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CATALAN COMPETITIVENESS: SCIENCE AND BUSINESS

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CATALAN COMPETITIVENESS: SCIENCE AND BUSINESS

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Abstract

Science has been shown to be an important driver of economic growth and performance. In this chapter we take a careful look at a key ingredient of this driver for Catalonia: the link between science and business. We argue that the Catalan innovation system faces three important challenges in order to better connect science to business: 1) the need for a sufficient supply of high quality science; 2) the need for a sufficient demand for science by companies, and 3) the ability to connect science and business, i.e., science needs different channels to connect with business and requires coordinated efforts between the different players in the innovation system. We find that the science landscape at Catalan (Spanish) scientific institutions has improved considerably in the last decade. Demand for science by Catalan firms, on the contrary, is still very weak. Nevertheless, we do find that industry and universities use a large variety of channels for knowledge interaction. In addition, we show that the three large Catalan universities have very different profiles in their interactions with industry. However, our analysis does indicate that there is currently a lack of basic information about the Catalan innovation system to help inform and direct such important policy measures. Some coordination on recording this information systematically would improve matters considerably.

Keywords: Competitiveness, Catalonia, Science, Business.

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CATALAN COMPETITIVENESS: SCIENCE AND BUSINESS

1. Introduction

1.1. Why does Science Matter for Competitiveness?

A multitude of economic studies have shown the importance of *basic research* for technology, innovation and economic growth (Griliches, 1998). However, a coherent body of theory and insight into the multifaceted nature of the links between science and markets is still lacking (Stephan, 1996). There are some industries where the link between science and innovation is explicit and direct. Industries such as biotechnology, pharmaceuticals, organic and food chemistry are "science-based" in the classic sense and rely heavily on advances in basic research to feed directly into their innovations (Levin et al., 1987). In non-science-based industries much innovation also derives from activities not related to basic research. Nevertheless, even here innovation is facilitated by better use of basic research resources, such as the training of skilled researchers, which helps to increase the absorptive capacity of industry.

An important and recurrent concern in economics has been to understand to what extent science explains technological progress. The answer to this question has profound implications for public policy, notably for the decision to fund basic research conducted by private and public organizations. The works by Jaffe (1989) and Adams (1990) have shown the importance of basic science (inputs, e.g., public research expenditures or outputs, e.g., publications) for economic growth. At the same time, research by Acs et al., 1992, as well as by others, has revealed the significant externalities (spillovers) stemming from local academic research on private R&D and patenting. The importance of science for economic growth, together with the fact that spillovers are generated for the private sector, has led to several forms of government policy intervention for funding science directly through funding of university research and research centers or by providing grants to firms and other organizations participating in science. Moreover, public policy has focused on the attraction of talented researchers from abroad; either nationals that have gone to work in research centers in another country or foreigners that want to move to Spain and Catalonia.

Recent studies suggest that the links to basic research by private firms have actually been increasing in the last decades and they manifest themselves today in multiple ways: such as university-industry collaboration (e.g., joint research, sharing of equipment and research tools) and contracting, industry financing university research, university spin-offs and patent licensing, mobility of university researchers, citations to university patents, Ph.D. theses directed by company researchers, and so on. One of the most visible indications of growing science linkages by industry is found in the citations to science in patent documents. Narin et al. (1997) reported a threefold increase in the number of citations to academic literature in industrial patents in the United States through the mid 1990s. Accordingly, 73 percent of the papers cited by industry patents were authored at academic, governmental, and other public institutions and had a strong national component in citation linkage, with inventors preferentially citing locally authored papers. Branstetter (2004) found that such a dramatic rise was closely linked to the new technological opportunities generated by academic research in the cross-field of biosciences and biotech-based technologies. Nevertheless, he also shows an important shift in the methods of invention, with an increased emphasis on the use of the knowledge generated by university-based scientists in later years to generate new inventions by firms. The greater availability of scientific literature has also increased in the last decade, and a wider access (Internet, open access) to scientific journals and databases and their ease of searching may also explain this rise.

The discussed patterns evidence the increasing role played by links to science in the search for competitive advantage through innovation by private firms. Corporations appear to look more extensively towards public science as one of the external sources allowing rapid and privileged access to new knowledge, especially in the life sciences. Fuelled by the notion that strong (local) interactions between science and industry become more important for the success of innovation activities and ultimately economic growth, the economics and technology management literature have started only very recently, independently of each other, to investigate in more detail how the fruits of academic research can be exploited in a market environment.

1.2. Channels to Science

The previously-discussed studies on the channels linking to science typically do not directly relate this behavior to innovation performance of the firms. Surveys have provided some estimates of the importance of basic research for industrial innovation and economic performance. For instance, relying on a survey of 76 United States firms in seven industries, Mansfield (1991) found that 11% of new product innovations and 9% of process innovations would not have been developed (without substantial delay) in the absence of recent academic research. In addition, firms declared that 8% of their products were developed with substantial input from recent academic research (6% of process innovations). Both the 1983 Yale Survey and the 1994 Carnegie Mellon Survey (CMS) of R&D have shown the relevance of university research for innovation as conceived by managers. According to the CMS, American firms consider publishing by universities and patenting amongst the most important sources of knowledge to innovate (Cohen et al., 2002). A different perception is found in Europe. The evidence from the European Community Innovation Survey shows that only a small fraction of innovative enterprises consider scientific information, i.e., information from universities and public research labs, as an important information source in their innovation process. In the Eurostat-Community Innovation Survey CIS-III (1999-2000), of all reporting innovative EU firms (excluding United Kingdom), 4.5% rated universities as important sources of information, while 68% indicated universities as not important at all. The CIS results also show the importance of science as an information source to be highly firm-size and technology specific. Could the way of interaction between science and companies affect the performance of the innovation process? We believe it very well might and, as Belderbos et al. (2004) show with European data, cooperating with universities does lead to higher growth in sales of 'new to the market' products.

Opportunities to link with science to spur economic growth and well-being should be explored more actively, but this will require important changes in incentives, organizations and policy. As a recent article in *Nature* (Butler, 2008) indicated, there is an urgent need to cross the "Valley of Death" that exists between biomedical research and actual new treatments, diagnostics and prevention. The study shows that the number of grants by the NIH to PhD scientists has increased dramatically since the explosion of molecular biology in the 1970s. At the same time, R&D expenditures in the pharmaceutical industry have increased, but new molecular entity output has been steadily decreasing. Investing in bridging this valley, i.e., translation, is now being pursued by the NIH through the organization of Clinical and Translational Science Centers. The research culture is reinvented by organizing larger, multidisciplinary groups, including basic scientists and clinicians, but also bioinformaticians, statisticians, engineers and industry experts. It also requires evaluating scientists through not only publication output, but also by their reaching milestones and their ability to work in multidisciplinary groups. Alternative measures are patents, clinical trials and collaborations with industry. While specifically related to the biomedical research area, we believe that this evolution characterizes the overall trend in linking science with industry.

1.3. What we do in this Study

In this study we attempt to measure and map direct links between Catalan Science and industry. Most existing studies provide rather aggregate evidence of a relation between science and industry. For example, in the case of citations to public science mentioned before, can we really say that these citations indicate a true knowledge connection between (Catalan) science and industry? In what follows we describe the different types of interrelationships that exist. On the one hand, there are the relations that arise through the fundamental research and education mission of the universities through the collaborations with industry (joint publications) and the training of qualified graduates that are contracted by industry. On the other hand, there have been universities that are more active in direct participation in industry through the contracting, patenting, licensing and spinning off of companies directly from the university, i.e., the "entrepreneurial" university. Data on all these activities is available at an aggregate level through a survey that the CRUE (Conferencia de Rectores de las Universidades Españolas) performs in Spain. However, we lack a more in-depth knowledge of these different interactions, their intensity, their drivers and their consequences. In this report we attempt to provide a first small step in mapping these industry-science links. We believe that a more focused (sectoral/technology) approach is required for Catalonia in order not to dilute already limited resources. While an overall effort is needed to improve the Spanish and Catalan science and innovation standing relative to other countries, Catalonia needs to identify its developing strong points and leverage them. *This requires collecting data at a much more disaggregated level.* Policy makers will need to stimulate this focus through providing incentives without being too prescriptive on which paths to follow. Firms and institutions should have autonomy to develop and support interesting areas of interaction.

2. The Case of Catalonia

2.1. What do we Know about Catalonia? (and how does this Compare?) How do Catalan Firms link to Science?

Industry-science links refer to the various types of interactions between the industry and the science fields. These include formal relationships, such as collaborative agreements between science and industry, R&D contracting, own licensing policies and intellectual property management, and, spin-off activities of science institutions. But behind this multitude of formal relationships lies a myriad of informal contacts, gatekeeping processes, personnel mobility and industry-science networks based on personal or organizational relations. These informal contacts and human capital flows are ways of exchanging knowledge between enterprises and public research and creating spillovers. These flows are more difficult to quantify, but nevertheless extremely important and often a catalyst for instigating further formal contacts.

Schartinger et al. (2002) show that there are a multitude of channels through which science and industry meet (see Table 1). Furthermore, they show that different sectors and different faculties put varying weight on these relations. To provide a more complete picture of industry-science links it is important to map various relations simultaneously. Unfortunately, such information is typically not available on a larger and comparative scale.

We believe it is interesting to classify these interactions into two groups as done in Table 1:

1) Related to fundamental research and the scientific research frontiers – scientific research collaborations between academics and industry, resulting in publications and PhD theses, and their mobility towards industry, etc.

2) Related to the development of applied knowledge – research contracts between the university and industry, patents, licenses and spinoffs. We discuss each in turn for the Catalan case with the scarce data available.

In what follows, we concentrate on the "*" links in Table 1

Table 1

Types of interactions between science and industry

1. The Scientific Research Frontier
Joint publications in scientific/technical magazines*
Employment of graduates by firms*
Mobility of researchers between universities and firms
Conferences or other events with firm and university participation
Joint supervision (university department and firms) of Ph.D. and Masters theses
Sabbatical periods for university members/internships
Lectures at universities, held by firm members
Firm members' participation in Social Council of the university
Joint participation in committees and councils (assessing, organizing conferences, awards, juries...)
Co-organization of international conferences
Joint managed post-graduate programs

2. Applied Knowledge Development
Collaborative research, joint research programs*
Contract research and consulting of the firm to the university*
Licensing of university patents by firms*
New firm formation (start-ups) by university members*
Purchase of prototypes by firms, developed at universities
Use of university facilities by firms
Analysis contracts in university laboratories
Master students actively working in firms
International delegations from/to firms and universities
Research parks
Visiting of fairs
Affiliation of academics with professional organizations

Source: adapted from Schartinger et al. (2002).

2.2. The Catalan Innovation System[1]

Links between science and business can only develop if there is both a supply of high quality science and a demand from an interested and active private sector for tying into this science base. We briefly discuss the complex Catalan science and innovation system before taking a specific look at the interaction between the science and innovation. Compared to other countries, the Catalan starting point provides three specific challenges. First, Catalonia is in the process of developing high quality scientific output which could serve as an input for the innovation process and attract companies that want to source such knowledge. This leads exactly to the second connected challenge. A vibrant innovative business sector is required to spur demand for scientific links. Anchor tenants, i.e., large firms with important applied R&D activities, seem to stimulate this interaction in the local environment. Catalonia and Spain do not have very enviable positions in the EU rankings for innovation and especially innovation that ties into science. Finally, as discussed before, translation of scientific results into commercially viable products, processes and services seems a challenge for all countries, companies and fields. As others are struggling to cross this valley between science and business, can Catalonia improve on the first two challenges – supply and demand – while leapfrogging others in this final challenge?

Figure 1 is a schematic representation of the different players in the Catalan research and innovation system. A first glance at the figure already indicates that it is a rather involved system where efforts are somewhat dispersed and fragmented over different policy makers and agents. Especially, if one considers the amount of government spending on R&D and innovation, the number of administrations and agents involved seems excessive.

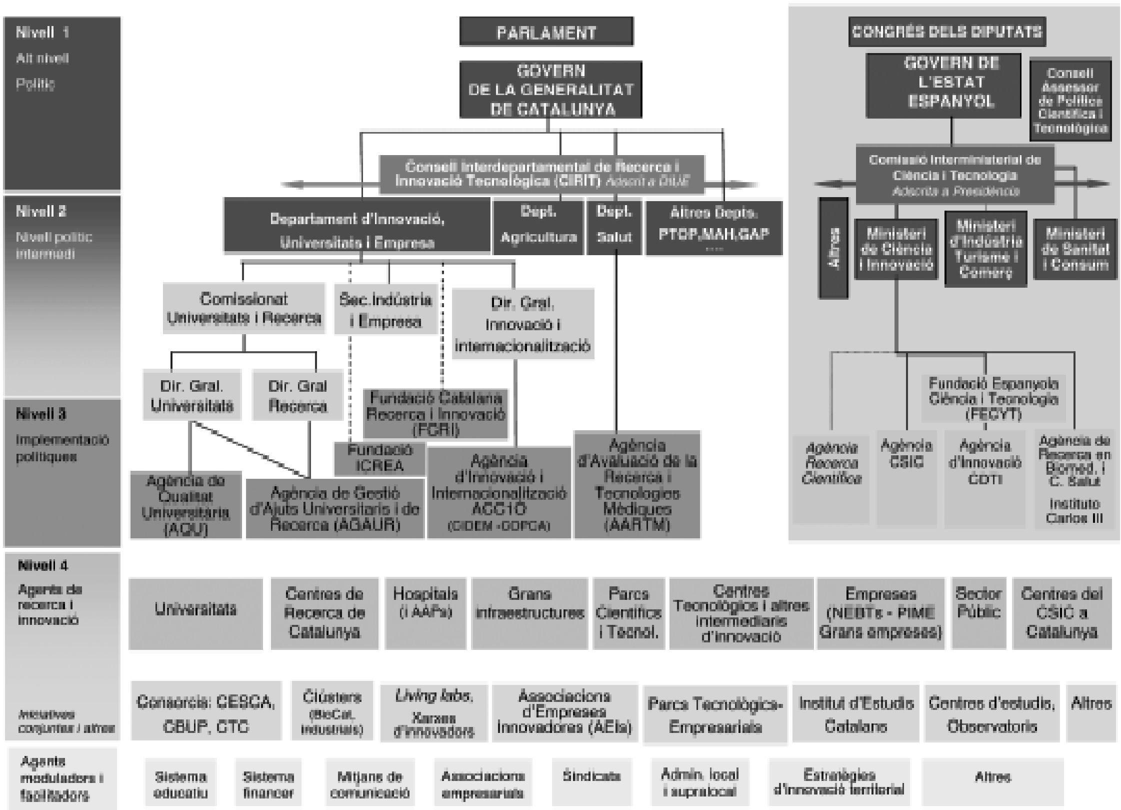
The Statute of Catalonia states that the Government of Catalonia has exclusive powers in research while the Spanish government has exclusive powers in the promotion and general coordination of scientific and technical research. The Spanish Government has full powers in the realm of taxation and inspection of R&D and innovation activities, and in intellectual

[1] This section draws heavily on the recent publication "Pacte Nacional per la Recerca i la Innovació," 2008.

property; the Government of Catalonia can only implement directives under the legislation established by the Spanish Government. This leads to an overlapping of powers, but there is no systematic co-ordination between the Governments of Spain and Catalonia in terms of the governance and development of a strategic and operational policy for science, technology and innovation. The Ministry of Innovation, Universities and Enterprise of the Generalitat has responsibilities in the main areas related to research and innovation, but other ministries such as Health and Agriculture also make an important contribution in these fields. An Inter-ministerial Council, the CIRIT, co-ordinates the ministerial policies on science, technology and innovation at an operational but not a strategic level. This Council is responsible for the research and innovation plans of the Government of Catalonia (the Plan for the period 2005-2008 is currently being implemented). In terms of implementing policies, there are four main agencies in the Catalan research and innovation system. There is a support agency for innovation and enterprise, mainly in the industrial sector, the CIDEM, and an internationalization agency, COPCA, with 40 offices all over the world, which also includes a market and outlook observatory. These agencies are currently being merged (into the ACC1Ó Agency). The Agency for Management of University and Research Grants (AGAUR) operates in practice as an administrative and technical office of the Directorate General for Research. Finally, there is the University System of Catalonia Quality Agency which is an independent agency, responsible for assessing and improving the performance of universities. In the Spanish government, the Ministry of Science and Innovation is responsible for the CSIC research centers (Consejo Superior de Investigaciones Científicas, Spanish National Research Council), the Carlos III Institute, the CDTI – the Centre for Industrial Technological Development which produces policies and programs that are available on a competitive basis for research and innovation actors in Catalonia, and is also in charge of the development of the national RDI plans that affect participants in research and innovation in Catalonia. Within the context of this chapter the CDTI probably provides an important contribution to linking science and industry through its CENIT and CONSOLIDER programs, which form part of the Spanish effort to implement the Lisbon Strategy through their ambitious INGENIO2010 program. CONSOLIDER is focused on the development of top quality science, while CENIT really operates through linking science and business by sponsoring large scale projects aimed at strategically important sectors and technologies. CENIT does require the collaboration of large and small private enterprises and the integration of one or more public research groups. Furthermore, the program attempts to enhance mobility of PhDs to industry through its Torres Quevedo program. The challenge of aligning the various policies produced by the Spanish Government and the Government of Catalonia is significant but, as regards Catalonia, it is also important to effectively unite the Catalan research and innovation agents in order to increase efficiency and effectiveness. Spain adopted the Lisbon Strategy, and the new National RDI Plan 2008-2011 proposes to increase annual investment by 32%. The role that the research and innovation policies of the Government of Catalonia have historically played, compared to the policy of the Spanish Government, are in strengthening programs that have not received enough support from the Spanish policies. More importantly, the Catalan government has implemented programs that focus on vertical strategies and basically focus on the creation of Catalan research institutes or on the creation of technological centers in fields which meet the needs of the production network.

Figure 1

The Catalan Science and Innovation System



Source: Departament d'Innovació, Universitats i Empresa.

The Catalan science and innovation system basically consists of universities, the public research centers of the Government of Catalonia, hospitals, technological centers, the research centers of the Spanish government (CSIC) and the RDI departments in the private sector. The establishment of research centers of the Catalan government (CERCA) has been an interesting experiment in organizing high powered research in Catalonia. The number of centers has grown from 12 in 2000 to 29 centers by 2007 while employing about 3,000 researchers, PhDs and technical personnel. Furthermore, the Catalan government has invested in research infrastructure such as the Barcelona Supercomputing center or the new synchrotron in Cerdanyola del Vallès which might attract new researchers, labs and organizations. Nevertheless, expenditure on R&D in Catalonia (1.43% of GDP) is far behind the leading countries despite the fact that the annual average growth in recent years has been very high.

As mentioned, in order to stimulate interaction between science and industry, the first order of business is to stimulate excellence in science in an attempt to generate demand from private companies for the local science base. The first steps have been set in this direction and the PNRI proposes to reinforce this search for and development of talent. However, we believe that *now is the time to monitor improvements in the measures picking up this link between industry and science*. We turn to an analysis of these measures, but our main conclusion is that the Catalan government should put these measurement systems in place together with the necessary structure to incentivize and collect the information for making better policy decisions. Next, we discuss how universities and research institutes interact with business, both through their primary objective, as research based organizations moving along the research frontier, and as developers of applied technologies for business. First, we turn to the research frontier.

3. The Scientific Research Frontier

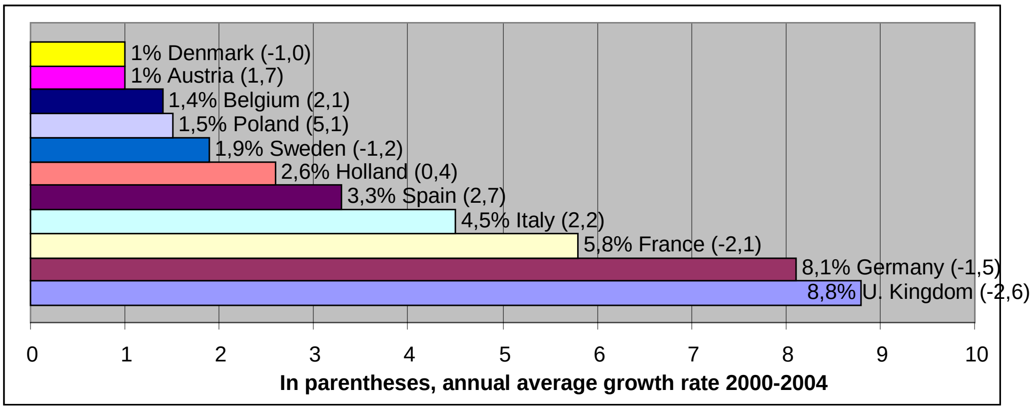
In what follows we discuss the publicly available data on how the scientific research frontier interacts with business in Catalonia. In particular, we look at scientific publications of firms and of firms jointly with research institutions. Second, we look at the production of PhD's and their possible flow to business.

3.1. Joint Publications Academia-Business

In overall publication excellence, Spain has been moving up in the rankings. Publication output has been increasing at an average of 2.7% per year over the 2000-2004 period, with 3.3% share of world scientific publications (see Figure 2, COTEC, 2008).

Figure 2

Publications at Country level (each country's total share of world scientific publications)



Source: Authors, using data from COTEC, 2008.

The growth in the number of publications in Catalonia, however, outstrips the Spanish growth rates. Only the Valencian Autonomous Community has been growing faster in the number of publications, starting from a much lower base (see Table 2).

Table 2

Total Publications of Catalonia compared to other Regions

	1992-1996	1997-2001	2002-2006	2006	1992-2006*
Spain Overall	75,145	109,983	142,576	30,406	89.73
Madrid	23,156	23,482	39,538	8,139	70.75
Catalonia	16,515	25,692	34,600	7,751	109.51
Andalusia	10,622	15,693	21,738	4,713	104.65
Valencia	6,983	11,278	16,449	3,634	135.56

* percent change between 1992-1996 and 2002-2006.

Source: Méndez-Vásquez et al. (2008).

The quality of Catalan publications measured as the average number of citations per document has been maintained over time. Nevertheless, one should carefully interpret these results as citations are quite sensitive to the areas of research (see Table 3).

Table 3

Citations per Document (all scientific fields)

	1992-1996	1997-2001	2002-2006*
Catalonia	17.49	14.94	5.16
Valencia	15.79	13.27	4.67
Madrid	15.66	13.40	4.60
Spain Overall	14.59	12.23	4.22
Andalusia	12.88	10.16	3.65

* Average citations decrease when analyzing more recent periods because documents have less time to be cited.

Source: Méndez-Vásquez et al. (2008).

The most striking growth has been realized in recent years when the Catalan government has started to strongly support the creation of Public Research Centers (see Table 4). Many of those centers only were created in the last decade with a strong emphasis on research excellence. Publications growth between 1992 and 2006 has been around 200%, arguably starting from a very low base. Unfortunately, for most of these Public Research Centers it is too early to examine their impact on industry, but this is a very interesting evolution for policy makers to follow and encourage firms to tap into this resource of recent creation.

Catalonia has grown most spectacularly in the areas of engineering, computing and technology, but in sciences and biomedical research growth rates have also been above the Spanish averages (see Table 5).

Table 4

Publications by Institutional Sector

	1992-1996	1997-2001	2002-2006	1992-2006*	%Cat**
University	11,652	17,885	24,586	111.00	71.06
Health	5,042	7,594	10,161	101.53	29.37
CPR/OPI	2,922	5,618	8,760	199.79	25.32

* percentual change between 1992-1996 and 2002-2006.
** percentual share over total documents in Catalonia.

Source: Méndez-Vásquez et al. (2008)

Table 5

Publications by Scientific Area

	1992-1996	1997-2001	2002-2006	1992-2006*	%Cat**
Science	7,774	12,027	16,051	106.47	46.39
Biomedicine	8,101	12,272	15,611	92.70	45.12
Engineering, comp., techn.	1,967	3,546	6,196	231.87	17.91

* percentual change between 1992-1996 and 2002-2006.
** percentual share over total documents in Catalonia.

Source: Méndez-Vásquez et al. (2008).

An interesting analysis of the quality of areas of research can be made by looking at Highly Cited Papers (HCP). HCPs are papers that receive 10 times or more cites than the average cited paper in the area. As a result one can control for area specific citing behavior and get an idea of how many important papers are published in a particular research area.

Table 6

Highly Cited Publications by Area

FIELD	Documents	HCPs	%HCPs
Internal and General Medicine	1,865	47	2.52
Biochemical and molecular biology	3,480	25	0.72
Oncology	1,694	25	1.48
Chemical/Physical	2,254	20	0,89
Informatics, Theory and Methods	1,434	17	1.19
Pharmacology	2,326	16	0.69
Electric and electronic engineering	1,485	16	1.08
Cardiovascular system	993	16	1.61
Neurosciences	2,066	15	0.73
Chemicals	1,713	15	0.88
Microbiology	1,587	15	0.95

Source: Méndez-Vásquez et al. (2008).

As Table 6 shows, Internal and General Medicine stands out with a large number of important publications. But also other areas such as Cardiovascular, Oncology or Informatics perform rather well. Other areas, not shown in the table, such as Mathematics, Statistics and Mathematical Physics, Instrumentation and Economics, have fewer highly cited publications but perform rather well on the average number of HCP in the area.

Disaggregating the scientific publication output further to the university level, we find that the three largest Catalan Universities (Universitat de Barcelona, Universitat Autònoma de Barcelona and Universitat Politècnica de Catalunya) do quite well, not only in total number of publications, but, more importantly, in overall research impact, measured as the average number of citations per scientific publication (see Table 7, Buson, 2006).

Looking at the 2007 Shanghai University Index which ranks universities according to their scientific quality, Universitat de Barcelona is ranked as the leading Spanish university at 151st out of 500 in the world. The only other ranked Catalan university is Universitat Autònoma de Barcelona around the 305th place. Both Universidad Autónoma and Complutense de Madrid are ranked higher (place 203). In Europe this translates into a rank of 57th for the University of Barcelona.

Table 7

Publications and Impact by University

	Number of publications	Number of citations	Impact index
CSIC	16,133	50,681	0.86
U. Barcelona	9,678	33,705	0.84
U. Complutense Madrid	8,274	22,444	0.70
U. Autónoma Madrid	6,723	32,916	0.99
U. Valencia	5,620	18,964	0.91
U. Autònoma Barcelona	4,803	16,803	0.84
U. Granada	4,222	8,690	0.56
U. Santiago de Compostela	3,866	8,983	0.69
U. Zaragoza	3,807	8,655	0.76
U. Sevilla	3,626	8,523	0.63
U. País Vasco	3,564	7,789	0.68
U. Politècnica de Catalunya	2,476	4,558	0.85

Source: Busom (2006).

When examining the performance of the different universities in different fields, Universitat de Barcelona comes out on top in number of publications and impact of these publications in biomedical research and sciences. Interestingly, Universitat Pompeu Fabra (not shown in table) makes a very noticeable climb in the rankings in the last decade both in number of publications and their impact. Its impact is really related to its involvement in the Human Genome project. In engineering, computing and technology the Universitat Politècnica de Catalunya tops the number of publications, but their impact is rather low. Indeed, the Universitat de Barcelona and the Universitat Autònoma de Barcelona produce more impactful publications in these areas (Méndez-Vásquez et al., 2008).

These numbers at the university level tell us about the overall quality of research at Catalan and Spanish universities and the marked improvement on the supply of high quality research in the past decade. Unfortunately, the existing rankings and improvement of publications are not very revealing about the potential of these publications for industry or the translation of related research results into innovation, which is the objective of this chapter. One would hope that a high quality university system, high impact publications and the concentration of talent attract the interest of businesses.

We have therefore obtained all the Catalan publications registered in ISI for the period 1996 to 2006. From this we selected all publications that were either by private firms or a collaboration of private firms with other public institutions such as universities (data source: AGAUR; National Citation Report for Spain 1981-2006, Thomson-Reuters).

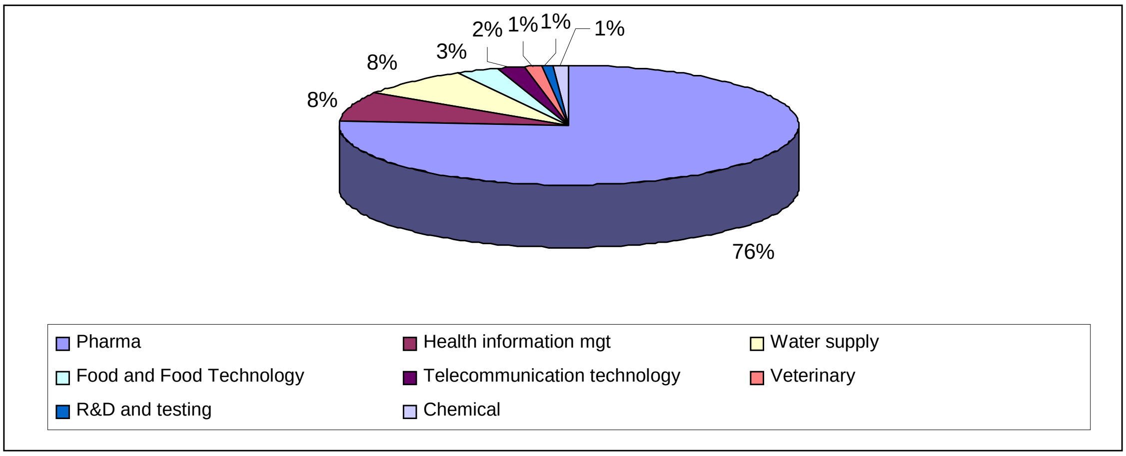
In this period, 852 joint publications have been analyzed with the participation of at least a private company. The average annual number of publications is around 8,000. For example, in 2001 total number of Catalan publications registered by ISI was 8,210 while in 2002 there were 7,626. Over this period (1996-2006) Catalan publications total 79,127. Therefore, only about 1% of the publications have the participation of a private company.[2] From these publications with private sector participation, 312 (36.6%) were signed only by one single company and the rest, 540 (63.4%) publications, were joint publications between companies and universities or research departments, mainly at public research centers and hospitals.

The sectoral distribution of the companies publishing alone (without any research partner) is shown in Figure 3. Data confirm the strong presence of the pharma sector in Catalonia in publications. 76% of the papers published by a company are related to the pharmaceutical sector. The pharma sector and associated activities is leading the expenses in R&D in Catalonia and is growing, with more than 360 million Euros in 2005 (Informe annual de l'R+D i la Innovació a Catalunya, 2008. ACC10. Generalitat de Catalunya, p. 44). Companies do not tend to publish with other companies. Only 4.8% of the pharma companies appear on the same paper with another pharmaceutical company. The fact that the publishing process involves some degree of interchange of information between co-authors can impede companies from sharing authorship with other companies.

[2] In comparison, in Flanders publications of private companies (joint or alone) represent about 6.5% of the total publications. Catalonia is, therefore, rather at the low end of interactions.

Figure 3

Distribution of Publications by Private Companies



Source: authors, using data from AGAUR.

In total, 109 different entities have participated in these publications, and only 26 were private businesses, the remaining 83 were research entities. The pharmaceutical industry is the most highly represented with several companies at the top of the authorship list: Almirall (participating in 117 publications out of the 852); Esteve (58); Uriach (55); and Ferrer (52).

A sector distribution shows how different sectors behave differently when publishing. Table 8 shows the percentage of types of academic partners a company chooses for publishing. "Non-Catalan universities" and "Non-Catalan hospitals" comprise universities and hospitals from different parts of Spain (Madrid, Valencia, Zaragoza, Seville, Granada, etc.). Out of the total number of 540 joint publications, 414 correspond to the pharma sector, 44 to health information management, 42 to water supply, 19 to food and food technology, 11 to telecommunication technology, 7 to veterinary, and 3 to chemical.

Table 8

Partners in Publishing of Private Companies (as percent of total)

	Total Publications	Catalan university	CSIC	Non-Catalan University	Catalan hospital	Non-Catalan hospital	Others
Pharma	414	27.1	16.9	28.0	14.8	12.6	0.6
Health Information mgt	44	14.3	12.2	59.2	12.2	0.0	2.0
Water supply	42	45.8	35.6	15.3	1.7	1.7	0.0
Food & Food technology	19	83.3	4.2	8.3	0.0	4.2	0.0
Telecommunication technology	11	0.0	0.0	100	0.0	0.0	0.0
Veterinary	7	45.5	9.1	18.2	18.2	9.1	0.0
Chemical	3	0.0	0.0	11.1	33.3	55.6	0.0

Source: authors, using data from AGAUR.

Overall, pharma companies also tend to publish with university partners. This fact confirms the need of this science-based sector for basic research. Moreover, Catalan and non-Catalan universities are equally distributed. On the other hand, food companies tend to publish with local universities, mainly the Universitat de Barcelona. Similarly, with the papers published by companies, 76.8% (415) of the co-authored papers (540) are signed by pharmaceutical companies. CSIC and Universitat de Barcelona are the institutions that co-publish most with the pharma companies. While pharmaceutical companies dominate the publications by firms, it is interesting to note that other areas enjoy a large number of publications; for instance, health information management and water supply each represent around 8% of these publications. It is important to identify so-called anchor tenants within the Catalan economy such as Aguas de Barcelona that can play a role in leveraging academic research and jump start these interactions between science and industry in addition to the pharmaceutical sector. The overall conclusion, however, is that while the science sector has improved its quality over time, this has not really been reflected in a substantial increase in interaction between science and business on the publishing front, as this would probably be the first area to experience an effect.

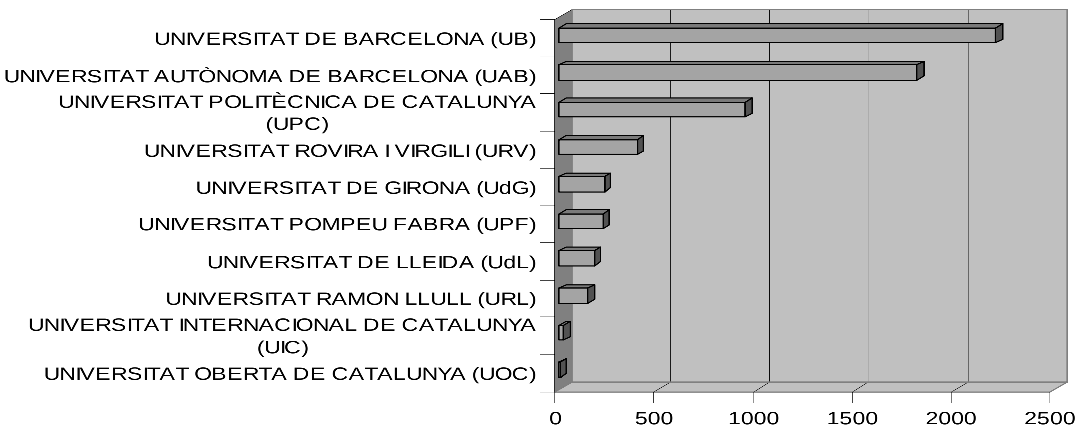
3.2. PhD Theses in Catalonia

While one key task of the university is fundamental research, the other is education. As we are analyzing science links, we focus on the education in research, by looking at the total number of PhDs graduated in Catalonia in different areas.

Figure 4 summarizes this result. Over the period 2000-2004, 6,106 PhDs graduated from Catalan universities. UB, UAB and UPC are the most productive in Catalonia. In Europe, Spain is the 5th most active country in producing PhDs, behind Germany, United Kingdom, France and Italy (see Figure 5).

Figure 4

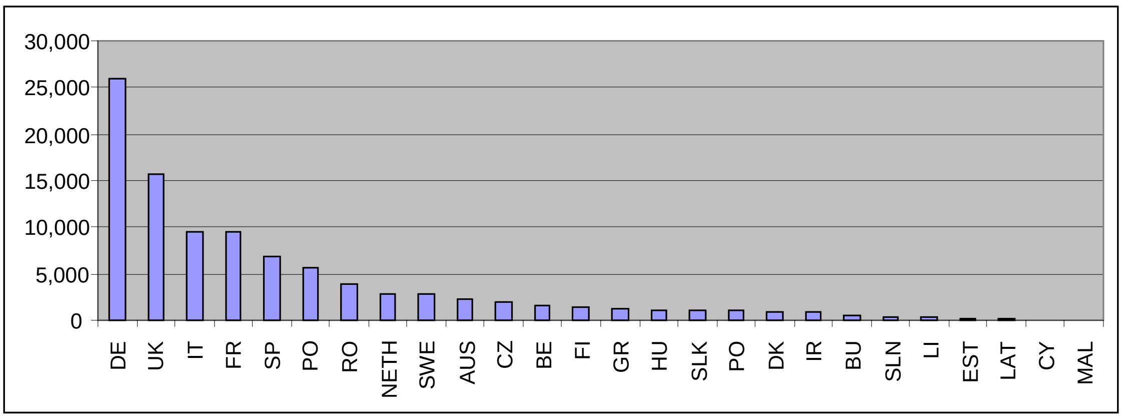
Production of PhDs by University in Spain



Source: Meridià (Research Observatory). Institute of Catalan Studies.

Figure 5

Production of PhDs in Europe in 2005



Source: Eurostat.

It is unfortunate that little is known about the destination of these PhD graduates, as the hiring of qualified graduate students would provide for a direct link between science and industry. The OECD is currently organizing a large scale study on the careers of doctorate holders. As the pilot study shows, in the United States about 34% of the PhDs end up in private business while another 14% move into the life sciences and health profession (see Table 9, OECD 2007).

Table 9

Employment of PhD Holders in 5 Countries

ISCO-88 code	ISCO-88 title	Arg. 2005	Can. 2001	Ger. 2004	Por. 2000-4	United States 2003
1	Legislators, senior officials and managers	1.0	11.5	4.3	2.8	10.5
2	Professionals	84.0	73.8	80.9	88.2	81.2
21	Physical, mathematical and engineering science professionals	20.5	15.9	18	6.6	16.2
211	Physicists, chemists and related professionals		6.5	5.0	3.7	5.2
212	Mathematicians, statisticians and related professionals	17.6	0.4		0.1	0.9
213	Computing professionals	0.4	3.9	2.1	0.3	3.8
214	Architects, engineers and related professionals	2.5	5.1	10.8	2.4	6.3
22	Life science and health professionals	21.5	9.4	34.3	2.3	14.2
221	Life science professionals	15.7	3.3	1.9	0.4	6
222	Health professionals	5.5	5.9	32.4	1.9	7.2
223	Nursing and midwifery professionals	0.3	0.2		0	1
23	Teaching professionals	36.4	37.1	13.3	78.3	33.1
231	College, university and higher education teaching professionals	35.4	37.1	6.6	76.4	29.7
232	Secondary education teaching professionals	0.3		5.3	1.5	1.9
233-235	Other teaching professionals	0.8		1.4	0.4	1.6
24	Other professionals	5.6	11.4	15.3	1.1	17.6
241	Business professionals	1.2	1.8	3.1	0.1	4.6
242	Legal professionals	1.4	0.8	3.9	0.1	0.4
243	Archivists, librarians and related information professionals	0.0	0.2		0.1	0.5
244	Social science and related professionals	2.8	8.5	3.1	0.9	7.6
245	Writers and creative or performing artists	0.0		2.3	0	1.8
	Other professionals			1.9		2.5
Other	Other ISCO-88 groups	10.3	14.7	14.8	8.6	8.4
Unknown		4.7			0.3	
TOTAL		100	100	100	100	100

Source: OECD Pilot Survey 2007.

Only 33% stay at the university whereas in Portugal 78% of PhDs stay within the academic or related institutions. While there is still no such data for Spain, we believe the numbers are closer to those of Portugal as many PhDs tend to stay around the university or move into teaching positions.

An important question, therefore, is why so few PhDs find their way into private firms. The problem might again lie both on the demand and on the supply side. On the supply side, Catalonia needs to ensure it delivers high quality PhD and Master's students that are competitive at international levels. Highly qualified human capital is indeed a motive for companies to locate and hire these people in Spain. At the same time, PhDs need to consider private employment as an option. Many PhDs seem to prefer to stay at the universities or teaching institutions accepting scholarships rather than employment contracts. On the demand side firms are not demanding PhDs and, even when subsidized through programs such as the Torres Quevedo program, demand does not seem very forthcoming. A thorough analysis of the results of this program would be in order to understand this lack of demand. But again, with few firms innovating in the Catalan economy, it should not be surprising that the private sector cannot absorb the supply of PhDs from the universities. Furthermore, the lack of business skills by PhDs may be also a barrier towards the flow of PhDs to industry.

3.3. Conclusion on the Research Frontier Interaction Between Science and Business

As demonstrated by the scientific publications data, the supply side of science has made important progress in the past decade. It is important that policy makers now undertake steps to support and stimulate interaction between these newly created pockets of scientific excellence and actual businesses. At the moment there seems little interaction at the research frontier except for the usual interactions in publishing in the pharmaceutical sector. Nevertheless, the volume of this interaction is low relative to the numbers from other regions. Therefore, it will be important to monitor progress in these and other areas. We did highlight the water business as a sector that might deserve some further scrutiny where possibly a large local company could spur some research. On the flow of PhDs to industry, it is clear that Spain and Catalonia need additional effort. For instance, it would be interesting to see where the PhDs and Post-docs formed in the newly created Public Research Centers end up. However, given their recent creation it is a little early to draw any conclusions. In the end, quality and not quantity of PhDs should matter in any of the policy directions taken. Giving universities' incentives to develop internationally-competitive PhD programs will, at the same time, increase the quality of the supply of PhDs and attract talented faculty to work with and train these PhDs.

4. Applied Knowledge for Business

Universities generate (fundamental) research and educate graduates in the latest knowledge and techniques. However, research and invention is not innovation. To realize innovation and economic growth from the activities of the universities we need an additional step to connect the knowledge generated at science centers to practice. As discussed before there are different channels that can lead to industrial production based on this scientific knowledge. This has lead to two different views about the reach of the university. On the one hand, the university can hand off their knowledge to industry in the form of applied knowledge jointly developed between private firms and the university in collaborative contracts. On the other hand, the "entrepreneurial" university can wander into the business space and develop this applied knowledge. The university can then profit from this applied knowledge either through the management of intellectual property – the licensing of technology and patents – or the development of new companies as spinoffs from the university. Different universities take different positions along these dimensions and this will reflect on how they interrelate with industry in the quantitative measures. Below we discuss R&D contracts with private firms as a key measure for the first option, and patents, licensing and spinoffs as a key measure on the second option. It is clear however that both options stimulate the link between science and industry.

4.1. Overall Comparison: Catalonia within Spain

The Conferencia de Rectores de las Universidades Españolas (CRUE), through its R&D commission (RedOtri), organizes a yearly survey which collects information about the technology transfer offices (TTOs) of Spanish universities.[3] We use this information and

[3] We are thankful to Constantino Martínez from CRUE for providing us with the Data from the latest CRUE questionnaires.

complement it with specific information of the TTOs to understand the current situation in Catalonia. In addition, we attempt to compare this information on Catalonia to information from a European-wide survey.

Table 10 shows the relative position of Catalonia according to the different measures on science and industry links where more applied knowledge is developed. A first broad conclusion is that Catalonia does not seem to punch above its weight in Spain, with an average score of about 15 to 20 percent. Except for the increase in R&D contracting, not much of a trend can be discerned from the data. However, as argued before, Spain has only recently awoken to this trend in linking universities with industry, and many universities are in the process of setting up and organizing their technology transfer offices. From the numbers at least it seems that Catalonia does not particularly stand out and, given that Spain is a lightweight within Europe in science and innovation, we cannot really expect Catalonia to come out ahead. Nevertheless, we believe that a more detailed and sector specific analysis can shed some light on the Catalan science and innovation landscape.

Table 10

Applied Knowledge Generation by the University System in Spain

	Total Catalonia	Total Spain	% Catalonia	
Contracts (including services)	**In €000's**	**In €000's**		
2003	€43,032	€211,593	20%	
2004	€43,979	€241,840	18%	
2005	€51,647	€302,405	17%	
2006	€71,231	€381,128	19%	
Spinoffs				
2002	10	65	15%	
2003	64	113	57%	
2004	13	67	19%	
2005	7	70	10%	
2006	10	38	26%	
International Patents IPC				
2003	59	304	19%	National Patents
2004	15	91	16%	International Patents
2005	19	117	16%	International Patents
2006	67	391	17%	National + International Patents
Licensing Revenues	**In €000's**	**In €000's**		
2003	€247	€1,689	15%	
2004	€292	€1,895	15%	
2005	€214	€1,671	13%	
2006	€171	€2,177	8%	

Source: authors, based on data from CRUE.

4.2. R&D Contracts with Private Firms

The amount of research funding generated by Spanish universities through specific research contracts has been rising steadily over the past years. In 2006 Spanish TTOs gathered €381 million in research contracts, with the Catalan TTOs taking 19% or €71 million. The sources of this research funding are private enterprises, public institutions and government and the European Union. The split is usually not detailed. Below we attempt to provide such a split and focus on the research funding from the private sector.

In what follows, we look at the contracts of the TTOs of the three largest universities in Catalonia representing 80% of the total contract research money by Catalan universities and the CSIC in Catalonia. On average, these R&D contracts with private firms represent about 10% of the research funds of the university. We focus on these private contracts as they are financed by private money. We believe that this represents a statement by private enterprise about the value of the particular research group from the perspective of private enterprise, i.e., the demand side. Contracts by local, national and European governments are subsidies and, while there are good reasons to provide subsidies to link public research with private initiative, one cannot help feeling that subsidies are less likely to provide the correct incentives for private enterprise to participate in these contracts. In addition, such private R&D contracts for scientific knowledge at research institutes might provide a starting point for developing priorities for policy by revealing current strengths.

4.2.1. Contract Distribution UB (Fundació Bosch i Gimpera)

The Foundation Bosch i Gimpera serves as a center for knowledge transfer, technology and innovation of the Universitat de Barcelona. While the foundation covers many activities, we are interested in the research contract part in order to understand the direct relation the foundation maintains with the companies. In 2006 the Universitat de Barcelona attracted €34.7 million in contract money. The bulk of this funding is provided by the public administration and institutions (34%) and the European Union (38%). Only 28% of research contracts are funded by private companies. Actual contract research revenues from private businesses was €7.2 million for 2006.

Table 11 shows the research contracts signed between industrial sectors and faculties at Universitat de Barcelona. Not surprisingly, 39% of the contract money comes from the pharmaceutical and fine chemicals sector and flows mainly (54%) to the pharmacy faculty. Other important recipients of contract money from the pharmaceutical and fine chemicals sector are the biology, chemical and physics faculties. Other important contributing sectors to the Universitat de Barcelona are Metal and Electronics, Mining and Extraction, Chemicals, Public Services and Environmental. On the receiving end are the faculties of biology, pharmacy, chemistry, geology, physics and economics and business.

What is interesting to note is that, while the important contributors and receivers are as expected, several other sectors and faculties enter the picture, providing a more nuanced image of the contractual interrelations between science and industry. For example, the economics and business department generates €355K from the private sector, which is in addition to the individual consulting that faculty members do. What would be interesting to establish is whether there are any large local companies – the anchor tenants – involved in these contractual relations. For example, the geology department receives about €900K from the mining, oil and gas sector, and the biology faculty receives €300K from private firms active on issues related to the environment. Unfortunately, this information is not public, but it would lead both the Universitat de Barcelona and the Generalitat to prioritize both from the technology/knowledge perspective as well as from the societal progress and welfare perspective.

4.2.2. Universitat Autònoma de Barcelona Contracts

In 2006 the Universitat Autònoma de Barcelona attracted €11.1 million in contract money. However, an important part of this contract money, about 43% comes from local public institutions and not really from private enterprise. Unfortunately, the information on links between sectors and faculties is not readily available.

Table 11

Contracts of Fundació Bosch i Gimpera (UB) by Industrial Sectors and Faculties

	Biology Faculties	Pharma Faculties	Medicine Faculties	Chemistry Faculties	Psychology Faculties	Economics Faculties	Arts Faculties	Geology Faculties	Geography and History Faculties	Philology Faculties	Teaching staff education Faculties	Pedagogy Faculties	Facultat de Biblioteconomia I Documentació	Other	Physics Faculties	Management Studies Faculties	Fundació Bosch I Gimpera	Law Faculties	Total Sectors
Food and Beverages	63,712	13,524	74,622	49,590											56,000				
Motor vehicles					4,710														
Banking-Insurance					5,819	0													
Real Estate				10,000		41,000	2,586	19,769											
Consultancies	24,120	15,242			4,850	31,500			25,280						33,000				
Culture	3,705								8,174										
Editing-Communication						58,900				37,592	862	4,600							
Education											467								
Sport													138,232						
Pharma-Chemistry	278,884	1,540,277	36,600	201,754		131,829									691,494				2
Manufacturing				121,664															
Informatics			4,808	4,708			0												
Environtment	304,287	38,653		17,412				9,825											
Medical					7,099														
Metal-Electronics				315,795				5,429			29,000	72,121			321,101				
Mining-Oil	30,000			90,974				875,497	8,174										1
Optics				11,626															
Chemistry	46,218	90,400		469,096	11,486			42,404								1,440	22,237		
Health		0	15,136	9,750	9,938														
Trading Services						332						14,265							
Logistics									50,000										
Public Services	368,313			43,338		85,449	144,000	35,239										27,000	
Telecoms						6,900													
Total Faculties	1,119,239	1,698,096	131,166	1,345,706	43,902	355,910	146,586	988,162	91,628	37,592	30,329	90,986	138,232	0	1,101,595	1,440	22,237	27,000	7

4.2.3. Universitat Politècnica de Catalunya Contracts

Not surprisingly, Universitat Politècnica de Catalunya which is more active in informatics, computing and technology attracts relatively more research funding from the private sector. In 2006 UPC attracted €25.7 million in contract money, including services. This constituted about 43% of its revenues from research contracts.

4.2.4. CSIC Contracts

In 2006 the Catalan centers of CSIC generated €4.2 million in contracts with companies. Overall, private companies represent about 40% of the contract research funding of these institutions. The biggest part of the funding (30%) goes to the Instituto de Investigaciones Químicas y Ambientales de Barcelona "Josep Pascual Vila". The other two institutes, with 18% and 14% of the company funding respectively, are the Instituto de Ciencias de la Tierra "Jaume Almera" and the Instituto de Microelectrónica de Barcelona. Interestingly, company funding represents 84% of the total contract funding of the Instituto de Microelectrónica compared to the average of 40%.

4.2.5. Catalan Universities and CSIC Contract Research

Table 12 summarizes the Catalan situation for these four institutions. A total of €54.7 million was attracted from private sources. The important sectors active in contracting research from the university are in production technologies, environment and energy, telecommunications and pharma. However, it is interesting to observe how each of the institutions has different weight on these sectors. For example, UAB is really active in the public administration and social services contracts. UB is most active in pharma and the chemical sector, while UPC dominates telecom, environment and energy, production technologies and construction. The CSIC is relatively more involved in the medical and health sectors and dominates the environmental and energy sector links. Understanding and leveraging these different strengths is important for both the institutions and policy makers. *This table provides a starting point for understanding the strong points of Catalan research for industrial application and suggests that, rather than picking winners, policy should be geared towards incentivizing these interactions. Different Universities and research institutions will react differently towards these incentives given their current strengths in on area or another.*

Table 12

Contract Research by Catalan Institutions with Private Firms

		Total amount for 2006	% of total amount	Most important institutions
1	Firm Services	€512,506	0.9	UAB
2	Construction	€1,476,735	2.7	UPC
3	Food, Agriculture	€892,529	1.6	UAB
4	Pharma	€5,224,268	9.5	UB
5	Chemistry	€1,503,056	2.7	UB
6	Medicine, Health	€2,815,525	5.1	CSIC
7	Telecommunications	€6,553,901	12.0	UPC
8	Culture, Education, Editing	€548,648	1.0	UB/UAB
9	Public Adm.	€6,632,458	12.1	UAB
10	Environment, Energy	€8,101,007	14.8	CSIC/UPC/UB
11	Informatics	€781,126	1.4	UAB
12	Production Techs.	€9,061,525	16.6	UPC
13	Other	€10,638,236	19.4	UPC
		€54,741,520		

Source: authors, based on TTO reports.

4.2.6. Catalan Contracts in an International Context

Spain really trails other countries, where TTOs have a much higher income through research contracts with industry. German TTOs lead the way, where an average TTO generates €73 million per year for contract research. Spain, France and Italy are on the low end of the contract research spectrum with €12, €6 and €15 million per year on average (see Table 13). UB is an average player in the European context, while UPC does quite well when taking into account contract research from public providers such as local, national and European governments. UAB is rather at the low end and, as mentioned, links more to public administration than to private firms.

Table 13

Contract Research by European TTOs (€)

COUNTRY	Mean	Std. Deviation	N
Belgium	35,015,865.09	32,354,865	11
Germany	73,601,787.00	38,892,457	6
Spain	12,298,767.73	11,491,994	13
Finland	28,461,330.25	23,322,509	8
France	6,295,120.83	4,186,882	18
Italy	15,667,543.75	10,761,019	8
Netherlands	54,512,500.00	38,303,317	8
United Kingdom	45,840,000.00	26,864,437	5
Total	27,510,550.46	30,523,320	77

Source: Debackere et al., 2004.

4.3. Patents, Licenses, Spin-offs

Some universities have chosen the more entrepreneurial path towards applied knowledge and linking with business. In these cases patents, licensing revenue and spin-offs are probably better measures of their link with business.

4.3.1. Patents

Patents provide a legal claim on a new technology and, as such, are instruments in the innovation process in order to protect knowledge and monetize the value of the underlying research. Spain has a notoriously low patent rate compared to other industrialized countries. In relative terms, as Table 14 below shows (CIDEM, Busom, 2006), Catalonia does well compared to the other autonomous communities on the patenting rate per capita, but there is still a long way to go in reaching the EU average.

Table 14

Spanish Patents

	National[1]		European[2]		PCT[3]		Directly to EPO[4]	
	Number	Per million inhabitants	Number	Per million inhabitants	Number	Per million inhabitants	Number	Per million inhabitants
Catalonia	743	117	499	71.4	870	137	384	78.7
Madrid	553	102	232	47.8	736	136	224	42.8
Navarra	93	167	50	65	87	156	31	90
Basque Country	187	90	194	81	229	110	67	93
Spain	2,864	70	1,510	33.2	3,001	73	1,029	37

[1] Refers to requests of residents in Spain to OEMP.
2 Refers to requests of European patents applied by residents in Spain to OEMP and not directly to the EPO. They represent near a half of the European patents with Spanish origin. 2004 data is provisional.
[3] Refers to requests of protection in all signatory states of the International Patent Treaty using a unique international request.
[4] 2002 data is provisional and come from Eurostat. Last column is the simple average of years 2001 and 2002.

Source: Busom (2006).

While patenting activity is relatively weak in the whole of Spain (10,069 patents during the period 2000-2004), it is nevertheless interesting to compare the relative activity between firms and universities in different patent classes in Catalonia. In the analysis we use the patents registered at the Oficina Española de Patentes y Marcas (OEPM) during the period 2000-2004. Overall 2,388 patents were registered in Catalonia, of which 89.6% were to firms and 10.4% to universities and research centers. We compare the patents in Catalonia (Catalan Patents as a percentage of total Spanish patents) and the category of the owner of the patent (university owned patents versus company owned patents; data source: Portal Meridià, Institut d'Estudis Catalans).

We selected nineteen patent codes (A01, A23, A47, A61, B01, B60, B65, C07, C12, D01, D06, E04, E05, F16, F24, G01, G06, H01, H04), considering them the most representative in the whole range (International Classification of Patents, 7th edition, 2000-2005). In the matrix below we relate each patent class along two dimensions: a) whether the ratio of Catalan patents to Spanish patents of the patent class is above the average for the overall patent sample, i.e., whether there is relatively more activity in this patent class in Catalonia compared to the rest of Spain; and b) whether Universities patent relatively more than companies in the patent class compared to the average of university patents to company patents in the overall sample, i.e., whether universities are relatively more active than average in the particular patent class.

Table 15

Distribution of Spanish Patents

University vs. Company >> Catalan vs. Spanish patents	Above average	Below average
Above average	Basic electric elements (H01) and Technology elements (F16)	Biomedicine veterinary (A61), Vehicles (B60), Packaging (B65), Organic chemistry (C07), Fibers and filatures (D01), Textile treatment (D06)
Below average	Agriculture (A01), Food products (A23), Biochemistry, Alcoholic beverages, Enzymology (C12), Metrology (G01), Calculus (G06), Electronic communication (H04)	Domestic items and furniture (A47), General physical and chemical procedures (B01), Buildings (E04), Doors and windows (E05), Heating and air conditioning systems (F24)

Source: authors.

In the left column we find patent classes where Spanish universities are relatively more active. Interestingly, Agriculture, Food products and Alcoholic beverages are among these categories. However, only in the classes of Technology elements (F16) and Basic electric elements (H01) does Catalonia perform better than the average. In Agriculture (A01), Food products (A23), Biochemistry, Alcoholic beverages, Enzymology (C12), Metrology (G01), Calculus (G06) and Electronic communications (H04), the universities perform better that the average, but Catalan patents are still below the Spanish average. In Biomedicine veterinary (A61), Vehicles (B60), Packaging (B65), Organic chemistry (C07), Fibers and filatures (D01) and Textile treatment (D06) Catalan presence is higher but universities participate less in patenting in those classes. Finally, Domestic items, Furniture (A47), General physical and chemical procedures (B01), Buildings (E04), Doors and windows (E05) and Heating and air condition systems (F24) are below average for both the Catalan presence and the university performance. While this is a crude rendering of the performance of Catalan universities in patenting, the situation looks rather bleak. Therefore, it is difficult to draw any conclusions on the relative strength of the Catalan system based on patents. Not surprisingly, nearly 60% of the patents from universities and research centers are from the Universitat Politècnica de Catalunya, followed by the Universitat Autònoma de Barcelona (13%). This is consistent with our earlier finding that UPC is more active in research contracts in the areas of telecoms, energy and production technology.

Previous research has indicated that patenting and publishing are not substitute activities for important research groups (Van Looy, 2008). However, it is clear that claiming intellectual property of newly developed technologies needs to be rewarded by research institutions in addition to scientific publications. Furthermore, as Thursby and Thursby (2007) show, it is possible that top researchers are active in translating research findings into applications through their consulting activities. This can be measured by the company patents that have the academic researcher mentioned in the inventor list. Unfortunately, such information is not tracked systematically as it presents several important methodological problems to track from publicly available databases. Nevertheless, if Catalonia is serious about monitoring science-industry interactions, constructing such a measure would be very valuable.

4.3.2. Licensing

Licensing intellectual property owned by universities has been seen as an important activity for the technology transfer organizations of the universities. Nevertheless, these operations are usually not really successful in the generation of funds. Except for some rare cases of blockbuster deals as indicated in the figure below, most TTOs do not generate much revenue through this activity (Butler, 2008).

Table 16

Blockbuster Licensing Agreements

Inventing institution	Invention	What it does	Company licensed to develop invention	Amount (US$) royalty rights were sold for
Northwestern University	Lyrica (pregabalin)	Anti-convulsant and pain reliever	Pfizer	$700 million (to Royalty Pharma)
New York University	Remicade (infliximab)	Anti-inflammatory to treat autoimmune diseases	Centocor (later acquired by Johnson & Johnson)	$650 million (to Royalty Pharma)
Emory University	Emtriva (emtricitabine)	Reverse transcriptase inhibitor to treat HIV	Triangle Pharmaceuticals (later acquired by Gilead Sciences)	$525 million (to Gilead Sciences & Royalty Pharma)
Memorial Sloan-Kettering Cancer Center	Neupogen (filgrastim) and Neulasta (PEG-filgrastim)	Stimulates production of white blood cells	Amgen	$262 million (to Royalty Pharma)
Yale University	Zerit (stavudine)	Reverse transcriptase inhibitor to treat HIV	Bristol-Myers Squibb	$115 million (to Bristol-Myers Squibb)
The Wistar Institute	Rotateq	Vaccine to prevent rotavirus infection	Merck	$45 million (to Paul Royalty Fund)

Source: Butler, 2008.

For Spain, the survey of the CRUE (RedOtri) shows that only a total of €2.2 million has been collected for 2006 in licensing revenues across all participating universities. Compared to the contract research this is a paltry sum. For Catalan universities the total licensing revenue was €171,000 (see Table 10). It is clear that this channel of industry-science link is negligible for Spanish and Catalan universities. The situation is, however, not unlike other European universities where the average licensing revenue per TTO is also very low.

4.3.3. Spin-offs

Finally, spin-offs are a much hyped vehicle to transfer scientific knowledge to a new business. Looking at the numbers, it seems again that there is more talk about spin-offs than actual activity. True enough, university spin-off companies might revolutionize an industry through their innovative technologies, but, relative to regular start up activity and employment creation, these spin-offs make only a little dent. Furthermore, in terms of industry-science links, the question remains how spin-offs, licensing and patent activity measure up against PhD mobility and contractual research as a mechanism to promote innovation.

For an international comparison we again use the survey data.

Table 17

University Spin-offs in Europe

	Spin-offs	
COUNTRY	Mean	Std. Deviation
BE	20.55	21.002
DE	42.94	49.369
ES	12.00	18.757
FI	45.50	49.570
FR	6.11	5.063
IT	5.60	4.971
NL	39.60	50.866
UK	26.83	14.317
Total	23.32	39.228

Source: Debackere, 2004.

As Table 17 shows, Spain does better than Italy and France on the average number of spin-offs generated per year. As Table 10 (see before) shows, Catalonia does generate a total number of yearly spin-offs according to its size within the Spanish context but, nevertheless, the impact as a channel for transferring technology to the economy is probably limited.

As a concluding comment, an interesting comparison to make with a successful TTO in a comparable region is the TTO of the University of Leuven (Leuven LRD) in Flanders. The basic set up of the TTO is described in Debackere and Veugelers (2005). Leuven LRD generated about €32 million in contract research for 2006, 17 PCT patent filings were made, €19.2 million in licensing revenue was realized, and only 4 spin-offs were realized. As an individual TTO and for the size of the university, these numbers are impressive. However, the overall numbers for contract research in Flanders is comparable to Catalonia. The big difference in licensing revenue is related to a few blockbuster patents that the TTO licenses. Therefore, while the case for Catalan TTOs does not look very compelling, we need to remind ourselves that all European countries are struggling with crossing the valley between science and industry and none seems to really have found the solution. Catalonia needs to make sure it does not miss the opportunity to grow into a premier knowledge economy, and the first order of the day is creating supply and demand for science while facilitating the interaction. Some pockets of interesting research connecting to application have been highlighted and different universities have different strong points. Therefore, a more sector/discipline/technology-oriented 'lens' is needed to examine and track these interactions between science and business. However, each organization, whether university or public research institute, needs to receive the incentives and autonomy to take advantage of these opportunities.

5. Conclusions

5.1. Creating Priorities by Fostering and Cherishing Diversity

Knowledge interactions between industry and university show a complex pattern. A large number of scientific disciplines, and almost all sectors of economic activity, exchange knowledge in the course of industry innovation. However, industry and university use a variety of channels for knowledge interaction. In this chapter we distinguished between two broad classes of channels: direct links connecting science and business at the frontier of science, and translation links where scientific knowledge is translated into applied technologies. Different measures of these types of links have been proposed. A restriction of the analysis of industry-university links to only a few types of channels may produce misleading results as there are significant differences in the orientation on certain types of interaction by industrial sectors and fields of science. For instance, while the pharmaceutical and chemical sectors dominate the publication link, telecoms, energy and the environment become much more prominent when analyzing contract research paid for by industrial partners. Looking only at one channel, such as publications or patents, leads to a distorted picture of industry-university relations.

The analysis of the data gathered in this study (scientific publications, research contracts, patents, PhD theses, etc.) show that economic sectors in Catalonia have different patterns of behavior when in contact with university-research organizations. Deeper analysis is needed for final conclusions, but a sectoral-science field approach in the treatment of data will help in more carefully defining technology transfer and public R&D policies intended at stimulating these interactions.

In June 2008 a revision of the "Acord estratègic per a la internacionalització, la qualitat de l'ocupació i la competitivitat de l'economia catalana 2008-2011" was published. The document will become a major driver for the development of the Catalan economy when entering an economic recession. Among the 23 lines of action covered by this Agreement, the first one is Innovation and technology transfer, with 5 particular measures relating to: 1) deploy and foster technology transfer networks in Catalonia; 2) converge towards an entrepreneurial university that promotes knowledge and technology transfer; 3) value and commercialize research undertaken in Catalonia; 4) promote business innovation, and 5) facilitate SMEs access to R&D and innovation and promotion of public contracting. The Agreement lacks any particular sector/technology orientation. One of the main conclusions from our study, however, is that economic sectors behave differently when the relations between industry and university are analyzed. While we are certainly not arguing for policy makers to "pick winners," as industrial policy has tended to do in the past without much success, it is nevertheless clear that policy makers should provide incentives for different actors to leverage their strong points when designing the promotion of innovation policies. Only in this way will the multiple links necessary for the success of these interactions between science and business be stimulated. Knowledge transfer networks should include a variety of channels such as direct research collaborations but also human capital mobility, industry-university joint collaborations in scientific publications, patents, etc.

In short, current interactions between science and business should grow in their thickness dealing with the many possible channels of interaction among industry and university and generating more specialized clusters around key research areas of the universities. Policies providing incentives for universities and research centers to build on their research strengths in linking with business will create this richness of interactions compared to policies geared towards maximizing one particular measurement of interaction between science and business. But more research is needed in defining and measuring the specific mechanisms of interaction between the economic sectors and the university. Furthermore, common procedures for reporting industry-university relations in Catalonia would be needed in order to gather the correct data for R&D policy decision-making, including comparable data from the recently created Catalan public research organizations, and this may also help to make proper international comparisons and benchmarking. For this reason, we believe that a key policy decision would be the creation of an independent agency that measures and evaluates progress in Catalonia along different research and innovation dimensions, with a particular focus on links between science and industry.

5.2. Promote Mobility

Contracting PhDs by business is an excellent way to improve the interconnection between science and industry. On the one hand, the PhDs understand how research is done at the university, what the different university participants' incentives and interests are and what is the potential of the existing research and research staff. On the other hand, the PhDs working for a private company understand (or should understand) the business needs of the company while being able to match this with the offer (or potential offer) from the different departments of the university. They have the relevant questions and demands and, due to their knowledge, are able to reduce them to concrete research proposals and tasks. A grant system such as Torres Quevedo addresses this issue. The predecessor of the program "Incorporación de Doctores a Empresas" (IDE) showed that 75% of the researchers contracted through the program remained with the company after the subsidy ended, more than a third published scientific articles and their presence in these mainly small- and medium-sized firms improved the technology transfer (COTEC, 2004). The increase in intake of PhDs into private business will steadily increase the share of (joint) publications from private firms. In addition, it will increase the likelihood of research contracts originating from these private businesses and, as a result, improve the link between science and business. Unfortunately, the mobility of PhDs to industry is rather limited in Catalonia. This observation might be driven both by supply and demand factors. Catalan firms do not demand the incorporation of PhDs into their workforce. This might be related to the fact that, on average, Catalan firms are not very innovative and have little need for highly qualified PhDs in their workforce. On the other hand, the supply of PhDs might not be world class. In order to attract the attention of world class firms, the quality of Catalan PhDs needs to be world class. Improving the quality of PhD programs is therefore critical. The recently created public research centers and ICREA can play an important role in the development and improvement of these PhD programs.

Finally, we believe that business training for scientists and PhDs can improve mutual understanding and bring both parties closer together. The most important connection between science and industry remains the training of highly qualified scientists and engineers. Providing these recent graduates with a deeper understanding of business principles would be a first step in improving their sense for interesting research and technologies. It has been shown that scientist wanting to start up companies lack knowledge about basic management skills. Furthermore, the Catalan economy lacks a dynamic labor market for management talent in knowledge intensive businesses. Fostering such a labor market by making Catalonia an attractive alternative to work and live should be part of the policy measures considered.

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