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Regional Planning of R&D and Science–Technology Interactions in Andalucia: A Bibliometric Analysis of Patent Documents

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ABSTRACT *Andalucia is a southern European LFR (less-favoured region) with a high degree of self-government that has allowed it to design its own R&D policies that complement those implemented throughout Spain and the European Union (EU). Recently the Regional Government passed the Third Andalucian Research Plan 2000–2003, an R&D planning instrument that, as has become customary in previous Plans, attributes considerable budgetary weight to the scientific aspects of the science–technology–industry system (Andalucia allocates more of its own resources to promoting research than any other region in Spain). This paper provides deeper insight into the role played by science in driving the technological development of Andalucia, one of the LFRs of the EU. The aim was to answer five fundamental questions: How is basic science utilized by industry in Andalucia? Which sectors are the most dynamic in the employment of scientific know-how? Which scientific fields are most in demand by industry? Which types of institution utilize scientific knowledge most profusely? What delay is there in incorporating science into technology? The methodology that has been applied for investigating the links between science and technology is based on scientific citations in patent documents (NPC). The results in this article provide relevant information about the interconnection of scientific and technological systems and thus constitute a good point of reference for the development of future R&D plans.*

1. Introduction

Many European Union (EU) regions with a high degree of self-government have opted firmly for scientific research and technological development to drive economic growth and their citizens' welfare. Andalucia has been one of Spain's first Regional Governments to organize its efforts in science and technology ever since it assumed competence in these fields, in 1984.[2] Recently the Regional Government passed the Third Andalucian Research Plan 2000–2003, an R&D planning instrument that, as has become customary in previous Plans, attributes considerable budgetary weight to the scientific aspects of the science–technology–industry system (Andalucia allocates more of its own resources to promoting research than any other region in Spain).

This paper provides deeper insight into the role played by science in driving the

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technological development of Andalucia, one of the less-favoured regions (LFRs) of the EU. In this study we aim to answer the following questions: How is basic science utilized by industry in Andalucia? Which sectors are the most dynamic in the use of scientific knowledge? Which scientific fields are most in demand by industry? Which types of institution utilize scientific knowledge most profusely? What is the delay in incorporating science into technology?

Our ultimate goal is to supply facts about the links between science and technology that could contribute to the design of future R&D plans in Andalucia. This case study also has a bearing, albeit tangential, on the debate regarding how to strengthen the scientific system as an instrument for driving technological development and innovation. The methodology we apply to investigate the linkage between science and technology is based on scientific citations in patent documents (NPC), which dates back to the pioneering studies of Carpenter *et al.* (1980), Carpenter and Narin (1983), Narin and Noma (1985) and Van Vianen *et al.* (1990), and has recently been applied in the studies of Meyer (2000a), McMillan *et al.* (2000) and Tijssen (2001). The novelty of this study with respect to those undertaken on science–technology interactions is the consideration of a regional scale using the NPC methodology (the norm to date has been national analyses, generally of industrialized countries). It is also intended as a first approach to the science–technology interactions in Andalucia because, as the Regional Government itself has recognized, it is very hard to estimate how relevant the topics selected for research are for the needs of the productive system; until now, the true incidence of scientific research on the productive system has not been known (Junta de Andalucía, 2000, p. 14).

The paper is structured as follows: The next section presents a theoretical framework that establishes the relationship between science and technology and its measurement; section three is an analysis of the economic context and current planning of R&D in Andalucia; section four describes the principles underlying the methodology, the data and the statistical sources; section five is a detailed study of the scientific citations in patent documents, by means of which we propose to answer the questions raised. The paper finishes with some conclusions that may serve, together with other diagnostic instruments that complement the methodology used (e.g. descriptive studies, experts' opinions, etc.), as a basis of support for reflecting on the design of public policies for research and technological development.

2. Science–Technology Flows on Regional Scales: Theoretical Background

One of the principal reasons why economists have devoted considerable effort to the study of science and scientific policy is its influence on economic growth or, more specifically, on technological development as the intermediate stage between science and growth. The idea that basic scientific research generates a technological impulse and, consequently, has direct repercussions on economic growth, corresponded originally with a hypothesis of linearity of the innovation process that arose from the visible success of science in driving certain high technology activities in the US after World War II (Malecki, 1997, p. 52).[3] This linear model suggests that there is a one-way sequence from basic and applied research in universities and research institutes, towards the development of new processes and products, their production and, finally, their marketing and distribution. This simplistic version of the technology creation process has given way to a system in which science–technology interrelations are rather more complex than the linear model postulates. The technological impulse that the linear model assumes is insufficient to explain the two-way transfer of knowledge between science and technology. The appearance of numerous institutions (associations of companies, universities, research institutes and other institutions providing an interface for the integration of science and technology), through an organized system—sometimes voluntary, involuntary in other cases—has replaced the old linear model. The modern theories of innovation, based on evolutionary propositions, suggested in the pioneering work of Nelson and Winter (1982),[4] convey a more sociological view of innovation, in which knowledge as a resource and interactive learning are fundamental aspects of the process (Lundvall & Borras, 1997; Lundvall & Johnson, 1994). New organizational forms have appeared among institutional spheres—university, industry and government—that are indicative of the importance of knowledge and of the flow of learning for economic growth and social transformation: national/regional systems of innovation (Nelson, 1993; Lundvall, 1992; Braczyk *et al.*, 1998), systems of research in transition (Cozzens *et al.*, 1990; Ziman, 1994), the triple helix model (Etzkowitz & Leydesdorff, 1997, 2000; Leydesdorff, 2000), etc. In these approaches, the science–technology relationship is not linear in one direction: on the contrary, the flows are two-way and the interaction is continuous. In this new framework, the classic legitimacy for scientific research as a contribution to culture remains, together with military, public health and environmental objectives; however, the legitimacy of research in the future will be its capacity to generate new lines of economic development (Etzkowitz & Leydersdorff, 2000). Various lines of research have arisen utilizing different methodologies to examine the relationships between scientific knowledge and the development of innovations (Mansfield, 1995, 1998; Nelson & Wolff, 1997), to identify the scientific antecedents of innovation with the objective of explaining science–technology flows (Narin *et al.*, 1997; Meyer, 2000a; Tijssen, 2001), or to examine the contribution of universities to the innovative activity of companies (Meyer-Krahmer & Schmoch, 1998; Mansfield & Lee, 1996; Beise & Stahl, 1999). In general, all these studies serve to demonstrate the dependence of technologically-intensive industry on scientific research and how academic research contributes to the resolution of technological problems (Pavitt, 1998).

Yet does a regional approach fit into this debate? The modern theories of innovation based on evolutionary concepts have added new and solid reasons for more in-depth research into the spatial aspects of innovation. It has been argued that the social determinants of innovation (political, economic, industrial institutions, etc.) are profoundly different from one region to another, a viewpoint that illustrates the essential role of regional economies as constituent blocks of an increasingly globalized world (Storper, 1995, 1997). Further, various authors have stated that the economy based on knowledge, on the labour force and on the availability of strong companies is often more local or regional than national (Krugman, 1992, 1995; Porter, 1990; Cooke, 1997). This kind of reasoning has led many regional economists and geographers to try to bring into convergence the theory of innovation without a specific spatial content, with regional studies; in this way, several lines of research have arisen whose best-known exponents are the authors associated with the "Groupement de Recherche Européen sur Les Milieux Innovateur-GREMI" (Aydalot & 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). As products of these tendencies, concepts have been developed such as 'the learning region' (Asheim, 1996; Simmie, 1997; Morgan, 1997), structural competitiveness (Cooke & Schienstock, 2000), regional innovative capacity (Lawson, 1999; Lawson & Lorenz, 1999), regional innovation systems (Cooke *et al.*, 1998; Braczyk *et al.*, 1998), technology districts (Castells & Hall, 1994; Storper, 1995, 1997; Paci & Usai, 2000), etc. All this literature has a point of convergence: the importance of the locational and institutional factors that come together in one territory with the aim of fostering a collective learning that encourages a suitable climate for the increase of innovative activities and competitiveness. In general, the geographic distance, accessibility, clustering and the presence of externalities exert a powerful influence on the flow of knowledge, i.e. learning, which is the fundamental basis of technical change and the innovative process. This interaction often takes place on a regional scale. In this context, the analysis of particular geographical spaces, like high technology districts or regions (Markusen *et al.*, 1986; Saxenian, 1994; Sternberg & Tamásy, 1999; Wever & Stam, 1999), regional systems of innovation (Cooke *et al.*, 1998; Brazyck *et al.*, 1998) and some empirical (econometric) analysis (Varga, 1998; Anselin *et al.*, 1997, 2000), underlines the importance of university scientific research as an instrument for boosting regional economic development. These studies have emphasized that the availability of scientific knowledge is also relevant on a sub-national scale. The proliferation of this consistent literature illustrating the importance of physical proximity for knowledge flows and for the promotion and development of innovation, allied with the high degree of self-government enjoyed by many European regions, makes it clear that the study of science is relevant not only in national or supra-national contexts but also on a regional scale.[5] We will focus on these science–technology flows in a regional context.

3. The Economic Context and Planning of Innovation in Andalucia

Andalucia is Spain's most highly-populated Autonomous Region (7,478,432 inhabitants), accounting for 17.86% of the total national population (followed by Catalonia, Madrid and Valencia, in order of population) and covers 17.31% of the total national territory (87,597 km^2). In the context of the EU, Andalucia belongs to the group of LFRs. In 1986, its per capita gross domestic product (GDP) was 52.8% of the average for the EU as a whole, increasing to 64% in 2002, which is evidence of the convergence that is taking place, albeit very slowly. Levels of unemployment in the region are triple the average levels for the EU as a whole, and although all sectors of the population are affected, the highest differences with respect to the EU average are in female unemployment, where the rate is almost four times the EU average. The latest 2002 figures available on the productive structure of Andalucia (in gross value added (GVA) terms) show a distribution still disproportionately weighted towards primary activities: 8.22% of total production, compared with 13.72% for manufacturing, 9.67% for construction and 68.38% for the services sector. These figures contrast with the equivalent distribution of national production, in which the primary sector accounts for 3.87% of total GVA, manufacturing for 21.94%, construction for 8.33% and services for 65.85%.

In 2001, Andalucia's total R&D effort (total expenditure on R&D as a percentage of GDP) was 0.69%, below the average value for Spain (0.96%) and considerably lower than the average value for the EU (1.93%). Nonetheless, the global technological effort in the region has evolved very well in recent years, having doubled in just one decade and thereby pushing Andalucia up the ranking of Spanish Autonomous Regions. Universities account for more than half of all resources, having enjoyed a very substantial increase in the last decade (more than 400% in real terms). This spectacular rise in public expenditure has not been paralleled by private sector expenditure. Business expenditure on R&D in Andalucia represents a distinctly small proportion of total R&D expenditure in the region (27.77% of the total for 2001), particularly in comparison with the Spanish national average (52.37%), which itself can be considered low against the average value for the EU (64.5%).

These considerable deficiencies in respect of technology contrast with the indicators of scientific output and the region's participation in the national picture of scientific research. For example, the number of scientists with doctorate-level qualifications active in research groups has grown by 121.9% over the level of 1990, and in absolute terms now exceeds 10,212. Currently there are 17,923 scientists with University degree qualifications working in 1850 teams, comprising the system of scientific research of Andalucia. In 1987, this region accounted for 5.99% of all researchers in Spain; by 2001, this figure had more than trebled to 17.72%. With respect to scientific output, in 1987 Andalucia represented 9% of all scientific papers in international publications generated in the whole of the country, but by 2000 this figure had increased to 12.48% of the total. In this regard, Andalucia's scientific output exceeds the national average in the fields of agro-food, social sciences and information and communication technology (ICT).

For the coming years, some of the elements brought together in the Third Research Plan for Andalucia 2000–2003 (3rd PAI)[6] reveal the guidelines that will mark the organization of the system. This Plan lays out the basic lines of strategy for innovation and technological development foreseen for Andalucia in the near future (in keeping with the general principles included in the planning documents for the two broader spatial scales, such as the 4th National Plan for Scientific Research, Development and Technological Innovation (2000–2003) and the 5th Framework R&D Programme (1998–2002) of the EU). The general objectives of the 3rd PAI are the promotion and coordination of scientific research and technological development, together with a review of the situation in respect of the scientific-technical and productive systems in the Autonomous Region of Andalucia. In this global framework, four specific objectives are defined, three of which relate fundamentally to the scientific-university area and the other to the productive environment (to increase collaboration between the Public Centres of Research and the companies of the Region). After the 3rd PAI had been drawn up and been set in motion, an Andalucian Innovation and Technological Development Master Plan (PLADIT 2001–2003) was produced. This Master Plan was passed by the Government of Andalucia in the summer of 2001, and was scheduled to enter into force at the end of 2001.

4. Methodology and Data

As stated at the beginning of this study, the methodology we follow for the purpose of identifying science–technology relationships is based on the analysis of scientific citations in patent documents, an approach previously only utilized on the national level. We make the same assumption as in other recent studies (Meyer, 2000a, 2000b, 2000c, 2002; McMillan *et al.*, 2000; Tijssen *et al.*, 2000; Tijssen, 2001, 2002; Verbeek *et al.*, 2002) that the scientific citations in patent documents (NPC) are a proxy variable to represent a particular unit or item of scientific knowledge that is required or considered useful for the development of patented technology. Patented inventions generally incorporate public and private knowledge in different proportions, and this materializes in references to citations of other patents and scientific literature. In patent documents, as occurs in scientific articles, it is usual to provide references or citations, the objective of which is to describe the antecedents or 'state of the art' prior to the invention. The antecedents or state of the art include not only other patents that have been utilized as support for the invention, but also bibliographical references to scientific literature and technical publications. These citations provide some indications of the potential contribution of the published research to the inventions patented. But the essential question to confer validity to the procedure followed in this study is: Do the scientific citations in patent documents genuinely reflect the use made of scientific knowledge by the industrial sector? The following arguments will help to answer this question:

- The references included in a patent are less likely to be redundant or superfluous than those included in a scientific article, due to the control that is exercised over patents and to their legal consequences (Collins & Wyatt, 1988; Verbeek *et al.*, 2002).
- The empirical analyses conducted in various studies (Grupp & Schmoch, 1992; Schmoch, 1993; Narin & Olivastro, 1998; Meyer, 2000a, 2000b) 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.[7]
- The studies in aggregate seem to confirm that NPCs measure the intensity of the science supporting the innovations 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 utilize 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). Therefore, "it does not seem appropriate to use the linear science-push model to interpret patent citation data" Meyer (2000a), and also "One should refer to science and technology *interplay* rather than speak of science-dependence in the context of patent citations" (Meyer, 2000c). This lack of clear causality is also noted by Tijssen (2002) who refers to "the questionable validity of these citations as causal measures of knowledge flows from the science base to the technology domain". Summing up, various validation studies seem to have lowered the degree of optimism expressed in the initial studies of Narin and his coworkers 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, instead of causality, dependence or science-driving technology relationships, as postulated by a linear model.[8]

The conclusion after presenting these arguments can be summarized as follows: scientific citations in patent documents are useful indicators for reflecting the relationships between the scientific and industrial fields. Scientific citations in patent documents reflect the degree to which technological development makes use of scientific knowledge; by means of these citations, it is possible to determine the existence of prior scientific knowledge on which the development of a particular patent has been sustained, but they only constitute a partial perspective of the complex science–technology relationships: the part of codified knowledge that is utilized as a source of ideas, analytical methods and data: other interesting sources of tacit knowledge are not visible by means of this methodology.

The period analysed in our research extends from 1984 to 2000, both years inclusive. The choice of the starting year is because 1984 was the first year in which the Andalucian Regional Government assumed jurisdiction over science and technology matters. During this 17-year period, residents in Andalucia have registered a total of 500 patents;[9] this figure represents 4.52% of the national total of 11,072 patents. Of these 500 patents, we have conducted a comprehensive review of 336 documents (all those for which the complete text has been published). Hence the sample utilized in this study is considered sufficiently representative and accounts for 67.2% of all the patents registered by researchers resident in Andalucia. Tables 1 and 2 give, by industry/technology sector[10] and by levels of technical complexity, respectively, the total number patents examined, classified into three periods of time: 1984–1989 (from when the Andalucian Regional Government assumed competence in regional R&D matters, until the entry into force of the Andalucian Research Plan—the 1st PAI); 1990–1996 (period of applicability of the PAI and the transitional years until the entry into force of the 2nd PAI); and 1997–2000 (period of applicability of the 2nd PAI). In any case, the 1984–1989 period is, as indicated in note 6, not very significant. As may be seen in Table 1, the sample reflects the relative weight of agro-food activities (sector 14, Agriculture, food chemistry), since this industry plays an important role in the productive structure of Andalucia. In Table 3 the patents examined have been classified by the type of institution applying for the patent, and as can be seen, Universities account for nearly one third of the sample, consistent with their importance in the total capacity for obtaining patents, in the context of the whole region.

After classifying the total set of patents to be examined, we listed the scientific citations for each of the technological sectors of industry in Andalucia, on the basis of the seven scientific-technical areas or scientific fields defined in the Andalucian Research Plan (Junta de

Table 1. Number of patents, by technology sector and period

Technology sector	1984/89	1990/96	1997/00	Total	%
I. ELECTRICAL ENGINEERING					
1. Electrical machinery and apparatus, electrical energy	0	3	0	3	0.89
2. Audio-visual technology	3	5	1	9	2.68
3. Telecommunications	0	7	0	7	2.08
4. Information technology	0	4	4	8	2.38
5. Semiconductors	0	1	0	1	0.30
II. INSTRUMENTS					
6. Optics	2	2	0	4	1.19
7. Analysis, measurement, control technology	6	26	9	41	12.20
8. Medical technology	0	3	8	11	3.27
III. CHEMISTRY, PHARMACEUTICALS					
9. Organic fine chemistry	1	16	3	20	5.95
10. Macromolecular chemistry, polymers	0	0	0	0	0.00
11. Pharmaceuticals, cosmetics	0	3	6	9	2.68
12. Biotechnology	1	11	5	17	5.06
13. Materials, metallurgy	3	6	2	11	3.27
14. Agriculture, food chemistry	6	14	5	25	7.44
15. Chemical and petrol industry, basic materials chemistry	2	9	4	15	4.46
IV. PROCESS ENGINEERING, SPECIAL EQUIPMENT					
16. Chemical engineering	0	13	1	14	4.17
17. Surface technology, coating	0	1	1	2	0.60
18. Materials processing, textiles, papers	5	14	1	20	5.95
19. Thermal processes and apparatus	0	3	1	4	1.19
20. Environmental technology	1	7	2	10	2.98
V. MECHANICAL ENGINEERING, MACHINERY					
21. Machine tools	1	6	2	9	2.68
22. Engines, pumps, turbines	0	1	0	1	0.30
23. Mechanical elements	1	3	0	4	1.19
24. Handling, printing	11	13	1	25	7.44

Table 1—*continued*

Technology sector	1984/89	1990/96	1997/00	Total	%
25. Agricultural and food processing, machinery and apparatus	5	10	15	30	8.93
26. Transport	4	4	0	8	2.38
27. Nuclear engineering	0	0	0	0	0.00
28. Space technology, weapons	1	0	0	1	0.30
29. Consumer goods and equipment	1	6	0	7	2.08
30. Civil engineering, building, mining	2	13	5	20	5.95
TOTAL	56	204	76	336	100.00

Source: OEPM and author's own figures.

Table 2. Number of patents, by technical complexity and period

Level of complexity	1984/89	1990/96	1997/00	Total	%
High	11	53	29	93	27.69
Intermediate	7	21	5	33	9.85
Low	37	130	42	210	62.46
Total	56	204	76	336	100

Source: OEPM and author's own figures.

Table 3. Number of patents, by institution and period

Institution	1984/89	1990/96	1997/00	TOTAL	%
Private companies	54	132	36	222	66.07
Universities	2	72	40	114	33.93
Total	56	204	76	336	100

Source: OEPM and author's own figures.

Table 4. Types of citations, by periods

Periods	Papers	Books	Congresses	Theses	Total citations		Total citat./no. patents
					No.	%	
1984/89	24	0	1	0	25	2.06	0.45
1990/96	766	133	31	9	939	76.91	4.60
1997/00	217	25	13	2	257	21.03	3.38
Total	1,007	158	45	11	1,221	100	3.63

Source: OEPM and author's own figures.

Andalucía, 2000, p. 5) after excluding the fields related to economic and social sciences, law and humanities:

- AGR: Agro-food (agro-forestry, food technology, quality and safety, etc.).
- LSC: Life sciences (biology, biotechnology).
- HST: Health science and technology.
- NRE: Natural resources and the natural environment (atmospheric phenomena, marine ecosystems, water resources, etc.).
- PCM: Physics, chemistry and mathematics.
- PRT: Production technologies (manufacturing and production processes, automation and robotics, quality systems, engineering in general, etc.).
- ICT: Information and communications technologies.

Broadly speaking, it is difficult to draw clear boundaries between particular areas or fields of science. The criterion adopted when a particular paper could be attributed to two different scientific fields has been to attribute it to both.[11] This process was followed in preparing the tables in the next section, from which we have drawn the data needed to answer the questions we asked at the beginning.

5. Results

Table 4 gives the citations included in the 336 patent documents examined, classified into four types (papers in scientific journals, books, congresses and doctoral theses). It can be observed that the majority of citations refer to papers in scientific journals (82%), followed by books (13%), congresses (4%) and only a very small percentage refer to doctoral theses (1%). If we weight by the number of patents, on average about four scientific references are cited in each patent (last column of Table 4).

In order to determine which scientific-technical areas are most closely related to each of the industrial sectors (science–technology interactions), the bibliographical references cited in each document of patent were classified according to scientific fields. Whenever a citation could be classified under two different scientific fields, it has been allocated to both. Table 5 lists the distribution of the citations in papers, by scientific fields, and clearly shows that those most in demand by industry (those most cited in the patent documents) are, in the following order: PCM; HST; LSC. It can also be observed that, although Andalucia has a strong economic and technological specialization in the sector of food technology, the scientific field AGR only accounts for 9.29% of the total citations in papers. Table 5 shows that the greatest scientific contribution is made to the sectors with intensive technology use (analysis, measurement and control technology, and sectors related to chemical processing).

Clear conclusions may be drawn if one looks at the industrial activities that are most representative in terms of technology (those with higher expenditure on technological innovation and higher numbers of patents applied for, Table 6):

- Sector 14 (Agriculture, food chemicals), in which Andalucia presents a high degree of specialization, with 33.3% of the total expenditure on technological innovation and 7.4% of total patents, accounts for 6.5% of total citations, and is related mainly to the fields of AGR (40.5%) and LSC (36.7%). It can be observed that, in this case, there is a very high concentration in the two technological fields.
- Sector 7 (Analysis, measurement and control technology), with 8.2% of total expenditure on innovation, shows the greatest tendency to patent, with 12.2% of the patents registered; in absolute terms, this sector has the highest demand for scientific knowledge (24% of total citations). This demand spreads across nearly all scientific fields, although with more

Table 5. Number of citations by scientific fields and technology sector

Technology sector	Scientific fields (*)							Total citations		Citat./pat.
	AGR	LSC	HST	NRE	PCM	PRT	ICT	Total	%	
I. ELECTRICAL ENGINEERING										
1. Electrical machinery and apparatus, electrical energy	0	0	0	0	0	0	0	0	0.00	0.00
2. Audio-visual technology	0	0	0	0	0	0	0	0	0.00	0.00
3. Telecommunications	0	0	2	0	0	0	0	2	0.16	0.29
4. Information technology	0	0	0	0	2	2	1	5	0.41	0.63
5. Semiconductors	0	0	0	0	0	0	0	0	0.00	0.00
II. INSTRUMENTS										
6. Optics	0	0	0	0	0	0	0	0	0.00	0.00
7. Analysis, measurement, control technology	33	56	82	13	90	22	7	303	24.90	7.39
8. Medical technology	0	0	4	0	2	0	0	6	0.49	0.55
III. CHEMISTRY, PHARMACEUTICALS										
9. Organic fine chemistry	10	45	26	1	95	14	0	191	15.69	9.55
10. Macromolecular chemistry, polymers	0	0	0	0	0	0	0	0	0.00	–
11. Pharmaceuticals, cosmetics	0	18	47	0	7	2	0	74	6.08	8.22
12. Biotechnology	7	92	34	0	27	30	0	190	15.61	11.18
13. Materials, metallurgy	3	2	0	1	29	21	0	56	4.60	5.09
14. Agriculture, food chemistry	32	29	13	1	3	1	0	79	6.49	3.16
15. Chemical and petrol industry, basic materials chemistry	20	41	20	0	6	5	0	92	7.56	6.13
IV. PROCESS ENGINEERING, SPECIAL EQUIPMENT										
16. Chemical engineering	7	14	5	4	50	12	5	97	7.97	6.93
17. Surface technology, coating	0	0	0	0	44	34	1	79	6.49	39.50
18. Materials processing, textiles, papers	0	0	0	0	0	0	0	0	0.00	0.00
19. Thermal processes and apparatus	0	0	0	0	5	0	0	5	0.41	1.25
20. Environmental technology	0	0	0	3	4	5	0	12	0.99	1.20
V. MECHANICAL ENGINEERING, MACHINERY										
21. Machine tools	0	0	0	0	0	0	0	0	0.00	0.00
22. Engines, pumps, turbines	0	0	0	0	0	0	0	0	0.00	0.00
23. Mechanical elements	0	0	0	0	0	0	0	0	0.00	0.00
24. Handling, printing	0	0	0	0	0	0	0	0	0.00	0.00
25. Agricultural and food processing, machinery and apparatus	1	2	1	2	0	0	0	6	0.49	0.20
26. Transport	0	0	0	0	0	0	0	0	0.00	0.00
27. Nuclear engineering	0	0	0	0	0	0	0	0	0.00	–
28. Space technology, weapons	0	0	0	0	0	0	0	0	0.00	0.00
29. Consumer goods and equipment	0	0	14	1	2	3	0	20	1.64	2.86
30. Civil engineering, building, mining	0	0	0	0	0	0	0	0	0.00	0.00
TOTAL	113	299	248	26	366	151	14	1,217	100	3.62

(*) Scientific fields:
AGR: Agro-food (agro-forestry, food technology, food quality and safety, etc.). LSC: Life sciences (biology, biotechnology). HST: Health sciences and technology. NRE: Natural resources and environment (atmospheric phenomena, marine ecosystems, water resources, etc.). PCM: Physics, chemistry and mathematics. PRT: Production technologies (manufacturing and production processes, automation and robotics, quality systems, engineering in general, etc.). ICT: Information and Communications Technologies.
Source: Author's own figures, from OEPM data.

Table 6. Citations in the most representative sectors in the technology expenditure structure (*)

	Exp. (1)	AGR	LSC	HST	NRE	PCM	PRT	ICT	Total Citat.	% citat.	% pat	citat/ pat
14. Agriculture, food chemistry	33.3	32	29	13	1	3	1	0	79	6.5	7.4	3.2
26. Transport	12.8	0	0	0	0	0	0	0	0	0.0	2.3	0.0
7. Analysis, measurement, control technology	8.2	33	56	82	13	90	22	7	303	24.9	12.2	7.4
18. Materials processing, textiles, paper	7.6	0	0	0	0	0	0	0	0	0.0	5.9	0.0
13. Materials, metallurgy	7.1	3	2	0	1	29	21	0	56	4.6	3.3	5.1

(*) Scientific fields:

AGR: Agro-food (agro-forestry, food technology, food quality and safety, etc.). LSC: Life sciences (biology, biotechnology). HST: Health sciences and technology. NRE: Natural resources and environment (atmospheric phenomena, marine ecosystems, water resources, etc.). PCM: Physics, chemistry and mathematics. PRT: Production technologies (manufacturing and production processes, automation and robotics, quality systems, engineering in general, etc.). ICT: Information and Communications Technologies.

(1) Expenditure on innovation by technology sector in 1998 (percentage of total).

Source: Author's own figures, from OEPM and IEA data.

Table 7. Distribution of citations, by scientific field and the technical complexity of the patents (%)

Level of complexity	% of patents	Scientific fields (*)							Total
		AGR	LSC	HST	NRE	PCM	PRT	ICT	
High	27.69	8.46	18.97	34.62	3.33	25.90	6.67	2.05	100
Intermediate	9.85	5.37	27.29	11.32	1.16	37.16	16.84	0.87	100
Low	62.46	34.13	29.37	27.78	1.59	3.97	3.17	0.00	100
Total	100	9.38	24.81	20.58	1.91	30.04	12.12	1.16	100

(*) Scientific fields:
AGR: Agro-food (agro-forestry, food technology, food quality and safety, etc.). LSC: Life sciences (biology, biotechnology). HST: Health sciences and technology. NRE: Natural resources and environment (atmospheric phenomena, marine ecosystems, water resources, etc.). PCM: Physics, chemistry and mathematics. PRT: Production technologies (manufacturing and production processes, automation and robotics, quality systems, engineering in general, etc.). ICT: Information and Communications Technologies.
Source: Author's own figures, from OEPM data.

Table 8. Citations, by type of institution

Institution	Total citat. (%)	% pat.	Citat./pat.
Private companies	22.24	66.07	1.19
Universities	77.75	33.93	7.39
Total	1,217	100	3.43

Source: OEPM and author's own figures.

intensity in the fields of PCM, which accounts for 29.7%, and HST, accounting for 27%. A high proportion of the patents correspond to precision medical instruments.

- Sector 26 (Transport), with 12.8% of the total expenditure on innovation (divided into naval construction, 7.4%, and motor vehicles, 5.4%) and sector 8 (Materials processing, textiles and paper), with 7.6% of the expenditure on innovation, account for 8.3% of the patents. These sectors are of low technological intensity and, as is evident from Table 6, have a negligible relationship with scientific production. A similar situation occurs with sectors in which expenditure on innovation is not very high but the companies in general tend to protect their inventions with patents; sector 25 (Machinery and equipment for agriculture and the treatment of foods), sector 24 (Handling, printing), sector 30 (Civil engineering, construction and mining) together represent 22.3% of the patents applied for, but their relationship with scientific literature is practically zero.

Table 7 supplements these figures by giving the citations of papers broken down by the level of technical complexity involved in obtaining the patents. This shows that the sectors using high and very high technology are mainly related to the fields of HST, and PCM. Those sectors of low technological content are more related to the AGR and LSC fields.

To analyse the capacity in the use of science by companies and universities, Table 8 presents the citations attributable to each type of institution. It clearly shows that universities account for more than three quarters of all scientific citations, and in their patents cite six times more scientific papers than the companies.

Lastly, in order to examine the time lag with which new scientific knowledge is incorporated into technological developments, Table 9 lists the year of the last paper cited for all those sectors in which patents were obtained and scientific references exist. The dates clearly show that scientific output is incorporated into the generation of technology faster not only in sectors where technological competition is stronger or where there is greater propensity to patent (for example in sector 12, Biotechnology, and sector 7, Analysis, measurement and control technology) but also in those sectors where there is a high degree of technological specialization (sector 14, Agriculture, food chemistry).

6. Conclusions

Many EU regions, including the less-favoured such as Andalucia, have chosen to give a strong impulse to science, and particularly to scientific research in their universities. In this study, apart from describing the distinctive features of the planning system in Andalucia, we have tried to provide certain elements of judgment that enable regional science–technology relationships to be identified. The perspective adopted in this study could be useful—as another point of reference—for gearing policies in respect of expenditure on basic research in scientific contexts that may translate into industrial development. The results obtained, which are summarized later, have provided possible answers to the five basic questions made at the beginning:

Table 9. Year of the latest citation, by technology sector/scientific field

Technology sector	Scientific fields (*)						
	AGR	LSC	HST	NRE	PCM	PRT	ICT
I. ELECTRICAL ENGINEERING							
3. Telecommunications	–	–	1992	–	–	–	–
4. Information technology	–	–	–	–	1960	1994	1991
II. INSTRUMENTS							
7. Analysis, measurement, control technology	1997	1995	1998	1988	1996	1996	1987
8. Medical technology	–	–	1996	–	1995	–	–
III. CHEMISTRY, PHARMACEUTICALS							
9. Organic fine chemistry	1996	1995	1994	1974	1996	1995	–
11. Pharmaceuticals	–	1987	1998	–	1997	1996	–
12. Biotechnology	1997	1998	1996	–	1995	1998	–
13. Materials, metallurgy	1991	1988	–	1986	1995	1991	–
14. Agriculture, food chemistry	1995	1996	1997	1986	1995	1995	–
15. Chemical and petrol industry, basic materials chemistry	1994	1997	1995	–	1995	1990	–
IV. PROCESS ENGINEERING, SPECIAL EQUIPMENT							
16. Chemical engineering	1991	1995	1995	1988	1995	1991	1987
17. Surface technology, coating	–	–	–	–	1994	1994	1992
19. Thermal processes and apparatus	–	–	–	–	1993	–	–
20. Environmental technology	–	–	–	1983	1991	1991	–
V. MECHANICAL ENGINEERING, MACHINERY							
25. Agricultural and food processing, machinery and apparatus	1976	1984	1986	1984	–	–	–
29. Consumer goods and equipment	–	–	1994	1991	1976	1976	–

(*) Scientific fields:
AGR: Agro-food (agro-forestry, food technology, food quality and safety, etc.). LSC: Life sciences (biology, biotechnology). HST: Health sciences and technology. NRE: Natural resources and environment (atmospheric phenomena, marine ecosystems, water resources, etc.). PCM: Physics, chemistry and mathematics. PRT: Production technologies (manufacturing and production processes, automation and robotics, quality systems, engineering in general, etc.). ICT: Information and Communications Technologies.
Source: Author's own figures, from OEPM data.

- *Use of basic science by industry.* Andalucia's industry utilizes basic science fairly profusely; of the 336 patents in the sample, 28.27% are supported to a greater or less degree by scientific publications. However, the citations are heavily concentrated in very few sectors; two of them (sector 7, Analysis, measurement, control technology and sector 9, Organic fine chemistry) with 18.15% of patents account for 40.59% of all scientific citations and four (the previous two plus sector 12, Biotechnology and sector 16. Chemical engineering) with 27.38% of patents account for 64.17% of all scientific citations.
- *The sectors most dynamic in the use of scientific knowledge.* As expected, these are the very technologically intensive sectors (sector 7, Analysis, measurement and control technology, with 24.9% of the citations; sector 9, Organic fine chemistry, with 15.69% of the citations; sector 12, Biotechnology, with 15.61% of the citations). Sector 14 (Agriculture, food chemistry), in which Andalucia presents a high degree of specialization, accounting for 33.3% of total expenditure on technological innovation and 7.4% of patents, represents 6.5% of the total citations. Other sectors in which Andalucia specializes to a certain extent (sector 26, Transport, with 12.2% of the total expenditure on innovation, and sector 18, Materials processing, textiles, paper, with 7.6% of innovation expenditure) are low-technology intense activities that have a negligible relationship with scientific research output. A similar situation applies to those sectors that do not have such a high expenditure on innovation but that as a whole tend to protect their inventions with patents: sectors 25, Agriculture and food processing, machinery and apparatus; sector 24, Handling, printing; sector 30, Civil engineering, Building, mining, together represent 22.3% of the patents applied for; nevertheless, their relationship with scientific literature is practically zero.
- *Scientific fields most in demand by industry.* The scientific fields most in demand by industry are: PCM (30.07%), LSC (24.57%) and HST (20.38%). Andalucia is heavily specialized in the agro-food industrial sector (accounting for 33% of the expenditure on innovation), although the agro-food scientific field only represents 9.29% of total citations.
- *Institutions that make most use of scientific knowledge.* A far higher level of use of science is to be seen in the technology developed and patented by the universities than in the private sector. The Andalucian universities register six times as many citations as the private sector. This result is consistent with those obtained in other international research and confirms that the true use of science in the patented industrial inventions is made by the universities themselves, where scientific knowledge is generated and where the capability of understanding scientific literature is concentrated.
- *Delay in incorporating science into technology.* Scientific research output is incorporated into the generation of technology faster not only in sectors where technological competition is strong or where there is a greater propensity to patent (for example, in sectors 12, Biotechnology, and 7, Analysis, measurement and control technology), but also in those other sectors where there is a high degree of technological specialization (e.g. sector 14, Agriculture, food chemistry).

From the R&D planning viewpoint, these results basically have a bearing on the relationship between the priority scientific-technical areas of the Plan and the structure and potential of the productive system; it seems that more attention should be paid to those scientific activities with a clear technological application, or to fostering scientific research in areas of knowledge related directly to the productive sectors in which Andalucia is more specialized. Such more direct and closer linkage between scientific policy and technological development becomes difficult if the two current, and different, planning documents (PAI and PLADIT) remain in force under their two distinct executive bodies: one for scientific policy and the other for technological policy.

Notes

1. The authors are members of the CENTRA Foundation's Regional Economy Research Group (Regional Government of Andalucia/Junta de Andalucía).
2. Pursuant to Art. 13.29 of the Statute of Autonomy, the Andalucian Regional Government (*Junta de Andalucía)* has exclusive jurisdiction over research and its institutions, subject to the provisions of Art. 149.15 of the Spanish Constitution, which gives the State exclusive jurisdiction over the promotion and general coordination of scientific and technical research. The coordination of the scientific policies of the State Ministries and the Regional Governments is regulated by the 'Science Act' (Law 13/1986, dated 14 April), which is the legal framework within which the current 3rd Andalucian Research Plan (PAI) was drawn up. The PAI is planned, coordinated and monitored by the Interdepartmental Science and Technology Committee, which is formed by representatives from each Department and chaired by the Councillor of Education and Science. Consequently, here the planning process is controlled by educational rather than industrial interests, as in other Autonomous Regions of Spain.
3. Two problems are usually adduced in relation to this model (Malecki, 1997, p. 52): the first is the exaggerated emphasis placed on basic scientific research as the source of new technologies; the second, a purely technocratic point of view of innovation, as the path for the production of a new technical instrument. The theoretical background of this model rests on the neo-classical postulates (free availability of scientific knowledge), in which the justification for public intervention is based on the need to correct the failures of the market.
4. The common characteristic of the new theories of innovation and technological change is the perception of innovation as a complex process that involves elements of uncertainty and of accumulation of knowledge (Dosi *et al.*, 1988, p. 222). The majority of authors concur in identifying the work of Dosi *et al.* (1988) as the point of origin of these ideas. The ideas of Freeman (1990, 1994) are also solid contributions to the definition of the characteristics of innovation. The work published by the group of Danish economists of the University of Aalborg, led by B.A. Lundvall, on the 'learning economy' have provided a solid theoretical framework for explaining innovation from the evolutionary perspective, defining it as a process of learning that generates cumulative knowledge and in which the institutions play an essential role.
5. All the theoretical arguments outlined here would be sterile if regional policy decision-making bodies lacked sufficient room for manoeuvre to bring into play the measures necessary to implement the plans to reinforce research, technological development and innovation. As we shall analyse later in this paper, in Andalucia, as in other Autonomous Regions of Spain, this room for manoeuvre does exist.
6. The document in question is the 3rd PAI (http://www.cec.junta-andalucia.es/dgui/pai_iii/pai-II-ICG.pdf).
7. For example, the limited availability of patents in particular technological fields owing to 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 responsibility of including discussion of the prior art, utility, novelty, etc. of the invention), 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. In addition, there are differences in national practices (different patent offices have different working methods; it is well known that, in USPTO patents, the frequency of citations is higher in comparison with EPO patents).
8. An extensive review of this methodology is to be found in Acosta and Coronado (2003).
9. These 500 patents are those that refer to Andalucia as the place of residence of the first applicant; this procedure of indicating area of residence became general from 1988 onwards; therefore the true number of patents registered by residents of the Region in the period 1984–1989 is larger than the figure used here.
10. The patents have been classified in accordance with a suitable 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).

11. In order to allocate a scientific citation to one or other scientific field, the authors sought the help of specialists from the University of Cádiz and the Spanish Scientific Research Council (CSIC—*Consejo Superior de Investigaciones Científicas*).

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