THEORICAL CONCEPT AND CRITICAL SUCCESS FACTORS OF SCIENCE – INDUSTRY RELATIONSHIPS

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SUMMARY

In the last twenty years the call for "value for money" in research policy is increasing. Nowadays –especially in the context of the economic crisis- during the decision making process about public investments in scientific research the economic utility and "commercial results" are an important factor. Therefore Science Industrial Relationships (SIRE) play an important and growing role. This paper offers an analysis of the concept and importance of such relationships followed by a review of their critical success factors. Chapter 2 offers an approximation about the role of science in economic development; the importance of the science industrial relationships; taxonomy to classify the SIREs and the importance and usefulness of those mechanisms. Chapters 3 to 7 analyse the barriers and the critical success factors for technology transfer and science-industry relationships in relation with the broad contextual framework conditions of the economic structure and with the characteristics of the Innovation system.

KEY WORDS

Value for money, science industrial relationships, critical success factor, barriers, innovation system.

RESUMEN

En los últimos veinte años, la convocatoria de "valor por dinero" en la política de investigación es cada vez mayor. Hoy en día el proceso de tomar de decisiones sobre las inversiones públicas en investigación científica sobre la utilidad económica y los "resultados comerciales" son factores importantes. Por lo tanto, las Relaciones Ciencia Industria (SIRE en inglés) juegan un papel importante y creciente. Este artículo ofrece un análisis del concepto y la importancia de este tipo de relaciones seguidas de una revisión de los factores críticos de éxito. El capítulo 2 ofrece una aproximación sobre el papel de la ciencia en el desarrollo económico, la importancia de la relación entre ciencia e industria, la taxonomía para clasificar a los SIRES y la importancia y utilidad de estos mecanismos. Del capítulo 3 al 7 se analizan las barreras y los factores críticos de éxito para la transferencia de tecnología y las relaciones entre ciencia e industria en relación con las condiciones generales del marco contextual de la estructura económica y con las características del sistema de innovación.

PALABRAS CLAVE

Valor por dinero, relaciones cienci-industria, factores criticos de exito, barreras, Sistema de innovación

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1. - Introduction and methodology[1]

In the last twenty years the call for "value for money" in research policy is increasing. Nowadays –especially in the context of the economic crisis- during the decision making process about public investments in scientific research the economic utility and "commercial results" are an important factor. Therefore Science Industrial Relationships (SIRE) play an important and growing role. This paper offers an analysis of the concept and importance of such relationships followed by a review of their critical success factors.

The performance of a national economy in terms of innovation and productivity is strongly influenced by the intensity of co-operation between the scientific community and the production sector. A smooth, well developed link between science and industry is thus crucial to ensure a correctly-functioning innovation system and foster the creation of competitive advantage through quicker diffusion and application of new scientific findings. In this context the science-industrial relationships (SIRE) received a growing attention in the literature[2], especially in the literature about innovation systems[3] and the Triple Helix Model[4]. Both are based on the interactive model of technological change and underpin –in this context- the importance of SIREs and both refer to the multiple reciprocal relationships among institutional sectors (public, private and academic) (see also Box 1). In fact there exists an increased political pressure on universities to intensify their "third role" through industry involvement and to contribute actively towards economic development. However, technology transfer (TT) and science industrial links are not something new. What is new in the last two decades is the institutionalization of university-industry linkages through the direct involvement of the university and the design of a large number of new SIRE related policies (Geuna/Muscio, 2009). These novel tendencies are reflected in the increasing diversification, scale and complexity of the universities' activities and the systematic way in which most countries organise the SIREs on an institutional level. The increasing relationships between universities and industry as well as the commercial use of scientific results have been the subject of intense policy debates especially since the 1970s. This new approach led to the emergence of a new type of "entrepreneurial" university. (Clark 1998; Etzkowitz et al. 2000; Jacob et al. 2003).

Science and Industrial relationships are a very broad concept that includes a wide range of activities. It can be defined as: all mechanisms or channels of interaction between the scientific world and the production sector aimed at the dissemination or transfer of scientific findings to the production sector and/or aimed at generating feedback from the production sector to the scientific world. There exist a large number of channels or forms of Science and Industrial Relationships and their relationship is difficult to understand since these are often relationships made up of different category actors and come in different compositions. There

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[1] Thomas Alva Edison claimed over 1000 patents. Only seven were commercially successful: the light bulb, the phonograph, the alkaline battery, acetate film, the film projector, power production and transmission, and the microphone."

[2] (OECD, 2002; Geuna/Muscio, 2009 METER ALGUNA REFERENCIA MÁS)

[3] See also the work of Dosi, 1982; Kline and Rosenberg, 1986; Dosi/Freeman/Nelson/Silverberg, 1988 AND Malerba/Orsenigo, 1995

[4] Etzkovitz/Leydesdorf, 1997; Etzkowitz et al. 2000

is not one single setting of SIREs which one can identify as the ideal model for all circumstances, regions or countries and the setting of SIREs usually has to be adapted to national circumstances. The increasing importance and growth of SIRE and the related 'third activity' of the universities has to be understood as a result of the simultaneous influence of a wide array of factors of different natures. Evidently, the most important are the decreasing budgets[5] and the related demand for economic justification of the public expenditures (value for money) (Geuna, 1998, pp. 5–6). A second reason is the increasing understanding of the importance of technological change for a countries' competitiveness and the role of university research as a way to promote local knowledge spillovers and to stimulate regional economic growth and competiveness (Jaffe, 1989; Breschi and Lissoni, 2001). From the viewpoint of the cognitive factors, the enhanced interdisciplinarity of applied sciences and the emergence of new key or multi-purpose science-based technologies (such as bio- and nano-technology, computer science, molecular biology and material science) in combination with the more general growing scientific and technical content of all types of industrial production should be highlighted (Bercovitz/Feldman 2006).

Table 1: Evaluation of the policy instruments: A comparison of type of policy instruments based on the main priority of the instruments

Main policy priority	Number of instruments	At least % Ex ante	At least % Following up	At least % Ex post	Never evaluated
1 Support infrastructure (transfer offices, training of support staff)	12	8,3%	50,0%	25,0%	50,0%
2 Knowledge Transfer (contract research, licences, research and IPR issues in public/academic/non-profit institutes)	29	24,1%	34,5%	13,8%	51,7%
3 R&D cooperation (joint projects, PPP with research institutes)	101	30,7%	26,7%	23,8%	52,5%
Total	814	27,1%	28,4%	19,9%	55,9%

Source: Heijs, J (Coordinator); Baanante, I. y Moya, E. (2010)

Whilst economies around the world look for more responsible investments and increased "value for money", there is a growing perception of the importance for governments of investing in scientific research for long term increased competitiveness and economic growth[6]. This "value for money" approach is not only required from the universities but also from the policy makers in the case of their R&D and innovation policies. To ensure a better efficiency and effectiveness a growing number of such policies are evaluated. In the early eighties the United States and Germany were pioneers in such kinds of studies. Nowadays most countries carry out evaluation studies. Analysing the culture of evaluation in Europe it can be stated that of a sample 814 policy instruments that promote R&D and innovation of 27

[5] Initially the lack of funds was generated by the crisis of the 70-80s; later the restrictions on the public expenditures to meet the "Maastricht Criteria" for joining the European Common Currency (EURO) put pressure on the "value for money" (Geuna, 2001). While at the present time the financial crisis is once again putting pressure on the public funds for R&D.

[6] . Such efforts are broadly recognized even at European level and R&D is the centre of the Lisbon Strategy recently renewed in the so-called Europe 2020 strategy http://ec.europa.eu/research/innovation-union/pdf/innovation-union-communication_en.pdf

different European countries[7] almost 44 percent were evaluated and 20 percent were evaluated ex post[8]. On the other hand, 56% of the instruments were not evaluated at all (see table 1) In other words, only for one of each five instruments was the real impact evaluated. The ERA-watch database includes 142 instruments directly related with the Science-Industry linkages classified in three types of research policy priorities and the percentage of those instruments which were not evaluated is somewhat below average (50.2%, see table 1). The first one is the support for infrastructures for technology transfer (intermediates and promoters) and the second instrument is the support for public private cooperation (PPC). Around 24-25 percent of both types of instruments were evaluated ex post. The third group refers to the other support measures focused on knowledge transfer (excluding PPC). And only 14 percent of them were evaluated ex post.

The first part of this paper includes the introduction and offers a broad revision of the literature about the science – industrial relationships aimed at identifying critical success factors to promote and facilitate such relationships. Chapter 2 of this document offers an approximation about the role of science in economic development; the importance of the science industrial relationships; taxonomy to classify the SIREs and describe the importance and usefulness of the most relevant mechanism of knowledge transfer between the scientific community and the production sector. Chapters 3 to 7 analyse the critical success factors for technology transfer and science-industry relationships. These chapters analyse firstly the determinants for good practices based on the broad contextual framework conditions of the economic structure Chapter 3) and the characteristics of the Innovation system (Chapter 4). The next chapters analyse the barriers and critical success factors that impede or promote the success of the science industrial relationships (SIRE) based on the micro behaviour of the agents implied in such relationships; There is also an analysis of the micro level performance of the universities and the public research institutes (chapter 5); and the micro level performance of the Enterprises (chapter 6).

2.- Science Industry Relationships: importance and basic concepts

2.1.- The novelty of science Industry Relationships

The performance of a national economy in terms of innovation and productivity is strongly influenced by the character and the intensity of the interactions and learning processes among the producers, users, suppliers of knowledge and public authorities (Freeman, 1991; Lundvall 1992; Nelson, 1993; Patel/Pavitt, 1994). Science - Industry Linkages are indivisible and *"The nation that fosters an infrastructure of linkages among and between firms, universities and government gains competitive advantage through quicker <u>information diffusion</u> and product deployment. The performance of an innovation system now depends on the intensity and effectiveness of the interactions between the main actors involved in the generation and diffusion of knowledge" (DEST, 2002)*. In this context the SIRE received a growing attention in the literature (EC, 2001; OECD, 2002; Geuna/Muscio, 2009). And in fact there exist

[7] Based on the data the ERAWATCH database "European Inventory of Research and Innovation Policy Measures"

[8] First of all we would like to thank the ERA-watch organisation for their cooperation in providing us with the data set. On the other hand the percentages indicated in this section must be considered as only a rough estimation. The evaluation studies belong to the so-called "grey literature" which means that several studies exist that were never published. Therefore the data should be interpreted with caution. For more details see*: Heijs, J (Coordinator); Baanante, I. y Moya, E. (2010).*

growing political pressures on universities to raise research funding from industry and contribute actively to economic development.

However, the commercialisation of scientific results and industrial-scientific relationships can not be considered as a “new” revolutionary phenomenon and technology transfer (TT) and science-industry links are not something new. Technological predominance has the basis for wars since the prehistory of the human being. The Renaissance-Principle was based on the international mobility of the most gifted and talented people of the time visiting courts and universities. The host kings provided them with the best possible nurturing environment, tools and creative climate encouraging in this way the mutual learning, inspiration and collaborative enterprise. Segman (1989), who conducted a historical review of TT, traced the TT process from the Neolithic times, the role the Arabs played in transferring technologies from East to West and the transfer of English textile expertise to the American textile industry in the 18th and 19th Centuries (Cameron, 1960; Irwin and Moore, 1991). Also the protection of military and non-military technologies is a process that has existed for a long time although it was and is almost impossible to prevent the diffusion of new technologies. In the 18th Century, despite the English law preventing knowledge migration (by forbidding the export of machinery and the mobility of engineers that were not allowed to work in or for foreign countries) other countries like the Netherlands obtained machinery by illegal exports and the help of British engineers (……reference …..). France eventually managed to obtain ‘specialized steel making know-how’ by importing English workers and through industrial espionage (Cameron, 1960; Irwin and Moore, 1991).

Box 1.- History of the German universities and polytechnic schools

A very important characteristic of the German national and regional innovation system is the integration between science, higher education institutes (HEI) and industry. At the end of the 19th century, Germany began a dynamic phase in its industrialisation in which the regions played an important role. The creation of Technical *Fachhochschule* (polytechnics or technical colleges) in different cities can be viewed as an early variant of regional technology policy. Fachhochschulen or universities of applied sciences are a German speciality. And their special hallmark is the high level of practice-orientation. Tight organisation of the degree courses, teaching in small groups, examinations throughout the studies which count towards the final degree, and a choice of subjects which is orientated to job requirements, permit shorter average studies than are generally achieved at universities. This does not mean a lack of academic or scientific orientation. Universities of applied sciences not only teach but also research. This research, however, is also primarily geared to practical requirements and largely applications-based. The result of this is that "exotic" or purely theoretical degree courses are not to be found at universities of applied sciences. The range of subjects mainly follows the demand for professionals with practical and academic training in engineering, in business administration, in design and in the social services. The German universities of applied sciences are focused on helping German industry to maintain its competitiveness in the international field by supplying an increasing number of better qualified personnel with the capacity to solve practical tasks quickly and successfully on the basis of an academic training. This demand formed the starting-point for the universities of applied sciences

Although traditionally the most important aspect from the HEI is the preparation of human capital, the “Fachhochschule” have a clear role for technology transfer. The linkages between universities or polytechnics and -regional- industry are based on some simple but important mechanisms. A first important linkage is embodied by “work experience" for students, often in combination with their master´s thesis. This simple fact means that Professors and HEIs are obliged to be aware of the latest technological developments and to continuously update their schooling programmes to be able to coach their students during their practicals. Another simple but effective mechanism of interaction between industry and education is a precondition to be a professor in the polytechnics or technical colleges. Each professor has to have at least five years´ experience in industry or comparable activities with a certain level of responsibility. So they have a broad experience in the industrial sector and speak the language of the private sector.

An interesting linkage and characteristic of the polytechnics in the land Baden-Württemberg is the so-called **Steinbeis model.** Steinbeis[9] is a strictly non-profit foundation for technology transfer with over two hundred centres located in polytechnic schools or universities. The centres are focused on small practical technological problems of Small and Medium Sized Firms mainly from their own region. The market principle of the German technology policy is also implemented by the Steinbeis Model. State subsidies are limited and are only available for the purchase of equipment during the initial phase of establishing a Technology Transfer Centre. No funding is available for the ongoing operation or administration of a centre and 95% of the income is derived from the industrial projects. Each centre is an individual administrative unit which has to generate its own income and each year some centres are closed and others are opened following the changes in the demand of the technology markets. The only direct support consists of free "active short consultancy" of five hours for each firms paid by the regional government. The advantage is that the firm does not y have to pay directly but can see whether the centre really can help them. After those five hours the firms are charged, which is a good measure for the legitimisation of their existence (Löhn, 1989).

Also the involvement of the universities is not something new. The interactions between companies and university professors (not necessarily organised on a university level or initiated by the universities themselves) can be traced back to the development of the chemical industry in the nineteenth century In Germany (Haber, 1958; Borscheidt, 1976; Meyer-Thurow, 1982; Lehrer et al, 2009) or at the beginning of the XX century in Holland (Vledder et al. 1994; Faber, 2006)

However, what is new is the institutionalization of university-industry linkages through the direct involvement of the university and the design of new SIRE related policies (Geuna/Muscio, 2009). This is reflected in the increasing diversification, scale and complexity of the universities' activities and the systematic way in which most countries organise the SIREs on an institutional level. All of this leads to the emergence of a new type of "entrepreneurial" universities, moving from what we could define as "craft" production to something transferring towards of "industrial" production. However the pace and timing of such changes differs broadly not only between countries but also within countries where only a limited number of institutions really show significant changes towards an entrepreneurial university.

[9] The Steinbeis foundation did not build up a broad R&D infrastructure of their own, but, rather, makes use of already existing government owned facilities in polytechnics and most of the most technology consultants are also working on the polytechnics. The model has overcome the problem of high overhead costs , which make the TT-agencies of the Steinbeis foundation cheaper and more competitive. The managers at the centres are also professors at the polytechnic and must have at least five years´ industrial experience or similar contact with business

In the last decades universities have become more active in commercialising their research work and in establishing linkages within industry. Moreover the public government has launched a large number of policy schemes and programmes to support university-industry collaboration and commercialisation of scientific results generated by public research institutes. Although these developments showed a different pattern, characteristics and pace in different countries. Geuna and Muscio (2009) argue that in the last 30 years a slow but continuous process of reorganisation of European universities has been developed. "The overcrowding of higher education, the increased scale (and scope) of university research and the more important role of knowledge in the production process have transformed small elite institutions, managed by academic peers in a collegial way, into large multi-task organizations in need of new governance structures to manage all the tasks and roles of these institutions today" (Geuna/Muscio, 2009).The increasing relationships between universities and industry as well as the commercial use of scientific results have been the subject of intense policy debate especially since the 1970s. This new approach by the universities can be denominated as the entrepreneurial university (Clark 1998; Etzkowitz et al. 2000; Jacob et al. 2003). The concept of an entrepreneurial university refers to the adoption of the dual cognitive research mode focusing on achieving fundamental advances in knowledge and inventions that can be patented and marketed (Webster & Rappert 1997). Often the concept "third function" is used for the commercialisation of scientific outcomes in addition to education and research (Etzkowitz 1989, 2003). This discussion was maintained alive in the political arena where the concept and implications of the so-called "European Paradox" was broadly accepted. By this paradox Europe was one of the leading areas on a scientific level but was clearly weak in the case of commercialisation of the scientific results, while other countries, like Japan or the US take advantage of the European academic progress. The 'European knowledge paradox' was or is of great concern to policymakers because a lack of or failing channels for technology transfer between science and industry limit potential economic growth. This discussion generated several empirical studies that do not find hard evidence to confirm the existence of such a paradox. Dosi et al (2005) put it as follows: "we soon realized [...] that the paradox mostly appears just in the flourishing business of reporting to and by the European Commission itself rather than in the data".

2.2.- The existence of a growing attention for SIREs

The growing role of the "third" activity of the universities has different complementary interrelated causes. A first cause was the decreasing budget that generated a culture of value for money. During the economic crisis of the seventies and the limits of the public budgets as a result of the "Maastricht Criteria" during the introduction of the Euro severe restrictions for the public budgets[10] for research existed. This situation generated incentives for the universities to look for other financial resources. On the other hand the budget restriction generated a demand of economic justification of the public expenditures (value for money) and a new focus aimed at maximising the social returns on public investments in research by stimulating university technology-transfer (Geuna, 1998, pp. 5–6). The second reason of a more intensive attention to SIREs was the increasing understanding of the role of technological change for the countries´ competitive position. The regional governments started to consider university research as a way to promote local knowledge spillovers (Breschi and Lissoni, 2001; Calderini and Scellato, 2005; Feldman and Desrochers, 2003) and lead to regional innovation processes (Jaffe, 1989; Varga, 1998). This improvement of the regional

[10] In several countries the reduction of R&D expenditures was –besides the economic crisis- also related with the downturn of the military expenditures on research (Like in the US especially after the fall of the West Berlin wall in 1989 (Gauna and Muscio, 2009)

innovation system is considered as a way to stimulate regional economic growth and competitivity. Third the cause of the growing attention for SIREs is based on the growing interdisciplinarity of the applied sciences and the emerging of some key or multi purpose science based technologies (like bio and nano technology computer science, molecular biology and material science) in combination with the more general growing scientific and technical content of all types of industrial production (Bercovitz/ Feldman 2006;

To conclude, at the same time that governments require more responsibility and value for money the importance of the R&D for competitiveness and economic growth is broadly recognized. This recognition generated a growing public support of the R&D on European level reflected in the Lisbon Strategy and its objective to come increase the R&D expenditures to a 3% of the GDP. The new concept of "value for money" and the need for the commercial impact of R&D generated in the last years important changes in the public support for R&D. First of all a large number of instruments were reoriented to support the cooperation between the scientific community and the production sector. Secondly, the R&D support for universities and public research organisations moved away from direct block funding to competitive tenders.

2.3.- Importance of science and certain channels of SIRE

The differences in the importance of scientific results[11] for sectors or(of)??? technological fields are demonstrated in several studies. A first way to analyse the importance of science is comparing it with the importance of other external sources of knowledge. The study of Arundal and Geuna (2004) compares the importance of science with the importance of other external sources; affiliated firms, customers, reverse engineering, joint ventures, and suppliers. The analysis of tem, repeated for 16 sectors (see tables 2 and 3) showed that on average only 17 percent of the firms indicate that science is the most important source. In only two of the 16 analysed sectors do the firms consider science as the most important source (aerospace and utilities[12]) while for half of the sectors science is not very important.[13] The most important sources for the majority of the firms are the affiliated firms, and custumers.

A second way to analyse the sectoral differences for SIREs and the role of science is offered by Meyer-Krahmer and Schmoch (1997). They created an index on the level of technological fields about the importance of science based on the patent descriptions. Their results showed that, in the case of Germany, the highest science linkage is found for biotechnology. The other areas with an above average score are mostly related to chemistry and information technology—including semiconductors. The areas below average are generally linked to mechanical engineering and civil engineering (For details see table 4 and Meyer-Krahmer/Schmoch, 1997).

Another empirical study work on the level of technological fields (Marsili and Verspagen, 2002) confirms that the fields with a science-based regime (e.g. an important knowledge base) are life sciences and physical science typified by a high level of technological opportunity, intense R&D activities and direct links with academic research. A good example is the pharmaceutical industry, biotechnology or nano technology.

[11] See among others Meyer-Krahmer/Schmoch, 1997; Marsili and Verspagen 2002; Arundal/Geuna (2004)
[12] Public service sector
[13] In another 5 sectors between 17- and 23% consider science as the most important external source, for 2 sectors, around 10% consider it as the most important one and for 6 sectors less than 5 percent of the firms consider science as the most important source.

Table 2: Percentage of Firms by Sector Giving Their Highest Score to one of the Six External Sources of Technical Knowledge for Innovation (Weighted by R&D Expenditures).

Sector (ISIC class, 3rd revision)	N	R&D by sales (%)	Public research	Affiliated firms	Customers	Reverse engineering	Joint ventures	Suppliers	Total (%)
Food (15)	44	0.60	23.5	38.1	11.8	19.1	2.3	5.2	100
Petroleum prod (23)	17	1.07	18.0	24.4	25.9	10.6	3.2	18.0	100
Non-metallic minerals	24	1.51	16.9	40.5	4.7	18.4	11.4	8.1	100
Basic metals (27)	18	1.45	3.3	7.3	31.2	33.3	13.0	11.9	100
Manufactured metal	14	1.73	1.9	53.8	3.1	3.0	9.4	28.8	100
Utilities (40)	25	1.33	55.9	7.8	10.6	1.9	20.6	3.3	100
Low technology sectors	41	1.09	13.1	31.0	32.6	10.0	6.7	6.5	100
Chemicals (24 excl.	77	3.19	16.6	29.4	0.8	17.3	7.0	28.9	100
Plastic and rubber	11	4.20	21.7	0.4	46.7	22.4	0.1	8.8	100
Machinery (29)	48	2.66	10.5	8.3	33.4	25.0	3.0	19.7	100
Automobiles (34)	46	3.95	9.4	24.7	32.8	14.7	10.0	9.0	100
Medium technology	8	2.97	29.8	8.6	14.1	25.9	20.5	1.2	100
Office equipment and	13	5.97	5.4	22.7	28.1	18.2	4.8	20.9	100
Electrical equipment	17	7.41	0.5	52.2	7.7	3.5	30.3	5.9	100
Telecom equipment	18	8.80	3.8	20.0	10.7	18.4	31.5	15.6	100
Instruments (33)	17	8.96	4.0	12.2	10.4	35.4	9.9	28.3	100
Aerospace (3530)	19	21.35	57.4	3.9	2.3	19.2	13.5	3.8	100
Pharmaceuticals (2423)	36	12.82	23.1	18.1	7.3	14.5	34.3	2.7	100
All sectors: weighted by	493	3.49	17.3	23.7	17.4	15.1	14.7	11.9	100
All sectors: unweighted	588	–	16.4	18.9	16.3	19.9	9.5	18.9	100

* For each sector, the total R&D expenditures are totalled across all firms and divided by total sales across all firms.

Taken from Arundal/Geuna, 2004

Table 3: Percentage of Firms by Sector Giving Their Highest Score to one of the Seven Methods for Learning about Public Research outputs

Sector	N	Publications	Conferences	Hiring trained staff	Informal contacts	Personal exchanges	Contract research	Joint research projects	Total (%)
Food (15)	43	15.2	10.3	37.6	15.6	4.8	8.5	8.0	100
Petroleum prod (23)	17	3.8	8.0	25.7	21.9	0.3	37.7	2.6	100
Non-metallic minerals (26)	22	19.0	23.5	1.4	30.1	11.5	10.3	4.2	100
Basic metals (27)	18	10.2	7.2	26.0	16.7	0.0	11.4	28.4	100
Manufactured metal products (28)	13	4.2	1.5	10.3	6.2	0.5	mm3.0	54.4	100
Utilities (40)	25	14.9	14.9	11.1	17.6	1.0	36.2	4.3	100
Low technology sectors (nec)	39	11.8	17.4	34.2	20.9	6.1	5.5	4.2	100
Chemicals (24 excl. 2423)	76	18.4	5.4	33.6	14.4	0.0	12.7	15.5	100
Plastic and rubber products (25)	11	1.9	1.6	76.8	2.4	1.5	2.2	13.6	100
Machinery (29)	48	30.3	12.6	22.1	26.1	1.4	4.7	2.8	100
Automobiles (34)	45	4.7	9.5	23.4	18.5	0.0	30.5	13.4	100
Medium technology sectors	8	16.2	9.7	31.4	14.5	0.0	6.5	21.8	100
Office equipment and computers (30)	12	11.4	24.9	20.9	9.5	8.1	14.0	11.1	100
Electrical equipment(31)	17	1.7	1.1	76.3	17.8	0.6	1.2	1.4	100
Telecom equipment (32)	18	34.7	16.3	26.0	10.9	2.2	2.3	7.6	100
Instruments (33)	17	15.2	16.9	12.9	39.2	0.1	9.7	6.0	100
Aerospace (3530)	18	7.7	7.9	18.0	23.0	0.0	16.0	27.5	100
Pharmaceuticals(2423)	36	11.3	12.3	20.0	41.4	1.0	1.7	12.4	100
All sectors: weighted by R&D	483	10.4	9.3	29.0	20.8	0.8	17.1	12.6	100
All sectors: unweighted	574	24.1	12.3	20.9	18.2	2.8	9.3	12.8	100

Taken from Arundal/Geuna, 2004

Table 4: Relationship to science of 30 technology fields, measured by the relative science reference indices at the European Patent Office for 1989–1992 (Technology fields Index)

Above average		*Below average*	
Biotechnology	81	Nuclear technology	- 1
Pharmaceuticals	66	Polymers	- 5
Semiconductors	61	Electrical engineering	-12
Organic chemistry	58	Environmental technology	- 27
Food chemistry	52	Materials processing	- 33
Data processing	37	Chemical engineering	- 34
Optic	36	Machine tools	- y44
Audiovisual technology	30	Food processing	- 46
Telecommunications	29	Engines	- 57
Material	28	Handling, printing	- 63
Control technology	20	Thermal processes	- 64
Basic materials chem.	15	Medical technology	- 67
Surface technology	9	Space technology	- 78
..		Transport	- 78
		Mechanical elements	- 84
		Consumer goods	- 87
		Civil engineering	- 91

Source: Group et al. 1995

The main inputs of such sectors are scientific results[14] and therefore they have a rich number of diversified types of science industry relationships due to the great opportunities for innovation. A last study that can be highlighted is the work of Klevorick et al. (1995)[15]. They showed that the fields of university research with the highest relevance for firms are: computer sciences, material sciences and mechanical engineering. On the other hand, geology, physics and mathematics score very low. However, in certain fields many of the spillovers may well be indirect. For instance, fundamental research in physics, probably of little use to firms, is beneficial to mechanical engineering, which itself is very important for firms.

2.4.- Advantages and disadvantages of the "entrepreneurial" or commercialised" university

A very important discussion in recent decades is whether SIRES and the corresponding engagement of universities in entrepreneurial activities is a positive or negative development (see box 4). There is some agreement on the potential positive impact of the SIRE on economic growth and the positive effects of the technological capabilities and level of competitivity of the enterprises and the regional innovations system. For example SIRES foster a more rapid diffusion of new knowledge, increase the technological capabilities of a regional innovation system and generate extra income for the universities. However, some negative effects can also be expected. In this short review three or four main aspects are discussed.

1. Commercial use of publicly funded research results by firms could create a distortion of the free market in which some particular firms obtain advantages and monopolise, at low costs, the use of new knowledge paid for with public money while other firms are excluded from the benefits.

2. This distortion is directly related with the second problem because it implies the loss of the "open innovation" culture. In such culture the public research results can be used by every agent of the production sector as a kind of "Arrow" based public goods. More secrecy and privatising of public knowledge by firms will lead to less disclosure. Therefore stronger links with business could reduce the disclosure of academic output, due to a conflict in the incentive structures of universities and the business world.

3. The third main problem is the impact of the commercial approach on the orientation of the research. This could take the form of a negative impact on the investment on basic research with an apparently low level of commercial interest and on long term research activities whose payback period is a long way in the future. In other words, stronger ties with business could crowd out fundamental research to the benefit of more applied research by academics

4. Some other effects are the negative effects on the behaviour of public researchers and universities (such as giving less attention to teaching and their students).

The commercialisation and the readjustment of the academic system to "entrepreneurial universities" may have two or three unintended consequences. Firstly the commercialisation could lead to more secrecy and less disclosure, because the stronger links with business could reduce the free publication and disclosure of academic output, due to a conflict in the incentive structures of universities and the business world. This implies on the one hand (point 1) a distortion of the free market due to the commercial use of publicly funded research results by firms, especially in the case where the licenses offer exclusivity for a low price to some specific enterprises excluding other competitors. And on the other hand (point 2) it implies the loss of the "open innovation" culture in which the public research results can be used by every agent of the production sector as a kind of "Arrow" based public goods. The second type of unintended consequences is that the entrepreneurial

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[14] 60% of university licences in the U.S. were biomedical inventions (Pressman, 1995)
[15] Based on the Yale survey among 650 R&D directors in large US firms

university could drift away from fundamental long term research to the benefit of more applied research (point 3). An excessively entrepreneurial approach would have a negative impact on the investment on basic research which has a payback period a long time in the future and with an apparently low level of short term commercial interest. The third problem would be the negative effects on the behaviour of public researchers and universities (such as less attention to teaching and other responsibilities).

Box 2.-The cost of disclosure versus open science: Empirical evidence.

"Several case studies bring up evidence that disclosure restrictions and delays in publications do occur in practice. In their widely cited survey of Industry/University Cooperative Research Centres (I/UCRCs), Cohen et al. (1994) find that 35% of the research centres allowed firms the ability to delete information from reports and 50% allowed firms to delay publications. Blumenthal et al. (1997) find similar evidence of disclosure restrictions among researchers in life sciences who received industry support. In their analysis, delaying publication longer than 6 months was predicted by two main variables: receiving funding from industry and being involved in commercial activities. But the empirical literature also provides some counterevidence. More specifically, publishing and patenting by scientists seem to be complements rather than substitutes. Stephan et al. (2002) study the hypothesis that faculty patents crowd out faculty publications, i.e. that scientists engaged in patenting activities have incentives to restrict disclosures of findings and thus publish less. Using data on the Survey of Doctorate Recipients about publishing and patenting activities in different academic fields, they find that the number of articles published in the last five years has a strongly positive (and statistically significant) connection with the number of patents issued in all fields, except computer sciences. In other words, patenting and publishing are two complementary activities, rather than substitutes. This can be explained by the fact that scientists may want to publish some results, while monopolising the use of some other findings, so that it becomes more difficult (or even impossible) to reproduce their work. Similarly, in a related study at two departments at MIT, Agrawal and Henderson (2002) conclude that patenting is not substituting for more fundamental research, and might even be a complementary activity. Another study is Behrens and Gray (2001), who finds no evidence for the claim that industry sponsorship would result in erosion of academic freedom (using data on graduate students at six US universities). Sponsorship by firms has no negative effect on outcomes in terms of publications, career goals, and perceived academic freedom. It should be noticed that these results may suffer from selection problems, e.g. when industry selects well-known scientists to work on projects and scientists are steered towards patenting".

Taken from Canton et all (2005, P.36/37)

The first two points -the problems of disclosure versus secrecy in entrepreneurial universities- refer to the impact of scientific results on the market and the productive sector. As mentioned by Arrow in his classic article on technology as a "public good", the state should support R&D and make it publicly available for the whole production sector broadening in this way the technological frontier and indirectly the competitive advantages of a country and its enterprises. The conflict between the norm of disclosure of science and the secrecy norm in the business sector might increase if the link with the business sector becomes stronger (Dasgupta and David, 1994; Stephan, 1996). Canton et al (2005) argue that the fact that not all research results are disclosed reduces the social benefits from university research because secrecy could lead to useless duplication of research, slowing down the advancement of science and diminishes broader technological transfer towards other firms which are not collaborating with universities. Licensing the ownership of the output of publicly funded scientific research implies the appropriation of public goods by certain private enterprises and diminishes the potential technological spillover to other firms. This fact would be a threat to the "open science" culture (David, 2004; Nelson, 2004; Geuna and Nesta, 2006). Moreover, in the event of the knowledge being sold for a low price the commercialisation could reduce the free market competition. The ownership of research results at the end of project -and even in intermediary phases- is a problem because openness in research and publications can be hindered by commercial need for confidentiality and can delay the diffusion of the results. However some doubts exist on this argumentation.

The supposed limiting role of patenting and licensing in the diffusion of the new scientific breakthroughs could be partially tackled by a more creative way of licensing specifying non exclusive rights (Antonelli, 2008). A study of Feldman et al. (2007) shows that in specific cases non-exclusive licensing is the most suitable approach to maximize the diffusion and use of a new scientific outcome. It can be pointed out that firms that do not have some kind of exclusivity are not or are less interested in further development of the embryonic scientific results because in this case other firms can also develop similar product or imitate the new innovations developed by the enterprises. In other word if firms are not sure that they can appropriate the new developments deriving from public research they will not make the extra R&D investments for further development which will lead to an underinvestment in R&D. The way of non-exclusive licensing could assure the firms that their investment in a specific application will be protected, which increases the overall R&D investment, However, simultaneously it does not impede other enterprises from using the scientific result for other purposes. Other authors support the interaction between science and industry to assure a higher level of utility and usefulness of the research paid from public funds. Murray (2005) argues that the private use of scientific ideas does not imply a monopoly or complete privatization of the research results because academic scientists' defend "open science" and created a hybrid economy in which both company and academic inventors use patents to protect and exchange their new knowledge. However this new situation may be less efficient than the previous reliance on pure "open science" because of the transaction costs associated with patenting (Geuna/Muscio, 2009).

Box 3.- Trade-offs associated with university-industry relationships

Benefits	Drawbacks
• Additional revenues for University	• Negative impact for culture of Open Science (Nelson, 2001)
• More rapid technological diffusion	• Negative impact on students/adviser relations
• Choices regarding technological emphasis	• Could reduce quality and quantity of basic research (Louis at al. 2001; Siegel at al. 2003)
• Positive Effects on Curriculum	• Negative Effects on Curriculum
• Local/Regional Economic Development	• Could affect negatively the type of research questions addressed (Stephan, 2001)
• Two way-knowledge transfer	• Academics could spend less time on teaching and services (Stephan 2001)

Adapted from Poyago Theotdky, Beath, Siegel, 2002

Also Cohen et al. (1998) suggest solutions for a partial solution of the conflict between disclosure and secrecy. They mention that the state could reduce the tax benefits for firms that collaborate with universities and include strict disclosure conditions. Another alternative is a well developed internal regulation of the universities for research disclosure in the case of cooperative projects with firms[16]. In fact a balance has to be sought to bridge both contradictory interests. The above mentioned regulations can generate a situation in which firms become more reluctant to outsource their research

[16] For example in the case of the Polytechnic schools in Germany the staff can carry??? obtain finance for R&D in two schemes. The first one is by public funds and in this case the results have to be published. A second form is by private funds and in this case there is no obligation to disclose the results.

to the higher education sector. The advantages of the secure disclosure of research results should then be weighted against reduced financing from the market.

A third argument in favour of licensing of public research results to private firms has to do with the specific character of scientific results as tacit knowledge The public private cooperation is necessary in the case of scientific wisdom. The outcome of academic research becomes publicly available if the knowledge is codified by the researchers and is published in scientific journals, the technical descriptions of patents etc…). However not all the relevant aspects of knowledge can be codified and often some relevant aspects are excluded or kept (intentionally or not) secret. The tacit knowledge is necessary to fully understand the scientific idea and without this knowledge its diffusion is not easy. This is particularly true in the case of the new emerging scientific disciplines –with a low number of experts and a low level of codification and standardisation- and thus heavily based on tacit elements difficult to codify. In such fields the knowledge transfer is more difficult and personal contacts and face to face interactions are required. Canton et al (2005) highlight that scientists that limit their diffusion to publications (motivated by their reward system) limit at the same time the so called open science approach. The optimum commercial use of academic results is clearly limited without a direct interaction with industry to transfer the tacit knowledge. This means that many enterprises are not able to use academic knowledge. This argument is directly related with the vision of scientific results as a ”public good” accessible for everybody versus the scientific results as “ a private good” due to its tacit aspects that are only partially accessible by a small group of agents with a high very specific technological capabilities. In this aspect the importance of the geographical proximity can be stressed by the argument that the indissoluble combination between tacit and codified knowledge and the need to face to face contacts do limit the knowledge spillovers to local agents. In fact the literature studying the channels of knowledge transfer between universities and firms showed that spillovers are locally concentrated (Mansfield, 1995; Jaffe, 1989; Adams, 2002).

Another unintended consequence of an excessive commercialisation of the universities is the undesired impact on the orientation of basic research activities and other aspects of the behaviour of the universities and its researchers. A too intensive involvement of researchers in industrial activities and to much pressure of the “value for money” culture may damage academic research in the following ways[17]: by promoting a shift of the orientation of long term basic scientific research activities to short term applied research; diminishing the interest in good basic research especially in fields whose commercial interest apparently is less promising: undermining the commitment to teaching and the research freedom or autonomy of the universities and scientists.

An important discussion in the literature about the science industrial relationship is its possible impact on the orientation of the research that could shift away from fundamental or basic research to applied research. The public support for fundamental research is justified on the basis off their specific characteristics, especially, the long term risks in combination with the high investments. Moreover, their output often generates a kind of public good that can be copied almost for free by other agents. In this case enterprises are reluctant to finance such R&D activities avoiding the risk and the problems of appropiability. Although the basic research may not result in ready-to-use applications the state finances such activities because it could generate in the long term a scientific breakthrough that could be very important for the economic growth or to solve societal problems (such as health, security and protection of the environment. The involvement of the industry could reorient the academic research to more short term applied research activities. The execution of long term basic research is important not only for society as a whole but also for the universities themselves. The comparative advantage for university is on basic research, even if it could also develop applied research and development. To assure their competitive advantages in the future they will also have to combine the short term applied research with long term strategic research projects

[17] Feller 1990; Faulkner & Senker 1995; Senker et al. 1998; Ziman 1994, 1996; Cohen et al. 1998; Blumenthal et al. 1997.

and maintain a balanced portfolio of diversified long and short term projects. The commercial approach of the university research activities could create conflicts of interests and therefore influence the development of a common research project by determining tension for choosing research directions. Scientists generally are mainly driven by their knowledge and instinct, while the industrial partner is driven by other criteria (timing, uncertainty, possibilities for application, etc. One of the problems already mentioned is the choice between applied and basic research. In some other cases as well as the fear that disaffection in an industrial partner could influence the decision to research one product (for instance because it is produced by the industry itself) and this would affect academic freedom. It deals with culture and values question, based on the assumption that freedom of inquiry is the unavoidable condition for knowledge production. The empirical studies show that the science industrial relationships influence the selection of the R&D activities, though the exact effects are unclear. Mansfield (1995) indicates that more than 50% of the interviewed academic researchers state that their research orientation is the results from their interactions with the industrial world and also around 50% indicate that the direction of their work was influenced by potential sponsors and users. However the study of Mansfield analysed only a few technological fields such as electronics and chemistry, which are in fact highly applied disciplines. However several studies (Blumenthal et al. 1997; Mowery and Ziedonis, 2002; and Thursby and Thursby 2000) argue that there is no clear relationship between the SIRE and the reorientation of the R&D to basic research and the causality between those two aspects are not clear. The increase of the licensing activities is not an effect of the reorientation of R&D, but rather of a changing attitude of the scientists who became more interested in the protection of their results due to growing entrepreneurial climate. Based on the mentioned studies Canton et al (2005) conclude that there is no strong evidence in the literature that science-industry interaction leads to problems in the disclosure of scientific research results or to a shift away from fundamental research to applied research in academics. Moreover several of those problems could be solved partially by the governmental influence on the distribution of the fund. For example a certain percentage of the funds has to be oriented to basic research.

Box 4 also suggests some advantages like the additional income of universities in doing R&D, for example, the more rapid diffusion of knowledge and regional technological spillovers Moreover industrial funding offers the researchers new ideas and research topics and is positively correlated with publication output (Gulbrandsen and Smeby, 2005).

2.5.- Taxonomy and importance of science- industrial relationships

2.5.1.- Taxonomy of science-industrial relationships

Nowadays large numbers of different channels of science-industrial relationships are identified. Due to the large number of involved agents, the diversity of activities and objectives and the great number of formal and informal channels it is almost impossible to offer a taxonomy that satisfies everybody. In this paper a three-level classification is proposed based on four principal mechanisms (see Table 7.1)

1. Mechanisms based on applied research (focused on the commercialisation of the scientific results)
2. Training, schooling and mobility of human capital mobility
3. Informal mechanisms of science-industrial relationships
4. Intermediary mechanisms (Including the legal setting and the institutional promotion)

In fact the first three mechanisms include specific type or channels or modes that refers to direct technology transfer while the fourth mechanism includes the institutional, organisational and legal setting in which the technology transfer is embedded and this setting facilitates or promotes technology transfer. Each principal mechanism includes several types of channels of technology transfer between the scientific world and private enterprises. And the third level includes the specific modes or forms of technology transfer. In this case a broad range of modes is offered, although the list is possibly not complete and other modes could be imagined[18].

The singular character of the first mechanism (applied research to commercialise scientific results) is the execution of research activities or R&D related services. In this case three types of channels are identified: (1.1) subcontracting or cooperation in R&D projects; (1.2), contracting R&D related consultancy or services and (1.3) Independent applied (science- based) research organisations. The first one is based on the cooperation or direct outsourcing of R&D (subcontracting) based on formal or informal agreements. In this case the scientific researchers working in universities (UNI) or public research organisations (PRO) carry out applied research projects under contract or work together with industrial researchers within a cooperation agreement. In general such projects are directly focused on applied research. However, on some occasions, basic research can also be carried out, especially in the case of emerging technologies (like biotechnology or nano technology) or in specific fields where basic and applied research are interwoven (like medicine and pharmaceuticals). The second channel involves applied or experimental research of a more superficial technological level including testing and measuring. In this case the activities are considered as R&D-related consultancy activities or S&T services. The third channel based on the execution of applied research includes the applied research institutes that are independent from the scientific community and can also be placed outside the network of normal enterprises. In other words it is not the scientific community or the firms (individually or in cooperation) that execute the conversion or commercialisation of the scientific results, although this is done by external organisations (technology centres or institutes) independent from the scientific or production sector. Most of these external organisations have intensive relationships simultaneously with universities, public research organisations and enterprises and play a bridging role or act as a node between both subsystems. Normally they are not considered as a type of SIRE because often the technology centres or institutes are considered as part of the industrial system. However they are not real enterprises and often are government owned and financed. This channel can be considered as a very important systematic mode to convert scientific results into commercial products. Moreover the main objectives of such centres include the commercialisation of scientific results like in the case of the science based technology institutes as the Fraunhofer Society in Germany, the Carnot Institutes in France or the applied research centres in the US.

The second main mechanisms involve human capital. In this case two different channels can be differentiated. The first one includes all kinds of activities related with the training, instruction and education of the researchers, engineers or other S&T professionals. The second one is related to the mobility of researchers between the scientific community and the industrial or production sector. The first type or channel of technology transfer based on human capital refers to the traditional main function of the universities: schooling and instruction of the students. Besides the basic education in the scientific disciplines nowadays the university also offers a large number of general masters or expert courses for professionals. Including highly specialised short vocational training programmes or courses contracted by firms. Especially the growing importance of lifelong learning (*ongoing education* or *continuous training*) opened such opportunities. Moreover the decreasing number of students that enter in the universities encourages them to look for such new "business" opportunities. The second type or channel related with the human capital is the mobility of researchers. There exist several modes of mobility of human capital between the scientific community and the production sector. It is not uncommon for scientific researchers move to enterprises and a small group of researchers work simultaneously in both types of organisations. A specific form of mobility of

[18] In a good classification all modes and channels could be assigned without any doubt to one specific class and those classes should be or are mutually exclusive (E.G. each class represents one specific mode. However in the case of the technology transfer modes this is almost an impossible mission and some specific modes can be included in more than one type of channels or mechanisms.

human capital is based on the creation of academic spin-offs. In this case, the researcher with his broad experience and tacit knowledge creates a firm which is often in the neighbourhood of the university. Less common is the number of researchers of private firms that went to the university, basically due to the differences in the salaries[19]. Other modes of mobility of human capital are the temporary interchange of researchers and the exchange of graduate, master and PhD students who do training-ships or apprenticeships in enterprises. In this case an extra value is obtained if there is an intensive supervision of the scientific researcher, although this is not always the case.[20]

The third basic mechanism includes a broad set of different informal and/or indirect science industrial relationships that are not formalised and often difficult to track, measure or identify. It includes transfer channels based on the attendance of researchers of both communities at conferences, workshops, seminars or expositions etc.; the preparation of co-publications by researchers of both communities; and the informal contacts between researchers and entrepreneurs (Alumni societies; professional society's friendships, etc… Another informal channel for technology transfer would be the scrutiny and examination of publicly available scientific knowledge and results (for example academic publications and patents) by enterprises in order to obtain new ideas and acquire new knowledge useful for their innovation activities.

The fourth basic mechanism of our classification includes the intermediary mechanisms that should facilitate or embody the technology transfer mechanisms mentioned in the first three groups. In other words these modes of SIRE do not involve direct relationships in themselves, but they do generate promote or smooth the progress of technology transfer and interaction -as a mutual learning process- between the scientific community and production sector or other potential users of scientific results. In this group three types of channels can be distinguished: (4.1) Institutional promotion for direct interaction (4.2) Direct institutional support for technology and knowledge transfer and (4.3): the legal setting

The first one, the (4.1) refers to a set of instruments of the institutional promotion of the interaction based on the proximity principle, fostering the regional co-location of science and industrial activities. This is the case of the creation of science and technology parks. Such parks should facilitate the location of innovative firms and public or private R&D centres with similar although complementary technology or scientific capabilities in the same geographical area. It is supposed that close geographical proximity increases the formal and informal interaction between both communities (see also section 3). This type of channel also includes instruments aimed at the increase or institutionalisation of the interaction of already co-located agents such as the cluster and network policies. However, this latter set of instruments is not only operating on a level of geographical proximity.

Some cluster or network policies are geared to increasing interaction between complementary R&D organisations and enterprises on a national or international level as a way to obtain access to external (scientific) knowledge. In the group of institutional promotion of SIREs the joint use of S&T infrastructure or the creation of "internet-based" networks" can also be included, because this would be another way to bring together researchers of the private and public sector as a way to increase their formal or informal interaction and subsequently the mutual learning and technology transfer.

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[19] Although in some countries it is more likely. For example to obtain an appointment as a lecturer in the polytechnic schools in Germany, you need at least five years experience in S&T activities in a firm on a certain level (Heijs, 2007).

[20] There is one mode of SIRE related with human capital which is difficult to assign to one of the mentioned channels. This is the case of the graduate students, those that obtained their master´s degrees or PhD holders that afterwards start to work in the production sector. In this case it can be considered as mobility although also as a consequence of the schooling and training of researchers.

Box 4.- Channels and mechanisms of SIRE

1. Execution of applied research focused on the commercialisation of the scientific results

1.1.- **S**ubcontracting or cooperation in R&D projects

1.1.1. Contract research based on projects
1.1.2. Cooperative projects financed by private enterprises
1.1.3. Cooperative projects financed with public funds
1.1.4. Research sponsored by industry
1.1.5. PhD thesis related research oriented to applied problems (Including the supervision)

1.2.- contracting R&D related consultancy or services
1.2.1. Transfer or know-how of experts
1.2.2. Tests, measurement and technological services
1.2.3. Access to facilities and equipment (to the scientific and technological Infrastructure)
1.2.4. Subcontracting of prototypes

1.3.- Independent applied (science based) research organisations
1.3.1. Technology centres or institutes (
1.3.2.- Private or public foundations or other organisations of applied research (or ones that carry out such activities)

2. - Training, schooling and mobility of human capital

2.1.- Human Capital: Schooling and training

2.1.1. Schooling of graduate students
2.1.2. Schooling of PhD and master´s students
2.1.3. Masters for professionals (Lifelong learning)
2.1.4. Provision of specific ad hoc courses for professionals contracted directly by firms or sectoral organisations (Lifelong learning)

2.2.- Capital: Mobility of researchers and students

2.2.1. Mobility of researchers from public knowledge institutes to industry
2.2.2. Mobility of researchers from industry to public knowledge institutes
2.2.3. Academic spin-of enterprises as a specific form of mobility
2.2.4. Researchers that work simultaneously in the public and private sector (Double appointments)
2.2.5. Young graduates of the university (Master´s degree, PhD, etc..) that start to work in the production sector
2.2.6. Knowledge exchange during the joint use of the S&T infrastructure by public and private researchers
2.2.7 Temporary exchange of personnel
2.2.8. Trainees and their supervision (PhD students; Students doing their master´s thesis etc…)

3. Informal and/or indirect science-industrial relationships

3.1. Attendance of researchers at conferences, workshops, seminars or expositions etc…
3.2. Joint publications

3.3. Analysis of academic publications and patents by enterprises
3.4. Informal contacts between researchers and entrepreneurs (Alumni societies; professional societies,; friendships, etc…
3.5. Cooperation in education (Influence of entrepreneurs in the university schooling programmes; inclusion in university boards; sponsoring education in specific scientific fields

4.- The intermediary mechanisms (Including the legal setting and the institutional promotion)

4.1.- The intermediary mechanisms: Institutional promotion for direct interaction
4.1.1. Scientific parks; Technology parks and Science and technology parks
4.1.2. Cluster policies and Networks that promote indirectly the interaction between science and industry
4.1.3. Joint laboratories Access of the S&T infrastructure to firms
4.1.5. Incubators
4.1.6. Promotion of academic spin offs and fund for seed or risk capital
4.1.7. Computer and internet based networks

4.2.- The intermediary mechanisms: Direct institutional support for technology and knowledge transfer
4.2.1. Technology transfer organisations
4.2.2 Independent commercialisation enterprises or agencies
4.2.3. Information brokers or points
4.2.4. Intermediaries at the level of industry association and other private organisations

4.3.- The intermediary mechanisms: the legal setting
4.3.1. Law of intellectual property Rights (IPR)
4.3.2. Regulation of the licences of IPR
4.3.3. Regulation on mobility of researchers or contract research

Source: Own elaboration

The second type of channel included in the intermediary mechanisms is the (4.2) direct institutional support for technology and knowledge transfer. This includes organisations or institutional mechanisms created specifically to promote the technology transfer from the scientific world to the production sector. One type of those institutional organisations is the "technology transfer organisations" created in most universities of the advanced countries. There also exists a small group of different intermediary agents like the independent enterprises for TT, the information brokers or information points like some associations of enterprises or (semi) governmental organisations. The last type of intermediary mechanism would be the legal setting or context (4.3). In fact this channel refers to the rules, norms and legal framework in which the S-I relationships are embedded and that can facilitate or limit the level of technology and knowledge transfer. Intellectual property rights in particular play an important role because the regulations of patents and licensing can limit or facilitate the interests of researchers and universities in knowledge transfer.

The taxonomy presented of the different modes or classes of relationships between the scientific and production communities are not always mutually exclusive and not always can a mode be attributed to one single class. For example technology transfer of recently graduated students can be assigned to three different types of knowledge transfer. First of all it can be considered a form of mobility of human capital or the consequence of schooling and training. However, it can also be considered as an informal way of technology transfer because it is difficult to track or identify whether there is a real effect of technology transfer. Moreover on the vast majority of occasions the knowledge transfer is based on a set of complementary forms or types of channels. For example the joint projects often include the interchange of researchers (mobility), extra training, and also involve a large number of informal knowledge exchanges (such as the attending at conferences and seminars, co-publications or network building). Therefore it can be stated that our taxonomy is a classification from an analytical point to facilitate the study and discussion on this topic.

As a final comment (taken from EC, 2001) it is worth pointing out that SIREs are not simply transactions that reflect a clear-cut division of labour in knowledge production. They represent an institutionalised form of learning and provide a specific contribution to the stock of economically useful knowledge. They should be evaluated not only as knowledge transfer mechanisms but also in their other capacities (e.g. building networks of innovative agents and increasing the scope of multidisciplinary experiments).

2.5.2.- The use, usefulness and importance of the different channels of SIRE

It may be misleading to generalize the existence of a higher level of SIREs with better market behaviour for all the firms. *"Industry's demand for scientific knowledge, and thus the enterprises' demand for interaction with public science institutions, depends heavily upon the specialisation of enterprises and sectors on certain types of products, markets and associated stages of product life cycles"* (EC, 2001). Although there is a trend towards knowledge-based economies (see OECD 1999a), the vast majority of enterprises derive their competitive advantage from: close market contacts; client-oriented (incremental) innovations; rapid adoption of new technologies previously introduced by other enterprises; flexible production and marketing strategies in niche markets; or the acquisition of input factors (labour, capital, initial products) at favourable prices in factor and good markets. Only a small portion of enterprises gain competitive advantage and high profitability from directly exploiting the commercial potentials of basic R&D results and new scientific findings (EC, 2001). In other words, SIREs are only one of multiple channels to obtain or develop new technologies and the low level of SIRES could be caused by the intensive use of alternative sources for innovation. On the other hand, there is no doubt about the fact that the competitive advantages of the leading countries like the U.S., Japan, Germany, the Netherlands etc. are directly related with the scientific development and the application of the scientific results especially those of the emerging technological fields. However in most countries –even the direct followers (like Portugal, Greece, Ireland or Spain- the role of science in creating competitive advantages is underdeveloped.

The importance and complementarity of the different channels for knowledge transfer between science and industry is directly related with the concept of scientific results as codified information versus tacit knowledge (See Box 5). New knowledge is developed in a tacit form, (in the inventor's head) and requires a codification (Publications or patents) However such codification[21] is not always possible, often is too costly or not carried out to assure the appropriation by the inventor. Therefore part of the new knowledge will remain tacit. Such tacit knowledge can only be transmitted through personal interaction between the sender and the recipient and possess in a certain way some characteristics of a 'normal' economic commodity in the sense that it is rival and excludable (and thus tradable on markets).

Nevertheless, the difference between both concepts is not that clear, since often firms require tacit knowledge to understand the codified information or to make optimal use of that information. Certain channels do transmit codified information (such as publications or patents) available almost for free for everybody while other channels (based on personal contact and interaction) permit the transfer of tacit knowledge, like the case of cooperation, mobility and exchange of researchers, or highly specialised conferences. This means that often the use of different transfer channels is complementary because the receivers require at the same time codified information and tacit

[21] Cowan and Foray define knowledge codification as "the process of conversion of knowledge into messages which can be processed as information" (p. 2, 1997).

knowledge to make an optimum use of new knowledge because both aspects are complements in the transmission of knowledge. Moreover the need for personal contacts implies that knowledge transfer is partially limited to a certain region (Frenken/Van Oort, 2004) and therefore the co-location of science and industry (S&T parks, cluster polices) could be important transfer channels.

Box 5.-Some relevant comments and aspects of the theory of technological change: Codified versus tacit knowledge, learning and the linear and interactive model[22]

An important distinction has to be made between explicit or codified information and tacit knowledge. Technology and scientific results are normally a combination of both. The codified information is the part of science and technology that can be expressed and explained (codified) in standardised pieces of explicit data that flows between university and industry in the form of patents, scientific articles, books, et cetera. New knowledge is developed in tacit form, (in the inventor's head) and requires a codification, although such codification is not always possible or too costly. Researchers may even prefer to maintain the information secret. Therefore part of the new knowledge will remain tacit. The individual's insights and skills that form tacit knowledge in human resources and which are gained through personal experience, are hard or impossible to articulate or transfer (Kogut and Zander, 1993; Nelson and Winter, 1982; Nonaka, 1994; Polanyi, 1962, Simonin, 1999a). One thing is the availability of codified knowledge; another thing is to make use of it in an optimal efficient way. Often people need tacit knowledge to understand and to make use of codified knowledge. This is especially so for a certain activity where a large amount of codified knowledge is needed and used in a complementary way. A good example is the use of a language. The rules are based on the very large number of grammatical and phonetic rules. However, the understanding and use of a language also requires tacit knowledge about the culture and history of a country. Even more difficult is to understand jokes or culture-based expressions. With this example it has to be made clear that even the codified information is not always easy to transfer and in the case of tacit knowledge the technology transfer is even more complicated. The firm's tacit knowledge is not easily communicated and shared as it is highly personal and deeply rooted in action and in an individual's involvement within a specific context (Nonaka, 1994). Tacit knowledge acts as "the glue that integrates mechanism in learning" (Dhanaraj et al., 2004). On the other hand, explicit knowledge, which is very simple to codify and transmittable in formal and systematic language, acts as "the building blocks" (Polanyi, 1967; Nonaka and Takeuchi, 1995). Tacit knowledge is embodied in people and the transfer is based on personal face to face contacts or working together (like the apprenticeships of craftsman). It is the knowledge obtained by the accumulation of professional experience (learning by doing) and the continuous face to face interaction with experts. Bekker and Verspagen (2006) argue that not all tacit knowledge can be transferred to explicit knowledge. They gave the example of the search heuristics. An experienced operator of a complex system, such as a chemical plant, will use a certain search heuristic to find the factor that causes the problem. It is very hard, maybe even impossible, to translate this search heuristic into explicit knowledge and only the daily face to face interaction can transfer the knowledge between employees or researchers. Although due to the ICT-revolution, the importance of explicit information is increasing in some sectors, the transfer of tacit knowledge is often considered to be a very important element of knowledge transfer (David and Foray 1995). In certain research fields and especially in science industry linkages the tacit knowledge is very important. First of all in multi disciplinary research projects focussed on new inventions and technological progress based on combinations of knowledge from different disciplines. A good example of this (Bekker and Verspagen, 2006) is the aeronautical engineering. In this field of technology the

[22] This box offers a short introduction about this subject for a broader discussion see Rothwell, 1983; Pavitt, 1984; Kline and Rosenberg, 1986; Dosi/Freeman/Nelson/Silverberg, 1988; Malerba/Orsenigo, 1995.

engineer has to have knowledge regarding physics, mechanical engineering, material technology, electro technical engineering, aerodynamics, etc.

Poyago et all (2002) argue that *"basic research generated new fundamental ideas that are still at an embryonic stage and only a fraction of the knowledge is actually codified, while the remaining fraction is tacit and can only be acquired through interaction and discussion with the scientists. In some cases, when the firm cannot understand the whole idea through these channels it is necessary to employ the relevant scientists for transmitting the knowledge and help to develop that knowledge into some commercial product/technology".* Canton et al (2005) argues that an implication of the fact that knowledge remains partly tacit is that spillovers will be limited geographically. Frenken and Van Oort (2004) find that 'hybrid' collaborations, i.e. collaborations between an academic and a non-academic organisation, are characterised by a higher degree of geographical localisation than other types of collaboration. In this perspective Adams (2002, p.2) argues that "*Since academic research is usually regarded as more of a public good than firm research, this finding poses something of a puzzle. The solution requires one to see that geographic localization of university spillovers reflect ease of dissemination of normal science, which takes place through nearby institutions".*

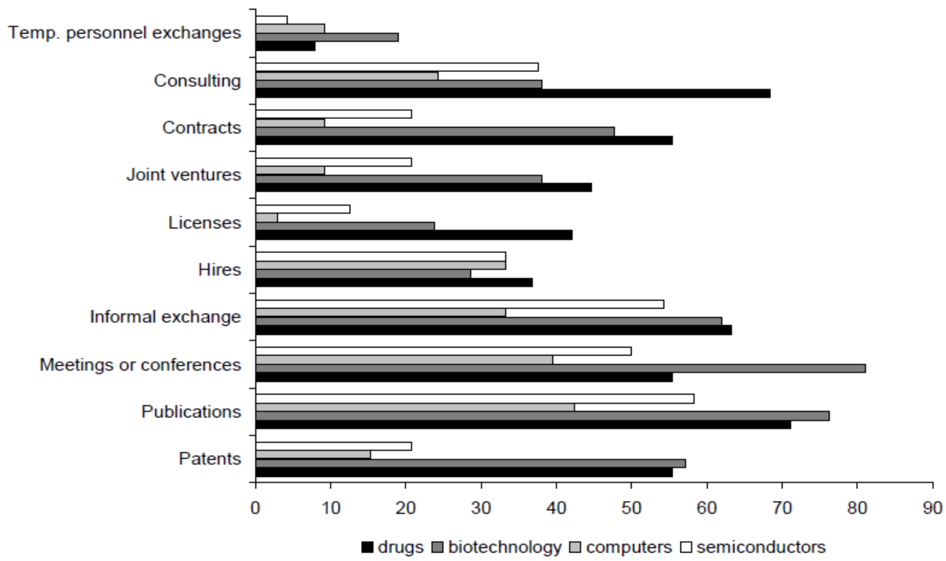
The distinction between codified information and tacit knowledge is the basis for the models of technological change. Until the early 1980s the technology policy of most developed countries– especially the finance of scientific research and the promotion of SIRE- was based on the *linear model*. This model views R&D as an isolated activity performed in research centres without the direct influence of market considerations. Innovation is considered as a linear, sequential process occurring in isolated stages, beginning with basic research and extending through to the introduction of an innovation-based product onto the market. Under this model, technology transfer –based on codified information- is supposed to take place automatically and without significant costs or delay through the mechanism of the "invisible hand": technology is seen as codified information converted into an Arrow-like public good that can be transferred for free and immediately. The linear model virtually neglects factors such as the influence of institutions, strategic and competitive behaviour of other firms or countries, or factors related to demand and education. Policies based on the linear model are aimed at the generation of innovation, for example through the establishment of research centres and support for basic research on key new technologies. An alternative model gained ground in the nineties and fuelling radical changes in the design of technology policies is the *interactive model*, based on the notion of continuous interaction and feedback between different actors and between the different stages throughout the innovation process – from basic research to industrial development, commercialisation, and introduction onto the market. While the linear model highlights only the activities of a firm's R&D department, the interactive model stresses the tacit and accumulative character of knowledge and the firm's technological capabilities and entrepreneurial attitude. And it considers innovation management as an integrated, strategic corporate activity in which the entire firm is involved. Technology transfer is viewed as expensive and difficult, while understanding new technologies (tacit knowledge) is seen as time-consuming. This model implies that support for basic research and the generation of new technologies is not enough, and that R&D policies should promote technology transfer, the SIREs and the improvement of innovation capabilities (learning) within enterprises.

Brennenraedts et al (2006) indicate that applied research is often much more multidisciplinary than academic research. The new products are based on the combination of existing technologies and scientific findings of a broader set of technological field. Therefore the need to use the research in an actual product (or service) will probably demand much more interaction between disciplines than only discovering the 'proof of the principle'. Therefore, academic research that is more multidisciplinary will be more congruent with industrial research and therefore easier to absorb by industrial companies.

Several empirical studies[23] analyse the importance of different forms of science-industrial relationships. Cohen and Walsh (2000) analyse channels of SIRE in four industries (drugs, biotechnology, semiconductors and computers). Based on the 1994 Carnegie Mellon Survey they show the importance of ten different ways of technology transfer[24] (See Figure 1). The most important channels[25] are patents, publications, meetings or conferences and the informal contacts followed by consulting. The study of Cohen et al. (1998) found similar conclusions indicating that the four dominant transmission channels (in order of importance) publications and reports, public meetings and conferences, informal information channels, and consulting. Moreover they showed complementarity in the use of those channels using a factor analysis. In other words the four transmission channels tend to be used together, which supports the idea that tacit and codified knowledge are complements in the knowledge transfer process.

Figure 1.- The importance of channels of knowledge transmission

Figure 2.3 Channels of knowledge transmission (% of respondents reporting that a given source is at least 'moderately important')



Source: Cohen and Walsh (2000).

Another question that highlights the importance of the SIRE is the complementary role of basic science in relationship with other forms of research. The 'Frascati manual' (OECD 1994) distinguishes three types of research. The first one is basic research that is aimed at gaining insight into the world surrounding us and does not directly pursue applications. The second form is applied research focused on the use of actual knowledge, for example in artefacts and new products or processes. A final one is the experimental research that tries to identify whether a certain variable has an effect on another variable. Private firms may have almost no incentives to carry out basic research (Nelson, 1959), because normally there is a high level of uncertainty and a long time horizon with regard to the future technological and commercial results and the integration of the scientific results into products ready for the market. However, despite the fact that basic research does not lead to immediate monetary pay-off several reasons exist for private firms to undertake basic research especially –although not only- in high tech industries that depend heavily upon a basic research

[23] See among others Meyer-Krahmer and Schmoch, 1997; Cohen et al, 1998; Cohen/Walsh, 2000; Arundel/Geuna 2004.

[24] Patents, publications and reports, meetings or conferences, informal exchange, hires, licenses, joint ventures, contracts, consulting, and temporary personnel exchanges.

[25] Percentage of respondents that consider the channel as at least 'moderately important' (i.e. scale 3 or 4).

capability (Rosenberg, 1990). Pavitt (1993) argues that basic research *"might give researchers working in firms an access ticket to the academic community, where they can pick up useful ideas and knowledge".* He argues that the main economic value of basic research for enterprises is not only the creation of codified information which in fact is a public good (see Box 5). Basic research carried out by firms also provides the human capital with the capacity to solve complex technological problems and create tacit research skills, techniques, and instrumentation. Moreover complex links and complementarities exist between basic research and applied research. Basic research enables firms to understand better how and where to conduct applied research and the outcome of much applied research cannot be properly evaluated without a sufficient capability in basic research (Rosenberg, 1990). The existence of internal basic research capabilities in a firm will enhance the efficiency by which other types of research are conducted and upgrade firm specific advantages by widening and deepening their scope[26].

Pavitt (1991) pointed out that th**e** responsibility for the creation of new scientific knowledge — and for most of its applications — "*rests on that small body of men and women who understand the fundamental laws of nature and are skilled in the techniques of scientific research" (Bush, 1945)*. In other words, it depends on those persons or enterprises that possess tacit knowledge. An exclusive emphasis on the economic importance of codified information reinforces a constricted view of the practical relevance of basic research by concentrating on direct (and more easily measurable) contributions, and neglect the indirect value and importance of scientific research and results. This could led to an excessive concentration on policies to promote "commercial" basic research and neglect the policies to promote the creation of science-based skills to solve complex technological problems (Mowery, 1983). Anyhow science and technology are not the same and furthermore, science in universities - being too general - is different from science in business, which tends to be relatively specific. It is accepted that the results of science are a "public good", but they are not a "free good", i.e. being cost-free to apply as a technology. Rosenberg [1990] argued that basic research in large firms is very often undertaken to solve practical problems and essentially evaluate and absorb research being conducted elsewhere Seyf, 2000).. In fact enterprises –except the large firms and multinationals- are scarcely involved in basic R&D and that makes the role of SIRE more important. On the other hand, those firms that do basic R&D are more likely to cooperate and interact with scientific organisations.

2.5.3.- Sectoral and intra sectoral differences of SIREs

The evolutionary theory underpins the diversity of the knowledge base and the innovative behaviour of the agents of an innovation system and a broad set of literature analyses this diversity[27]. Without any doubt the use of certain mechanisms and forms of science- industrial relationships is related with the typical characters of technological fields and sectoral innovative behaviour. And, as mentioned before, not in all sectors is science an important input. According to Malerba and Orsenigo (1993) and Breschi and Malerba (1997), four main characteristics are relevant in order to explain differences in innovative activities across industries.

(i) The nature or characteristics of the knowledge base upon the firms innovative activities are based" (Breschi and Malerba, 1997, p.136). These characteristics differ in many aspects among technological fields or across industries. Technologies can be generic or specific,

[26] Pearce [1999], Rosenberg [1990] Pavitt [1991]

[27] The innovative regimes (Nelson and Winter; 1982) The Schumpeter Mark 1 and Mark 2 regimes (Malerba and Orsenigo, 1996), or the sectoral classification based on their innovative behaviour of Pavitt (Producers of traditional consumer goods, Providers of traditional intermediate goods, Providers of specialised machinery and equipment, Scale intensive sectors and mass assemblers , Science based sectors) (1984) that recognise supplier dominated firms, production intensive firms and science-based firms and amplified by Marsilli (2001) : science-based, fundamental processes, complex systems, product engineering and continuous process

codified information or tacit knowledge, simple or complex, independent or systemic (i.e. embedded in a system) (Castellacci, 2003).

(ii) The appropiability conditions that indicate ´to what extent new technologies can be considered as a public good, which is easy to transfer or can be considered as a private good with tacit complex characters that are difficult to imitate is difficult and costly in time and financial resources. In other words what possibility has a firm to appropriate the benefits of its R&D investment by protecting innovations from imitation through a variety of means, such as patents, process secrecy and know-how, design and R&D know-how, and other non-technical means (Castellacci, 2003).

(iii) The cumulativeness conditions –directly related with the tacit aspects of technology- indicate the importance of experience and learning in creating technological capability. The work of Cohen and Levinthal (1989 and 1990) underpins this aspect and indicates that the absorptive capacities, knowledge competencies and organizational capabilities depend on accumulation of experience in the past. The importance of cumulativeness conditions differs across industries and is even different for firms of the same sector but with different innovation strategies. In the case of the technological leader the accumulation of experience is much more important than the followers and imitators. The accumulativeness affects the intensity and direction of technological change in each sector (Castellacci, 2003).

(iv) Technological opportunities, is the possibility of a firm to obtain benefits from its investment in R&D by the introduction of new product in the market. Technological opportunities can be very high in the emerging sectors, and rather low in more traditional low-tech industries (Von Tunzelmann and Acha, 2004).

Several empirical studies[28] analyse the importance of different forms of science-industrial relationships (see tables 2 - 4). Arundal and Geuna shows that "publications" are rated as the most important source for scientific knowledge by 24% of the analysed firms, closely followed by "hiring trained staff" (21%), and "informal contacts"(18%). (Arundel/Geuna 2004). They also show the differences in importance of certain SIREs on a sector level. In table 2 it can be observed that almost all seven forms[29] of SIRE (except the interchange of personnel) are the most important for at least one of the 16 sectors. Hiring trained staff is the most important form for 6 of the 16 sectors and the informal contacts for 3 sectors. The contract research and joint research projects are considered respectively by 3 and 2 sectors as the most important type of knowledge transfer. Finally, publications are mentioned by 2 and conferences by 1 sector[30].

Meyer-Krahmer and Schmoch analyse the differences in the importance of certain SIREs between certain technological "fields or areas" in the case of Germany (see table 4). They also showed that the ranking of the interaction types is not uniform across all fields For example the relevance of collaborative research and informal contacts is important in microelectronics, software, and biotechnology. However, in production technology contract research is in first place, together with collaborative research. In all other fields contracts are only in third or fourth place. In the basic field of chemistry, the teachers see the education and provision of personnel as the most important transfer channel in the same rank as informal contacts and collaborative research. In this special field, industrial grants or donations without clear deliverables were introduced as a further interaction type. This channel is less important in most areas of academic research but in chemistry it has a long-standing tradition and it ranks in first place.

[28] See among others Cohen et al, 1998; Cohen/Walsh, 2000.

[29] Publications, Conferences, Hiring, trained staff, Informal contacts, Staff l exchanges, Contract research, and Joint research projects.

[30] Arundal and Geuna (2004) analysed the importance of seven different mechanisms of technology transfer. Their results (table 3) show the percentage of firms that consider a certain form of SIRE as the most important one.

The differences of the role of science and the importance of tacit knowledge versus codified information also involve differences in the importance of certain channels for knowledge transfer. Those differences are based not only on the consequence of the differences of specific technological fields or sectoral characteristics but also on the disparities in culture, economic specialisation and habits in different countries or regions. In this introduction some examples and explanations will be given on the importance and intensity of the differences moreover some brief comments will be offered on the sectoral and national differences in the importance and use of SIRES.

As demonstrated above the role of specific mechanisms and forms of SIRE differs clearly in their use, usefulness and importance. The diversity implies that each type of sectoral innovative behaviour uses a different subset of knowledge transfer mechanisms. However, there is also a high diversity of innovative behaviour between firms of the same sector or subsector. The heterogeneity of knowledge transfer channels within industries is related to the characteristics of the individuals involved and the competitive strategy of the firms[31]. (Geuna/Muscio, 2009) argues that firm size is a major factor explaining the type and level of interaction (Laursen and Salter 2004; Mohnen and Hoareau 2003; Fontana et al. 2006). Large firms and multinationals have more resources to invest or deploy in various types of interactions with university researchers, while the resources and capacity for small and medium sized enterprises (SME) may be limited, except in the case of small specialised high tech firms. Moreover in each sector there are technological leaders and direct followers that base their competitive advantages on their technological level. Those high tech firms also compete with imitators based on less advanced products in combination with a low cost strategy.

2.5.4.- National differences

The analyses and international comparison of the use and importance of the different channels of SIREs are complicated because there exists abroad a level of heterogeneity and diversity in their use and application on country, sector and firms level. This fact is important to take into account in the case of international comparisons –which is the case of this CIA4OPM project-. The indicators used by the EC report of 2001 to compare the National Performances on SIRE of a large number of countries show considerable differences in the performance of industry-science relations among the countries analysed. These differences could be explained from different reasons mentioned by the EC (2001).

First, the channels used depend on the specific characteristics of the agents of a country such as the enterprises (size and innovative level of the enterprises, sector and competitive strategies, etc) and the institutional and legal setting of the scientific system (such as the disciplinary orientation, level of excellence or size of research groups). The empirical information available suggests that there are very considerable differences within one country, while similar groups of actors tend to show similar ISR behaviour across countries. Therefore the differences in national ISR performance may be attributed to the structural differences[32]. As mentioned by The EC (2001) different channels for knowledge and technology transfer suit different types of knowledge to be exchanged. As industries demand different types of knowledge[33], differences in industrial structures cause different patterns of ISR. This is especially true for the commercialisation of new research results through patenting & licensing, and start-ups. These may be appropriate channels for new breakthrough technologies such as microelectronics, biotechnology and genetic engineering, where basic research results may lead to totally new products and short time processing. On the other hand, most innovations in the

[31] Innovative leader versus follower; a strategy based on quality and diversification versus a competition strategy based on low prices.

[32] For example the significantly lower relevance of science as an information source for innovation projects could be explained by the important role of the service sector in the production structure of a country.

[33] Which is a result of the prevailing innovation strategies, market demands and types of technological changes (e.g. embryonic inventions versus cumulative technology development, radical product innovations versus permanent process innovations)

enterprise sector are not science-driven but are facilitated by the interaction with other market actors (customers, competitors, suppliers) as well as in-house R&D, which provide the main sources for innovation. This is especially true for the service sector in which direct interaction with clients is expected and the SIREs are less important.

However not all differences can be explained by the structural differences between countries. Also the cultural, legal and institutional difference plays an important role. Some channels are substitutes for each other and a less intensive use of a specific mode could be explained by a higher frequency of other channels. In fact the EC report of 2001 shows that high levels of interaction for some forms of SIRE are associated with rather low levels in others. Therefore this points to important aspects which should be considered when looking at aggregate levels of ISR in any one country.

Box 6.-Different strategies for SIREs

Hence, a low level of SIRES in a specific country may be caused by a well-developed supply of alternative modes of knowledge production and exchange. A good example is the alternative ways for formal research co-operation. Such cooperation is only one way for enterprises to acquire expertise available in public science. In some countries, other channels of exchanging new scientific knowledge have evolved. For example, faculty consulting with industry is a commonly used method by university researchers in many countries, to supply enterprises with specific technological and methodical knowledge which they have accumulated. There are different modes of remunerating researchers for these services but typically there are no, or only a small number, of direct flows to the university. In Japan, for example, the low level of industry funding of research in public science may be partially explained by the high significance of consulting activities by faculty members. Consulting as an important channel of ISR is also reported in Austria, Germany, the UK and the USA. In Japan, personal contact between university professors and researchers in enterprises is reported to be the most important method of technology transfer. For example, many professors are involved in stable, long-term oriented personal networks with industry, maintained, amongst other methods, through the recruitment of graduates by the firms involved in the network. Within these networks, industry demand for specific R&D activities is communicated to universities, and professors often directly distribute new findings to the enterprises without claiming IPR (but receiving some indirect remuneration in the form of research equipment and visiting research personnel from industry). Therefore, this type of interaction seems to substitute for a number of other channels and reduces the need for enterprises to enter into formal collaborations.

Taken from the EC, 2001(p. 324)

A second reason mentioned by the EC (2001) is that the modes of exchanging knowledge and technology between industry and science are substitutive, i.e. if industry strongly relies on one type of ISR, the level of interaction in other types will be low. This paper mentions as an example that if enterprises follow a human capital oriented strategy of knowledge acquisition, such as recruiting young top-level scientists, continuous training for their in-house R&D staff (including temporary visits to scientific institutions) and a high intra-industry mobility of researchers, there will be less demand for direct co-operative research with science. The more intensive use of certain channels of SIRE may depend on the R&D policies or the institutional or legal setting. Policies could foster the use of scientific results in technology centres. In the USA there exists a growing importance of industrial co-operative research organisations, which may contribute to a higher share of basic R&D carried out in the enterprise sector itself (EC, 2001).

Thirdly the choice of the use of external providers depends on the firm's strategy to acquire new scientific knowledge (Box 6). A firm can decide to perforrm internal basic R&D to protect its results, it can do collaborative research with other enterprises (such as sectoral research networks and consortia); or the use of private R&D enterprises that offer specialised R&D services for specific industries. In such cases the transfer of scientific knowledge is not based on direct cooperation with scientific organisations and will be based on indirect mechanisms. Therefore the low level of SIRES in a region or country can be based on differentiation in strategies in firms to obtain external knowledge.

3.- Best practices and critical success factors (CSF) for science industrial relationships

3.1. Introduction

Economic development and innovation are two processes that are based on the action of continuous forms within a system and it is almost impossible to separate each activity or aspect in a framework of causes and effects. Economic growth and technological progress are based on the accumulation of experiences and learning. Furthermore, the evolutionary economic theory shows that all aspects depend on the others. Therefore to analyse the critical success factors of SIRE the whole economic and innovation system has to be screened. Von Bertalanffy, generally recognized as the father of the General Systems Theory, explained it this way: It is necessary to study not only part and processes in isolation, but also to solve the decisive problems found in the organization and order by unifying them, when resulting from dynamic interaction of parts, and making the behaviour of parts different when studied in isolation or within the whole (Von Bertalanffy, 1968, p. 31).

To analyse the context in which SIRE operates we tried to identify and discuss briefly some critical success factors required to assure good and smooth SIREs. Such factors include, on the one hand, the organisations involved and their interaction and, on the other, the specific characteristics of their geographic, political, economic or innovative environment. In **¡Error! No se encuentra el origen de la referencia.** The main Critical Success Factors (CSF) for science-industrial relationships (SIRES) are grouped in five broad components or clusters. The first component is the overall broad contextual framework conditions that impose constraints on innovation and production and consequently on the SIRE. Also the national and regional innovation system (NIS) places constraints on the Science Industrial linkages. The most important aspect of this second component is the specific R&D and innovation policy framework and the institutional and legal setting of the NIS. In other words it is that part of the broad contextual framework directly related with the R&D and innovation policies. Two other components that impose constraints on the SIRES and offer important CSFs are the internal organisation and R&D performance of the two main agents of SIRES: The micro behaviour of the enterprises and other non-scientific private research organisations, on the one hand, and of the High Educational Institutes (HEI – basically universities) and the Public Research Organisations (PROs) on the other. The fifth component would be the interaction mechanisms between the two main players in SIREs (e.g. industrial enterprises and scientific research units). These interaction mechanisms underpin the systemic processes which are restricted or fostered by the aforementioned overall contextual framework conditions and the R&D&I policies. The five components include a broad range of actors and aspects that interact with each other and can generate a positive (facilitating or promoting) or negative (hindering or impeding) effect on SIRES. It is clear that all the aspects included in those five components do interact with each other and function as a system.

The next part of this paper analyses the main aspects of each of the five components (See Figure 2). This third chapter analyses the determinants for good practices based on the broad contextual framework conditions of the economic structure and chapter 4 reviews the characteristics of the Innovation system and the R&D&I policies. The following chapters analyses the barriers and critical success factors that impede or promote the success of the science-industrial relationships (SIRE) based on the micro behaviour of the agents involved in such relationships, the micro level performance of the universities and the public research institutes (chapter 5) and the micro level performance of the Enterprises (chapter 6)

Figure 2.- **Critical success factors of the science and industry relationships (SIRE)**

The broad contextual framework conditions of the innovation system and the SIRE

1. Production structure (Firm's size, sectoral specialisation, presence of multinationals, etc.)
2. Market structure (Size of the domestic market, export and internationalisations, etc.)
3. Cultural aspects (Level of entrepreneurship, customs, traditions etc)
4. The innovative culture of the firms (R&D intensity and regularity and the orientation of their R&D –applied versus basic-)
5. Banking and financial system (risk capital, industrial versus financial based system, etc.)
6. Legal framework (Property right legislation etc.)

Internal organisation and performance of R&D in public and private scientific R&D organisations (Incl. universities)

- Level of excellence and productivity
- Quality and the commercial usefulness of the research results
- R&D culture and interest of the researchers in SIRE
- Strategic planning of teaching and research
- Selection and promotion mechanisms of researchers (meritocracy vs. endogamy)
- Selection of R&D activities (excellence vs. personal interest; fragmentation vs. critical mass; long vs. short term; etc…)
- Organisational setting of the TT activities

Interaction mechanism and system performance

- Cultural attitudes toward SIRE
- Compatibility of knowledge supply and demand
- Market demand and Technology development
- Intermediaries and TT facilitating organizations

Internal organisation and performance of enterprises and other not scientific private research organisations

- R&D and technological capability
- Learning or absorptive capability
- Innovative culture of the firm
- Qualification of the human resources
- Sector and geographic market of the firm
- Balance of R&D orientation (Basic vs. applied)

Specific characteristics of the innovation system (especially the framework of R&D and innovation policies).

1. Institutional setting of the scientific and university system (Culture of meritocracy and excellence versus endogamy; Autonomy and regional or national embeddedness or proximity; etcetera…)
2. Political structure and the R&D and innovation policies (Competitive tenders versus block funding; priority setting and critical mass; etcetera…)
3. Specific policies focussed on Science – Industrial Relationships (Cooperative projects; technology centres; science and technology parks etcetera…)
4. Critical mass and proximity as a determinant for Science – Industry Relationships

3.2. The broad contextual framework conditions of the innovation system and the SIRE

An in-depth analysis of most aspects of the broad contextual framework conditions are outside the scope of this final report. Therefore only some basic aspects and their influence are mentioned except for some specific aspects that have direct influence on the quality and quantity of the SIRE. The aspects mentioned in the following sections and chapters determine a large part of the innovative behaviour and performance of the enterprises and the scientific organizations, limiting and/or facilitating the R&D and innovation in each of the agents and specifically they have an important impact on the technology transfer between public and private organizations. Some important aspects of this framework are:

1. Production structure (Size of the firms, sectoral specialisation, existence of multinational firms, etc.)
2. Market structure (Size of the domestic market, export, etc.)
3. The innovative culture of the firms (R&D intensity and regularity and the orientation of their R&D –applied versus basic-))
4. Cultural aspects (customs, traditions etc)
5. Banking and financial system (venture and risk capital, industrial versus financial based banking system, etc.)
6. Legal framework (Property right legislation etc.)

As already mentioned most aspects of the innovation system and its broad contextual framework conditions are outside the scope of this paper and will only be treated in a marginal way. Among the reasons for this is the fact that a large number of these aspects are very difficult to change. Often they are basic characteristics and changing them needs a long period of adaption (like the sectoral specialisation or the presence of headquarters of multinational enterprises). Therefore only some basic aspects and their influence are mentioned, except some specific aspects that have direct influence on the quality and quantity of the SIRE like the innovation policies and the intermediary organisations focussed on technology transfer.

- **Production and market structure and innovative intensity**

The production structure is an important constraint for the innovative system and consequently the SIREs, especially the sectoral specialisation and the size of the firms. A production structure specialising in high tech and science-based industrial sectors with a high number of large firms and multinationals has a much more favourable context for science-industry relationships than low tech countries or regions.

A first important constraint of the overall economic framework is the specialisation of the production structure. Specialisation of the production sector towards high tech and/or science based industrial sectors facilitates the SIRE. In particular, regions or countries with a high presence of science based sectors (Cf Pavitt, 1984) like nano or biotechnology or electronics and ICT have a more favourable context for science- industry relationships than low tech countries or regions with a lack of large firms. However, in medium or low tech sectors R&D and science can also play an important role especially multinationals of these sectors doing basic R&D and/or absorbing scientific results (see also Campos, 2010). For example the Netherlands has in the European context a relative low level of R&D expenditures per GDP due to their specialisation in some specific sectors such as food, agriculture or energy. However, at the same time, this country is considered as one of the technological leaders in these low tech sectors. Among others this is due to the fact that this country owns some of the most important multinationals in those sectors. Also the existence of a group of large firms and/or multinationals has a positive impact on the innovative activities. Often such firms are very active in R&D and are the locomotive for the creation of a cluster of firms and public agents that cooperate and interact in innovation. The presence of headquarters of large firms or multinationals is important because they are normally intensive in R&D[34] and have a high level of in house R&D capabilities which makes them more able to use and absorb external scientific findings. Moreover they normally have large domestic R&D centres and cooperate with firms and research institutes in the region or country, creating clusters or networks that include universities or public R&D centres as well as small and medium sized firms that can take advantage from the SIRE initiated by those large firms. The lack of such large and/or multinational) firms impedes or make more difficult the creation clusters based on public-private cooperation and science industry linkages. In peripheral regions this role can be taken up by technology centres and research units of PROs or HEIs. However, this is only possible if they have a dynamic entrepreneurial culture. Another aspect of the production sector –overlapping with the innovation system- is the intensity and regularity of the R&D activities of the firms. Again this aspect is directly related with the size of the firms and the presence of headquarters or R&D centres of multinational enterprises. Another aspect of the production sector –overlapping with the innovation system- is the intensity and regularity of the R&D activities of the firms. This aspect is directly related to the size of the firms and the presence of headquarters or R&D centres of multinational enterprises.

Furthermore, the degree of complementarity between academic research and industrial application is a key factor in fostering interaction with industry. This is likely to depend on the composition of the local industrial structure and on the existence of a critical mass of firms in the area (Geuna/Muscio, 2009). Calderini et al. (2007) underline that policy related to university funding, which includes the possibility for a university to increase industry funding, should keep in mind that the final outcome will depend on the characteristics of both the local scientific institutions and the local industry.

The market structure and especially the export behaviour have a positive impact on innovation. First of all, the firms that enter the international market have to compete on the technological frontier by offering the best quality for the lowest price, which obliges them to innovate in product or processes. Large domestic markets or access to international ones create advantages of scale and scope which ensures the payback of investments in R&D which would not be possible in small countries. In this case the existence of a unified European market generated large advantages for the EU enterprises. Looking to the market structure it can be mentioned that countries or a region with a higher GDP per capita are more prone to demand technological advanced products with a high quality and level of performance, which has a positive impact on the R&D of the domestic production sector. In both cases –that of the pressure of the high-tech demanding domestic market or the pressure of the international market- the possibility that science and therefore SIRE plays an important role increases clearly.

- **Cultural aspects**

It must also be borne in mind that cultural and social attitudes which shape the actor's perception and outlook on innovation, co-operation, and the role of science in society, make up another important feature of national innovation systems and are likely to affect the potential for ISR. Unfortunately, cultural attitudes are difficult to measure and there is no systematic information available on the relevance of such attitudes in shaping ISR, or on national differences in such attitudes (EC, 2001)[35]. In fact, culture is an important aspect with a high influence on economic

[34] The multinationals account for more than 66% of all the private R&D expenditures in the world.

[35] For example in countries with a low level of SIRES, national experts report little awareness for or even objection to interaction with the other side by both industry and science. In Japan, cultural and social traditions, as well as the specific history of industrial innovation, appear to favour little strong interactions between industry and science very little. In the case of Belgium and the UK, a high awareness of the importance of technology transfer between

behaviour and innovation (Beugelsdijk, 2007). Herbig and Dunphy (1998:14) highlight the significance of culture for the adoption of innovative technologies. They stated that *"existing cultural conditions determine whether, when, how and in what form new innovations will be adopted. If the behaviour, ideas and material apparatus which must accompany the use of innovation can affect improvements along lines already laid down in the culture, the possibilities of acceptance are much greater."*

An important aspect directly related with innovation is the dynamism or culture of entrepreneurship. Entrepreneurship is generally considered to be of great importance for economic development (Porter, 1990; Baumol, 1993; OECD, 1998) and the innovator is an entrepreneur who searches for innovations that break the existing economic equilibrium by the introduction of a new product into the market making obsolete or competing with the dominant products of the old market equilibrium (Schumpeter, 1939). In a first instance, one may think of the effects of an entrepreneurial culture in terms of higher start-up rates (Kangasharju, 2000), which are considered as an important SIRE especially in the case of academic spin-offs. In fact several empirical studies analysed the effects of it on new firm formation and the entrepreneurial culture (Kangasharju, 2000; Davidsson, 1995; Georgellis and Wall, 2000). Entrepreneurship is not only associated with the formation of new firms but with all kinds of novel applications. Entrepreneurship can be defined as "starting something new", and this can be associated with the alertness in finding new products or combinations of innovations within the existing technological frontier (Wennekers and Thurik, 1999). The study of entrepreneurship must then focus on how knowledge, know-how and systematic innovation are managed by entrepreneurs, as this might be an important source of the observed differences in the culture of entrepreneurship (Julien 2007). According to Penrose (1959), entrepreneurs are important for the growth of firms since they provide the vision and imagination necessary to carry out opportunistic expansion. One of the main problems for SIREs is the lack of entrepreneurship of the scientists or the scientific organisations (see also chapter 5). This in fact is based on the self perception of scientists who can consider themselves as the "independent and autonomous scientist in his ivory tower or could be open to the application of their results and entrepreneurial activities. In the last decades policy makers are struggling with the question how to create the entrepreneurial university, not only to foster or create public private cooperation or academic spinoffs but also to promote other forms of SIREs.

- **Banking and financial system (venture and risk capital, industrial versus financial based banking system, etc..)**

The banking and financial system also impose clear constraints on innovative behaviour and consequently on SIRES. Important in this aspect is the availability of venture and risk capital to finance the creation of new technology-based enterprises and academic spinoffs. Moreover the financing of R&D projects is not easy and depends on the experience and the entrepreneurial culture of banks. R&D is a highly uncertain activity and the value of its outcomes is difficult to estimate and ensure. Often it is easier to finance investments in R&D in a banking system with an industrial background than banks with a more financial decision making system. Moreover banks are more willing to finance short term innovation projects with a relatively low technical and commercial risk than long term science based R&D projects. These constraints mean that the financing of science based (cooperative) R&D projects in particular is not always guaranteed (Branscomb et al, 1999). In some countries the financial restrictions for R&D in enterprises originated by the financial crisis are used to reinforce the science –industry relationships. The Dutch government as part of their anti crisis policies introduced a new instrument that increases the SIRE and at the same time solves some of the problems of financing R&D activities of firms.

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public science and industry can be identified as a facilitating factor for the observed high level of SIREs in these countries (Taken from EC, 2001) P. 344

This new instrument is aimed at firms that have temporary problems to maintain employment in R&D because they lack funds to finance the salaries. In this case the researchers of such firms are allowed to work during a certain period in public research organisations or universities. The HEI and pro receives the salary costs from the State and the researchers do not give normal classes but instead give seminars at the university and PROs to communicate his/her knowledge and experiences. Also they can participate in R&D projects.

- **Legal framework (property right of the patent generated by the universities and PRO)**

General legislative issues (i.e. laws and legal regulations not directly related with the innovation system) are perceived as having only small effects on the SIRE, in a positive or negative sense (EC, 2001). However, some exceptions exist such as the regulation of the environment protection that triggered the innovation in this field. Another exception is the legislation or regulation of some specific areas like intellectual property rights which has an important impact on SIRE. For example some countries foresee substantial rewards for public researchers if they patent their work while in other countries researchers of public organisations obtain almost no benefits from their patented research results. On the other hand some laws and legislation are directly related with the agents of the innovation system such as like the institutional setting of research system. Such was the case of Spain where until 1983 the contracts between industry and universities were forbidden

4.- The innovation system and the general framework of R&D and innovation policies

Several specific characteristics of the innovation system have a direct impact on the science-industry relationships. The most outstanding ones that will be highlighted in this chapter are: the institutional and legal setting of the scientific and university system; the policy framework in the field of R&D and innovation; and the organisational setting of technology transfer (R&D performing organisations directly involved in technology transfer and intermediary organisations). Moreover some specific attention will be given to the concepts of critical mass and proximity**.**

4.1.- Institutional and legal setting of the scientific and university system

The institutional setting of the scientific and academic system is an important restriction that blocks or facilitates science-industrial relationships. First of all, the legal setting determines in a certain way the openness of the scientific system to the production sector. Are science industry linkages allowed? And in what way do the entrepreneurs have influence in the decision making process of universities? One of the main aspects of the setting is the autonomy of the universities or public research organisations. Another aspect is the legal status of researchers (civil servants versus private contracts) and the financing of scientific research. Two other important aspects are the rules for selection of researchers and the establishing of priorities for investments in research activities and researchers. Both aspects are directly related with the culture of meritocracy and excellence versus endogamy and the orientation of the research to overall societal interest. The autonomy of the universities –and especially the use or abuse of this autonomy- affects the SIRE directly (See for example

Box **7**). In some countries the universities are autonomous isolated organisations that are financed by block funding and hardly ever do they render responsibilities about how they spend their budgets. In such countries the academic autonomy could be used to defend the personal interest of the researchers (corporative behaviour) above the general interest of society as a whole. In other countries the law foresees universities integrated in the overall social and economic system. In these countries the policy makers requires “value for money” and the scientific organisations have to focus their activities to the overall interest of the society as a whole. Other aspects of the institutional setting are: the selection and distribution mechanisms of the financial funds for research; the selection and promotion mechanisms for researchers; and the procedures to establish the salaries of the scientists and their career track (promotions). The distribution mechanisms of the funds devoted to R&D vary broadly between countries. Some countries support science by block funding and let the scientific organisations decide in which fields or technology they invest. In other countries the government has a strong influence on the distribution by scientific areas. In the last decade most countries have introduced competitive funding schemes where the different public agents compete for funds based on criteria of excellence and criteria based on the economic or societal usefulness of the expected outcomes. The second component is the selection of the researchers and the mechanism of their promotion and salaries. In some countries the salaries are fixed in advance and HEI or PROs can not pay extra payments (or only very small ones) to attract the best talented researchers. In some countries only a very small part of the salaries are based on the quantity and quality of their performance of the researchers, which does not stimulate productivity. Moreover it is very common that the promotion mechanism for researchers does not include criteria that reward the interaction with the production sector. This implies a lack of incentive to create science-industry linkages or to create the "entrepreneurial university".

Box 7.- The autonomy of universities: the Spanish case.

The "University Autonomy" is protected by the Spanish constitution and implies a broad level of self-government. On an individual level, the academic staff of the universities has total freedom to arrange their research activities, which hampers coordination and strategic planning and created a fragmentation of the research groups. The academic autonomy on an institutional level is often used to defend the personal interest of the researchers (corporative behaviour) above the general interest of society as a whole. The appointments of the rector, deans of the faculty or directors are decided by direct elections and therefore they are prone to defend the interest of their voters. Therefore, most universities or research centres in Spain can be characterised as a closed community with a low level of transparency rather than an open dynamic organisation based on meritocracy. This situation directly affects –in a negative way- the quality of the research activities. Several authors have a critical view on the use of the Autonomy of the Universities in Spain. For example Sanchez (2008) argues that the *"democratic model is not capable of managing the university with a criterion of efficiency and rationality",* because the chosen managers have debts with their voters and the pressure groups that supported them during the elections." For example, the vast majority of the "study" plans (curricula) are designed taking into account the interests and power of the largest and oldest departments without any serious analysis about future needs in the labour market. The individual and institutional autonomy coexists with a reduced level of financial autonomy. Most financial resources come from the regional public budgets, though this economic dependency has never been used to force universities to open up and professionalize their institutions. Block funding is based on number of students, while excellence measured by research results has only a marginal role in the funding decisions. Block funding financed the salaries and current costs while specific R&D projects and activities are mostly financed by competitive tenders and contract research. Some regional governments (such as Madrid) attempted to base block funding of the universities on productivity indicators. However, there is clear opposition from the universities and this new trend is still in an experimental phase. On the other hand, in some aspects the lack of autonomy impedes strategic planning and the attraction of the most talented researchers. For example the salaries for scientists in Spain are prefixed and extra payments for merits and productivity are almost non-existent and are less than 5% of the wages.[36] Spain also lacks strong mechanisms that ensure a high level of excellence and productivity of research institutions. Some new instruments are implemented to encourage excellence, but it is difficult to change the historical culture of inefficient assignments of funds and human resources often based on internal autonomous decisions and interests of the research organisations.

As a concluding remark, it can be pointed out that the autonomy of the universities and research organisations is a tricky question. It is not the question of more or less autonomy, but its application and the use or abuse of this freedom has to be taken into account. The Spanish research institutions need more freedom (especially in the case of salaries and budget cycles) to allow long term strategic planning and to compete with R&D institutes abroad. However, if such policies are not implemented simultaneously with mechanisms that guarantee an efficient and effective use of this freedom -based on competitiveness and meritocracy- the final result will be the perpetuation of the existing situation

4.2.- Political structure and the R&D and innovation policies

Political structure and R&D and innovation policies have of course a direct effect on science-industrial relationships. In this section some specific aspects of those policies -with a direct effect on SIREs- will be commented on briefly. Maybe the most import one is the research financing model which can be done by competitive tenders versus block funding. Another important aspect is the priority setting (briefly indicated in Box 8) and critical mass. This last point has already been mentioned but here some short comments will be made on the relationship between those two concepts. A last part of the policy structure is the policy framework to promote technology transfer by the creation of intermediate organisations which will be analysed in section 4.3.2.

As mentioned before, the science-industrial linkages are not a new phenomena, however, the novelty consists in the fast growing attention of policy makers and its systematic approach. For example, 17.5% of the 816 instruments included in the ERA-watch database[37] focus on the promotion and improvement of the science – industry relationships absorbing 10.8% of the funds. Moreover the new concepts of “value for money” and “entrepreneurial university” -both directly related with the commercial use of scientific results- generated important changes in the public support for R&D.

First of all a large number of new instruments were introduced in support of the commercialisation of basic R&D and to promote the cooperation between the scientific community and the production sector. Among others there were the intensification of the support for academic spinoffs and S&T parks and additional support to foster public private partnerships. Also several changes were introduced in the legal setting and formal regulations to facilitate SIRE. Moreover a large number of instruments –not directly focused on SIRE- were reoriented to promote public private cooperation. For example in several countries they included in the public tenders for support for R&D projects in firms or scientific organisations selection criteria that gave a higher priority to those projects based on the application of scientific results or those carried out in cooperation between scientific and industrial agents. Those criteria include the usefulness of the

[36] Formally Spain has several mechanisms to pay some small extra payments. However they are based on a minimum required production level with almost no discriminatory power. For example the extra payments for “good teaching” is assigned –with very few exceptions- to everybody. Moreover the evaluations for research are not valued on a scale but just on the accomplishing of a low minimum level (yes or no). Also in this case it is relatively easy to obtain such payments for productivity.

[37] See Heijs, Baanante y Moya, 2010.

results for the production sector or the society as a whole. In other words, support measures not directly focussed on SIRE do implicitly promote such S-I linkages by the adjustment of the selection procedures and criteria.

Box 8.-Potential Advantages and Disadvantages of Competitive Grants Systems

Advantages	Disadvantages
Increases research **effectiveness** by directing resources to the most productive scientists, by merit (improves quality and accountability of research)	**Limited nature of funding** (funds only operation costs, lack of support to core budget salaries and maintenance of research facilities)
Increases research **efficiency** by reducing: direct costs via competition and co-financing schemes, duplication of efforts, lack of accountability of research resources, underutilization of infrastructure by providing operating resources	**Short term funding**, lack of support for medium- to long-term research agenda
	Low institutionalization, lack of support to human capital development and to new research infrastructure
Promotes the identification of and consensus on national research **priorities**	Higher funding **uncertainty** could affect long-term projects and reduce confidence of research staff
Increases **flexibility** to focus on newly emerging national/regional priority issues	**High transaction costs** from grant seeking, proposal writing and implementation reports, less time for research
Promotes a **goal-oriented** and demand-driven national research system	Reduces research **flexibility** to focus on additional (not open for competition) issues when researchers discover new research opportunities
More **diversification of funding** by involving scientists from outside traditional organizations, promotes “system”	**Higher risks** involved when research consortia involves less-well-known organizations
Strengthens **links** among national, regional, and international public and private research organizations, promotes “spill-ins”	**Low sustainability** of funding when national constituency is weak and external funding sources dry up (unless it is an endowment)
Merit review process provides expert feedback to researchers’ proposals and objectivity of the competitive process, **improving research quality**	Needs a **minimum market size**, a research system with a minimum number of competitors (larger countries probable best suited)
Induces **institutional change** in the national innovation system, separating research policy, funding and implementation	May be **biased towards strong research organizations**, increasing “equity issue” due to lack of competitive capacity of poorer/smaller organizations
May mobilize **additional funding**	Legal, financial, administrative and technical **costs of setting up and administrating**
	Possibility of “**rent-seeking**” in the process of allocating resources to research

Source: Echeverría, 1998 p.11 (with some minor changes).

A second change in the R&D policy framework is that the R&D support for universities and public research organisations drifts away from direct block funding towards competitive tenders based on criteria of excellence and usefulness for the economy or society as a whole. This change was very important for SIREs because the new finance model was introduced to promote a more market driven distribution of the basic R&D funding This approach is specifically focused on the usefulness of basic research and the public private cooperation. Box 8 shows the potential advantages and disadvantages of the new model based on competitive grants (Echeverría, 1998 p.11). The most important advantage is the increase in the research effectiveness and efficiency. The new model orients the resources to the most productive scientists (effectiveness), based on their merits and productivity. The improvement of efficiency is reached by reducing, among others, the duplication of the same R&D activities, the direct costs via competition and co-financing schemes, the lack of accountability of research resources or, underutilization of infrastructure. Moreover this type of competitive finance obliges the HEI and PRO to take into account the usefulness of their activities.

The most important disadvantages are the short-term funding orientation of the competitive grant system which implies a lack of support for a medium- to long-term strategic research agenda. In other words it will strengthen the short term application of scientific results but it does not guarantee that new long term projects will be initiated to ensure in the distant future new scientific results useful for the production sector. Therefore a combined system could be recommended although the decisions on the priority setting and orientation of the long term basic research should be made based on a consensus between the different agents and the government.

4.3.- The organisations with specific tasks in the field of technology transfer

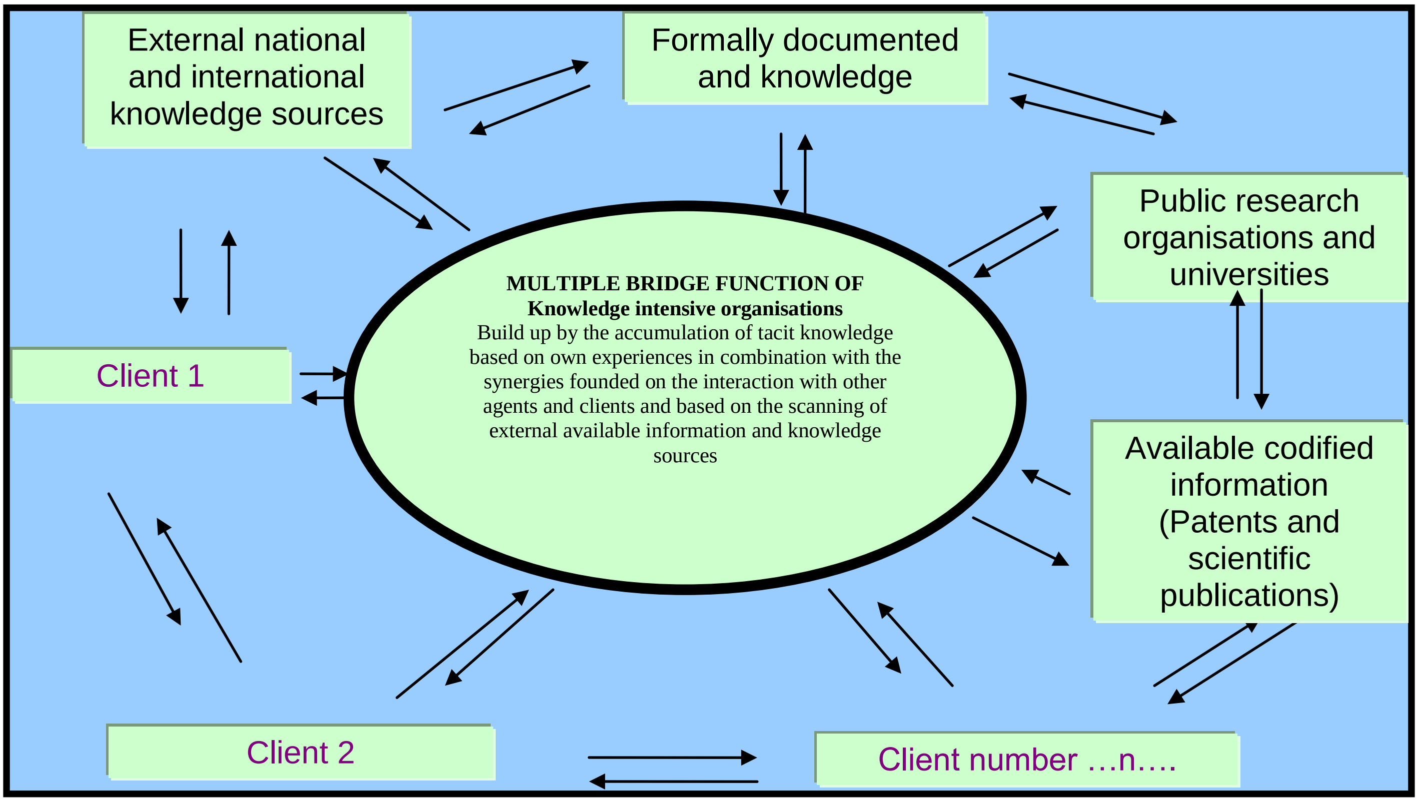
The organisations with specific tasks in the field of technology transfer play an important role in the innovation systems as a producer, facilitator, carrier and source of innovation (Miles et al 1994, Muller and Zenker 2001, Den Hertog 2000) and, therefore the SIREs. These organisations can be divided into two groups. Firstly those knowledge-intensive organizations directly involved in technology and knowledge transfer (PRO, HEI, technology centres or Private consultancy firms and engineering companies). Traditionally the universities and public research organisations are involved almost exclusively in basic or fundamental R&D; the technology centres do or did applied R&D, innovation and technology transfer and the private consultancy firms and engineering companies were devoted to innovation oriented to technical problem solving. Nowadays all these organisations carry out simultaneously several of those activities. The enterprises and the firms for advanced R&D services do basic R&D because this type of research is –as mentioned in section 1.4- complementary with applied and experimental R&D. In the meantime the HEI and PRO do applied research and offer R&D services as a way to obtain additional funds. Secondly a group of organisations exist that are not directly involved in the process of transfer of technologies but do have a facilitating role as a promoter of the technology and knowledge transfer, like the technology transfer offices/centres, Information offices, training offices; the technology, science or science and technology parks. Moreover a certain number of associations of enterprises and cluster-like organisations also have such an intermediating role. Both types of organisations will be discussed briefly.

4.3.1.- Knowledge intensive organizations directly involved in technology transfer

The multiple roles of knowledge-intensive organizations (KIO) directly involved in technology and knowledge transfer can be described by different aspects. KIOs are not only *generators* of ideas and technology (technology push), they are also learning and problem solving partners of companies and public institutions. For many companies KIOs are institutions that help them learn to manage or handle new technologies. They should not be considered as merely external technology suppliers but as partners related, on the one hand, with universities and public research organisations while operating as a partner for the enterprises with a near the market orientation for applied R&D, knowledge based services and consultancies.

The KIO have on the one hand *a direct general effect on the region* as part of the intensive knowledge-based sector by generating qualified employment and human resources; by creating demand of knowledge, pushing the growth of new knowledge based service sector; and by being a focus of attraction for R&D related investments (FDI, new technology based firms or academic spinoffs). Moreover they generate spillovers and/or externalities by the introduction of new innovations in the region; the creation of spin-offs; and are a source of supply of new employees of qualified human capital for the labour market (by specific training programmes and the mobility of their own researchers). Maybe the most important role of the KIO is its position as a hub for the interchange of best practices. The KIO accumulates a broad pool of knowledge, based on a broad number of sources. These take the form of the experience obtained from the interaction with a broad number of clients (firms or other innovative organisations); the accumulation of their experiences based on their internal basic and applied R&D activities –often based on contracts of firms- and the accumulation of external knowledge (by screening all kinds of sources of knowledge from outside the regional or national innovation system).

Figure 3.- Knowledge intensive organizations (KIO) as a knowledge hub



The accumulation of all these experiences and knowledge will be available for local firms or other clients. This role makes them especially important for intermediation between technological supply and demand. They can provide objective information to their clients about their position and technical level in relation to competitors and the technological frontier and they disseminate information of new knowledge and trends. Moreover they play a role in the alignment of the needs and demand of their clients with the existing technological possibilities, partially solving the imperfection of the information. This means that firms can take better and faster advantage of new technologies. Another important effect of technology centres and other KIOs is the creation of a critical mass and division of labour in R&D by the creation of complementary R&D and innovation capabilities and services, and by offering access to technical infrastructural equipment and installations for their clients. At the same time this improves and augments the regional technological capabilities and reduces the costs and risks, creating therefore a critical mass and scale advantages which are especially important for small and medium sized firms.

In other words, the KIO like the technology centres can vertebrate a regional innovation system due to its multiple bridge function (See Figure 3). First of all it closes the gap between science and industry using the basic R&D results as an input for applied research; secondly it acts as a hub of communication to diffuse best practices obtained by the interaction with their different clients and interfaces with their cooperation partners (firms or other agents of the innovation system; and third it is a bridge conceptualised as a central antenna to select, channel and transfer the most recent novel publicly available knowledge and information into the region (see Figure 3).

To conclude, technology centres and other Knowledge Intensive Organisations can be considered as a bridge or a hub between different agents of the innovation system and between basic R&D and business applications and as a catalyst of the technological potential of a region –including the science-industrial relationships- reflected in their multiple roles for the creation of a favourable context within a region

- Attractors and generators of talent and human resources
- Suppliers of scientific knowledge or results , rather than just technologies
- Increasing the stock of formal codified information and tacit knowledge - know how-
- Increasing stock of contacts and potential cooperation partners - networking and knowhow –
- Provider of S&T infrastructures and large R&D installations (institution-building)
- Facilitating learning at various levels
- Contributing to local governance and learning region strategies
- A “bridging” role to create networks, to integrate the agents of the NIS and to diffuse best practices and the most recent technologies

4.3.2.- Intermediaries and promoters of technology transfer

The main purpose of the organisations of the intermediary structure is to increase the level of SIREs by tackling several market failures, such as transaction costs and information asymmetries. On the one hand such organisations offer support in terms of searching for partners, negotiating contracts, and building up mutual trust. While on the other hand they (should) play an active role in the distribution of information on technological capabilities and the tacit knowledge that exists in the universities and PRO. Despite the existence of a large number of such intermediary organisations their impact or effectiveness in promoting SIRE is not clear and in some cases non-existent (EC, 2002). On the one hand the intermediary agencies can have problems to organise their activities in an effective and/or efficient way. In this aspect the EC report of 2002 mentions the following shortcomings: The network of intermediaries is often too large, their supply of services difficult to survey and often, unknown to the target group; Many intermediaries do not specialise in certain services but attempt to provide a huge package of support services which often do not correspond properly with their level of available resources; There is a growing supply of private intermediary services and public intermediaries may upset competition. On the other hand the effectiveness of intermediaries is rather limited because their success depends on the behaviour of the firms and scientific organisations and the usefulness of the scientific research outcomes. Moreover their success also depends on the accomplishment of other critical success factors for SIRE mentioned in this chapter. These include appropriate incentive schemes and institutional settings as well as the level of excellence and orientation of scientific R&D activities. These aspects cannot be shaped by intermediaries themselves and therefore they often fail to foster SIRE due to the existing constraints and barriers.

4.4.- Some selected specific contextual conditions: critical mass and proximity

4.4.1. Critical mass: synergies and complementarities

Two important aspects of the national innovation system that should ensure the success of knowledge and technology transfer and SIRE are the **critical mass and geographical proximity**. A large number of articles and papers suggest the basic role of critical mass as a success factor for economic development and competitiveness. This aspect is even more important in the case of innovation related activities due to the indivisibility and scale advantages of R&D. In fact, there is no doubt about the fact that innovation and even more scientific research activities are highly concentrated[38]. The critical mass and scale advantages are one of the explanatory factors of the growth of Silicon Valley or Route 128.

However, "critical mass" is an abstract concept difficult to define. Some descriptions of critical mass related with innovation are: (1) A "relevant" quantity of innovative activities and a relevant number of agents, (2) Existence of a nucleus or hub of enterprises or institutions[39] that can lead and guide the national and regional innovation systems (or clusters) or (3) Combination and accumulation of reach, scope, scale and synergies. The main advantages of critical mass are: Concentration of complementary high quality agents and factors (package of completeness) that ensure the right combination of quality and quantity. Minimum sizes or critical mass guarantee the justifying of the major investments due to the existing synergies based on scope and depth of activities that permit a rapid response to changes and new opportunities. The main characteristics of the critical mass are:

- Scope and deepness
- Combination of quality and quantity
- A package of completeness
- Concentration of high quality
- A minimum size that guarantees or justifies the major investments due to the existing synergies
- The possibility to respond quickly to changes and new opportunities

The existence of such a "critical mass" offers a broad range of advantages such as (1) the improved opportunities division of labour (or specialisation) on low costs and the efficient use of expensive highly specialised equipment and installations. (2) Better opportunities for interdisciplinary activities and research. (3) Creating a magnet for the best talents (entrepreneurs, researchers, students, etc.), leading innovative firms, and investments of private and public research institutes and firms. (4) Moreover it generates power in the market. These advantages correspond to the characteristics of the "Law of circular and ***cumulative causation***" developed by M***yrdal (***1957) and the virtuous circles create circles of auto or retroalimentation (feedback) in which the critical mass creates its own growth cycle and increases its own critical mass.

In the case of technology transfer the work of Azzone and Maccarrone (1997) shows that the critical mass of demand for technologies and in technical competences is the major factor that determines the success of technology transfer. The critical mass is also fundamental for science – industry linkages because it facilitates the division of labour in R&D by the construction of a broad technological infrastructure (especially important for SMES). The existence of a large demand or market for R&D accompanied by the division of labour facilitates the specialisation which consequently permits the creation of excellence and the reduction of the costs and risks for R&D-

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[38] 8 of the 219 European regions (EU-25) spend more than 25% of the R%D expenditures, 31 one do spend 50% of the total amount

[39] Multinationals, universities, technology centres, etc…

related services. On the one hand this is due to the full use of complementary R&D production capacity and the joint use of the R&D infrastructure of SMES or conglomerates of other firms. On the other hand, this is due to the learning process based on specialisation and standardisation[40]. Critical mass and interaction are necessary although not sufficient to create an innovative region with successful science-industrial relationships. For example not all agents of a region can take advantage of such critical mass advantages like those enterprises which are (auto) excluded from the regional innovation system or that lack the technological capabilities (see chapter 6) to take advantage of the opportunities. Therefore specific policies have to be introduced to promote interaction and SIRE in regional innovation systems.

Critical mass is a concept directly related with proximity –discussed in the next part of this section- especially taking into account the concept technology as tacit knowledge. It is true that technology conceptualised as codified information (e.g. written down, expressed in a formula, or in a design) can be transferred freely and in real time by e-mail, publications etc….. However if we use the concept of tacit knowledge we face another reality. In this case spillovers are not generated automatically and closer proximity would help exploit knowledge spillovers in a better and faster way (Canton et al 2005). The transfer of tacit knowledge requires face to face interaction and therefore is geographically localised. Moreover for a good interaction you need different complementary agents (critical mass). So you need proximity at the same time because tacit knowledge is not codified but is in people's heads and you need enough people with such knowledge. In the following pages the role of proximity will be explained in detail.

4.4.2.- Proximity and distance as determinants for TT

The concept of proximity (or distance) is broadly commented on in the literature of innovation and is used in a varied number of aspects or meanings and dimensions (organisational, cognitive, social technological, cultural, geographical, cognitive, or institutional proximity), which makes it a fuzzy concept. Nevertheless, in all these dimensions proximity apparently plays an important role in the promotion of technology transfer and it seems to facilitate knowledge spillovers. *"Proximity in geographical, industrial, and technical space matters here in that it provides reluctant and sceptic, risk-adverse adopters with the opportunity to assess the actual profitability of the new technology and hence to adopt it." (Antonelli 2003: 9-10).*

The exact conceptual discussion of the different forms of proximity and their consequences are not discussed broadly,[41] although it is clear that proximity is a key aspect to ensure good and successful science-industrial relationships. Boschma distinguishes between five forms of proximity (organisational, cognitive, social; geographical, and institutional[42] proximity) and analyses the relationships between them in relation to their impact on technology spillovers. A central question is the relationship between geographical proximity and other dimensions of proximity. Do they serve as substitutes or as complements to geographical proximity? (Boschma 2005). Being located in one country or region means in general a higher level of social, institutional and geographical proximity, which would lead to a higher level of cognitive proximity. However Boschma claims that "geographical proximity per se is neither a necessary nor a sufficient condition for learning to take place. Nevertheless, it facilitates interactive learning, most likely by strengthening the other dimensions of proximity". (Boschma 2005). According to him, you may also need other forms of proximities such as:

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[40] Due to the critical mass and a sufficient demand the firms that offer R&D-based services can themselves specialise by increasing the specific R&D capabilities (learning) of their services. This improves the quality and can reduce the costs.

[41] See Boschma 2005 for such a discussion

[42] Includes also the cultural proximity

The **institutional proximity**: This aspect of proximity includes the cultural differences common values and common routines and ways of behaviour. The cooperating organisations are close institutionally if they work under the same laws, values, etc. Institutional proximity is an important determinant of technology transfer (Cummings/Teng, 2003; Boschma, 2005) and several empirical studies confirm that this problem is one of the main barriers (Eto et al, 1995; Roger et al, 1998[43]; Heijs/Buesa, 2007). The reason is that similar cultures and value systems allow for a smooth working relationship between the knowledge transfer parties. After all, culture and shared norms define what is acceptable and unacceptable in a workplace (O'Reilly and Chatman, 1996). Cummings and Teng use the concept "norm distance" defined as the degree to which knowledge transfer parties share the same organizational culture and value systems (2003). Early research on technology transfer has shown that differences in work values and organizational cultures can significantly impair knowledge transfers (Allen, 1977; Tushman, 1977).

To reduce the cultural distance between researchers and users, knowledge and technology developing agents and receptor organizations are encouraged (1) to expand the number and diversity of people interacting in the transfer process to increase mutual understanding of values, attitudes and ways of doing things; (2) to involve a broad range of personnel in the transfer process; (3) to hold knowledge and technology transfer seminars to bring together researchers and users; (4) to encourage and fund on-site visits to research and receptor organizations; and (5) to conduct workshops to provide personnel with a better understanding of the culture and product strategy of transmitters and receptors (Cummings/Teng, 2003).

The **social proximity** implies the relations between the organisations will not be only based on business and professional activities but also include aspects of confidence, familiarity, common experiences, friendship, etc. Such proximity is directly related with the geographical distance.

The **organisational proximity** is the way in which the relationships are formalised in organisational conventions. The organisation proximity involves the interdependent relationship between the firm and the scientific organisation that can be organised by networks, clusters, bilateral agreements, or informal arrangement. In fact this proximity can vary from a hierarchical dependence to total autonomy. In the case of SIRE the situation depends on the contractual agreement and the accomplishment of the agreed aspects.

Geographical proximity refers to the physical distance between organisations involved in the technology transfer. This is considered very important in the case of the transfer of non-- codified tacit knowledge that requires a face to face contact and apprenticeship. Moreover geographical proximity facilitates other forms of proximity. Geographic proximity facilitates coordination of technology transfer (Feldman, 1994; Carrincazeaux et al, 2001) and indirectly organisational proximity. It also increases the existence of frequent --face to face- contacts (Breschi y Lissoni, 2001a; Oughton et al, 2002) and informal meetings (Audretsch/Stephan, 1996) In this way it facilitates the creation of cooperation or interaction in the field of innovation based on mutual trust, friendship and respect, or in other words social proximity (Boschma, 2005). Institutional proximity is supposed to be high in the case of two organisations of the same country or region especially in the case of the cultural background. Moreover geographical proximity reduces the costs and time needed for the meetings or the search process for partners (Goe et al, 2000; Oughton et al, 2002) Feldman, 1994/1999). Moreover the absence of possible scientific organisation in the same region could be an important barrier to initiating SIRE. A firm could decide not to enter into such relationships, an argument of particular importance for small and medium sized firms.

[43] Taken from Bozeman 2000

The geographical proximity is neither a necessary condition (Boschma, 2005) nor a sufficient condition (Howells, 1999; Fritsch, 2003; Boschma, 2005) to ensure interaction between external sources of knowledge or to improve the use of such knowledge. However, there is no doubt about the fact that it offers advantages to improve interaction and learning especially in the case of tacit knowledge. The creation of knowledge-intensive business services (KIBS) is correct but not sufficient. If its creation is not accompanied by the creation of demand or a market for R&D services it will be a stand alone project like a "Cathedral in the Desert". Enterprises are the motor of economic and technological development and therefore they have to be the main clients of the local or regional technological infrastructure

A very important aspect is the **cognitive proximity**. This last aspect of proximity is defined as the difference in technological level between the two partners involved in the technology transfer and in this case the conversion of scientific results into commercial applications. For R&D knowledge transfer, a particular difficulty is that the R&D contexts of the source and the recipient can be quite different. The R&D output of the source is often the R&D input of the recipient, and the cognitive proximity or distance is the level of overlap and complementarity between the R&D activities of the two parties. The knowledge is distributed in an asymmetric way between the members of the innovation system on a national and international level. However the transfer of knowledge and technologies is not easy and not everybody has the capacity to appropriate them and adapt them to their own circumstances. Boschma (2005) mentions two basic reasons that justify the need for cognitive proximity. (1) The agents of the innovation system have a "limited rationality", which means that cognitive restrictions exist that impede optimal behaviour (Simon, 1955). (2) Knowledge is not a public good produced outside the economic system and which is directly and available free of costs for everybody. The firms that want to absorb a certain technology need a minimum level of technological capacity to handle the external knowledge (Perez/Soete, 1988). Normally firms look for knowledge or new technologies close to their cognitive capacity –in the same sector or technological field-. In other words firms normally build ahead of their own technological trajectory by the way of incremental innovation and accumulation. In conclusion, the cognitive gap can not be too big and the cognitive proximity has to be sufficiently near to facilitate the communication between the involved agents and to understand the new knowledge and technologies (Boschma, 2005). This is especially important in the case of technology transfer between science and enterprises. The novel scientific findings are often tacit and can not be codified and their implications in the future are uncertain. This means that only the firms with a high absorptive technological capacity and commercial insight are capable of making use of scientific findings.

However, at the same time technology transfer requires some **cognitive distance** for two reasons (Boschma, 2005). The first is to ensure the existence of complementarities. Innovation is basically the application of existing technologies in new combinations (Schumpeter, 1938) and novelty generates new ideas and creativity (Cohendet and Llenera, 1997).Therefore heterogeneity and complementary knowledge (cognitive distance) is necessary to generate technology transfer and synergies. In fact Boschma argues that a successful technology transfer process requires at the same time a technological capability (cognitive proximity) and complementary novel technologies (cognitive distance). Secondly the existence of cognitive proximity could generate path dependency and a lock in effect which impede that enterprises react in the case of important technological changes. The accumulation of successful routines could blind the organisation and impede the creation of new competences to get rid with new threats and opportunities.

Concluding, learning (or technology transfer) requires a cognitive distance (in terms of competences and technological capabilities and abilities – see also chapter 6) based on a variety and differentiation of the activities which is sufficiently novel to assure that the receiving firm acquires new knowledge and ideas complementary to the existing competences in the firm. At the same time successful technology transfer requires common knowledge and similar competences to facilitate smooth communication and assure an optimum and level of understanding of the novel scientific results in order to assure the absorption of the new knowledge. A certain equilibrium between both has to be found to avoid the disadvantage of too much proximity and at the same time to take advantage of new technologies or knowledge that are sufficiently at arm's-length to create some new complementary advantages. So it can be stated that the relationship between transfer success and knowledge distance between the source and the recipient is curvilinear (an inverted U-shape). (Cummings/Teng, 2003), where too much or too little distance must be avoided.

5.- The micro level performance of the universities, public and private scientific research institutes and technology centres

5.1.- Basic aspects of the micro level performance

As argued in the former sections the attitude and absorptive capabilities of individual firms are important to ensure the efficient use of scientific results and their relevance to transforming products which are marketable. On an aggregate level the structure and specialisation of the production sector in combination with the competitive pressure of international markets and domestic demand are important constraints for the innovative level of the firms. However, the success of SIRE also depends largely on the behaviour of the scientific organisation. Often their attitude and behaviour are criticised (see for example Box 5). Therefore in this subsection the basic constraints and obstacles for SIRE related with the micro level performance of the scientific organisations will be analysed.

Box 9.- Some quotes on SIRES by R&D managers in Swedish firms44

- Our problems are very practical and not often fulfilling the academic requirements in terms of scientific relevance as imposed by the universities
- It is difficult or impossible for universities to keep the results of our collaboration confidential, so we are forced to limit collaboration to areas that are 'nice to know' and we are not able to work jointly on truly strategic areas
- Students do not have any understanding of our business-reality so their start-up time before really adding any value to our business is too long
- Academic researchers often lack the project management skills to act as reliable partners in a business-context
- What we need is to get a few solid answers to one clearly defined problem, but academic research more often aims at developing a long list of additional questions – as interesting spin-offs from the originally defined problem

Taken from the *Vinnova Project on the Entrepreneurial University* Sigvald.Harryson

The specific characteristics and micro level performance of universities and scientific research organisations have a direct influence on the intensity, quality and level of success in science-industry relationships. Universities and scientific organisations are often considered as both barriers and facilitators for knowledge transfer and commercialisation of scientific results. In this section five types of aspects of micro behaviour are distinguished, however, (as will be explained later) most of them are interrelated.

[44] Akzo Nobel, Bang & Olufsen ICEpower, Gambro, SCA, Swisscom, Telia Sonera, Tetra Pak

1. The self perception of HEIs and PROs about their main mission (independent basic reach based on a culture of openness).
2. Level and the commercial and social usefulness of the outcome of scientific research directly related with the quality of the R&D and its commercial orientation.
3. Internal incentives and evaluation mechanism on the excellence and quality of research
4. The planning and priority setting of scientific research activities financed with public funds
5. The institutional and cultural setting of the scientific community and its organisations including the behaviour of its agents and individuals.

The scientific community has in general a *self perception* about their main mission based on independent basic reach in combination with a culture of openness and free access of publicly funded R&D results. They have a historical, traditional view of science as an independent objective activity carried out in the "ivory tower" unrestricted by the problems of profits and the market where commercial activities are outside the scope of a self-respecting academic scientist. This view directly affects the difficult commercial and social usefulness of scientific research and its results. Three problems of this "usefulness can be highlighted. Firstly the projects have to be oriented to those scientific areas that are of interest to the production sector and secondly the utility depends on the quality or level of excellence and productivity of both the researchers and their investigations. However not in all countries does there exist an integrated quality control system to measure the excellence of the academic researchers and their projects. The utility of the research outcome also depends on other factors. Its use is only successful if they permit the creation of comparative advantages on the (inter)national market. Besides the technical aspects, success in the market depends on the fact that research projects have to be carried out: within a pre-established time frame; with a high level of efficiency to ensure certain limits of low costs (to ensure prices acceptable in the future markets); and the results have to be kept secret. Concluding, the commercial usefulness of the research results is not only a technical question but also a question of timing, costs and secrecy. These are attributes that often conflict –as will be discussed later- with the interest and culture reflected in the micro behaviour of academic scientists.

The fourth aspect that should ensure the commercial usefulness of the scientific research is the priority setting and the long term planning of the research activities. The setting of the research agenda and the distribution of the funds between specific technological areas is important to generate sufficient interest by firms to cooperate or participate in basic research. First of all public funds have to support those scientific fields whose potential outcome is interesting for future commercial applications or social needs. Secondly the distribution has to avoid the dispersion and fragmentation of the R&D efforts by ensuring a sufficient critical mass that allows scale advantages. In an optimal situation the national government together with the HEI, PRO and the production sector should design a long term strategic plan taking into account the interest of society as a whole. In other words, establish clear objectives to solve problems of the social environment and the production structure. This planning should take into account the distribution of financial and human resources by the technological field or scientific discipline and in terms of basic versus applied research. In section 1.3 the importance of basic research was explained. However, the results are only useful if they are translated into products or innovations introduced in the market or solutions for specific social problems. Therefore it is important to establish the right balance between basic and applied research. The prevalence of commercial usefulness of basic R&D and the promotion of short term applied research should be combined with the strategic planning of research towards long term basic or fundamental research objectives.

The government -as main investor in scientific research- has a specific role in research fields with a public character[45] that explains the differences in specialisation patterns. However, the

[45] Like health safety and environmental concern.

government also invests in other scientific disciplines which may be considered of national importance or for generating the critical mass in any given production sector. Where there is a clear government commitment in any area, the potential for science-industry interaction increases. However, the “autonomy” of the research sector in those fields is by and large the integration of mutual coordination. Often the allocation of funds for public research is the result of historically determined factors and the inertia of policy making implies the maintenance of this historical distribution. Such inertia is common practice in many countries (Canton et al, 2005), although this may be suboptimal and impede the reinforcement of investments in newly emerging technological fields. This problem is particularly visible in those countries where management of the PRO and HEIs is based on internal democratic mechanisms. In such organisations the departments with a long tradition and a high number of researchers have a significant power (by their votes) of influence while smaller departments working in emerging and promising technological fields may lack support in democratically elected management boards. Once a research organisation or a department establishes itself and specialises in a certain field, it could prove difficult to diversify and introduce changes. Even if the technological strengths of that department may lose their relevance/importance it is difficult to close down or even to change their R&D orientation to more promising fields due to traditions and other factors such as lack of willingness by the researchers to explore new areas other than their expertise or fear of unemployment. In such cases it usually behoves the government and political parties to lead the changes towards a well designed mechanism and a re-orientation of priorities.

The fifth group of barriers or problems that limit the science-industry relationships relate to the institutional and cultural setting of the scientific community and its organisations including the behaviour of its agents and individuals. Some important and interrelated aspects are:

- Reward structure of academic scientists
- Publication and open science versus secrecy and commercialisation
- Lack of entrepreneurial culture in favour of an academic tradition
- Organisational setting of the TT activities
- Rules of ethics and standards
- Fear of unemployment

Probably the most important stumbling block is the formal and informal reward structure for scientists in the public research sector which is clearly oriented to scientific outputs while the commercialization of research results and cooperation with industry is not recognized in the appraisal of the researchers’ activity expressed by their salaries and their public scientific reputation. In fact the commercial activities of a scientist can have an indirect negative effect on his/her salary and often on his/her academic reputation. Canton et al (2005) argues that scientific recognition is based on a “publish or perish culture” and its reward structure does not encourage activities to bring science to the market. Of course the incentives for researchers to engage in science-industry relationships vary between countries or even between universities of the same country. For example, in the United States, universities are considered units that compete with each other for financial support and R&D contracts due to their level of excellence and the interest of their research for enterprises or (semi)public foundations and agencies. They compete by attracting top researchers offering better wages and working conditions. In Spain, for instance, all university researchers have by law the same wages so discrimination is avoided in terms of salaries between the most talented or productive researchers and the less productive ones. On the other hand, in England academics have private contracts and their continuity and promotion depends among other factors on their capacity to attract third stream funds for research or teaching.

One of the most common aspects of the cultural differences between firms and scientists –and directly related with the reward system and the possibility of cooperation in joint projects- is the disclosure norm versus secrecy. This has already been touched upon, private enterprises often need to keep research results secret to avoid their dissemination or imitation by potential competitors. While the "publish or perish culture" mentioned by Canton et al (2005) underpins the need for a scientist to publish in order to improve his/her academic recognition, this is contradicted in the private sector for the reasons already explained. Therefore a scientist could be reluctant to cooperate with the industry if it will be more difficult or impossible to publish the results and allow for sufficient exposure. At the same time industry is less interested in financing research whose results will be published and accessible to its competitors. The 'norm of disclosure' from the scientific community is in contradiction with the "norm of secrecy" common in the market sector and the private enterprises (Dasgupta and David, 1994) because firms would like to keep the research results (or at least part of them) secret to overcome the problem of appropriateness in the results of their investment (discussed briefly in section 2.4) and to maintain their competitive advantages in the market. *"This means that science-industry interaction could be hampered when academic scientists are mainly rewarded for their performance as measured by publications. Because without personal interaction with scientists, many firms will not be able to utilise academic knowledge"* (Canton et al, 2005).

Another important barrier for conversion of scientific results into commercial products is the lack of entrepreneurial spirit by the academic scientists. The good entrepreneurial culture means that the researcher understands and identifies possible commercial applications and secondly has the capacity to develop such an application within a reasonable timeframe and costs. The scientific researchers often stop at the 'proof of principle' stage publishing their results and are, in general, not involved in commercialising their ideas. Usually, the new scientific wisdom can be considered as tacit knowledge and in this case it would be the researcher him/herself who best understands the future implications and possibilities. However, history made it clear that even firms and well known entrepreneurs do not always understand the market potential of their own research results, especially in the case of new hybrid technological fields. There are several causes of this lack of entrepreneurship. As already mentioned, traditionally scientists consider academic research as an independent objective activity that legitimates their existence (Louis et al, 1989), and commercial activities are outside the scope of any self-respecting academic scientist. Moreover on an individual level a number of researchers consider applied research as a rather boring activity and far away from the original abstract idea (Thursby/Thursby, 2002). The development of experimental research or a prototype is time consuming and often requires less academic experience and expertise. Due to this traditional view and the schooling of young researchers in this tradition academic researchers lack experience in firms[46], and this means that most researchers are not aware of the possibilities in the market or of the way to ensure a good product development and commercial introduction. Even if scientists were aware of market opportunities, they might lack the required qualifications to run the whole process of commercialisation and protection of their innovations.

Other factors worth a mention, relate to the laws of ethics and standards imposed either by a firm, organisation or the national government. Such laws lay down the rules on the limits permissible on scientific research. Ethical standards are often contained in a 'code of ethics' and normally restrict research, very often interference with the human body features prominently in such codes (whether written or unwritten).

5.2.- Strategic Critical Success Factors of the technology transfer activities of scientific and applied research centres

[46] An exception is the polytechnic schools in Germany. To get a job there you need at least 5 years experience in a firm and on a certain level.

In this section a strategic approach is offered on the critical Success Factors of the technology transfer activities of the main scientific and applied research centres (technology centres, universities, PROs, etc…). Such centres or knowledge intensive organisations can have a multiple bridge function in the case of the commercialisation of scientific research outcomes based on the technological capabilities built by the accumulation of tacit knowledge based on own experiences in combination with synergies founded on the interaction with other agents and clients and based on the scanning of available external information and knowledge sources (see figure 2). They can have a leading role as facilitator of a regional innovation system or clusters in more peripheral regions or can have a leading role as high-tech strategic advanced competence centres in the leading technological regions.

Schmoch (2000) offers an analysis of the Critical Success Factors of the technology transfer activities of the main scientific and applied research centres in Germany by analysing the practices of technology transfer in the major research institutions[47] and the technology transfer units ("Intermediaries"). The CSF mentioned by Schmoch can be divided into two groups. The first indicates the CSF of the internal performance and organisation of the in-house research activities to ensure a satisfying technology transfer in both the short and long term. In fact these aspects are similar to the concepts of the strategic management literature. The scientific organisation could be compared with the firms that are looking not only for the current "sales" of knowledge but also to their future markets in the medium to long term. Therefore they have to analyse their portfolio of products (knowledge) by strategic audits and secure future "business" by strategic long term R&D planning and investments. They should carry out a realistic assessment of existing competencies and capacities in order to adjust and reorient their strategies to new scientific and technological trends. Such strategic audits should include a broad range of external experts from science and industry who should design a clear view about the future integration of scientific and industrial demand and requirements. This discussion is similar to the one about the funding model (block versus competitive funding) for public R&D (see also section 2.3.3. and Box 4)

Technology centres as well as the "entrepreneurial universities and/or market oriented public research centres should pursue a correct balance between short and long-term activities. They should distribute their financial funds between long term strategic projects based on the outcome of strategic audits to ensure a sufficient long-term vision for research and competence building. Simultaneously they should carry out regular contract projects for industrial clients to obtain or maintain their knowledge on industrial trends and market requirements not only at the institutional level but also to allow individual researchers to participate in both types of activities. If the researchers and research institutes participate in too many applied projects, they could be losing out on resources which could be needed in other crucial areas for the competitiveness of the organisation. In the short term this applied research from short-term projects could reflect an apparently successful institute but they may lose their future long term success options. To ensure the long term science-industry relationships a joint public/private institutional set-up could be recommended based on co-funding of strategic research by public and private partners. Such a set-up could foster the reconciliation of public and private interests and ensure institutional responsibility of the private agents, which should lead to industry being more willing to provide finance for long-term scientific R&D.

The second type of CSF is related with the organisational setting of transfer activities. How to put on the market our products or knowledge and which distribution channels are the most effective and efficient? In the case of the balance between long term strategic R&D and short term applied R&D the joint public/private institutional set-up is already mentioned. Another organisational aspect mentioned by Schmoch (2001) is the decentralisation of the transfer responsibility. The

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[47] *Universities, Max Planck Society, Fraunhofer Society, Helmholtz Association*

separation between a central transfer department and scientific departments would have negative effects for technology and knowledge transfer. The responsibility should be assigned to the departments and researchers for transfer in combination with the establishment of incentive structures for transfer. This does not mean that external technology transfer units in support of the scientific departments are not necessary. In fact some of the transfer activities could or should be externalised –although with direct involvement of the scientific department- especially those related to direct market oriented exploitation (development of prototypes, experimental production etc.). Such externalisation is important because these activities require special skills often beyond the competencies of scientific researchers and some legal problems may exist. However, as already mentioned, such externalisation should be combined with close institutional linkage of the external units to the central institute and its scientific departments.

5.3.-- What are the positive and negative aspects of the entrepreneurial university

A very important discussion of the last decades is whether the universities´ engagement in entrepreneurial activities is a positive or negative development. There is some agreement on the potential positive impact of the SIRE on economic growth and the positive effects of the technological capabilities and the level of competitiveness of the enterprises and the regional innovation system. However some negative effects can be expected. In this short review three main aspects are discussed.

The commercialisation and the readjustment of the academic system to "entrepreneurial universities" may have two unintended consequences. Firstly the commercialisation could lead to more secrecy and less disclosure, because stronger links with business could reduce the free publication and disclosure of academic output, due to a conflict in the incentive structures of universities and the business world. This implies on one side a distortion of the free market due to the commercial use of publicly funded research results by firms, especially in the case that licenses could offer exclusivity for a low price to some specific enterprises, thus excluding other competitors. This also implies the loss of the "open innovation" culture in which the public research results can be used by every agent of the production sector as a kind of "Arrow" based public goods.

Another type of consequence is that an entrepreneurial university could drift away from fundamental long term research to the benefit of more applied research. An excessive entrepreneurial approach would have a negative impact on investment in basic research whose payback period is far in the future and with an apparently low level of short term commercial interest. The third problem identified here would be the negative effects on the behaviour of public researchers and universities (such as less attention to teaching and other responsibilities).

The problems of disclosure versus secrecy in entrepreneurial universities refer to the impact of scientific results on the market and the productive sector. As mentioned by Arrow in his article on technology as a "public good", the state should support R&D and make it publicly available for the whole production sector thus broadening the technological frontier and indirectly the competitive advantages of a country and its enterprises. The conflict between the norm of disclosure of science and the secrecy norm in the business sector might increase if the link with the business sector becomes stronger (Dasgupta and David, 1994; Stephan, 1996). Canton et al (2005) argue that the fact that not all research results are disclosed reduces the social benefits from university research because secrecy could lead to useless duplication of research, slowing down the advancement of science and reduces broader technological transfer towards other firms which are not collaborating with universities. Licensing the ownership of the output of publicly funded scientific research involves the appropriation of public goods by certain private enterprises and diminishes the potential technological spill-over to other firms. This fact would be a threat to the "open science" culture (David, 2004; Nelson, 2004; Geuna and Nesta, 2006).

When knowledge is sold for a low price, commercialisation could reduce free market competition. The ownership of research results at the end of the project -and even in intermediary phases- is a problem because openness in research and publications can be hindered by commercial needs for confidentiality and can delay the diffusion of the results. The supposed limiting role of patenting and licensing in the diffusion of the new scientific breakthroughs could be partially tackled by a more creative way of licensing specifying non-exclusive rights (Antonelli, 2008). A study by Feldman et al. (2007) shows that in specific cases non-exclusive licensing is the most suitable approach to maximize the diffusion and use of a new scientific outcome. It can be pointed out that firms that have some kind of exclusivity are not (or are less) interested in further development of the embryonic scientific results because in this case other firms can also develop similar products or imitate the new innovations developed by the enterprises. In other words if firms are not sure that they can appropriate the new developments derived from public research they will not make the extra R&D investments for further development which could lead to underinvestment in R&D. The availability of early licensing of ideas could ensure that firms are able to address this issue and their investment in a specific application will be protected. This could lead to an increased commitment which increases the overall R&D investment. Such licensing however does not completely impede other enterprises from using the scientific results for other purposes.

Other authors support the interaction between science and industry and feel that this ensures a higher level of utility and usefulness of research paid through public funds. Murray (2005) argues that the private use of scientific ideas does not simply imply a monopoly or complete privatization of the research results because academic scientists' defend "open science" and created a hybrid economy in which both company and academic inventors use patents to protect and exchange their new knowledge. However this new situation may be less efficient than the previous reliance on pure "open science" because of the transaction costs associated with patenting (Geuna/Muscio, 2009).

A third argument in favour of licensing of public research results for private firms has to do with the specific character of scientific results as tacit knowledge The public-private cooperation is necessary in the case of scientific wisdom. The outcome of academic research becomes publicly available if the knowledge is codified by the researchers and is published in scientific journals, the technical descriptions of patents etc. However not all the relevant aspects of knowledge can be codified and often some relevant aspects are excluded or kept (intentionally or not) secret. Tacit knowledge is necessary to fully understand the scientific idea and without this knowledge its diffusion is not easy. This is especially so in new emerging scientific disciplines –with a low number of experts and a low level of codification and standardisation- these are heavily based on tacit elements difficult to codify.

In such fields knowledge transfer is more difficult and personal contacts and face to face interactions are required. Canton et all (2005) highlight that scientists that limit their diffusion to publications (spurred by their reward system) do limit at the same time the so called open science approach. The optimum commercial use of academic results is clearly limited without a direct interaction with industry to transfer tacit knowledge. This means that many enterprises are not able to use academic knowledge. This argument is directly related with the vision of scientific results as a "public good" accessible for everybody versus the scientific results as a "private "good" due to its tacit aspects that is only partially accessible by a small group of agents with highly specific technological capabilities. In this aspect the importance of geographical proximity can be stressed by the argument that the indissoluble combination between tacit and codified knowledge and the need for face to face contacts do limit the knowledge spillovers to local agents. In fact the literature studying the channels of knowledge transfer between universities and firms showed that spillovers are locally concentrated (Mansfield, 1995; Jaffe, 1989; Adams, 2002).

The second unintended consequence of an excessive commercialisation of the universities is the undesired impact on the orientation of basic research activities and other aspects of the behaviour of universities and their researchers. The intensive involvement of researchers in industrial activities and too much pressure to ensure the “value for money” culture may damage academic research by[48]: shifting the orientation of scientific long term basic research activities to short term applied research; diminish the interest in good basic research especially in fields whose commercial interest apparently is less promising; undermining the commitment to teaching and the research freedom or autonomy of the universities and scientists.

Box 10.- Trade-offs associated with university-industry relationships

Benefits	**Drawbacks**
• Additional revenues for University	• Negative impact for culture of Open Science (Nelson, 2001)
• More rapid technological diffusion	• Negative impact on students/adviser relations
• Choices regarding technological emphasis	• Could reduce quality and quantity of basic research (Louis at al. 2001; Siegel at al. 2003)
• Positive Effects on Curriculum	• Negative Effects on Curriculum
• Local/Regional Economic Development	• Could affect negatively the type of research questions addressed (Stephan, 2001)
• Two way-knowledge transfer	• Academics could spend less time on teaching and services (Stephan 2001)

Adopted from Poyago Theotdky, Beath, Siegel, 2002

An important discussion in the literature about the science-industrial relationships is their possible impact on the orientation of the research that could shift away from fundamental or basic research to applied research. The public support for fundamental research is justified due to the specific characteristics of the long term risk investment that often generate a kind of public good that can be used by other agents. In this case enterprises are reluctant to finance such R&D activities avoiding the risk and the problems of appropriateness. Although basic research may not result in ready-to-use applications, the state finances such activities because it wants to generate long term scientific breakthroughs that could be very important for economic growth or to solve societal challenges (like health, security and the protection of the environment). The involvement of industry could reorient the academic research to more short term applied research activities.

The execution of long term basic research is important not only for society as a whole but also for the universities themselves. The comparative advantage for university is in basic research, even if it could also develop applied research and development. To ensure their relevant competitive advantages also in the future they have to combine short term applied research with long term strategic research projects and maintain a balanced portfolio of diversified long and short term projects. The commercial approach of the university research activities could create conflicts of interests and therefore influence the development of a common research project by determining research directions. Scientists are generally driven by their knowledge and instinct, while the

[48] Feller 1990; Faulkner & Senker 1995; Senker et al. 1998; Ziman 1994, 1996; Cohen et al. 1998; Blumenthal et al. 1997.

industrial partner is driven by other criteria (timing, uncertainty, possibilities for application, etc.) One of the problems as already cited is the choice between applied and basic research. In some other cases the fear of disaffecting an industrial partner could also influence the decision to investigate one product (for instance because it is produced by the industry itself) and this would affect academic freedom. It deals with culture and values questions, based on the assumption that freedom of inquiry is the unavoidable condition for knowledge production.

The empirical studies show that science-industrial relationships influence the selection of the R&D activities, even though the exact effects are unclear. Mansfield (1995) indicates that more than 50% of the interviewed academic researchers indicate that their research orientation is the results from their interactions with the industrial world and also around 50% indicate that the direction of their work was influenced by potential sponsors and users. However the study by Mansfield analysed only a few technological fields of applied disciplines such as electronics and chemistry. However several studies (Blumenthal et al. 1997; Mowery and Ziedonis, 2002; and Thursby and Thursby 2000) argue that there is no clear relationship between the SIRE and the reorientation of the R&D to basic research and the causality between those two aspects is unclear. The increase in the licensing activities is not an effect of the reorientation of R&D, but rather of a changing attitude of the scientists who became more interested in the protection of their results due to the growing entrepreneurial climate.

Based on the above-mentioned studies Canton et al (2005) conclude that there is no strong evidence in the literature that science-industry interaction leads to problems in the disclosure of scientific research results or to a shift away from fundamental research to applied research in academics. Moreover several of those problems could be solved partially by the governmental influence on the distribution of the fund. For example a certain percentage of the funds have to be oriented to basic research.

6.- The micro level performance of the Enterprises and other non-scientific private research organisations.

6.1..- Why do firms cooperate with scientific organisations or other RTOs

Due to the substantial increase of the cooperation between the agents of the innovation systems in the last 30 years (Sharp/Shearman, 1987; Mytelka, 1991; Hagendoorn et al, 2000; OECD, 2002), technological cooperation has been extensively studied in the recent literature[49]. The most common academic topics that are covered by these multiple studies[50] are: (1) appropiability problems of the technological results; (2) growing complexity and interdisciplinarity of the innovation directly related with learning; (3) increasing costs to maintain the position on the technological frontier linked with the decreasing shorter market life cycle of the products; and (4) strategic reasons[51]. However it must be underlined that normally cooperation is a consequence of a combination of these arguments.

The appropiability issues are related to technology as a source of information. The fact that the competitors could easily copy or imitate without cost could turn the results of research and

[49] See among others: Sharp/Shearman, 1987; Mytelka, 1991; Herden/Heydenbreck, 1991; Dodgson, 1992, 1994; Hagendoorn, 1995/2002; Fritsch/Lukas, 2001; Tether, 2002; Belderbos et al 2003. Or, as in the case of Spain, Costa/Callejón 1992; Garcia Canal, 1992; Molero/Buesa, 1995; IESE, 1995; Acosta, 1996; Aguado, 1999; Acosta/Modrego, 2001;Bayona et al 2001/2003; Fernández-Ribas, 2001; Navarro, 2002; Heijs, 2002; Heijs et al, 2004ª/2004b; Busom/Fernández-Ribas, 2004.

[50] For a review of the literature see Hagedoorn/Schakenraad, 1989; Vonortas, et al, 2003

[51] Like the Joint promotion of world wide industrial standards or the entry into a new market or technological field (new countries or new product lines).

innovation processes –according to Arrow - into a public good difficult to appropriate. This assumption could mean that the level of private investment in innovation is below the social optimum. Despite the legal constraints and protection – patents, copyright or other intellectual property rights- companies believe that their competitors will take advantage of their innovation efforts through undesirable externalities. Cooperation between potential users of the new technologies means not only sharing costs but also reducing risk of such undesirable externalities and spillovers through competitors. The literature based on the Industrial Organization Theory has developed theoretical models that link horizontal cooperation with appropiability and undesirable externalities problems (See Spence, 1984/1986; Aspremont/Jacquemin, 1988/1990; Katz, 1986; Suzumura, 1992; Kamien et al, 1992; de Bond et all. 1992; Simpson/Vonortas, 1994). According to Belderbos et al (2003) these models point out that horizontal cooperation – i.e. cooperation between competitors – internalizes the externalities (called synergies) between the partners. If the level of synergies generated is high enough – above a critical level – the cooperation generates more investments in each of the companies because it neutralizes the potential disincentives prompted by the undesirable externalities to other competitors. In fact horizontal cooperation will have higher effects over the global R&D expenditures than the vertical one (Steurs, 1995). Anyhow -as a third conclusion-, it could be pointed out that the models developed in the literature also show that other modalities of cooperation create benefits. The appropiability problem is intensively reflected in basic R&D, the results and findings of which are more difficult to protect by legal instruments. Moreover, as these new findings are transferred into industrial applications faster and faster (shorter knowledge life cycle) and their development involves high and growing costs, they require the optimisation of the economic resources (Kulicke, 1997). Therefore, basic R&D is frequently considered as a public good that usually generates undesirable externalities making it, as a consequence, suitable for collaborations[52]. Regarding the appropiability, it must be taken into account that not all the theories consider the technologies generated by the R&D and innovation activities as a public good. The evolutionist theory regarding the technology change and the economic development argues that technology is knowledge with a high tacit content, difficult to copy, and therefore, companies can appropriate it themselves and own it. This means that the relation between the appropiability problems related to the cooperation is not clear. On the contrary, it could be said that companies are more interested in the cooperation in technological fields or problems with a high degree of appropiability because it could be the only way to have access to their competitor's technologies (Pyka, 2002). For complex technologies, technology transfer is related with direct communication and mutual learning due to the fact that in this kind of technology simple imitation is not possible (Winter, 1987). On the other hand and according to the Industrial Organization Theory, only the companies that can protect their own R&D results –which are of strategic importance for their competitiveness-, would participate in collaborative projects (Belderbos, et al, 2003). But, what is more, the companies with a relatively lower innovative capacity are interested in participating in collaborative projects in order to take advantage of the other companies' knowledge. Therefore, the problem of appropiability implies that during the choice of potential partners the reliability and integrity must be taken into account to prevent abuse and free riding.

These critics follow the same line as the second argument for cooperation -with a growing importance-: the growing scientific complexity and interdisciplinary: this tendency requires a broad set of capacities and experience in different technology areas. This demand for diversification is – even for the biggest companies – too costly in time and in financial terms (Sharp/Shearman, 1987; Teece, 1992; Geroski, 1995; Hagendoorn/Narula, 1996; Kulicke, 1997). In the case of innovation the division of labour and specialisation is not easy to obtain through the market mechanisms, since it requires different kinds of cooperation (Geroski, 1995). Therefore,

[52] It is just this type of cooperation that in the last 25 years received public support from the public administrations and especially the E.U.

companies are looking for partners with complementary and advanced knowledge in order to achieve scale economies that permit them to react fast in the case of the market changes. A contribution to this second approach is offered by the business management literature, - based on the Theory of Transaction Costs or Resources-Based Theory (Tyler / Steensma, 1995) and the work on learning (Cohen / Levinthal, 1989)[53] -. The first one shows that cooperation can reduce transaction costs because it offers a better technology transfer control in comparison to market mechanisms. This capacity to control the innovation process through cooperation, is mainly related to the complementarity of knowledge between partners (Kogutt, 1988, Teece, 1992; Hagendoorn, 1993, Geroski, 1995, Das / Teng, 2000; Hagendoorn et al, 2000). The aim for the creation of alliances is to acquire knowledge and skills of the members, as a learning process, to create new competencies (Hamel, 1991; Steensma, 1996) especially when a company wants to enter a new technical field which is unknown to it (Sakakibara, 1997). A successful collaboration between companies should have a level of absorption or learning depending on experiences related to innovation activities (Cohen / Levinthal, 1989; Hamel, 1991; Steensma, 1996). In addition to that cooperation would prevent one´s own success only depending on their existence in the market for complementary technologies necessary to perform their own projects. In this way the company is active in conducting innovative guidance and is co-owner of the technologies developed.

Box 11.- Principle motives for cooperation in innovation between public and private sector (See also Hagedoorn/Schakenraad, 1989; OECD, 2002; Caloghirou, et al. 2003; Vonortas, et al, 2003)

1.- Problems of appropiability of the technical results

- Public good (Arrow; 1962)
- Access to tacit knowledge (Pyka, 2002)
- Patent race (Dasgupta/Stiglitz, 1980; Pérez/Castrillo, 1990)
- Avoid the technical spillovers to competitors

2.- Growing complexity and interdisciplinarity of the technological change

- Need for advanced knowledge in several disciplines
- Need of learning and complementarity of knowledge between cooperation partners (Kogutt, 1988; Teece, 1992; Hagendoorn et al 2000)

3.- Growing costs to maintain a position on the technological frontier

- Reduction of the life cycle of products and technologies
- Interdisciplinarity and the requirement of diversification in several technological fields is too costly (Teece 1992; Hagendoorn/Narula, 1996)
- Avoiding duplication of costs
- Scale advantages (Critical mass and indivisibilities)
- Risk and uncertainty of future markets (Patent race)

4.- Strategic reasons

- Promotion of technological standards and key technologies
- The access to new markets or technological fields
- Lack of knowledge and experience in enterprises considered as "followers" or imitators.
- Access to new technologies not available in the market

5.- Cooperation can correspond or be a combination to each of the mentioned aspects

[53]The relationship between the learning capacity and experience in innovation is confirmed empirically in the Spanish case in the work of Heijs: Innovation capabilities and learning: a vicious circle (2004, IJIL)

The third approach that would justify innovation cooperation -directly related to the above mentioned- would be the costs (Hagendoorn / Schakenraad, 1989, Teece, 1992; Brockhof et al, 1991; Vonortas et al, 2003). Many of the new scientific challenges are becoming more capital-intensive while the time available to recover the investment has been shortened because of the steadily decreasing life cycle of new products and processes. Furthermore, the process of deregulation and liberalization increases, on the one hand, the competitiveness in the domestic market comparing to the introduction of innovation by foreign firms. And, on the other hand, it allows access to new international markets, each of them with its own preferences and requirements. This diversity requires more costs for adaptations of the innovative products. Collaboration can avoid duplication of costs by providing advantages of scale and dispersion of risks. This could be especially important for SMEs with limited financial assets. The possibility of sharing the costs of expensive projects would provide benefits of scale. Furthermore, cooperation can reduce the possible losses in case of competition in innovation between companies developing similar technologies (or different ones for the same end-use). This would be the case in which two or more companies compete in the same market which is too small for the existence of two profitable alternative technologies. In such a situation the projects for some of the individual companies could become obsolete before their introduction in the market[54]. Therefore we might expect a propensity to cooperate in the case of very expensive projects or in the case of complex and multidisciplinary technologies. A company would be less likely to cooperate if it is a technology leader, especially if they can totally appropriate their results and consider their technological capabilities as a strategic asset for their competitive position. Additionally it could be argued that cooperation does not always produce benefits for the economy as a whole. First, cooperation could lead to a monopoly where firms that own new technologies can impose, not only price, but also the technological standards on its competitors. Second, individualized activities could generate different technologies to solve the same problem, while cooperation could be a bet for only one possible solution among all possible options. In the case of being wrong such a choice could seriously slow the technological progress.

Admitting these issues and trends -the problem of appropiability, the rising costs with reduced life cycle of products, and the increasing complexity and interdisciplinary nature of new technologies- the R&D and innovation processes require higher and higher investments, often difficult to bear by individual agents, which led to a wide range of policies to promote technological cooperation. Most developed countries have implemented instruments to promote cooperation in innovation, which has led them to analyze and explore the increase of cooperation as a result of technology policies. On the other hand firms do consider the role of external knowledge of growing importance.

But the question is: why should the government encourage cooperation? The above theories suggest that the companies would also cooperate without public support. Still, the externalities related to cooperation may justify active policies aimed at accelerating collaboration. The new theories of technological change (evolutionary theory) say that cooperation generates externalities for the economy and society, and that interaction creates a mutual learning process and leads to increased efficiency of the Innovation System as a whole. Aspects of learning include: technology transfer to improve the technological capabilities of the participants in the projects of cooperation, exchange of information flows (feedback) between industry and science, which may help to reorient the scientific programs to the needs and problems of industry, accelerating innovative solutions for social problems (SARS, AIDS, etc..) or the development of key technologies to ensure the competitive position of the national economy. Another important argument in favour of

[54] Known as the concept of Patent Race (See among others: Dasupta/Stiglits 1980ª y 1980b; Pérez/Castrilli, 1990)

state intervention in matters of R & D is to overcome the barriers to cooperation. Despite the benefits of cooperation (reduced cost and risk), companies and scientific institutions are avoiding work due to various barriers and challenges to cooperation (such as the complexity and challenges to design and coordinating partnerships, property rights, differing interests between industry and scientists, etc ...).

To conclude, the modern theories on technological change justify the government support for R&D, first, due to the generation of externalities in the Innovation System as a whole (collective learning) and, secondly, because companies are not really sure that such cooperation offers clear advantages. Throughout the different levels of the administration, policies have been designed to promote cooperation. Despite the existence of a large number of public programs and actions, very rarely have these policies been analyzed extensively and they have not been evaluated comprehensively.

There exists a large number of empirical studies that analyse the motives to cooperate and they confirm that the technological reasons are much more important than the costs or the obligations to obtain public support. The same is the case for Spain where a study of Heijs/Buesa (2007) showed that most important reasons for co-operating were access to the infrastructure (mentioned by 70% of the firms), acquisition of experience or know-how (70%) and the access to unavailable specialities (65%). Moreover these three reasons were considered much more important (round about 3.3 with a maximum of 5) (see table 5). On the other hand, other reasons were considered less often and as less important, for example the importance of fulfilling the requirements to obtain aid (56%) and the cost reduction (45%) was 2.5 point of a maximum of 5).

Table 5: Reason for cooperation in R&D

Motives	Mean	Importance of the motives (%)			Size	R&D expenditures by sales	Sector
		Baja	Media	Alta			
Access to expertise and qualifications that do not exist in the own Enterprise	3,4	22	23	56	0	0	0
Acquisition of experience and knowledge	3,3	25	23	52	0	0	0
Access to infrastructure and large R&D facilities	3,2	32	21	47	0	2	0
Following up of new technological advances	3,1	30	30	40	0	0	0
The project would be unviable if done alone	3,0	36	23	41	0	0	0
Obligations to obtain support	2,5	51	23	26	2	0	0
Saving of costs	2,3	57	24	19	0	0	0

Source; Heijs/Buesa 2007 (FECYT/IAIF-survey) . The last columns indicate the statistical significance of the $\chi 2$ de Pearson "0" not significant and; "1", "2" y "3" implies significant differences on a level of respectively 90, 95 y 99 percent, * The statistical test is not believable due to the lack of sufficient cases

6.2.- Absorptive or learning capacity, financial constraints and risk capital,

As explained above, enterprises have a broad range of reasons to cooperate with scientific organisations. First of all it offers them access to new knowledge and complementary R&D resources not available within their operation. Through making use of SIRE they gain access to innovative networks, large scale R&D infrastructures and establish contact with external R&D personnel with varying skills. This means that SIRE contributes directly towards the amplification of their internal technological frontier and a reduction of the costs for in-house R&D. However, not all firms have the same possibilities to cooperate with HEIs and PROs and to take advantage of the possibilities that are offered by the public research system. In this subsection some aspects of the micro level innovative performance of the enterprises will be briefly analysed identifying the facilitators and obstacles for science- industrial relationships.

Canton et al (2005) indicate three main aspects that could involve difficulties related with the knowledge transfer from scientific organisations to the production sector. The first is the firm's potential to benefit from knowledge spillovers (absorptive or learning capacity). This depends on the accumulation of experiences in the past based on the firm's own R&D efforts and on the education, experience and talent of their human resources. A second important aspect is their financial capacity to finance R&D projects. Innovation is a risky activity with a high level of uncertainty about the technological and commercial level of goal achievement which makes finance of R&D problematic. The availability or the lack of venture capital in Europe is crucial towards the determination of whether to innovate or not, especially in the case for SMEs. A third threshold mentioned by Canton et all is the resistance in firms to adapting new technologies due to the loss of power of the managers and the loss of employment that lead to the resistance of labour unions. In other words a lack of a dynamic entrepreneurial culture (see also section 2.2) can be a determining factor in this case.

The absorptive capacity is probably the most important determinant to ensure a smooth transfer of the scientific results into commercially-oriented applied research. Cohen and Levinthal (1989, p. 569) define such capacity as "the ability to exploit outside knowledge of a more intermediate sort, such as basic research findings, that provide the basis for subsequent R&D". In the case of the absorptive capability it has to be stated that the modern theories on technological change shows that technologies are a mix of codified information that can be easily copied, however it has to be complemented with tacit knowledge that is not easy to transfer, understand or imitate (see box 2). Therefore learning and the accumulation of tacit knowledge are an important aspect to ensure an absorptive capability. According to Cohen and Levinthal (1989, p. 572), "when outside knowledge is less targeted to the firm's particular needs, a firm's own R&D becomes more important in permitting it to recognize, assimilate and exploit valuable knowledge."

The absorptive capability is also an important determinant for the success of SIRES. First of all this is because scientific research organisations are the main suppliers of cutting-edge research broadening the scientific frontiers and the most excellent universities are important sources of novel knowledge. Nonetheless, only those firms that have a well developed technological and scientific capability can make use of such scientific expertise (Rosenberg and Nelson, 1994). A firm with an open mind can use novel scientific developments in order to complement its existing internal knowledge. As mentioned by Canton et all (2005) "The scientific results complete the firm's existing technology portfolio and the integration of this new knowledge could lead to ground-breaking innovation (Canton et all, 2005). ''A new technology is a complex mix of codified data and poorly defined 'know-how' (Mowery and Rosenberg, 1989, p. 7).

The research outcomes and wisdom in new scientific disciplines or in the early stage of new projects has a high load of tacit knowledge which is not easy to transfer or assimilate by other agents of the innovation system. The successful transfer of such tacit wisdom requires close and ongoing interactions between the inventor and the purchaser (Teece, 1985). This can be particularly critical if the receiving enterprise lacks sufficient experience and has low technological capabilities. Canton et al (2005) argue that "academic research, whether basic and largely uncodified or applied and codified in the form of patents, represents only the raw material from which commercially competitive technological innovations are constructed" (Von Hippel, 1998; David et al., 1992; Dasgupta and David, 1994). A firm needs an absorptive capacity to be able to use scientific knowledge, and this absorption capacity is dependent on the firm's own research efforts and its connections with the scientific community. If the industry is not sufficiently advanced to utilise the research (in terms of absorptive capacity), there could be little public value.

To conclude, accumulated absorptive scientific and technological capability is a necessary requirement to ensure that firms can take advantage of and assimilate new scientific findings. Therefore the creation of local or regional capabilities should be an important policy objective in order to facilitate successful science-industrial linkages. Such policies should ensure that society and the production sector can benefit from fundamental research. From the other way around, it ensures that the scientific results are to be used and concentrated in useful artefacts and applications.

There are several reasons why firms have difficulties in committing financial investments towards R&D and innovation. The first problem is the identification of the result-form of the Research carried out. In cases where the outcome has the form of codified information there is a problem/fear to maintain secrecy or to protect the results with intellectual property rights. Inventions of artefacts or specific products and the accumulation of the tacit knowledge are included in the human capital of the firms. In fact over 50% of the investment in R&D is usually committed to salaries of highly qualified personal (scientists and engineers) (Hall, 2002) But the accumulated tacit knowledge is only part of the intangible capital of enterprises (E.G. the firms’´ property) as long as the involved scientists or engineers stay.

The second barrier to obtaining finance for R&D is the uncertainty of the final success of the project in terms of the technological goal achievement for reasonable cost levels and the commercial success on the expected future market (see also section 2.3). Especially in the case of science based R&D the uncertainty is greater. They are often long term projects based on emerging technologies far from the market. Their success depends on the final time schedule, final costs and the accomplishment of the potential future market provisions. Already during the planning stage, firms have to know exactly what the risks are and have to calculate these risks posed by the varying uncertainties. Furthermore, if they are seeking external funding through financial institutions, they are expected to offer exact data on the planned activity and the new technologies/products and therefore a further risk is posed on revealing the plans of a particular firm – this is more critical in highly competitive markets. This situation is usually known as the market failure of asymmetric or imperfect information. The uncertainty is greater at the beginning of a project and diminishes during the evolution of the project.

Whilst banks and financial institutions require certainty about the success of the R&D project, firms are not always ready to give guarantees at the beginning of the project. Furthermore firms may not be in a position to divulge all the information due to competition issues. If financial institutions are not sure about the future success they still ask for guarantees that back up the credits or they require a higher interest rate. Access to finance, whilst helpful, has its problems and becomes more complex when no guarantees can be given (Whited, 1992; Marra, 2007)[55]. Sometimes these restrictions encourage firms to finance themselves rather than seeking external sources. (Teece/Pisano, 1994; Helfat, 1997).

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