge of the technological antecedents of innovations (patent citations) between the less developed (objective no. 1) regions and those of intermediate development (Catalonia, the Basque Country).

H4. There exist significant differences in knowledge of the technological antecedents of innovations (patent citations) between the less developed (objective no. 1) regions and the most developed region (Madrid).

As in the first case, these hypotheses will be tested by taking into account the degree of technological complexity of the technology sectors.

5. Methodology

The difficulty of attempting to measure science–technology links quantitatively is well known; the flows of tacit knowledge and codified information are numerous, difficult to identify and even more difficult to quantify. The methodology applied in this study to investigate the links between science and technology is based on the non-patent citations (NPCs) in patent documents.[3] This method originated with the pioneering papers of Carpenter et al. (1980), Carpenter and Narin (1983), Narin and Noma (1985). In the 1990s, studies including those of Van Vianen et al. (1990), Grupp and Schmoch (1992), Narin and Olivastro (1992, 1998), Noyons et al. (1994), Narin et al. (1995, 1997), Meyer-Krahmer and Schmoch (1998), among others, have demonstrated that the average level of NPC references is an appropriate indicator to describe science–technology links. Recently, various analyses with differing levels of aggregation have been developed, which are enabling advances to be made in the interpretation of the role played by scientific citations in patent documents, as a means of quantifying science–technology links (Meyer, 2000a,b,c, 2002; McMillan et al., 2000; Tijssen et al., 2000; Tijssen, 2001, 2002). In this part, we aim first to clarify some aspects in relation to this methodology and, in continuation, to describe the procedure followed in our analysis.

5.1. *Scientific citations in patent documents*

The idea underlying the NPC methodology, in which it is accepted that patents are a reflection of technology, is that the scientific citations in patent documents, as reflections of the scientific knowledge incorporated in the corresponding invention, show the relationship existing between science and technology in that particular field.

The NPC methodology consists in approaching science–technology links quantitatively, by means of the average number of NPC citations in the patents of a specific field of technology. We shall comment next on the logic of the procedure, and we shall pose certain questions that will help to interpret correctly the results derived from our empirical analysis.

In patent documents, as occurs in scientific articles, it is customary to provide references or citations, the purpose of which is to describe the *prior art* or the state of the technique prior to the invention. The prior art not only includes previous patent citations, it also includes bibliographical entries referring to scientific literature and technical publications (known as NPCs). These citations provide indications of the potential contribution made by published scientific research to the inventions patented. The references included in a patent are less likely to be redundant or superfluous than those incorporated in a scientific article, due to the control that is exercised over patents and to their legal consequences (Collins and Wyatt, 1988; Verbeek et al., 2002).[4]

The NPC methodology and its capacity for reflecting science–technology flows has been analysed by many authors; To give a better understanding of the scope of the conclusions that we shall reach by using this methodology, we shall next list and comment on some of the papers dealing with questions relating to its interpretation.

The empirical applications using NPCs reveal that, in general terms, the patents in which scientific literature is cited are relatively few, and that, furthermore, a certain bias can be found towards some sectors of technology or some countries. For example, the recent study of Iversen (1999) shows that, during the period 1990–1996, approximately 30% of the patents of residents in Norway granted in the USA cite journals, books and a variety of more commercial literature (a total of 716 NPCs, of which 393 are scientific references, are analysed in 183 patents). The two industries most associated with scientific literature are pharmaceuticals and instruments; in both, scientific references account for 60% of the total citations. The papers of Grupp and Schmoch (1992) and Meyer-Krahmer and Schmoch (1998), state, using indices applied to the patents issued by the European Patent Office during the period 1989–1992, that the closest links with

[3] The identification of science-technology links has been dealt with through a variety of different procedures that are not necessarily mutually exclusive: (a) econometric studies (the reviews given in the articles of Griliches (1995) and Salter and Martin (2001) reflect the proliferation of this type of study); (b) descriptive studies (the regional studies contained in Braczyk et al. (1998) and the descriptions of certain high technology zones and parks (Markusen et al., 1986; Saxenian, 1994) are examples of this type of analysis); (c) surveys (the work of Beise and Stahl (1999) is a good example of this methodology). Surveys are usually an initial method for gathering information to which various types of statistical treatment are subsequently applied; (d) non-patent citation (NPCs): these are oriented towards the direct examination of a particular innovation and the historical roots of a particular technology.

[4] For an extensive empirical analysis of the differences between the citations included in a patent and those incorporated in a scientific article, see Meyer (2000b).

science are found in the field of biotechnology, together with other areas related to chemicals production and information technology. The areas below the average in citations are generally related to mechanical engineering and civil engineering.

If we go back to earlier studies, in these the sectorial or national deviations in NPC citations are stressed: "These science linkages occur most heavily in pharmaceutical, chemical and electronics patents .... The science cited varies significantly for patents in the different major countries, at least partially reflecting the national differences in technological emphasis, including the strong electronic emphasis for Japanese patenting, and the US and UK strengths in pharmaceuticals" (Narin and Olivastro, 1992). Citations are not made in all sectors; this latter situation does not imply that there is no relationship between science and technology in non-citing sectors, but rather that there is a different type of interaction (through the mobility of scientists and engineers, or co-operation between a university and a company, for example). It should be taken into account, therefore, that the analysis of patent citations offers only a partial picture of the flows between science and technology, since what is really being quantified is the link between the scientific literature published and inventions patented; this is one of its principal limitations. In addition to those already mentioned, some obstacles of operational character have been indicated: incomplete databases, difficulty of processing all the information (Verbeek et al., 2002; Meyer, 2000a), and identification of the publications cited as a representation of either basic or applied research (Meyer-Krahmer and Schmoch, 1998).

The empirical analyses conducted in various studies (Grupp and Schmoch, 1992; Schmoch, 1993; Narin and Olivastro, 1998; Meyer, 2000a,b) help in understanding why there are sectorial or national differences, and even differences between the entities applying for patents. These studies identify a number of reasons why examiners, applicants or inventors incorporate NPCs in patents or do so with different intensities or frequencies, and not all are related to possible interrelationships with science. For example, the limited availability of patents in particular technological fields in consequence of the rapid advance of certain technologies and the consequent time-lag in the publication of the patent documents, the legal context of patents (their obligatory nature, and the possibility of including discussion of the prior art, utility, novelty, etc. of the invention), and the social nature of the process (involvement of various actors—inventor, examiner, attorney, etc.) are integral elements in the development of the patent and exert influence on its final form,[5] or that there are different national practices (the presence of different patent offices with different methods of work; it is well known that in USPTO patents the frequency of citations is higher in comparison with EPO patents). In the particular case of Spanish patents, we can add to these preceding reasons several others that could affect the relative propensity to cite. Normally the patents applied for by universities cite proportionately much more frequently than those applied for by companies or private individuals. Apart from the greater knowledge of scientific literature presumably available in a university, another possible reason could be the differences in the objectives of the various kinds of applicant: "The businessman wishes to secure protection for the commercial exploitation—in a monopolistic position—of a product or a productive process; for the university applicant, the patent is an academic merit, although it may also be exploited commercially. Furthermore, the patent applications that are presented in the OEPM can be complemented by professionals or by the inventors themselves. In this latter case, more deficiencies are apparent when it comes to collecting and documenting the antecedents and even in the actual description of the invention" (Carlos Velasco, personal communication).[6]

The key question, after this synthesis, is: up to what point does the NPC methodology really measure, or is capable of capturing and quantifying the science–technology links? In principle, the studies in aggregate seem to confirm that NPCs measure the intensity of the science supporting the innovations

[5] The citations may have been made by the applicants for the patent or by the examiners in the process of evaluation of the patent (in the body of the patent, or on the front page, respectively). The examiners are more inclined to take NPCs when the invention is not sufficiently documented with previous patents (Grupp and Schmoch, 1992; Tijssen et al., 2000). In a case study, Meyer (2000b) illustrates how the citations of the examiners are related to those of the applicants, and show different types of behaviour; and although this study does not allow a global conclusion to be drawn, it does demonstrate that the examiners do not include all the citations made by the applicants.

[6] Carlos Velasco is chief examiner of chemical patents of the Spanish Office of Patents and Trade Marks (OEPM).

patented; however, a more diffuse panorama appears when one tries to determine the type of relationship between research published and inventions patented (Tijssen et al., 2000; Tijssen, 2002). Narin et al. (1997) are relatively optimistic in respect of the NPC methodology for measuring the relationships of dependence of technology on academic research (they utilise this conclusion to argue that "public science is a driving force behind high technology"). Other authors are less optimistic when it comes to describing science–technology links and prefer to speak of interactions (Schmoch, 1993). The case study of Meyer emphasises: "One should not use a misleading term like "science-dependence" of technology either; the results from the cases show that there are several ways in which science and technology relate to each other and that even in those fields, technology is more than just a receiver and transformer of scientific results. Therefore, it does not seem appropriate to use the linear science-push model to interpret patent citation data" (Meyer, 2000a), and also "One should rather refer to science and technology *interplay* than speak of science-dependence in the context of patent citations" (Meyer, 2000c). This lack of clear causality is also noted by Tijssen who refers to "the questionable validity of these citations as causal measures of knowledge flows from the science base to the technology domain" (Tijssen, 2002). In summary, various validation studies seem to have lowered the degree of optimism expressed in the initial studies of Narin and his co-workers when interpreting the results obtained from the study of NPCs, and it seems that it would be more appropriate to speak of interactions, links or science–technology flows, in place of relationships of causality, of dependence or of science driving technology, as postulated by a linear model. It should be remembered that scientific citations only reflect one part of the contribution of science to technology, above all, the part of codified knowledge that is utilised as a source of ideas, analytical methods and data: other interesting sources of tacit knowledge are not visible by means of this methodology.

Finally, this study concentrates on science–technology relationships; however, given the characteristics of some of the regions that are featured in the empirical analysis (objective no. 1), it is convenient—as a complement to the regional empirical analysis of scientific citations—to explore patent citations to examine whether, in particular sectors, the relationships are found to be more with the industry itself than with the scientific field. In various studies, it has been shown that patent citations can be utilised as a good indicator of the knowledge flows between industries (Jaffe et al., 1993; Jaffe and Trajtenberg, 1999; Stolpe, 2002; Fung and Chow, 2002). As in the case of scientific citations, a correct interpretation of the results derived from the study of patent citations requires attention to be paid to differing practices in the process of making the citations and to the bias in favour of particular fields of technology.

5.2. Analysis of the science–technology interactions in the autonomous regions of Spain

The methodology followed in this article differs in two aspects from other studies carried out and reviewed in the previous part. First, contrary to what is becoming habitual, the empirical analysis has been conducted utilising domestic patents (NLP) rather than European (EPO), international (PCT) or United States (USPTO) patents. The essential reason is that the particular objective of the study is to conduct a regional comparison. In the least favoured (objective no. 1) regions, the EPO, PCT or USPTO patents are, on the one hand, not very representative of the technology that is developed in these zones, and on the other hand, the greater part of the patents that follow a European, international or American route have previously followed the national NLP route, utilising this as a priority to becoming European or international patents subsequently.[7]

The second of the modifications introduced in the methodology presented in the previous section concerns the citations. Those included and classified in

[7] In Andalusia, one of the objective no. 1 regions, of the 283 patents existing, 280 have been requested via the national (NLP) route; 32 of these have then been converted into international or European patents, making use of the priority obtained by their granting by national route, while only three documents out of the total of 283 are original international or European patents. Therefore, our empirical analysis omits only 1% of the inventions made in this region and provides us with a larger number of observations. These percentages remain similar in the rest of the Spanish regions, although a slight tendency is observed towards an increase in the direct applications for European, United States or international patents in the more developed regions.

our study are the citations included in the complete text; in other words, we consider the citations made by the inventor. In this way, we avoid a possible under-estimation of the science–technology links.[8]

The procedure for identifying the science–technology links is based on the NPC methodology; but although in the initial phase all the non-patent references have been collected, the percentage distribution by scientific fields has been made only from the citations in scientific journals (other type of references, such as text books, marketing journals, internal documents, and other non-scientific literature have therefore been excluded). The procedure for obtaining the citations has been manual: an exhaustive examination of the set of patents selected for empirical analysis has been carried out. The classification of the scientific references has been made by experts in bibliometry of our University and researchers active in the scientific fields selected. In continuation, all these aspects are clarified in greater detail.

We have conducted an exhaustive review of all the patents applied for in the period 1998–2001 by companies resident in the "objective no. 1" regions, Catalonia, Madrid and the Basque Country. Firstly, the total number of patent applications in these years was classified by technology sector. In total, the field-work involved an exhaustive analysis of 1010 patent documents, from which a total of 1162 scientific citations were extracted. The basic statistical source used is the databases of the Spanish Office of Patents and Trade Marks (OEPM). Having classified the patents, the scientific citations (all references included in the complete text of the application document) were collected and categorised. For this purpose, we employed the seven scientific or scientific–technical fields which are used as basic divisions in regional planning documents in Spain (the non-relevant fields of economics and other social sciences, law and the humanities were duly excluded):

1. AGR: agro-food (agriculture and forestry, food and drink technology, food and drink quality and safety, etc.);
2. CVI: life sciences (biology, biotechnology);
3. CTS: health science and technology;
4. RNM: natural resources and the environment (atmospheric phenomena, marine ecosystems, water resources, etc.);
5. FQM: physics, chemistry and mathematics;
6. TEP: technologies of production (manufacturing and other production processes, automation and robotics, quality control systems, engineering in general, etc.);
7. TIC: information and communication technologies.

It is generally difficult to establish clear boundaries between scientific areas, however they are classified. The criterion adopted when an article of a multidisciplinary character could equally be allocated to two different scientific fields has been to consider it to fall under both. From this process a series of tables have been prepared from which we have attempted to draw the answers to some of the questions initially posed. However, to test the hypotheses formulated, we have adopted more rigorous statistical methods (mean equality test).

Lastly, we have opted to include the number of patents referenced by the patent examiner. As is well known, the examiners include in their report the previous inventions, already patented, that have some degree of similarity, total or partial, with the document analysed. In the Spanish patents, the report of the examiner appears at the end of the document and is given the name: "Report on the State of the Technique".

6. Data and results

6.1. Descriptive analysis

Table 5 gives the total numbers of patents and scientific citations that have been examined. It may be observed that of the 1010 patents reviewed, 11.29% on average (for the whole of Spain) are based to a greater or less degree on scientific knowledge (patents that cite

[8] The results, at the aggregated level, of the study of Narin and Olivastro (1998) reveal that approximately half of the citations in the complete text are also listed in the front page (USPTO patents); in consequence, for these authors, it is reasonable to utilise this source of data on citations instead of the complete text. In most of the studies using NPCs, the references of the examiners, which are those appearing in the front page of the USPTO patents, are utilised; this approach is adopted because of the technical difficulties in computing the NPCs contained in the complete text and made by the applicants themselves. However, as already stated by various authors, this practice under-estimates the contribution of the relevant science to the technology patented (Tijssen et al., 2000).

Table 5
Number of patents and scientific citations, by region (1998–2001)

Regions	No. of patents (PAT)	Patents with scientific citations		Scientific citations (NPC)			Patent citations (PC)		
		No.	%	No.	Total = 100	NPC/PAT	No.	Total = 100	PC/PAT
Objective no. 1	253	22	8.70	217	18.67	0.86	1149	26.38	4.6
Madrid	248	34	13.71	395	33.99	1.59	1019	23.40	4.2
Catalonia	417	52	12.47	459	39.50	1.10	1799	41.32	4.4
Basque Country	92	6	6.52	91	7.83	0.99	387	8.89	4.2
Total	1010	114	11.29	1162	100	1.15	4354	100	4.3

Source: authors' own, based on OEPM data.

scientific articles). In the breakdown by regions, differences may be appreciated both in the proportion of patents that cite scientific articles, and in the number of citations per patent. In both indicators, the "objective no. 1" regions appear unfavourably. Firstly, in line with the pronounced territorial polarisation of technological activity, there is also a regional concentration in the scientific citations: two autonomous communities—Madrid and Catalonia— account for 73.5% of total citations in patent documents. In Table 6, these scientific references have been classified by level of complexity (high, medium or low). As these data demonstrate, and as has been shown in several previous studies, science–technology flows are more frequent in the high technology sectors. This characteristic is common to all the regions studied, independently of the level of economic development. However, certain differences can also be appreciated in respect of the intensity of those flows within the high technology sectors; in principle, these differences derive from the differences in regional industrial specialisation.

In Table 7, the numbers of citations classified by type and by technology sector are presented. This represents the primary information on which the following discussion of the previously raised questions is based:

- The greatest science–technology linkages occurs in relatively few sectors directly involved with

Table 6
Number of patents, by technological complexity (1998–2001)

Complexity	Objective no. 1 regions							Madrid						
	a	b	c	d	e	f	g	a	b	c	d	e	f	g
High	45	119	9	128	2.8	200	4.4	111	198	29	227	5.0	448	4
Medium	160	67	16	83	0.5	761	4.8	111	185	14	199	1.2	477	4.3
Low	44	31	2	33	0.8	188	4.3	19	12	1	13	0.3	94	4.9
Total	249	217	27	244	1.0	1149	4.6	241	395	44	439	1.8	1019	4.2
Complexity	**Catalonia**							**Basque Country**						
	a	b	c	d	e	f	g	a	b	c	d	e	f	g
High	79	135	10	145	1.8	324	4.1	14	59	5	64	0.8	56	4.0
Medium	288	302	28	330	1.1	1307	4.5	69	32	1	33	0.1	292	4.2
Low	41	22	4	26	0.6	168	4.1	9	0	0	0	0.0	39	4.3
Total	408	459	42	501	1.2	1799	4.4	92	91	6	97	0.2	387	4.2

Source: OEPM and authors' own data. *Note*: a, no. of patents; b, citations in journals; c, other citations (books, congress papers, theses); d, total citations; e, citations/no. of patents; f, patents cited; g, patents cited per patent. Sector 20 cannot be rated by technological complexity.

chemical processes. From the break-down of total patents into 30 technology sectors, a pronounced concentration is observed in the use of science: for Spain as a whole, 85% of the citations are accounted for by only three sectors (organic fine chemistry, pharmaceuticals and biotechnology). The ratio of *citations to number of patents* confirms that the biggest science–technology flows in Spain take place in these three sectors.

- The technological advances in the high and medium-high technology sectors associated with electrical engineering and instruments make relatively little use of the relevant scientific literature; rather, they are based fundamentally on the

Table 7
Patents and type of citation, by technology sector (1998–2001)

Technology sector	Objective no. 1 regions							Madrid						
	a	b	c	d	e	f	g	a	b	c	d	e	f	g
(a)														
I. Electrical engineering														
1. Electrical machinery and apparatus, electrical energy	8	0	0	0	0	56	7.0	14	3	2	5	0.4	70	5.0
2. Audio-visual technology	4	0	0	0	0	16	4.0	14	0	0	0	0.0	51	3.6
3. Telecommunications	1	0	0	0	0	5	5.0	38	1	2	3	0.1	166	4.4
4. Information technology	1	0	0	0	0	5	5.0	4	0	0	0	0.0	5	1.3
5. Semiconductors	2	0	0	0	0	14	7.0	0	0	0	0	0.0	0	0.0
II. Instruments														
6. Optics	0	0	0	0	0	0	0.0	1	0	0	0	0.0	5	5.0
7. Analysis, measurement, control technology	15	0	0	0	0	69	4.6	26	2	1	3	0.1	108	4.2
8. Medical technology	11	0	0	0	0	62	5.6	11	0	0	0	0.0	47	4.3
III. Chemistry, pharmaceuticals														
9. Organic fine chemistry	2	13	2	15	7.5	7	3.5	13	161	7	168	12.9	18	1.4
10. Macromolecular chemistry, polymers	2	16	2	18	9.0	6	3.0	5	1	1	2	0.4	18	3.6
11. Pharmaceuticals, cosmetics	8	61	0	61	7.6	21	2.6	8	12	3	15	1.9	46	5.8
12. Biotechnology	3	58	9	67	22.3	8	2.7	9	183	23	206	22.9	20	2.2
13. Materials, metallurgy	6	21	8	29	4.8	22	3.7	6	0	0	0	0.0	30	5.0
14. Agriculture, food chemistry	15	31	2	33	2.2	60	4.0	6	12	1	13	2.2	22	3.7
15. Chemical and petrol industry, basic materials chemistry	4	13	3	16	4.0	10	2.5	5	4	1	5	1.0	17	3.4
IV. Process engineering, special equipments														
16. Chemical engineering	11	4	0	4	0.4	48	4.4	4	2	3	5	1.3	20	5.0
17. Surface technology, coating	5	0	1	1	0.2	22	4.4	2	14	0	14	7.0	8	4.0
18. Materials processing, textiles, paper	11	0	0	0	0	47	4.3	7	0	0	0	0.0	31	4.4
19. Thermal processes and apparatus	8	0	0	0	0	43	5.4	2	0	0	0	0.0	10	5.0
20. Environmental technology	3	0	0	0	0	17	5.7	4	0	2	2	0.5	18	4.5
V. Mechanical engineering, machinery														
21. Machine tools	7	0	0	0	0	32	4.6	4	0	0	0	0.0	14	3.5
22. Engines, pumps, turbines	5	0	0	0	0	25	5.0	1	0	0	0	0.0	6	6.0
23. Mechanical elements	5	0	0	0	0	24	4.8	1	0	0	0	0.0	6	6.0
24. Handling, printing	22	0	0	0	0	105	4.8	9	0	0	0	0.0	40	4.4
25. Agriculture and food processing, machinery and apparatus	21	0	0	0	0	105	5.0	7	0	0	0	0.0	40	5.7
26. Transport	9	0	0	0	0	56	6.2	13	0	0	0	0.0	65	5.0
27. Nuclear engineering	0	0	0	0	0	0	0.0	1	0	0	0	0.0	4	4.0
28. Space technology, weapons	1	0	0	0	0	2	2.0	3	0	0	0	0.0	13	4.3
29. Consumer goods and equipment	29	0	0	0	0	128	4.4	13	0	0	0	0.0	72	5.5
30. Civil engineering, building, mining	34	0	0	0	0	153	4.5	17	0	0	0	0.0	80	4.7
Total	253	217	27	244	1.0	1168	4.6	248	395	46	441	1.8	1050	4.2

Table 7 (*Continued*)

Technology sector	Catalonia							Basque Country						
	a	b	c	d	e	f	g	a	b	c	d	e	f	g
(b)														
I. Electrical engineering														
1. Electrical machinery and apparatus, electrical energy	63	0	0	0	0.0	302	4.8	9	0	0	0	0.0	51	5.7
2. Audio-visual technology	14	0	0	0	0.0	54	3.9	0	0	0	0	0.0	0	0.0
3. Telecommunications	5	0	0	0	0.0	22	4.4	6	0	0	0	0.0	29	4.8
4. Information technology	0	0	0	0	0.0	0	0.0	1	0	0	0	0.0	4	4.0
5. Semiconductors	1	0	0	0	0.0	2	2.0	0	0	0	0	0.0	0	0.0
II. Instruments														
6. Optics	3	0	0	0	0.0	11	3.7	0	0	0	0	0.0	0	0.0
7. Analysis, measurement, control technology	14	0	0	0	0.0	58	4.1	4	6	0	6	1.5	17	4.3
8. Medical technology	14	1	1	2	0.1	75	5.4	1	0	0	0	0.0	5	5.0
III. Chemistry, pharmaceuticals														
9. Organic fine chemistry	40	302	26	328	8.2	138	3.5	5	32	1	33	6.6	23	4.6
10. Macromolecular chemistry, polymers	1	0	0	0	0.0	3	3.0	0	0	0	0	0.0	0	0.0
11. Pharmaceuticals, cosmetics	23	68	5	73	3.2	84	3.7	0	0	0	0	0.0	0	0.0
12. Biotechnology	5	66	4	70	14.0	18	3.6	2	53	5	58	29.0	1	0.5
13. Materials, metallurgy	7	0	0	0	0.0	28	4.0	6	0	0	0	0.0	20	3.3
14. Agriculture, food chemistry	15	22	4	26	1.7	47	3.1	0	0	0	0	0.0	0	0.0
15. Chemical and petrol industry, basic materials chemistry	6	0	0	0	0.0	19	3.2	1	0	0	0	0.0	8	8.0
IV. Process engineering, equipments														
16. Chemical engineering	10	0	0	0	0.0	46	4.6	2	0	0	0	0.0	8	4.0
17. Surface technology, coating	8	0	1	1	0.1	37	4.6	1	0	0	0	0.0	6	6.0
18. Materials processing, textiles, paper	25	0	0	0	0.0	118	4.7	2	0	0	0	0.0	6	3.0
19. Thermal processes and apparatus	3	0	0	0	0.0	13	4.3	4	0	0	0	0.0	17	4.3
20. Environmental technology	9	0	0	0	0.0	35	3.9	0	0	0	0	0.0	0	0.0
V. Mechanical engineering, machinery														
21. Machine tools	11	0	0	0	0.0	46	4.2	9	0	0	0	0.0	36	4.0
22. Engines, pumps and turbines	7	0	1	1	0.1	33	4.7	2	0	0	0	0.0	6	3.0
23. Mechanical elements	12	0	0	0	0.0	50	4.2	3	0	0	0	0.0	12	4.0
24. Handling, printing	44	0	0	0	0.0	219	5.0	9	0	0	0	0.0	32	3.6
25. Agriculture and food processing, machinery and apparatus	11	0	0	0	0.0	53	4.8	5	0	0	0	0.0	19	3.8
26. Transport	17	0	0	0	0.0	83	4.9	4	0	0	0	0.0	21	5.3
27. Nuclear engineering	0	0	0	0	0.0	0	0.0	0	0	0	0	0.0	0	0.0
28. Space technology, weapons	0	0	0	0	0.0	0	0.0	0	0	0	0	0.0	0	0.0
29. Consumer goods and equipment	26	0	0	0	0.0	121	4.7	9	0	0	0	0.0	39	4.3
30. Civil engineering, building, mining	23	0	0	0	0.0	119	5.2	7	0	0	0	0.0	27	3.9
Total	417	459	42	501	1.2	1834	4.4	92	91	6	97	1.1	387	4.2

Source: OEPM and authors' own data. *Note*: a, no. of patents; b, citations in journals; c, other citations (in books, congresses, theses); d, total citations; e, citations/no. of patents; f, patents cited; g, patents cited per patent.

accumulated technological knowledge acquired as a result of the development of previous technologies. This conclusion is supported by the number of patent citations.

- As in the country taken as a whole, in the context of the more developed regions the linkages between scientific research and technology are heavily concentrated in a few sectors. In the autonomous

Table 8
Scientific citations by sector and field of knowledge (1998–2001)

Technology sector	Objective no. 1 regions							Madrid						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
I. Electrical engineering	0	0	0	0	0	0	0	0	0	0	0	0	4	0
II. Instruments	0	0	0	0	0	0	0	0	0	0	0	0	2	0
III. Chemistry, pharmaceuticals														
9. Organic fine chemistry	0	0	0	0	13	0	0	0	64	68	0	26	3	0
10. Macromolecular chemistry, polymers	7	9	0	0	0	0	0	0	1	0	0	0	0	0
11. Pharmaceuticals, cosmetics	1	10	40	0	10	0	0	0	2	8	0	2	0	0
12. Biotechnology	5	40	5	0	7	1	0	7	117	23	0	20	16	0
13. Materials, metallurgy	0	0	1	0	8	12	0	0	0	0	0	0	0	0
14. Agriculture, food chemistry	9	0	13	0	1	8	0	8	0	0	0	2	2	0
15. Chemical and petrol industry, basic materials chemistry	6	6	0	0	0	1	0	0	4	0	0	0	0	0
IV. Process engineering, special equipments	0	1	1	0	2	0	0	0	0	0	0	11	0	5
V. Mechanical engineering, machinery	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	28	66	60	0	41	22	0	15	188	99	0	61	21	5
Total = 100	12.90	30.41	27.65	0.00	18.89	10.14	0.00	3.86	48.33	25.45	0.00	15.68	5.40	1.29
Technology sector	Catalonia							Basque Country						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
I. Electrical engineering	0	0	0	0	0	0	0	0	0	0	0	0	0	0
II. Instruments	0	0	1	0	0	0	0	0	0	0	0	0	6	0
III. Chemistry, pharmaceuticals														
9. Organic fine chemistry	0	42	167	0	93	0	0	0	1	16	0	15	0	0
10. Macromolecular chemistry, polymers	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11. Pharmaceuticals, cosmetics	1	14	42	0	10	1	0	0	0	0	0	0	0	0
12. Biotechnology	1	31	19	0	8	7	0	0	29	24	0	0	0	0
13. Materials, metallurgy	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14. Agriculture, food chemistry	13	1	4	0	0	4	0	0	0	0	0	0	0	0
15. Chemical and petrol industry, basic materials chemistry	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IV. Process engineering, special equipments	0	0	0	0	0	0	0	0	0	0	0	0	0	0
V. Mechanical engineering, machinery	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	15	88	232	0	111	12	0	0	30	40	0	15	0	0
Total = 100	3.28	19.21	50.66	0.00	24.24	2.62	0.00	0.00	35.29	47.06	0.00	17.65	0.00	0.00

Source: OEPM and authors' own data. *Note*: 1, agro-food (agriculture, forestry, food technology, food quality and safety, etc.); 2, life sciences (biology, biotechnology); 3, health science and technology; 4, natural resources and the environment (atmospheric phenomena, marine ecosystems, water resources, etc.); 5, physics, chemistry and mathematics; 6, technologies of production (fabrication and production processes, automation and robotics, quality control systems, engineering in general, etc.); 7, information and communications technologies.

community of Madrid, the sectors active in organic chemistry and biotechnology account for 85% of the citations (and in the Basque Country, this figure is 97%). In Catalonia, the sectors of organic chemistry and pharmaceuticals account for 80% of the citations. In contrast, in the "objective no. 1" regions the dispersion is wider: in the three sectors accounting for most of former links (biotechnology, pharmaceuticals and food chemistry), 65% of all the citations are concentrated; in these regions the citations of the six most active sectors must be taken together to present a similar percentage

Table 9
Mean equality test between regions

	No. of patents with citations	Means			
		Total citations	Citations in C2	Citations in C3	Citations in C7
Objective no. 1 regions vs. Madrid					
Total sectors					
Madrid	41	10.76	9.40	4.50	2.93
Objective no. 1 regions	24	10.17	5.08*	4.62	2.77
High technology sectors					
Madrid	18	12.61	11.90	2.82	2.20
Objective no. 1 regions	11	11.64	5.00**	4.50	2.13
Objective no. 1 regions vs. Catalonia					
Total sectors					
Catalonia	61	8.21	4.63	5.83	2.78
Objective no. 1 regions	24	10.17	5.08	4.62	2.93
High technology sectors					
Catalonia	19	7.63	5.00	5.64	1.80
Objective no. 1 regions	11	11.64	5.00	4.50	2.13

Source: authors' own data. *Note*: the scientific fields correspond to the following: C2, life sciences (biology, biotechnology); C3, health science and technology; C7, physics, chemistry and mathematics. The results of the test of means coincide with the results of the test of medians, and with a test using the whole sample.

* 10% significance.

** 5% significance.

concentration as the top two sectors of the more developed regions.

In consequence, the strong science–technology relationship in the chemical sectors, and the relative absence of relationship between sectors of engineering technology and the scientific citations, at least in Spain, is independent of the level of regional development and specialisation. However, the concentration of citations in only a few sectors, which characterises the more developed regions (Madrid, together with Catalonia and the Basque Country), is not observed in the "objective no. 1" regions.

Table 8 presents the number of citations broken down by scientific fields. On average (i.e. for Spain as a whole), the scientific fields where we observe the most science–technology flows are health science and technology (37.5% of total citations), life sciences (32.4% of citations) and physics, chemistry and mathematics (19.8% of citations). It may be observed that the detailed analysis by regions produces a somewhat similar picture in the scientific fields to that found in the technology sectors: the more developed regions present a strong concentration of citations in two or three fields, whereas this degree of concentration is not seen in the "objective no. 1" regions. Again, the relative degrees of economic specialisation seem to explain these results: in the more developed regions, specialised in sectors related to chemical processes and biotechnology, patents mainly cite articles on life sciences and health technology, whereas the less developed regions are basically specialised in sectors of medium-to-low technology, in which patents cite articles on the fields of agro-food research and technologies of production.

6.2. Mean equality test

In addition to the information extracted from the preceding tables, the results of the statistical tests of means conducted are given in Tables 9 and 10. This analysis enables us to determine whether the difference in behaviour of the variables observed in the descriptive analysis of the data in the tables is significant or not. The test of means between groups becomes more relevant when the number of observations is limited; in these cases, a difference can be found but this may not be significant. The results are as follows:[9]

- In respect of hypothesis H1, the data given in Table 8 show that, although there are differences between

[9] The same results are obtained from a test of medians, which avoids possible distortion due to anomalous observations.

Table 10
Mean equality test for the patents referenced

	No. of patents	Patents cited
Objective no. 1 regions vs. Madrid		
High technology sectors		
Madrid	111	4.04
Objective no. 1 regions	45	4.39
Sectors of intermediate complexity		
Madrid	111	4.3
Objective no. 1 regions	160	4.77*
Sectors of low complexity		
Madrid	19	4.95
Objective no. 1 regions	44	4.27
Objective no. 1 regions vs. Catalonia		
High technology sectors		
Catalonia	79	4.1
Objective no. 1 regions	45	4.39
Sectors of intermediate complexity		
Catalonia	288	4.52
Objective no. 1 regions	160	4.77
Sectors of low complexity		
Catalonia	41	4.1
Objective no. 1 regions	44	4.27
Objective no. 1 regions vs. Basque Country		
High technology sectors		
Basque Country	14	4
Objective no. 1 regions	45	4.39
Sectors of intermediate complexity		
Basque Country	69	4.23
Objective no. 1 regions	160	4.77*
Sectors of low complexity		
Basque Country	9	4.33
Objective no. 1 regions	44	4.27

Source: authors' own data.
* 10% significance.

each type of region, these differences are not statistically significant between "objective no. 1" regions and Catalonia.[10]

- H2: The test of means shows that there does exist a significant difference in respect of field 2 between "objective no. 1" regions and Madrid.

  Breaking the data down by scientific fields, it can be observed that the differences are found in field 2; in other words, that in the more developed regions, scientific articles are cited more, on average, in field 2—related to the high technology sectors—than in the "objective no. 1" regions. These differences are sharper when the high technology sectors are considered. The explanation for these results lies, once again, in the degree of specialisation. In those regions where there is a high degree of specialisation in high technology sectors with strong science–technology linkages (Madrid), a high degree of concentration in respect of the citation of scientific literature is found, as previously demonstrated. However, such concentration is not found with the "objective no. 1" regions, where the scientific fields that are cited in patents are much more widely dispersed.
- In respect of hypotheses H3 and H4, the analysis of means shows that the differences occur in sectors of intermediate technology, and always in favour of the "objective no. 1" regions, which are more specialised in this category of technology.

7. Conclusions

As confirmed in the preceding sections, the "objective no. 1" regions of Spain, are characterised by specific circumstances that may condition science–technology flows: technological specialisation is in sectors of medium and low complexity; a relatively small number of companies undertake high technology activities; and those few high technology companies that do operate are of a smaller average size and present a lower productivity than similar companies in the more developed regions. Based on these initial premises as the main conditioners of science–technology flows, from the application of an established methodology of analysis to the regional level using the scientific citations in new patent documents (NPC), we have been able to identify certain regional characteristics of the science–technology flows and to test our working hypotheses. The following are the main results obtained:

- Significant differences exist in the science–technology flows in sectors where the application of technology is intensive, between the "objective no. 1" regions and Madrid. In the "objective no.

[10] The analysis has been conducted only with Catalonia: in the case of the Basque Country, the number of observations is insufficient. When the number of observations is less than 5, the test of means has been omitted.

1” regions, relevant scientific literature is cited less frequently in patents, on average; however, such differences are not observed between “objective no. 1” regions and others of intermediate economic development (Catalonia and the Basque Country).
- Significant differences exist in the knowledge of the antecedents of innovations (patent citations) between the “objective no. 1” regions and Madrid, in sectors of intermediate technological complexity. No such differences are observed between “objective no. 1” regions and Catalonia (which is classified as a region of intermediate economic development).

The reason for these differences lies in the degrees of specialisation of the regions. Madrid is weighted relatively heavily in importance among all the regions of Spain, and presents coefficients of specialisation higher than unity in sectors where the use of technology is intensive. Therefore, in this region, there is a greater diffusion of codified knowledge that is utilised for the development of innovations in such sectors.

On the contrary, the objective no. 1 regions (and those of intermediate development, such as Catalonia) are more specialised in sectors of moderate or low technological complexity, that generally have little involvement with scientific research to support new developments, relying instead more on knowledge accumulated from previous technological development. The data obtained reveal that these regions are more knowledgeable in technology of medium to low complexity and hence in these sectors, tacit knowledge of the technological antecedents of specific previous innovations is more prevalent.

It is appropriate, lastly, to include some reflections on the implications of the results obtained for regional policies in respect of the planning of R&D. In the “objective no. 1” regions, substantial efforts are being made to strengthen the resources in higher education and, in some cases, to encourage research groups working in fields related to the technology employed in sectors where there exists a certain degree of regional economic specialisation. This calls for reflection on the relevance of such efforts when the sectors involved are of low technology and show a relatively low utilisation of the results of scientific research for innovation and extensive use of technological knowledge included in patents.

Finally, our intentions in respect of future investigations are directed towards extending the period of study, to respond to other questions such as how locally generated scientific knowledge is applied by local industry and by “out of region” industry. Another proposal is to put forward a micro-economic model to identify the causes of regional differences in particular sectors and scientific fields; to explain these differences, one must take into account not only the external factors and the regional context but also certain micro-economic characteristics of the companies.

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