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Higher education systems and industrial innovation

Eric Verdier, Alice Lam, Christoph Buechtemann, Helena Lopes, Lorenz Lassnigg, Jean-Michel Plassard

► **To cite this version:**

Eric Verdier, Alice Lam, Christoph Buechtemann, Helena Lopes, Lorenz Lassnigg, et al.. Higher education systems and industrial innovation. 2001. halshs-00087424

HAL Id: halshs-00087424

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HIGHER EDUCATION SYSTEMS AND INDUSTRIAL INNOVATION

January 1998 to 31 May 2001

**Final report of contract n° SOE 1-1054 - project n° 1297
Funded under the Targeted Socio-Economic Research
(TSER) Programme - Directorate General Science, Research
and Development/Directorate F
European Commission**

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JULY 2001

FOREWORD

This final report was carried out under the contractual liability of LEST, LIRHE and CRIS International with the assistance of other teams (see in appendix 1 the complete list of the members).

In the same manner, one will find at the end of the general introduction the list of the deliverables produced by SESI teams. These deliverables are accessible on the web site SESI (<http://www.univ-aix.fr/lest/sesiweb/sesi/>).

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GENERAL INTRODUCTION

General objectives

The SESI project tackles the question of how higher education institutions influence the innovation activities of private-sector firms, which provide the basis for economic competitiveness and societal wealth generation.

The objective of the research was to gather empirical evidence about efficient ways of organising the linkages and interfaces between higher education institutions (including research units) and private-sector firms in order to optimise the flow of knowledge and information between them and thereby spur industrial innovation.

In this respect, the SESI project aims to answer three main questions:

- What are the components and configurations of the knowledge transfer between higher education institutions and industrial innovation activities?
- Under what conditions does the knowledge transfer between higher education institutions and firms benefit innovation capacity and performance?
- How do different national higher education systems perform in supporting industrial innovation capacity?

The answers to this series of questions should enable those engaged in the project to make (public) policy recommendations.

General approach: the innovation space as an "interactive" and "embedded" approach to innovation

Innovation is self-evidently multidimensional and goes hand in hand with changes in the organisations and institutions in which the actors' strategies unfold. This is why any partial approach to innovation, focusing, for example, on the strategy pursued by any one of the actors involved, remains partial when it comes to drawing conclusions, since very little in the way of general lessons can be derived from it. At the same time, however, holistic approaches to innovation do little to make good this deficiency. Such approaches frequently lead to the definition of an institutional environment that guides the decisions taken by any of the actors, who are reduced in consequence to mere agents; as a result, they plot only a fraction of the coordinates of an actor seeking to solve problems and redefine his system of constraints before eventually managing, more or less convincingly, to reconstruct his action system, which remains immersed in an environment made up of organisations and institutions.

The definition of innovation adopted in this project derives from the evolutionary and societal analysis approach. Innovation is regarded as the outcome of a twofold process whereby resources are created and also appropriated by firms, which construct an innovation space integrated into local, national and international institutions. Picking up

on famous Lundvall's work in this field¹, the main point here is no longer the process of calculation and decision-making but the process of learning and creating complex bodies of knowledge within innovation systems. These include not only firms' internal processes but also the interaction between firms and public R&D organisations as well as education and training establishments.

Innovation encompasses a number of processes - technical, organisational, institutional and cognitive - all contributing to technology design and development, but it also has two additional defining characteristics.

Firstly, innovation constitutes a firm's specific capacity to construct its stocks of knowledge and competences, its relationship with technology and the practices it adopts in its cooperation with its industrial and academic environment. The outcome of these processes, particularly in multinational firms, is a truly distinctive capacity for generating technological and organisational resources in a bid for global competitiveness.

Secondly, a firm constructs its innovation space by interacting with its industrial and institutional environment². To innovate, it must acquire and hence choose the resources which it lacks and deems necessary. In order to appropriate these resources and utilise them effectively for its own development, it will specify them according to its particular needs, in order possibly to convert them into innovative routines (see the evolutionary theory of the firm and in particular Nelson³) that cannot be purchased in the market.

Thus firms are faced with a permanent tension between, on the one hand, the preservation of routines that construct, order and maintain knowledge and know-how as a coherent whole and, on the other, the search for new routines that might produce renewal. In other words, firms are not only structures for the management and accumulation of specific knowledge but also entities endowed with rules governing their functioning, which embody the collective lessons learnt in the course of their history, and with rules governing their development, through which new knowledge can be acquired.

Depending on the capacities they have built up over time and their ability to evolve, research and higher education establishments enable firms to explore more or less rapidly the opportunities offered by the emergence of new technological and scientific fields. This is what is meant by the "embeddedness" of the strategies of the various actors operating within an economic area, the limits of which need to be defined. This question of the limits of contingency is especially pertinent to this project: to what extent can a firm's strategy be related to a particular innovation system? Can innovation systems still be defined on a national basis? What impact do the strategies of multinational companies - and for that matter those of "research universities" - have on

¹ Lundvall B-A. (1992) *National Systems of Innovation, Toward a Theory of Innovation and Interactice Learning*", Pinter Publishers, London.

² In the perspective of the "Societal Effect Theory", see Lanciano-Morandat C., Maurice M., Nohara H. and Silvestre J-J. (eds.) (1998), *Les acteurs de l'innovation*", Editions L'Harmattan, Paris.

³ Nelson R. (1988), Institutions supporting technical change in U.S., in Dosi G. et alii, *Technical Change and Economic Theory*, Pinter Publishers, London.

national innovation systems?

The links between higher education and innovation reveal that industrial firms are key actors not only in the circulation but also in the production of knowledge. After all, if they are to innovate successfully, firms must of necessity be part of the general process of constructing scientific and technical knowledge. This process has always existed, of course, and R&D activities have always had a strong international dimension, but nowadays it takes the form of an all-out race to produce academic knowledge and for this to be absorbed by firms.

It is here that the main focus of our project lies, the object of investigation being the relations between actors from two different worlds - higher education and firms - which have separate and not necessarily convergent goals. It was decided to focus on firms' behaviour in the organisation of R&D activities and on the links between that aspect of their behaviour and the practices they adopt in cooperating with higher education. One of the consequences of this was that two major social phenomena had to be investigated.

- The first is the dynamic of the linkage between the global and local dimensions: to what extent do firms' strategies affect scientific and technological organisation and policies, both nationally and locally? Similarly, what opportunities do national institutional infrastructures provide for companies and their practices, particularly multinationals?
- The second is technological innovation, regarded as a process that unfolds within the dynamics of particular industries or sectors. Taking Pavitt's well-known typology as its point of departure⁴, the project set out to analyse the consequences of the emergence of new technological systems, the emblematic examples being biotechnology and the convergence of information technology and telecommunications.

An interpretative "framework" of local and national differences in industry-science relations

The project started from the hypothesis that "societal" differences in respect of innovations - whether "incremental" or "radical", to use the standard terminology - are linked to the nature and quality of links between higher education establishments and firms. One of the project's principal aims was to combine two dimensions which are often considered separately: firstly, the construction of the competences and the professionalities of the actors involved in innovation, and, secondly, transfers of knowledge from higher education to firms and *vice versa*.

Three variables were deemed particularly crucial and singled out for special attention: the acquisition of "professionalism" by the engineers, researchers and managers involved in the innovation process, the organisation of innovation activities in firms and the

⁴ Pavitt K. (1984), "Sectoral Patterns of Technical Change: Towards an Taxonomy and a Theory", *Research Policy*, 13, 343-373.

positioning and roles of the various institutions involved in the relationship between higher education and company innovation.

The competences of the actors involved in innovation

At issue, then, is the circulation of the knowledge and competences produced (in particular) by higher education and embodied in individuals. This professionalism itself comprises several dimensions:

- the construction of curricula and of competences in the context of education/training processes (to what extent should occupational profiles be specialised or interdisciplinary?);
- the linkage between theoretical gains and the application of knowledge to firms' industrial and commercial problems;
- the processes of mobility which, through transitions from education to the labour market or in mid-career, may (or may not) forge links between academic research and the actual development of new products and processes.

Thus earlier studies by the project teams focused on the impact of societal differences between French and British engineers, on the one hand, and their Japanese counterparts, on the other⁵. The method of "producing" lecturers and researchers likewise contributes significantly to the way a country positions itself relative to any given innovation profile (see Hollingsworth's study of the German case).

The organisation of innovation activities in firms and, more broadly, modes of corporate organisation

This dimension brings into play the relations between firms' various internal functions, the degree to which the organisation is hierarchised (its cohesion) and the firm's capacity to open up to its environment in order to tap into and disseminate knowledge and know-how. Thus an earlier comparison between France and Japan (see namely the studies by researchers of the SESI network) compared the compartmentalisation of functions that "traditionally" characterises French companies, the relative isolation of research and development from the other functional components of the company - the production unit in particular – to the point where the latter might even be driven to establish its own capacity for developing new products or processes. Conversely, R&D

⁵ On the France/Japan comparison, see Lanciano-Morandat C., Nohara H., Maurice M. (1992) "Innovation: acteurs et organisations; les ingénieurs et la dynamique de l'entreprise, comparaison France-Japon", LEST, Aix en Provence; on the United Kingdom/Japan comparison, see Lam A.. (1994) *The utilisation of human resources : a comparative study of British and Japanese engineers in the electronics industries*, Human Resource Management Journal, vol. 4, n° 3, 22-40

in Japanese companies gained its legitimacy from a strong capacity to appropriate basic knowledge and incorporate it into the internal innovation process.

In similar vein, the more closely intermeshed the material and service dimensions of products are, the more crucial the ability to learn lessons about innovation from relations with customers (producers/users) becomes. Indeed, product reliability (maintenance) and adaptability to customer requirements are so dependent on this that they are key factors in competitiveness. The knowledge acquired from these links with customers circulates all the more effectively if it is underpinned by appropriate occupational profiles or methods of work organisation.

The lessons learnt, like those resulting from a cognitive relationship between producers and users, will foster the emergence of incremental innovations. This reveals the extent to which the construction of professionalism, firms' internal organisation and the capacity to engender a particular type of innovation are linked. Moreover, it is this linkage that lends legitimacy to the concept of a (national) innovation system, particularly from Lundvall's perspective, when he describes innovation as a "socially embedded process" within a specific institutional setting. Besides, this is absolutely explicit in the final variable taken into consideration here.

Actors and institutions involved in the relationship between higher education and company innovation

The nature of this relationship depends to a not insignificant degree on the manner in which knowledge and competencies are diffused through the occupational mobility and modes of organisation discussed above. A good illustration of this phenomenon is the relative propensity of university researchers in one country or another to engage in mobility with a view to founding companies ("spin-offs") in order to bring innovative products to market. As we have seen, such initiatives receive greater encouragement in the United States than in Europe, as a result of the different societal modes of constructing researchers, the influence of which is compounded by the impact of funding structures (see Soskice's work for an explanation of the genesis of different "varieties" of present-day capitalism⁶) and, above all, the ability to attract capital for high-risk ventures. The same sort of approach could be applied to the question of mobility among engineers and managers in large firms with a view to starting up their own businesses to develop new products. More specifically, we need to examine the effects of the different incentive structures, whether they relate to funding, mid-career access to training or marketing advice.

The likelihood of spin-offs from universities and their research centres, or even from large firms, depends partly on the existence of interface institutions and, more broadly, those offering support to small firms. Such bodies may take an innovative form, for example technical centres at industry or regional level.

⁶ Soskice, D. (1999) "Divergent Production Regimes: Coordinated and Uncoordinated Market Economies in the 1990s" in Herbert Kitschelt et al., eds., *Continuity and Change in Contemporary Capitalism* NY: Cambridge University Press.

More generally, it is the whole range of institutional relationships between higher education establishments and companies that are at issue in this project, provided that they entail some degree of innovation. For instance, do they take the form of a standard commercial contract (where a company places an "order" with a university) or are they more akin to consortia, in which competition and cooperation mix and mingle? Are they based on more individualised relationships resulting in particular from the direct involvement of company employees in the construction of graduates' individual competences, either by teaching on university courses or acting as tutors for students on work placements?

It is not sufficient to be concerned solely with the establishment of institutional relationship between higher education and companies; we must in addition examine the cognitive and symbolic dimensions of these same relations in order to understand their scope and economic effectiveness. Thus, in the case of France, it is habitually pointed out that the country's success in certain fields (aeronautical and space industry, telecommunications, high-speed trains (TGV), nuclear industry, etc.) has its roots in the existence of a "body" of engineers educated at the most prestigious *grandes écoles* (the elite engineering and business schools). Since these "engineers" are employed as managers in large companies, in specialist research centres (National Space Research Centre, Atomic Energy Commission, National Telecommunications Research Centre, etc.), in the higher echelons of the civil service and (to a certain extent) in the financial sector, they are in effect the vehicles for institutional, cognitive and symbolic coordination across the nation.

Developing a dynamic approach to links between higher education and firms

The three aspects discussed above were brought together in an effort to reveal the various ways in which the networks underpinning industry-science relations are constituted with a view to achieving innovation. Over and above this structural representation, it was important to develop a dynamic approach, since every national or local system has attempted to a greater or lesser degree to gain new competitive advantages. France for example has sought to move away from a policy almost exclusively geared towards large companies and, what is more, ones involved in large-scale industrial and technological programmes, in order to develop incentive structures for SMEs. However, this example surely suggests that merely decreeing into existence bodies to interface between scientific research and SMEs is not enough to ensure that such firms will manage to tap into new sources of knowledge and expertise and, better still, to appropriate them.

It was therefore necessary to develop a dynamic approach to these relations between higher education and firms, in order to examine the coherence and relevance of these reforms in the three spheres mentioned: institutional (resources, contractual arrangements, etc.), cognitive (what collective learning dynamics?) and symbolic (what cohesiveness, what sense of belonging to an "innovative community"?).

Methodology

The method was designed to reflect the problem areas and interpretative models at three distinct levels:

- Countries and sectors
- Firms and their relations with higher education
- Societal dynamics or the global/local interaction.

In particular, the aim was to take account of the interactions and interdependencies between the micro-economic level and that of the sectors and countries included in the project⁷.

Six countries and three sectors

Five European countries were selected in order to provide, at least by way of an initial hypothesis, national systems that were sufficiently disparate from the point of view of the resources "offered" to companies, be it in terms of institutions, organisations or actors. Higher education and innovation systems do in fact differ significantly from one European country to another. By way of illustration, it was noted in the initial statements explaining the choice of these five countries that:

- The United Kingdom has an education system which is elitist but undergoing radical change and there is a relatively low level of public funding for research.
- France has a dual system of higher education - universities and the *grandes écoles* - which has had a considerable influence on the "innovation space" of French companies, and its research system is heavily subsidised by the public purse.
- Germany and Austria have "intermediate" systems of education and R&D, bearing all the hallmarks of involvement by trade unions and employers' associations.
- Portugal has links between higher education and companies which are both more direct and more recent.

However, the aim was not to study the institutional specificities in themselves but rather to link them to sectoral dynamics. Three sectors were chosen in each country as being representative of the new challenges emerging for the relationship between higher education and industry in key sectors where generic technologies are tending to develop, albeit in different ways. The information technology sector, whose growth has been very rapid, is of interest because it brings together, in ways specific to individual

⁷ Before this methodology was adopted, a literature review on national higher education systems and innovation was carried out (see Deliverable of Work Package 1, available on the Sesi web site) . It was divided into three parts:

- human capital, competences and innovation
- production of knowledge, competences and innovation
- national innovation systems and an international comparison.

countries, industrial production activities and customer service activities. The telecommunications sector, which has undergone a huge amount of technological and organisational innovation, was seeing its links with the public sector being challenged by deregulation in various EU countries just as the project was being launched. The pharmaceutical sector, whose links with higher education and research date back further, was facing the biotechnology revolution.

It was essential to include the United States. Indeed, the relations between higher education and companies which have evolved in that country are undoubtedly an international point of reference, especially in terms of the universities' responsiveness to changes in their environment and to the demands of firms as well as particularly effective spin-off processes. It appeared, furthermore, that, far more than in other countries, large US universities with strong research capabilities have over the past two decades been the catalysts for the emergence of new industries (e.g. micro-computers). It therefore seemed appropriate to examine the funding, organisation and "governance" of these institutions, with a view to reflecting on the ways and means of creating an efficient European model of innovation. By the same token, but without any field work having been done, the case of Japan has been used as a point of reference in this project, above all because of the recognised expertise of two members of the network running the project.

It was discovered straightaway that a sizeable body of literature on innovation and the circulation of knowledge in these various countries and sectors had been produced in recent years. The first phase of the project, then, consisted in gathering together and analysing the corpus of existing studies and surveys, at both national and sectoral level. At sectoral level, the aim was to highlight the strategic orientations and the most important technological and organisational issues. At national level, it was a matter of determining the exact institutional context of industry-science relations and of understanding how the different countries' education systems and technology policies are structured. The second stage was to compare the various "societal" spaces studied. The aim was to gauge the significance of these sectors in the different economies (see appendix 4) and, above all, to compare the institutional vehicles for cooperation between firms and academic establishments. Special attention was devoted here to different types of policy on technology diffusion ("mission-oriented" or "diffusion-oriented" policies). The final step was to design relevant questions for the company surveys on the basis of these "assessments".

Selection of companies and examination of their links with companies

The investigations within firms form the empirical basis of this project.

Constructing the sample of firms

Three companies per sector and per country (two each in Portugal and Austria) were studied, making a total of 48 (see list in appendix 2). The initial idea was to take one

"foreign" multinational, one large "national" company and one SME for each sector, in an attempt to have a comparable sub-sample for at least two countries.

One of our objectives was to question these firms about the qualities of the different national systems (their "strengths and weaknesses"). In practice, a multinational creates a network of different national systems by incorporating them into its own organisational space. Thus it was relevant to investigate to what degree these firms, through their subsidiaries, attempt to pick up and "import" institutional and organisational attributes which they have identified outside of their country of origin or, conversely, to "export" their own original attributes.

As a result of mergers and take-overs, the differences linked to a company's "nationality" proved to be far less relevant than predicted. Such restructuring processes affecting production and finance had a decidedly adverse effect on our field work in companies, which took longer to complete than planned, for many reasons. First of all, it is necessary to stress the impact of the context in which the investigations in firms took place. We were operating during a difficult period of enhanced competition due to an accelerating globalisation of markets which leads firms continuously to re-examine their "area":

- In the pharmaceutical field, this process has led, notably, to a headlong rush into mergers. For example, two firms studied in this project, themselves already created from earlier mergers, became, for a while, the largest international pharmaceutical company. Relations with managers became appreciably more complex because they were not only asked to participate in the new internal restructuring, but at the same time they felt extremely insecure about their own future in a process for which the main motivation was a rationalisation of R&D.

- In the computer and telecom area, the (not insignificant) mergers have not taken place on the same scale as in the pharmaceutical industry. Nevertheless there is continuous internal restructuring; for example, the break-up of a major global firm into two parts, both of them studied in the SESI project. This reorganisation goes a long way to explaining why, in France, after responding positively for one whole year, this firm finally refused to participate in the SESI project.

As a consequence, interviews for the company surveys were more difficult than anticipated. The discussions took more time than planned, or less, and validation processes – an important feature of the methodology - were more complex due, for instance, to the replacement of our original contacts.

Data collection

The investigation of each company took place over a one-year period. Once the project had been presented, a confidentiality agreement was signed with each firm. A research protocol was drawn up in such a way as to ensure that both the project's initial intentions and the interviewees' arrangements were respected. This protocol made provision for an average number of interviews (at least 10 to 15, often around 20, each

lasting 2 to 3 hours), for factual and/or public data to be supplied by the company and for the findings to be handed back in the form of a case study and validated by the interviewees. The interviewees were selected partly from within the company and partly from within the universities and laboratories cooperating with the firm.

On the company side, these were R&D managers, project managers, researchers and engineers, HR managers and those responsible for related fields such as alliances and patents. Among their academic partners, interviews were conducted with heads of laboratories, departments and projects, sometimes with researchers. Semi-directed interviewing techniques were used with both types of partner, based on a standardised interview guide devised for all firms in the various countries. Before the interviews were held, the various organisations' strategies and structures were studied: this was done on the basis of documents supplied by management in the different organisations and supplemented where necessary by press reviews. For the firms, this enabled us to become familiar with the situation of the group or SME: competitive position, international development, technological trends, role of R&D, number of employees. For the universities, engineering colleges and public laboratories, the same documentary work was carried out in order to situate the organisation in its public context and in respect of cooperation with industry in general.

Finally, the interviews were conducted in such a way as to reveal (see interview guide in appendix 3):

- each firm's strategy (that of both the multinational and its local subsidiary),
- its general organisation and more specifically the role of the R&D unit,
- development of technology policy in conjunction with marketing policy,
- its practices relating to technological alliances,
- human resource management practices in general and for R&D in particular,
- the evolution of innovation coordination at national level,
- knowledge management practices,
- policies pursued in terms of intellectual property,
- the evolution of attitudes to cooperation with "academia",
- the funds committed to this effect.

The interviews conducted at universities and public laboratories were designed to explore in depth two major cases of collaboration, looking at them in terms of their organisation, funding and evaluation. Here we needed to highlight two methods of knowledge transfer: R&D cooperation and joint training for graduate students (including arrangements for job placements).

Data analysis

In accordance with the approach adopted for the SESI project, each case study is divided into two parts. The first deals with the firm's trajectory and strategy in respect of innovation, competences and knowledge. The second is given over to a presentation of some actual cases of collaboration between the firm and the higher education system in the two fields of research and training (competences).

As far as the sectoral context is concerned (technology, competitiveness and markets – or products), the first part is divided into three sections.

- The first aims to identify the firm's technological strategy and in particular to outline the evolution of its product/market position, on the one hand, and of its organisation, on the other (the two dimensions being closely linked in many cases).

- The second interprets applies these findings to three fields of crucial importance to the SESI project: human resources strategy, the orientation and organisation of R&D and relationships with the higher education and research system. The first and second of these interact strongly with the third: for example, the partial externalisation of internal R&D functions would entail a rapid increase in relationships with academic research or some intermediary research institutions.

- By way of a conclusion to this first part, it would be useful to identify the firm's dynamics in terms of competences and knowledge. A distinction will be made between explicit "knowledge management" strategies and the results of routines that make up firms' endogenous capacities for innovation.

The following diagram summarises the first part of the case study.

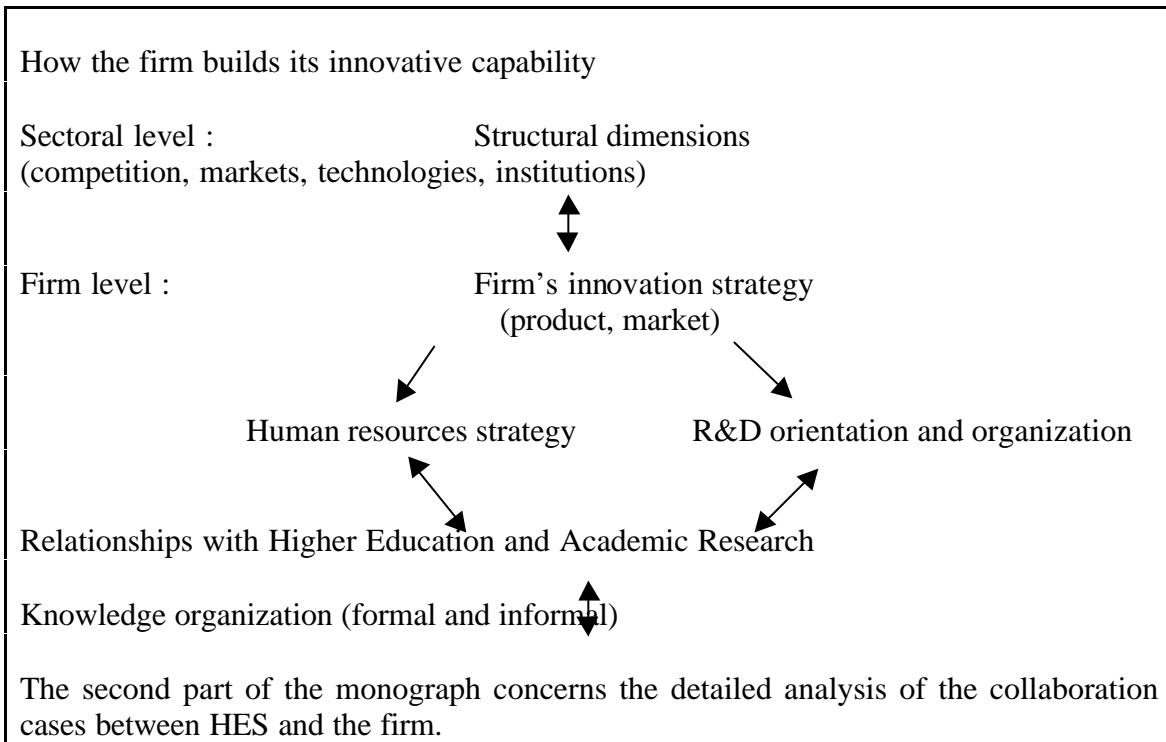
Typical structure of a firm monograph

Core of the SESI, these monographs aim to analyse the relationships between its innovative dynamics and the Higher Education and Research System (It isn't matter of reconstructing the whole coherence of the firm). In the SESI perspective, the monograph is made up of two parts. The first one concerns the trajectory and the strategy of the firm concerning innovation, competencies and knowledge. The second one systematically presents some precise cases of collaboration between firm and higher education system in the both fields, research and training (competencies).

Taking into account the sectoral context (technology, competitiveness and markets - or products), the first part is made up of three stages :

- The first one aims to identify the technological strategy of the firm : particularly, it's necessary to integrate the evolution of its position in term of products-market and its organization (these both dimensions are often strictly linked)
- The second one interprets these orientations in three crucial fields for the SESI project : the human resources strategy, the orientations and the organization of the R&D, the relationships with the Higher Education and Research System. The first and the second ones strongly interact with the third one : for example, a partial externalisation of the internal R&D would involve a fast increase of the relationships with the academic research or some intermediary research institutions .
- As a conclusion of this first part, it would be useful to identify the firm's dynamics in terms of competencies and knowledge. One shall distinguish the explicit strategy with an effective "knowledge management" and the results of routines which constitute endogenous innovative capabilities.

The following graph summarises this first part of the monograph



The second part of the case study comprises a detailed analysis of instances of collaboration between HES and the firm in question.

In order to ensure the relevance of the results, the content of each case study was discussed with the managers of the firms and institutions concerned. Indeed, this debate was an opportunity to test the coherence of the researcher's interpretations. In certain cases, this exercise led to a substantial revision of the case study.

The broader perspective: from micro-economic foundations to "societal" comparisons

Our cross-cutting analysis of these case studies began at the microeconomic level, with a dual perspective being adopted.

- In the first, the focus was on the organisational development of R&D processes, with an attempt being made to link the issues of competences and knowledge, in keeping with the initial intentions of this project. Two points of view - knowledge sourcing and project management – were pursued by analysing the effect of cooperation with higher education on processes inside and outside of firms.
- In the second, the focus was on industry-science relations, with the instances of collaboration studied in the firms forming the basis for the analysis. Particular attention was paid to two aspects: a typology of relations with regard to their aims, resources and evaluation and an analysis of the modes of intermediation between the

two "worlds" - firm and "academia", with particular emphasis on interface institutions.

The case studies, combined with the results of the previous phases, served as a basis for drawing up sectoral and national reports for each country. The idea here was to examine the main challenges encountered by national industries and institutional environments, in particular those linked to the global strategies of firms in these hi-tech sectors.

This stage prompted a more general question about the evolution of national innovation systems: are we witnessing a convergence of the institutional processes involved in cooperation between firms and higher education? Can we speak of the Europeanisation of national research and innovation systems? What lessons can be learnt from a comparison between Europe and the United States (with Germany serving in this instance as a "control country") ?

Summaries

Chapter 1 - Alice Lam, "Changing R&D Organisation and Innovation: Knowledge Sourcing and Competence Building"

The emergence of the knowledge-based economy has profound effects on the organisation of R&D activities, and the types of skills and knowledge required for productive and innovation activities. This paper argues that, at the top end, knowledge is now moving too rapidly to be encoded and institutionalised into a stable set of occupations, and hence new mechanisms are necessary to facilitate the effective generation and transmission of knowledge between higher education institutions and firms. The growing importance of 'Mode 2' knowledge (Gibbons et al 1994) in technological innovation calls for a reassessment of the institutional arrangements underpinning the 'professional model' of knowledge formation. Emerging evidence suggests that firms are responding by developing 'extended internal labour markets' (EILMs) through closer links with key universities. The social networks embedded in such EILMs facilitate training and rapid transmission of evolving (uncodified) knowledge. The study is based on case studies carried out in large multinational high-technology firms in Britain. The paper draws out the common trends and issues in the different sectors and discusses the implications of the changes for the education and training of the next generation of R&D knowledge workers.

First the type of skills and competence profiles required of R&D workers are now more demanding in multiple dimensions, particularly in the combination of technical disciplinary expertise with a broad range of business, management and social skills. The effectiveness of R&D workers depends on their ability to apply scientific and

technological expertise in shifting problem contexts, to operate in inter-disciplinary and trans-disciplinary environments and to sharpen their project management skills. Then there is a growing need for new or combined disciplines in the rapidly evolving innovation environment. Many of them are highly specific to certain industrial situations and problems, and cannot be easily defined in an academic context. This suggests that the creation of new disciplines and competences will have to be embedded in the problem solving process. Evidence from our case studies suggests that the reverse flow of knowledge from industry to academia through personal networks and research collaboration plays a crucial role in the creation and generation of new disciplines.

Chapter 2 - Claude Paraponaris, "The organisation of R&D and the management of cooperation: controlling a diversity of knowledge sources"

The focus of interest here is the construction of knowledge in firms viewed in the context of their approach to academic collaboration and against the background of transnational activities that bring into play local infrastructures for the diffusion of technologies.

The sample of multinational firms we have selected enables us to take stock of the moves towards industrial rationalisation taken by firms seeking to develop their technological globalisation strategies by exploiting a diversity of cognitive resources. Such an evaluation can readily be extended to include an examination of the structures of R&D organisation and of the processes of resource construction. We begin this examination by outlining its objectives and establishing the value of taking account of knowledge and competences in the management of innovation. We analyse the role of the structures of R&D organisation in the globalisation of technology strategies. We deal jointly with the internal organisation of activities (role of innovation projects, human resource management) and with the external organisation of academic collaboration. We underline that the management of knowledge and individual expertise constitute an autonomous framework for the construction of resources in the various R&D units.

Through its structures and processes, the management of knowledge represents an attempt not only to take advantage of opportunities but also to resolve organisational problems. The low level of mobility between subsidiaries and between research laboratories and business units does not aid the circulation of knowledge. The diversity of occupational profiles sought by multinationals can also lead to cognitive compartmentalisation. Finally, the introduction of project-based management makes it possible to organise R&D activities more efficiently while at the same time reducing the opportunities for knowledge accumulation. The practices put in place in order to overcome these difficulties show that several different paths can be taken. At the same time, they illustrate the changes firms are undergoing as technological globalisation advances. The various modes of knowledge management attach equal importance to the production and to the absorption of knowledge. Preparation for the recruitment and integration of young graduates and the forging of lasting relations between firms and their academic partners play crucial roles in the absorption of knowledge. As a result, they encourage the observer to examine very closely the institutional aspect of the

multiplicity of environments within which the subsidiaries of the same multinational operate.

Chapter 3 - Nicolas Carayol, "Research Agendas and Science Industry Relations"

The paper is highlighting the crucial importance of research agendas in both understanding the underlying logic of research collaborations settling between academic research units and firms, and in understanding the feedback effects of science industry relations on the pace of scientific knowledge production. The empirical data are original ones collected within the TSER SESI project network. It is made of interview based monographs of 50 science industry relations. These data were collected in six countries (A, F, G, P, UK, US), interviewing firms of the IT and Pharma/Biotech sectors and their academic partners. Our main empirical result is that we found six coherent types of science industry relations that we describe precisely. These results further confirm the criticality of research agendas compatibility, favoring two different ways of collaborating associating an industrial and an academic partner. We finally argue that this two different forms of collaborating are leading to two different models of science industry relations (A and B) presenting different but both socially valuable emergent outcomes. The following table summarizes these models.

The robust strategies of the academic and industrial players and the two models of science industry relations

| | | Strategies of the Academic players | |
|---|---|--|--|
| | | Increasing their volume of research by pooling information on needs and codifying solutions of industrial partners | Deepening their knowledge in a specific area of excellence by collaborating only within this field |
| Strategies of the Industrial players | Benefiting from research at a relatively low cost in an integrated, systematic and less risky way | Model A lower risk lower expected reward stronger ties dense networks Cumulativeness and social demand | |
| | Entering a research field by contributing to its emergence so as to benefit from an important advance on its competitors even if he has to bear greater risks | | Model B higher risk higher expected reward weaker ties bilateral relations Creativity and social demand |

Chapter 4 - Caroline Lanciano-Morandat, "Firms, higher education and research systems and public action: the principles animating the relationships between actors in the innovation process"

The purpose of this paper is to apprehend, by adopting an actor-based approach, the diversity of interactions between innovation systems in firms and higher education and research systems (HERS).

Based on societal analysis of innovation and Triple Helix, this analysis identifies four main types of intermediate actors:

- those actors who are the medium for an economic relationship between the firm and the HERS;
- the "gatekeepers", who work for a firm or a HERS and whose function is to coordinate the two systems;
- the hybrid actors who, by virtue of having worked in both the firm and the HERS, have been through the process of aligning the practices, rules and values of their "home" system (industry or academia) with those of their partner;
- those actors who are involved in the trilateral network but are independent or on the road to being independent of the partners.

Various sets of relational principles are constructed around these actors. Each set of principles tends to privilege one type of actor rather than another. Similarly, a trilateral relationship between a firm and a HERS unit may possibly, though not necessarily, fall within the scope of several different sets of principles. A distinction has to be made between those relational principles that are mediated mainly by relationships that fluctuate between the formal and the informal and those that are organised around relationships that are formalised in programmes of strategic co-operation. In the first case, three principles are identified, the "symbolic" principle, the "dormant" network, the creation of a new intermediate actor. In the second case, three other principles are valorised, the actors as a portfolio of resources, the embedded principle, the use of a constituted intermediate. The interactions between these different actors and these different relational principles characterised various intermediate spaces of innovation. This raises the question of which factors linked to the partnerships or the macro-economic context within which those partnerships function influence this typology of relational principles and intermediate actors mode of classification.

Chapter 5 - Hiroatsu Nohara, "Co-production of Competences between Academia and Industry: an emergent Bridging Institution"

In classic innovation literature, the Higher Education and Research System (HERS) and industry are held to be two autonomous, independent spaces for the production of knowledge and competences. Such a conceptual separation is increasingly remote from reality, if it has in fact ever reflected relations between the HERS and industry. On the contrary, the interaction between the HERS and the companies, notably where the production of human resources is concerned, creates recurring movements through which the different actors are to a greater or lesser extent channelled in the shaping of their competences and the development of their career paths. Labour-market entry of

graduates is one of the factors which allows us to introduce all the signalling/human capital/network problematics and relate it to the emergence of a new form of labour market which combines the mechanisms of the internal and external markets.

In this text, we focus our analysis on the different dimensions of this interaction between the HERS and the companies for the joint construction of competences and strategies for using the various mechanisms of collaboration (internship, hiring, selection, industry fellowships, temporary use of post-docs, contract research etc.). The institutional arrangements governing these relations and the practices resulting from them may be quite different depending on the sectors, the diploma levels of graduates or the individual companies, whose R&D strategy may differ even within a single sector. In other words, the building of networks or the signalling mechanism remain subject to extremely varied local contexts. In spite of this diversity of practices, however, we maintain the hypothesis that it is possible to identify dominant forms of these relations which differ from one country to another.

This hypothesis could be sustained, for example, by the fact that socio-occupational categories such as 'engineer', 'researcher' or 'technician' do not reflect a 'natural' order but rather, are social constructs, as we showed it in previous researches. In this sense, what we attempt to do in this text is to show 1) how the construction of the most significant actors in innovation, notably engineers and researchers, are embedded in the societal contexts specific to each country, 2) to what extent these professional figures can be considered as bearers of particular cognitive resources - because they correspond to the crystallisation of certain institutional, scientific and professional rationales- and 3) the way that such configuration of actors works as one of the major elements structuring the collaborative ties between the HERS and industry.

Chapter 6 - Alain Alcouffe, " National Innovation Systems and Industry Science Relationships in Europe"

Globalisation means radical changes in foreign affairs and consequently in tariffs. Domestic markets are no longer sanctuaries for big firms which are more and more multinational in their ownership, governance, scope and aims.

All these evolutions challenge the relevance of the "national" innovation system concept whereas American authors doubt if the American innovation system will be able to maintain its high level of performance as all of the central components of the innovation system now are undergoing change.

Structural changes in the national systems of innovation system, are not occurring in isolation and may well result in some "convergence" in structure which would imply that the *raison d'être* of the NIS analysis could disappear. The European integration sets up another challenge to the NIS analysis. What will come out from the old national innovation systems whereas there are currently three institutional settings to take into account to deal with industry science relationship ?

After reviewing some threats against the NIS, the paper shows that a great deal of globalisation is actually Europeanisation even if the European law framework is still very sketchy and analyses the possible emerging European innovation system. It insists

on the increasing human capital mobility in high tech sectors and supply some evidence of a an emerging European innovation systems. The small country case is also analysed with its variants as it appears when looking at Portugal and Austria. Simultaneously if the project driven ISR seems obsolete, innovation policies will more and more relying on the financing of basic research as well as on local, national, and European infrastructure. In the European case, it seems also important to improve the links between the higher education system and the SMEs.

In this perspective, it seems that proximity to the University has facilitated the development of human resource links through student placement and recruitment, but not necessarily formal collaborative links. Given the characteristics of SMEs, students and graduate recruitment probably provide one of the most important mechanisms through which they absorb academic knowledge and new skills. SMEs often face recruitment difficulties and the shortages of qualified technical staff can inhibit growth and innovation. Proximity to universities provides a recruitment advantage for them. For many SMEs, the importance of universities lies in their contribution to the formation of internal capabilities, and not necessarily in formal knowledge transfer through research links. Knowledge transfer is a social process which requires social and organisational proximity.

Chapter 7 - Christoph Buechtemann and Hans Thie, "Industry-Science Relationships in High-tech Sectors: Comparison of Germany and the United States"

The third chapter seeks to develop a "transatlantic" approach by comparing the NIS of two countries, the United States – the inescapable reference point in matters of innovation – and Germany – whose institutional arrangements, currently undergoing profound change, can be seen as representative of the countries of Continental Europe. Based on a hundred interviews with actors involved in innovation in both firms and academic organisations, this approach uncovers both the similarities and the differences in science-industry relations between the two countries. On the one hand, these relations contain mechanisms that pit the world of science and that of industry against each other in terms of objectives, time horizons and incentive systems. The gulf between the two worlds gives rise to the same type of problems, difficulties and dilemmas, that is "transfer gaps" that have to be bridged in one way or another. On the other hand, over the course of its history, each country has constructed a set of institutions, of legal and regulatory arrangements and organisations that are supposed to help bridge such transfer gaps.

Nevertheless, for various reasons, problems linked to intellectual property rights have emerged recently as core issues for science-industry relations in the two countries. Against the background of the increasing tensions between the existing rules and the changes being instigated by certain actors, they would seem to be emerging as the key element in these relations. The future evolution of NIS could depend on the way in which the protagonists in science-industry relations in each country succeed in negotiating solutions and putting in place new arrangements that strike a balance between public and private interests.

For instance in Germany, political moves are intended to weaken the professors' "free inventor" status in favour of universities as their employer. Because of reduced public funding there are increasing pressures on public research institutes to raise more external funding from industry contracts. Currently, universities still have a very lax attitude towards and a lack of expertise in IPR matters. But the IPR regime governing industry-university-relations is seen as moving closer towards the U.S. model. In IPR matters German public research institutes are facing a dilemma: They need to provide more pre-development type services for industry, involving stricter IPR claims from corporate partners and they also need to retain IPR in core areas of expertise in order to prevent a "bleeding out" and remain a partner for industry in the future. Similarly, universities face the problem of becoming a low-cost R&D provider for companies compromising their primary mission, i.e. the advancement of knowledge.

Chapter 8 - Jean-Michel Plassard et Eric Verdier, "Co-ordination of actors and micro-economic incentives: high skills and knowledge transfers"

In the first instance, the lessons and recommendations focus on the micro-economic aspects of these relations examined in the first part of the report. What forms does the coordination among the actors take? What institutional and organisational arrangements encourage effective relations? What are the consequences for each partner's internal organisations? What labour market regulations are, in principle at least, best suited to the current and future modes of these relations and will ensure that the protagonists have at their disposal the knowledge and competences they require?

A number of lessons can be learnt from the examples of successes and failures recorded in the case studies produced during the various phases of the SESI project. These lessons are located at the following three strategic levels:

- that of the factors of risk and uncertainty,
- that of the processes whereby interests converge and, finally,
- that of the interfacing institutions, agencies and "bodies".

Cooperation cannot in itself provide solutions to the various challenges faced by each of the categories of partners (firms and higher education institutions) unless the form it takes coheres with the partners' internal organisational choices. If there is a number of challenges specific to the different actors, effective joint responses are possible. For firms, the main objective is to resolve the problems posed by the transition from knowledge to competences, whereas for the university involved, the major challenge revolves around the emergence of new disciplines and academic entrepreneurship.

With an OLM of PhD level, the firms, especially very small ones, enable to have easier access to a suitably trained workforce. By promoting the circulation of knowledge, these markets help to reduce the previous conceptual gaps and to promote the creation of greater absorptive capacities at firms, as well as sustaining the spirit of mutual trust and reciprocity in which these networks were founded. From the individual point of view, doctoral candidates stand to obtain advantages like highly specialised technical know-how and the social skills which can be acquired via exposure to the complex multi-

disciplinary and multi-functional patterns of organisation generated by the management by projects approach.

Chapter 9 - Eric Verdier, "National Public Policies : Challenges for effective Knowledge and Competencies Transfers in the high tech Industries"

It is proposed to deal in the present chapter with the institutional specificities of the countries studied, with a view to drawing up some recommendations without losing sight of the specific national contexts.

Based on previous classifications, the lessons learned by public policy makers will be dealt with them in the following order:

- the United Kingdom, where the policies and regulations are typically market oriented and the orientation adopted as far as science, technology and innovation are concerned is undergoing a process of specialisation.
- France and Germany, where the relations between Science and Industry are facing fairly similar challenges, especially in comparison with those being met on the other side of the Channel, and where the scenario tends to alternated between radical change and a process of accommodation.
- Austria and Portugal, which have rather different technological and industrial structures, but are both facing the special challenge of adapting the small-scale national systems of innovation to the European Union and world-wide competition in general.

Yet each of these countries, with the possible exception of Portugal, will have to make compromises between divergent if not contradictory pathways for organising and regulating their national research and innovation structures. The compromises are first and foremost a question of how "top down" policies link up with interventions designed to promote "bottom up" processes.

Secondly, all the countries in question have been introducing measures for marketing the results of public and private research institutions, for creating more space for introducing the university entrepreneurship, and supporting local and regional initiatives in which both public and private research partners are involved.

The local mechanisms whereby skills and knowledge are produced and made to circulate are gradually diversifying the individual national systems of innovation. Both the national and European policies will have to gradually become less like prescriptions and more like reference frames providing a setting for the activities of the actors on the micro-economic scene (possibly forming clusters involved in networks and local initiatives). The success of scenarios of this kind depends greatly on how clearly the public authorities' incitements and modes of organisation are perceived.

List of Deliverables available on the SESI Web Site
(<http://www.univ-aix.fr/lest/sesiweb/sesi/>)

Deliverable 1. Development of a theoretical and macroeconomic Framework

WP 1 - Literature Survey "Systèmes nationaux d'enseignement supérieur et innovation"
(by Lest and Lihre)

WP 21 - National Monographs of Higher Education and Research Systems (by each national team)

WP 22 - National Monographs of the three selected Industries - IT, Telecom, Pharmacy
(by each national team)

WP 3 - Transversal synthesis (by LEST).

Deliverable 2. Fields Surveys : Higher Education, Innovation and Societal Coherences

WP 5 - Firms Monographs 9 : in the cases of France, Germany, UK and US, 6 for Austria and Portugal

WP 6 - Sectoral and National Reports by each national team, reports on 1. ICT and Pharmaceutical Industries 2. Policy Reforms on Academic-Industry Relationships

Deliverable 3. International comparison and lessons for public policies (final report)

WP 7 and WP 8 - Final report "Higher Education Systems and Industrial Innovation"
(by LEST, LIRHE and CRIS, with the help of each other team).

PART 1

The micro-Foundations of Knowledge and Competences Transfers

Introduction

The first part "exploits" the wealth of empirical material (more than forty company case studies) gathered in the course of this research project. The approach is structured around two levels of analysis. The first involves analysis of the conditions under which firms incorporate the new challenges of the knowledge and learning economy⁸ into their strategies. The chapters in this subsection focus on the organisation of R&D and human resource management and seek to locate the links between higher education and firms in this new competitive and cognitive context.

The second subsection focuses on the collaborative ventures between firms and higher education that were one of the two key aspects of the company case studies. The conditions under which they were set up, their objectives and the underlying principles animating the protagonists' behaviour are essential to any understanding of the strategic significance of these relations.

Although located themselves at the microeconomic level, these two approaches seek in their different ways to relocate their findings within a macroeconomic and/or societal framework in order to shed light on the challenges facing public policymakers.

Subsection 1 - R&D Organisations and Human Resource Management

Introduction

Firms today explicitly acknowledge scientific and technical knowledge as a major factor in their competitiveness. In consequence, they have to organise its production, accumulation and diffusion. To this end, firms put in place arrangements whose purpose it is to facilitate the recruitment of people whose competence profiles enable them to meet the challenges posed by the joint production of new knowledge in collaboration with higher education establishments and by the internal management of knowledge. These arrangements require the formalised development of genuine competences in the organisation and management of firms' cognitive resources. In this context, the mobility of human capital is an important factor in the production and diffusion of knowledge. The two chapters analyse the ways in which firms structure this mobility in order to create competitive advantages for themselves.

The first chapter defines the new environment in which knowledge is produced and circulated and in which firms operate⁹. Knowledge is being renewed at ever increasing rates, and this has a profound affect on the organisation of R&D by firms. In consequence, the nature of R&D work in firms is changing considerably and is giving rise to new "research worker" profiles that sharpen the tensions between the partners in industry-science relations. Universities have traditionally been concerned with the

⁸ See in particular Lundvall and Borras, 1997, "The globalising learning economy: Implications for innovation policy", Report based on the preliminary conclusions from several projects under the TSER Programme, DG XII, Commission of the European Union, Draft Paper.

⁹ Gibbons et al (eds) 1994, The new production of knowledge. London: Sage.

academic coherence of courses, whereas firms are now seeking profiles that combine technical and managerial competences. This new "generation" of knowledge management¹⁰ surely offers every encouragement for the increasing integration of the practices of firms and of higher education in the production of competences and skills.

The second chapter is devoted to firms' competences in the internal and external organisation of R&D. Taking as its starting point the acknowledgement that technological competitiveness is based on knowledge, it analyses the various tools developed by firms in order to manage knowledge. The major challenge is how to manage the diversity that has been created to a large extent by multinationals' globalisation strategies¹¹. The chapter begins by examining the main elements in this diversity in order to clarify the difficulties firms encounter in managing their businesses and maintaining some degree of internal cohesion. It then goes on to identify the major issues in the management of knowledge. In this regard, it is interesting to evaluate the role allocated to human resource management in knowledge transfer and firms' innovation capacity.

¹⁰ Reger G. and von Wichert-Nick D., 1997, "A learning organisation for R&D management" *International Journal of Technology Management*, Special Issue on R&D Management.

¹¹ Whitley R., 1992, "*European Business Systems*". London : Sage,.

Chapter 1 - Alice Lam - Changing R&D Organisation and Innovation: Knowledge Sourcing and Competence Building

Introduction

A dominant trend characterising the advanced industrialised economies over the past two decades has been a continuing shift of employment towards more knowledge and human capital intensive industries. The growth of the knowledge-based economy has gathered momentum since the early 1980s as a result of accelerated scientific and technological progress and intensification of global competition. The emergence of the knowledge-based economy has profound effects on the organisation of R&D activities, and the types of skills and knowledge required for productive and innovative activities. One fundamental challenge facing firms in the high-skill sector is whether the existing knowledge and skills formation system is capable of equipping future R&D workers with the requisite high-level skills and breadth of competences needed to take full advantage of new technologies and organisational innovations. This paper argues that the shifts in the nature of knowledge production in the knowledge-based economy, and the constant changes in the mix of skills and competence requirements within firms place great pressures on the very structure and orientation of the established knowledge and skills formation systems in the advanced economies. Drawing on empirical evidence from case studies carried out in large multinational high-technology firms in Britain, the paper examines how the changes in the organisation of R&D work and innovation activities affect the skills and competence requirements of firms and careers patterns of R&D workers. The paper looks at evidence of change, the strategies adopted by firms in skills and knowledge sourcing, and the ways in which firms interact with higher education institutions.

The study is based on six in-depth company case studies in the pharmaceutical, chemical, and information and communication technology (ICT) sectors in the UK. All the companies are large multinational firms. Data were collected by semi-structured interviews with managerial and technical staff in R&D labs and business divisions, and with the academics in the collaborating universities. A total of 89 detailed individual interviews had been conducted. Table 1 shows the interview sample in the six companies.

The analysis in this paper draws out the common trends and issues in the different sectors and analyses the strategies adopted by firms in response to the new situation. The paper also discusses the policy implications of the changes, and looks at some

examples of university-industry collaboration in the education and training of the next generation of R&D knowledge workers.

Table 1 - Interview sample

| Company | Sector | No of interviews |
|---------|----------------------|------------------|
| 1 | Pharmaceutical | 21 |
| 2 | Chemical | 14 |
| 3 | IT | 19 |
| 4 | IT | 13 |
| 5 | Telecoms | 10 |
| 6 | Telecoms/Electronics | 12 |

Two major problems of skills formation and knowledge transmission in the high skills sector

The basic argument of the paper rests on our analysis of two fundamental problems in skills formation and knowledge transmission in the high-skills sector. The first is the speed of knowledge advancement and the limits of codification for effective knowledge transfer in the labour market. At the top end, knowledge is now moving too rapidly to be encoded and institutionalised into a stable set of occupations. Traditional institutional signals (e.g. occupational qualifications) have severe limits in providing dependable information about the quality and contents of skills that individuals have. New mechanisms are necessary to facilitate the effective generation and transmission of knowledge between higher education institutions and firms.

A second related problem stems from the growing importance of 'Mode 2' knowledge in the new innovation context. In many sectors of the economy, the rapid pace of technological advancement and time-to-market pressures have meant that the traditional linear model of innovation is no longer viable. Instead, innovation activities now occur in a highly complex, interactive and open-ended way. Gibbons et al in their book on 'the New Production of Knowledge' (1994) argue that alongside traditional, disciplinary knowledge (which they call Mode 1), a new, broader, trans-disciplinary and contextual form of knowledge is emerging (Mode 2) which supplements Mode 1. Unlike Mode 1 knowledge which is accumulated through a professional specialisation that is largely institutionalised in universities, Mode 2 knowledge is accumulated through the repeated re-configuration of human resources in flexible forms of organisation. The knowledge content and boundary are not defined and controlled solely by the academic community or professional bodies. Instead, it is created in the context of application involving multiple actors and a diversity of institutions.

Gibbons et al (1994) argue that the emergence of Mode 2 knowledge reflects a fundamental change in the nature of innovation in the global economy. Within the advanced industrialised economies, there has been a shift from the search for economies of scale to economies of scope. Economies of scope derive from the ability of firms to configure their human resources, and particularly knowledge, in novel ways. This gives

them a comparative advantage over those which simply adopt and adapt production processes in low wage economies. Moreover, competition between firms within the advanced economies also depends on their ability to configure knowledge resources in specific and novel ways which cannot be easily imitated and replaced. The progress of information technology makes a vast amount of scientific data and knowledge available and easily accessible. The competitive advantage of a firm, therefore, lies not in enlarging the pool of proprietary knowledge which is subject to imitation as it is utilised, but the ability to access a wide spectrum of knowledge resources and configure them in unique ways. Hence, the need to redefine competence in innovation. As Gibbons et al note:

"Competence in innovation is being redefined in terms of the ability to solve problems by selecting relevant data and skills and organise them appropriately. When information is plentiful, perhaps too plentiful, competence does not derive from being able to generate yet more, but from the insight gained by arranging what exists in novel ways. Increasingly, this means connecting series of previously independent data drawn from different databanks. This notion of competence may come to define the meaning of "imaginative". If this interpretation is correct, a new cadre of specialists will emerge as problem solvers and problem identifiers" (Gibbons et al 1994: 64).

The growing importance of 'Mode 2' knowledge calls for a reassessment of the institutional arrangements underpinning the 'professional model' of knowledge formation. The professional model, as it has developed in Britain and the USA, is characterised by a high degree of disciplinary specialisation and the organisation of occupational expertise around academic specialisation. It refers to a particular approach to the formation of high-level expertise based on the use of academic knowledge and formal university training for the legitimation of occupational claims (Friedson 1986). It also refers to the way knowledge and skills are standardised and bundled into specific occupations, assuming a stable and one-to-one connection between a body of formal knowledge and an occupation. However, in the new industrial and innovation environment, knowledge is generated through the repeated combination and re-configuration of diverse disciplines and expertise in flexible forms of organisation. The trans-disciplinary nature of knowledge formation and the growing importance of networked and hybrid forms of knowledge suggest the need for the establishment of a new institutional framework for developing a new generation of technical and scientific experts.

The rest of the paper presents the empirical evidence based on the case studies, and examines the strategic responses of firms and the wider policy implications.

Changing nature of R&D organisation and innovation

Towards the "third-generation R&D" organisation

All the firms examined in this study are placing increased emphasis on improving R&D productivity and effectiveness by organisational restructuring and by enhancing their capability for internal and external networking and knowledge transfer. The recent changes in the organisation and orientation of R&D activities in the case study firms can best be captured by the concept of "Third generation R&D". This concept was first developed by Roussel/Saad/Erikson (1991; cited in Reiger and Wichert-Nick1997) to denote the contemporary development in R&D organisation and the process of formulating technology strategies in large enterprises. Evidence from the case studies shows that the knowledge and skills contents, and boundary of R&D work in the "third generation model" differ greatly from those in the traditional models of R&D organisation.

The "first generation R&D" was the dominant model (1950-70) at a time when R&D management was shaped by the technology-pull view. R&D was assumed to be the main driving force behind innovation and decisions about the technology that would be used by the enterprise. The main characteristic of this first generation R&D management is the pre-eminence of the professional ideology which stresses specialisation and autonomy of the R&D professionals. These professional specialists are regarded as the key "knowledge agents" whose formal training and qualifications give them a source of authority and a repertoire of knowledge they are ready to apply to technical problems within their disciplinary expertise. Innovation activities in the "first generation model" take place behind a screen of impenetrable science and are isolated from business problems and the rest of corporate activities. In other words, "science" and "commerce" are treated as two separate domains.

The "second generation R&D management" (1970 -late 1980s) is a transition stage towards the third generation. It began in the early 1970s when the technology-push view was overruled by the market-pull view. The most distinctive feature is the corporate focus on forging a strong link between business and R&D management. This is achieved through de-centralisation of R&D to business units, and the formation of a market relationship between R&D (as suppliers) and business divisions (as customers). This is a model dominated by managerialism and commercialism where academic specialists give way to generalists, and short-term R&D reduces the organisation's ability to cope with technological changes.

Most of the companies looked at in this study are undergoing a paradigm shift from the "first" and "second generation R&D" towards the "third generation R&D". This is characterised by an attempt to create long-term visions and to balance the R&D portfolio strategically across the whole corporation. It seeks to combine the benefits of market-driven, decentralised R&D with the technology-push benefits from a long-term orientated, fundamental R&D (Coombs and Richard, 1994). Unlike in the "first generation R&D", innovation is not an autonomous activity occurring within the

domain of "science" and driven primarily by the R&D experts. The "third generation R&D" requires the integration of R&D into the business and organisational context. Yet in contrast to the market-driven "second generation R&D", it seeks to maintain the ability to generate new knowledge beyond the existing core competence. Innovation in "third generation R&D" is generated in the context of application and networks of interaction within and external to the enterprise. It is a de-centralised, network form of R&D organisation. The ability to access knowledge from a wide variety of contexts and sources is critical for sustaining its capability to generate radical innovation. This new approach to R&D calls for a redefinition of the nature of R&D work and the type of knowledge and skills required for innovation.

Changing nature of R&D work

Innovation produced in the context of application

While the companies continue to stress the importance of technical excellence amongst their R&D staff, there is an increased expectation that research is about more than just inventing technology. R&D specialists are expected to operate in a flexible and interactive mode, engaging in strategic and operational partnership with business divisions and other corporate functions:

"...it's important to maintain your relationships in the businesses because whenever you bring research to a point where you want to transfer, you've got to have credibility, you've got to have the relationship that means that they are listening in the first place. If we lock ourselves away in an ivory tower, you get a reputation for being arrogant, remote..." (Researcher, ICT company).

Scientific and technological expertise have to be effectively combined with business and commercial understanding, and exploited in a succession of problem contexts. R&D work now involves a much wider spectrum of activities beyond technological innovation. The R&D worker is expected to have a broad understanding of the "context" and "strategic vision" that transcends traditional disciplinary expertise. A capacity to integrate technology with business and a broad understanding of the "context" is regarded as vital. The following remarks by the departmental managers in an ICT firm are illustrative:

"The portfolio of things that the labs will end up working will be broader... for things like the PCs and E-services, the sort of things that labs provide are more than just intellectual property for technology. It's knowing where the technology is going. Knowing who's doing what. Knowing what's going to be required in the next and future generations. When something like a third generation radio is going to be pervasive enough that you can build these new markets. It's going along and being technically competent in an area so that you can forge the standards that will keep [this company] in the game with all the other companies".

"...So business awareness probably isn't quite the right phrase I think. It's more awareness of the ecosystem. You kind of like them to have some idea of what's going on out there, and have a broader view of the world. You like them to understand what the issues are..." (Departmental manager, ICT Company).

Even at the most highly qualified PhD level in the pharmaceutical industry, companies are looking not just for candidates with "scientific excellence", but search increasingly for those with "the range of qualities" and "scope of competence" beyond the boundary of disciplinary specialisation. There is a general criticism that the education system in the UK tends to stress too much on academic specialism and that "there is not enough emphasis on training PhD in things just outside doing bench work". Companies are increasingly looking for PhDs with "general capabilities", "innovative potential" and those who "understand the background" in addition to solving problems in their own disciplines.

Cross-functionality and transdisciplinarity

In the "third generation" model, R&D work is increasingly organised on a multi-disciplinary basis. Innovation takes place in mixed project teams involving experts with a diverse range of scientific expertise as well as non-R&D groups. Flexible specialisation and "inter-dependent professionalism" are the characteristic features in "third-generation R&D". For example in the ICT firms, there have been efforts to recruit staff with a diverse range of expertise outside the traditional disciplines of computer science and electronics engineering. The importance of having "mixed skills" in the R&D labs is emphasised by many of the managers and researchers interviewed:

"Especially in these last years, I've been pushing in my own department to mix the skills. We have physicists, we have electrical engineers, we have optical engineers, we have mathematicians, we've been using these people. This Lab as a whole has got an interesting sub-mix of skills... We've moved from almost being purely algorithms and computer science-based to a very mixed skills..."

Similar trends can also be observed in the pharmaceutical firm: therapeutic project teams are now organised on a multi-disciplinary basis, involving experts from chemistry, biology and medicinal technologies. Although multi-disciplinary project teams seem to have become an established part of the work organisation in many of the firms, there are tensions and difficulties which may potentially inhibit their effective operation. Evidence from the interviews in the pharmaceutical firm suggests that these tensions stem from the disciplinary culture rooted in the cognition (i.e. knowledge structure) of the individual scientists, their social identity and the established career patterns. The latter are still structured alongside the conventional professional disciplinary boundaries. For example, although therapeutic project teams comprise chemists and biologists, there is a separate line management structure between chemistry and biology in the company. As a result, the researchers' career and social identity still lie within their own disciplines. More importantly, the line department continues to control the careers of the individual scientists. A senior project manager commented on the "divided loyalty" of the project team members:

"... although they're on a team, the reality is that the power, their career and their pay is controlled within the lines. They may get a bit too close an eye on what's going on in the line".

The dominance of the line in terms of career and status could well mean that project teams do not always get the best people. There is a general feeling that "project teams are poor cousins to the line" and that "team life is never as important as line life".

Tensions between the "line" and the "team" are symptomatic of all matrix organisations. However, in industries where innovation is increasingly problem-oriented and transdisciplinary in nature, the core of their activities tends still to be underpinned by specialist scientific knowledge. The difficulty in striking a balance between the two is much greater than in older industries.

External networking and collaboration

One of the fundamental features of the "third generation R&D", in contrast to the short-term oriented, business-driven "second generation", is to recognize the need to maintain long-term vision and a capability to create new knowledge beyond its existing core competence. The ability to exploit a wide spectrum of external knowledge resources and collaborate with external organisations is regarded critical for creating new knowledge. All the firms examined in the study are engaged in an increasing range of external collaborative activities such as alliances, joint ventures and R&D collaborations with other firms and academic institutions. For many of these firms, R&D activities now involve a complex arrangement of alliances and networked activities. The R&D lab is increasingly seen as "the integrating centre for a network of relationships outside". Such external networking and knowledge sourcing activities are particularly intense in the pharmaceutical sector where the scale of investment required for drug research and the need to integrate knowledge from many different domains are beyond the reach of internal R&D programmes. The locus of innovation is increasingly found in networks of collaboration. This means that the ability of R&D workers to collaborate and negotiate with external agents, and to exploit external knowledge is becoming a necessary part of their competence profiles. "Networking skills" and ability to "access and understand a much bigger data base" were frequently mentioned by many of the managers as something they look for amongst their R&D staff.

In many organisations, there has been a growing demand for R&D staff capable of performing a gate-keeping or boundary-spanning function. These are specialist roles responsible for internal and external coordination and transfer of knowledge across functional and organisational boundaries. These roles are usually performed by highly qualified scientists with managerial and business experiences, and also additional training in IPR matters. The type of knowledge and experience required is usually highly specific to the firm.

The new R&D knowledge worker

Re-definition of competence in innovation

The above evidence suggests that the contents and boundary of R&D work have become increasingly fluid, ambiguous and transient. The problems that R&D workers have to deal with are no longer contained within the boundary of individual specialisation and conventional disciplinary expertise. Standardised and "pre-packaged" professional knowledge is no longer sufficient to deal with the spectrum of activities and level of uncertainty that they have to cope with. A large part of the problem solving activities in the new R&D environment has very little to do with the application of narrow standardised expertise and more to do with the capacity to define problems and adapt to new situations. As noted by a manager in the pharmaceutical firm: "Research is about knowing what to do when *nothing is written down*. It is about learning to *anticipate the unexpected* and deal with it". Many of the managers interviewed were concerned that graduates did not have the type of "research skills" or "problem solving abilities" that the companies required. What they are looking for, according to the HR manager in the R&D lab of an ICT firm, is "a capacity to define the problems correctly in the first place; solving the problems is no more than a last step in the chain". A common criticism is that many of the graduates regard research as a process of solving problems that have been pre-defined.

The skills requirements for the new innovation context are now more demanding in multiple dimensions, particularly in the combination of technical disciplinary expertise with a broad range of business, management and social skills. R&D and innovation activities are no longer confined to the R&D labs but are widely distributed and dispersed throughout the entire business enterprise. The effectiveness of R&D workers depends on their ability to apply scientific and technological expertise in shifting problem contexts, to operate in inter-disciplinary and trans-disciplinary environments and to sharpen their project management skills. In other words, they are expected to operate in a Mode 2 rather than traditional Mode 1 context.

The type of knowledge and skills required for the new innovation context has a strong "tacit" component and collective dimension. The simple classification of knowledge categories developed by Lundvall and Johnson (1994) provides a useful illustration. The authors distinguish the following four different categories of knowledge:

- Know-what - refers to substantive knowledge and knowledge about facts
- Know-why - refers to understanding of basic principles, laws of nature
- Know-how - refers to human skills and competences necessary to act intelligently in a complex and changing environment
- Know-who - refers to the social capability to cooperate, to communicate and establish trust relationships.

Innovation in the high-skills sector demands the effective interface of all four categories of knowledge. However, the emerging evidence suggests that 'know-why' has become more important than 'know-what'. This is because 'know-what' knowledge can easily

become obsolete in a fast changing environment. Most important of all, 'know-how' and 'know-who' knowledge are absolutely vital in the new innovation context. They are critical capabilities needed for the production of 'Mode 2' knowledge.

Growing versatility and diversity of careers

The distributed and network form of R&D activities, coupled with the rapid pace of technological advancement and discontinuity imply that the careers and work roles of R&D staff will be increasingly characterised by versatility and diversity. Evidence from our case studies suggests that an increasing number of the R&D staff will be deployed outside the traditional R&D function. In many of the companies, there are growing concerns that the low-level of turnover among their R&D staff may inhibit innovation and the capability of the laboratories to create radically new competences. Many of the companies are now re-writing the psychological contract with their R&D staff. The idea is to encourage the mobility and internal transfer of the R&D staff on a more systematic basis. A common practice is to increase the transfer of staff from the R&D laboratories to the business units. In some companies, policies are being developed to enhance the two-way flow of staff between the corporate labs and business units. These policies are aimed at career development and also at the integration of technical and commercial capabilities.

Reduced strength of internal competence building

The general trend observed in many of the companies is the reduced strength of the internal competence building model. This has been caused by the need to speed up the learning process and to create new competences in an environment where the rate of change is dramatic. Hewlett Packard is a good example. As the company seeks to transform from a hardware manufacturer to an enterprise service provider and systems integrator, the internal competence building approach is proving to be too slow for adapting to the changes. The company has recently adopted a compromise strategy of allowing more openness in its career development and recruitment policies.

The end result of all these changes is that the majority of the R&D staff can no longer look forward to a settled and stable 'scientific' or 'technical' career path in a conventional sense. Their knowledge and skills are being deployed and continuously reconfigured in highly transient and flexible forms of project-based organisations.

Problems for firms in skills and knowledge sourcing

The changing nature of innovation and shifts in the skills and competence requirements pose a number of challenges for firms. The first is recruitment: whether universities from which they recruit most of their R&D workers are able to supply the graduates and post-graduates with the range of skills and competence required. Formal disciplinary knowledge acquired through conventional means of specialist education is still necessary but clearly no longer sufficient. Firms increasingly look for those with the following qualities: a) a good grasp of the 'knowledge of the basics' and a higher threshold of ability to ensure the ability to adapt and learn; and b) a broad portfolio of

competence and experience beyond traditional disciplinary expertise. In addition, all the companies in the study emphasise the importance of business experience. This is because of the time scale pressures in product development and the need for R&D staff to engage in customer interface. While graduate recruitment is important, many companies, especially those in the ICT sector reckon that they can no longer afford the time for the training and integration of a large number of graduates with no practical experience.

The second problem stems from the rapid evolution of knowledge and the limitations of institutional signals (e.g. occupational certification) in providing reliable information about the content and quality of skills and knowledge that graduates have. Codification is too slow a process for the transmission of rapidly evolving tacit knowledge. The assessment of quality is critical when the competitive advantage of firms depends on nonreplicable human resources. More effective mechanisms will have to be developed for the rapid transmission of knowledge between universities and firms.

The third problem facing firms is the growing intensity of labour market competition for scientific and technical talent. As competitive advantage depends increasingly on tacit competence and unique configuration of knowledge resources, firms will compete to hire the best and make sure that they have a stable supply of reliable core R&D workers. However, a fundamental dilemma facing many firms is the growing difficulty in attracting and retaining the best researchers, many of whom are reluctant to pursue a career in an industrial environment where firms can no longer provide stable research careers. Firms will have to devise new strategies to tackle the problem of 'intellectual resource immobility'.

Finally, firms also have to manage growing tension between greater openness and flexibility in skills and knowledge sourcing and the need to sustain the capability to move ahead rapidly within their core competences. The increased demand for scientific creativity and absorption of external knowledge is encouraging greater openness in firms' human resource policies. The potential danger is the weakening of their internal absorptive capacity and ability to accumulate knowledge and capitalise on learning. New mechanisms will have to be developed to promote the effective linkages of internal and external knowledge.

How are our case companies responding to these problems?

Towards a new approach: the "extended internal labour market model"

Building strategic partnerships with universities

A common strategy adopted by the companies in our study is to forge close institutional links with universities in order to gain early access to the best people and ideas, and to develop mechanisms through which they can influence the initial education and training of their potential recruits. In all the companies, there is an increased emphasis on "student placement" as an effective channel for graduate recruitment. Companies favour recruiting those who have spent a 6-month or one-year internship with them. The idea is

that these students have already gained the business understanding and organisational knowledge during their internships, and hence are more qualified and suitable than those with a pure specialist training from their universities. The placement period also allows the company to have a long period of screening and probation. It serves both the training and recruitment functions. It amounts to a kind of "informal apprenticeship" which gives the companies an opportunity to instill the specific competence and tacit knowledge for the type of work for which they are recruiting.

Another significant development observed in all the companies is the attempt to develop a more focused and targeted approach to the ways that they relate to academic institutions. The idea is to focus their attention and concentrate resources on a small number of key institutions from where they are most likely to resource their people and knowledge. The term "strategic partnership" is often used to denote an intention to forge long-term, multi-dimensional and trusting relationships with the key institutions. The relationships between the company and academic institutions would be sustained by a range of linking mechanisms including collaboration in research, industrial inputs to curriculum development, student placements, and exchange of staff. The intention behind all these, according to a senior manager responsible for university links in one of the ICT companies, is to have "early access to the most talented people" and trusted access to the best ideas":

"So it's early and trusted access to the best ideas. And so they know they have a good partner who's not going to rip them off. And that same thing applies, I think, to getting hold of the best talent, people. If you have a trusted relationship with faculty, they are going to say 'I've got this really good student, and at whatever stage, you really ought to take them on.' If they don't know you, they're not going to do that. They're going to send their best student to people they know, not to people they don't know" (Academic Liaison Manager, ICT company).

By becoming a trusted partner in the academic community, companies are not only in a better position to catch the best students early but also have an opportunity to influence the education and training of the graduates and future researchers. Activities such as giving seminars at universities and supervising student projects are often used to cement relationships with particular institutions and raise the industrial awareness of students:

"It's to be part of the wider research community, and we certainly expect that from our staff, making sure that people give seminars at universities. You haven't asked the question, but how do we make sure that universities actually produce people with business awareness. Well one answer to this is to go out and give business awareness to the universities that *we care about*. So we'll go out and give business related technology talks to graduate students in a particular department. So we seed some ideas, get them thinking about the space, and encourage them to start thinking about these issues" (Departmental manager, ICT company).

In the pharmaceutical company, forging close academic links has become so important that the company has recently created "strategic recruitment specialists" in chemistry

and biology, staffed by senior scientists with PhD qualifications, to liaise and develop strategic relationships with their "preferred institutions". The company recognises that it is to their advantage to use scientific experts to help personnel to identify the best recruits and also to "influence the universities":

"...So they would help promulgate interest in [our company].. They would influence the universities. They were in fact a very acceptable face, as opposed to just an HR department. But it's been a very useful strategy. It's worked very well. X took that role a few years ago, and he has tremendous contacts in the universities, in the chemistry schools. That works to our advantage. It means that we perhaps get to hear about the good people first. Tutors push them in our direction and so on and so forth. We now do the same in Discovery Biology" (HR Director, Pharmaceutical Company).

The companies also use research collaboration with individual academics or departments in universities to build up social networks so that they could gain early access to research results before they are published. Such social networks also facilitate a two-way flow of knowledge. They provide windows of opportunity for the companies to influence the process of knowledge production and training of future researchers, at the PhD and post-doctoral level:

"... by having the deep relationship with key universities, then you can spot and encourage people to come to you with the right skill. Because you've got this relationship with the lecturer, you can now influence what those PhDs do: We would like you to be in [this area X] and why don't you go and look at this particular area of X. Come and see what we do, come and see if you can improve it. They go away and do their PhD but at the end of that you've actually had them into your Laboratories, you've been down to their Laboratories, you've seen their PhDs, probably before its published, and you've got the inside track and then you've formed a view about these people would be just the sort of person I want to employ" (R&D Director, Chemical Company).

Evidence from our study shows that the 'reverse flow' of knowledge from industry to academia through various formal and informal mechanisms has been very important in enhancing the quality and relevance of curriculum contents and degree programmes at the partner universities. On some occasions, research collaboration with industry have led to the creation of new avenues of research and degree programmes.

Another significant strategy adopted by some of the companies is the creation of "hybrid research organisations" sitting on the interface between the companies and universities to forge close institutional links. The companies would usually provide initial funding for the setting up of the organisations and be closely involved in the recruitment of key research staff. Although the research staff are formally employed by the universities, in practice, they are "joint human capital" shared between the universities and companies. For the companies, these hybrid organisations constitute an important mechanism for attracting and gaining access to top academic researchers who are reluctant to pursue a career in an industrial environment. One of the companies explicitly pointed out that the hybrid organisation had become a "recruiting porthole"

for them. It also creates a permeable boundary between universities and firms and thus allow a two-way, interactive approach to knowledge generation and transfer.

Towards the formation of "extended internal labour markets" (EILMs)

The above evidence suggests that firms are devising new strategies to cope with the changing nature of innovation and competition, and to compensate for the limitations of the "professional model" in Mode 2 knowledge production. The concept of the "extended internal labour market" (EILM) would seem useful to interpret the significance of the new approach adopted by the firms. The concept of EILM, in a traditional sense, is used to describe the recruitment channels most commonly used by firms for non-skilled manual workers (Manwaring 1984). It refers to the practice of recruiting through existing employees of the firm and extending its internal labour market through their social networks in the local community. It therefore describes a recruitment channel and the relationship between a firm and its community. This paper applies the concept in a new context, stressing the active role of firms in developing social networks for knowledge and skills resourcing. Unlike earlier work which has focused primarily on recruitment channels, this paper highlights the importance of EILMs, in addition, as mechanisms for knowledge and skills generation and transmission between universities and firms in the high-skills sector. The EILM concept draws attention to the critical role of careers and mobility of people in the formation and transmission of knowledge in the high-skills sector.

For firms, developing their EILMs compensates for many of the shortcomings of the "professional model" in the generation and transmission of Mode 2 knowledge. The build up of social networks through EILMs serves three important functions: a) as a recruitment channel; b) as an informal "apprenticeship" system; and c) as a mechanism for sustaining boundary-spanning knowledge networks.

EILM as a recruitment channel

In areas where knowledge is advancing too rapidly to be easily identified and codified into specific occupations, social networks in EILMs provide more reliable information than formal certification about the type and quality of skills and knowledge that individuals have. As the competitive advantage of firms increasingly depends on nonreplicable human resources, the assessment of quality becomes critical (Zucker 1991: 167). Social networks enhance the richness and quality of information transmitted. They serve as sources of reliable information. As noted by Powell (1990: 304): "Networks are particularly apt for circumstances in which there is a need for efficient, reliable information... You trust information that comes from someone you know well". EILMs thus allow firms to have an established channel and trusted information sources to recruit a core of stable and reliable knowledge workers.

EILM as an informal "apprenticeship" system

EILMs also serve as interfacing mechanisms through which industrial practice penetrates formal academic training. They facilitate an interactive two-way flow of knowledge between university and industry. The traditional professional model assumes a sequential, one-way flow of knowledge: universities give the theoretical training, and

work in firms provides practical experience. In contrast, the EILM approach allows a two-way interaction between "theory" and practice and creates opportunities (e.g. student placement) for "learning in context", and for instilling the social and organisational skills specific to firms that employed them. This could remedy the shortcomings of specialist academic education and enhance the relevance of the knowledge and skills acquired. From the viewpoint of academic institutions, the EILM amounts to an "extended academic community"¹² with much movement of people between academia and workplace, as students, instructors and research collaborators. Such a community could provide a more effective forum for Mode 2 knowledge production. It has the potential to generate a new institutional infrastructure governing the education and training of high-skill personnel.

EILM as a boundary-spanning knowledge network

With the growing pace of knowledge generation and the diversity of expertise and disciplines required for innovation, firms increasingly need to enlarge the space for the search of knowledge and skilled personnel. EILMs serve to create and sustain firms' external knowledge networks. They enhance the permeability of firms' boundaries, allowing them to gain access to external knowledge resources and expertise without the commitment of full internal integration. Sourcing knowledge through external networks not only increases organisational learning, but also increases the flexibility of a firm's boundaries because each external expert represents "a strategic sourcing option" that the firm can exercise only when necessary (Liebeskind et al 1996: 431). The formation of EILMs for forging close links with universities is especially important for sustaining firms' ability to generate new knowledge. Unlike professional networks which are highly particularistic and bounded within specialist disciplines or occupations (Galaskiewicz 1985), the university represents a much more open and fluid knowledge network node. Moreover, universities offer stable career structures for members of the 'extended core'. By gaining access to the university through EILMs, firms are able to tap into the wider knowledge networks of individual academics. It broadens their boundary of knowledge exploration and potential for innovation. It also facilitates rapid and direct integration of evolving new knowledge into the routines of firms.

Rethinking the links between innovation and systems of competence building

The analysis presented in this paper illustrates how firms' models of R&D organisation and innovation co-evolve with their human resource policies and organisational learning capabilities. R&D is a learning process and the effectiveness of such a process is embedded in the development of human resources and systems of competence building. The existing literature on innovation, however, has rarely discussed the linkages between the two. This has resulted in a gap in our understanding of how firms' innovative capabilities are related to a wider set of societal institutions beyond the R&D and technological systems. Figure one gives an indication that there is a close connection between firms' R&D strategies and systems of competence building. It illustrates the importance of labour market institutions, and education and training

¹² The concept of "an extended academic community" was first raised in the MIT Report on Lifelong Cooperative Education (Bruce, James D et al eds 1982).

systems in supporting the different types of innovation and knowledge sourcing strategies. It also illustrates the changing role of university-industry relationships as firms move towards the third-generation R&D model of innovation.

Third-generation R&D and the EILM approach

The EILM approach has emerged as a human resource and organisational learning strategy developed by large firms to sustain the Third-generation R&D. It remedies the weaknesses of the traditional professional model in the generation and transmission of Mode-2 type of knowledge. The extension of the core human resource systems to external knowledge suppliers allows firms to combine internal and external learning in such a way that they can move ahead rapidly within their core competence without getting locked into narrow trajectories (Lam and Lundvall 2000). In a nutshell, the EILM seeks to solve the two key problems of knowledge generation and transmission in the high-skill sector: speed of knowledge advancement and the scope of knowledge needed for sustaining innovation. Much of the existing literature has focused attention on the importance of a community-based occupational labour market in providing the necessary social infrastructure and institutional framework to create and sustain the high-skills sector (Saxenian 1994; Finegold 1999). In some respects, the concept of EILM shares many common features with that of the occupational community. Both concepts stress the importance of social networks in sustaining knowledge creation and transmission in a sector where knowledge is evolving too rapidly to be codified. They both point to the importance of learning through networks of interaction and collaboration. Both the EILM and community-based labour market are possible solutions to remedy the inadequacies of the professionalised institutions in the high-skill sector. However, EILMs tend to arise in the large firm sector where employers have the market power and resources to forge stable institutional links with higher education. For SMEs and start-ups which lack these resources, the support of a region-based occupational community would seem critical.

Changing nature of university-industry interaction: the importance of human resource flows

A related development is the increased importance of academic institutions in firms' external knowledge networks, and shift in the nature of industry-academic relationships. The first and second generations R&D organisation were rooted in a linear model of relationship with academia. The university was a source of fundamental knowledge and supplier of certified competencies. The flow of knowledge was predominately one-way: from academia to industry. In contrast, the third-generation R&D is based on a much closer and interactive mode of relationships with universities. It stresses the importance of co-production of knowledge and human resources. The EILM constitutes an important institutional framework creating a permeable boundary between firms and universities to allow a two-way flow of knowledge and people. The greater degree of connectedness across institutional boundaries facilitates the transfer of both codified and tacit knowledge. The interactive model reflects a significant shift in firms' perception of the role of academic knowledge in innovation, and the emergence of what Gibbons

(1995) has described as the Mode 2 form of knowledge production. It suggests that academic knowledge can be a driving force of innovation and source of competitiveness for firms, but the process of linking it to industrial applications and technological problem-solving is indirect and roundabout. Moreover, with the rapid pace of knowledge advancement, the type of knowledge that firms look for has a strong tacit element. In this context, academic knowledge is not just a pool of codified knowledge available for all. Instead, its exploitation in innovation can be best achieved through knowledge embodied in individuals and transferred through institutional networks. Hence the increased emphasis on the importance of human resource flows and recruitment in all the companies examined in the study. The construction of social networks to facilitate a two-way flow of knowledge and mobility of people will be an increasingly important mode of interaction between industry and academia. Cyert and Goodman (1997) propose an 'organisational learning perspective' in judging university-industry relationships. They argue that the criterion for evaluating the relationship is not simply one of funding, technology transfer and papers. Instead, it is whether or not the relationship creates learning at the organisational level for both the university and the firm. Interaction and mobility of people constitutes one of the most effective means of learning and knowledge transfer.

FIGURE 1 INNOVATION AND COMPETENCEN-BUILDING: AN INTEGRATED MODEL

| Model of R&D | First-generation | Second-generation | Third-generation |
|--|--|--|---|
| Innovation & Knowledge strategies | Strong corporate R&D (Centralisation) Knowledge accumulation | Divisional R&D (Decentralisation & externalisation) Knowledge acquisition | Alliances and partnerships (Decentralisation & internal/external networking) Knowledge sharing and Creation |
| Organisational forms | Bureaucratic | Market-based | Network organisation |
| Type of knowledge workers | Mode 1 disciplinary experts (problems identifiers and problem solvers) | -----> | Mode 2 transdisciplinary experts (Problem identifiers, problem solvers and strategic brokers) |
| Competence building | ILM Internal core competence (careers and training) | Reduced ILM Sub-contracting and externalisation | EILM Extension of 'core' to external knowledge suppliers (e.g. universities) |
| University-industry Relationships | Linear model - supplier of fundamental knowledge -certified competence - pool of codified knowledge | -----> | Interactive model - partner in knowledge generation - reputation-based competence - tacit knowledge embodied in people and networks institutional |

Conclusions and policy discussion

The process of knowledge generation and transmission in the high-skill sector differs from conventional approaches to education and training. This paper has focused on how firms are responding to the changing nature of skills and knowledge requirements in the new innovation context. The EILM approach has emerged as a strategy developed by large firms to remedy the weaknesses of the professionalised institutions in dealing with the speed of change and the diversity and complexity of knowledge required. The analysis draws attention to a number of wider policy issues concerning the generation and transmission of knowledge in the high-skills sector.

The 'skills gap' and knowledge creation problem: limits of education and training policies

The first is the 'skills gap' problem and the limits of conventional academic specialisation in preparing the next generation of scientists and engineers to operate effectively in a Mode 2 rather than Mode 1 context. The type of skills and competence profiles required of R&D workers are now more demanding in multiple dimensions, particularly in the combination of technical disciplinary expertise with a broad range of business, management and social skills. The effectiveness of R&D workers depends on their ability to apply scientific and technological expertise in shifting problem contexts, to operate in inter-disciplinary and trans-disciplinary environments and to sharpen their project management skills. In other words, the acquisition of 'know-what' and 'know-why' knowledge (disciplinary-based Mode 1 knowledge) will need to be complemented by 'know-how' and 'know-who' knowledge (context-based Mode 2 knowledge). The latter two categories can only be effectively developed through 'learning in context'. Moreover, the increasingly distributed and network form of R&D activities, coupled with rapid technological advancement imply that the careers and work roles of R&D staff will be increasingly characterised by volatility and diversity. An increasing number of them will be deployed outside the traditional R&D function. Many of them will be expected to adapt to a more open and heterogeneous environment. A main challenge for educational institutions is to parallel this diversity of competence profiles and career paths in curriculum contents and design.

The second issue concerns the speed of knowledge advancement and the difficulty in marrying the specialist expertise produced in higher education with the shifting requirements of industry. This appears to be especially problematic at the most advanced PhD level. The traditional concept of a PhD involves the studying of a specialist subject in great depth for three years. However, the technological base of industries is now evolving within a much shorter time frame. For example, in the ICT sector, the demand for a PhD specialisation in soft technologies is eroding because of the rapid pace of change. The rapid changes in the technological and business environment have created considerable uncertainty about the future requirements for PhD science graduates.

A third related issue is the growing need for new or combined disciplines in the rapidly evolving innovation environment, namely, the trans-disciplinarity problem. Many of the new disciplines require a re-configuration of existing academic boundaries and re-arrangement of professional territories (e.g. bioinformatics). Others are hard to create and develop without the necessary industrial data set (e.g. the application of Mathematics for data management in telecommunications). Moreover, many of the new combined disciplines are highly specific to certain industrial situations and problems, and cannot be easily defined in an academic context. This suggests that the creation of new disciplines and competences will have to be embedded in the problem solving process. Evidence from our case studies suggests that the reverse flow of knowledge from industry to academia through personal networks and research collaboration plays a crucial role in the creation and generation of new disciplines.

In the United Kingdom, the government has recently introduced a number of policy initiatives to bring post-graduate training more closely in line with the needs of industry and more relevant to a wider variety of careers. The main thrust of the reforms has been towards the broadening of technical skills and professional competence, and developing a new generation of scientists and engineers capable of operating in more open and heterogeneous environments. For example, the Postgraduate Training Partnerships (PTPs) are a joint initiative of the Department of Trade and Industry and the Engineering and Physical Sciences Research Council (EPSRC). It allows research students to work in an industrial setting under cooperative guidance and supervision from the participating Industrial Research Organisations and universities. A key element in the partnerships is the multi-disciplinary nature of research topic selected for the students. Another example is the Engineering Doctorate Programme (EngD) started in 1992. It seeks to introduce a radical alternative to the traditional academic-oriented PhD. It takes the form of a four-year programme which provides business and technical expertise to complement doctoral level research training. One of the distinctive features of the programme is that it is cross-disciplinary. Each research engineer has two university supervisors (from two departments) as well as an industrial supervisor. Evidence thus far suggests that graduates from the scheme achieve better job offers and career progression than those carrying out more traditional PhD or MSc training (ERSRC 2000).

These government initiatives have gone part of the way to deal with the 'skills gap' problem at a generic national level. However, they are limited in scope and seek to address the problems primarily from a conventional education and training perspective. The problems of knowledge creation in the high-skill sector go far beyond the simple issue of skills supply or the re-design of education and training programmes. The structural issues of fostering institutional linkages and creating a system capable of responding to the growing complexity and diversity of the skills and knowledge requirements at the level of the firm or industry are at the heart of the problem. The EILM approach discussed in this paper addresses some of these structural problems from the point of view of individual companies, mostly large multinational firms with the resources to establish their own 'tailor-made' links with universities. As a single employer strategy, the EILM model can have only limited effects on improving the efficiency of knowledge creation and transmission in the national innovation system. An important question is whether this approach can be applied to groups of employers on a

wider scale to gain greater returns from the academic knowledge base, and to facilitate the generation and transmission of knowledge at the sector or industry level.

'Multi-employer EILMs' as knowledge creation communities ?

One possible approach would be to foster the development of 'multi-employer EILMs' as part of the institutional arrangements to enhance the co-production of knowledge and human resources between industry and university at the collective level. The concept of 'multi-employer EILMs' bears some similarities to Romer's (1993) idea of 'self-organising industry boards' - a form of intermediate institution deliberately created for producing knowledge through collective coordination. According to Romer, neither the government nor individual private firms are good at creating skills and knowledge at the industry level because of the diversity and complexity of situations. Moreover, the public aspect of industry-specific goods also raises a classical problem of market failure and thus resulting in under-investment in resources that are public goods. The idea of 'self-organising industry boards' attributes a central role to the coordinated efforts of employers in knowledge creation. These 'boards' are characterised by three principles. The first is a system of compulsory levy to avoid the problem of 'free riding'. The second is that the knowledge produced through the 'boards' is a public good available to all. And finally, the boards compete to capture resources and new boards can be freely set up to avoid institutional inertia. The fluidity of the boundaries of boards enables firms to configure their environment (e.g skills, research priorities etc) according to the evolving needs of industry.

The concept of 'multi-employer EILMs' also denotes the importance of coordinated efforts in knowledge production. However, unlike Romer's idea of creating an open 'public space', 'multi-employer EILMs' concern more the creation of overlapping 'private spaces'. The creation of such overlapping 'private spaces' within the EILM model might be a more effective strategy for dealing with the increasingly fluid and varied situations facing firms. The policy process for the creation of 'multi-employer EILMs' does not yet exist, but it could be modelled on the kind of self-organised research networks recently promoted under the UK government's Foresight Programmes (e.g. VCEs in telecommunications, and the Institute of Applied Catalysis). These are created on the basis of industrial subscription and public funding. Membership is open to companies on payment of a membership subscription available in shares, and to universities through a process of selection. A superstructure organisation unit is created to coordinate the collaborative activities. The knowledge generated is owned by the coordinating entity and shared by the subscribing members. The 'shared space' among firms and between firms and universities creates a community for the efficient generation and transfer of tacit knowledge. However, each individual firm may also maintain its own 'private space' by developing its own EILM through personal networks, funding of individual projects and the recruitment of students and researchers. The overlapping of these 'private spaces' could therefore generate a dynamic for the creation and continuous re-configuration of knowledge and human resources in accordance with the varied and evolving situations of firms.

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Chapter 2 - Claude Paraponaris, "The organisation of R&D and the management of cooperation: controlling a diversity of knowledge sources"

Introduction

It has become commonplace to analyse the management of innovation as an activity that cannot be reduced to the R&D function in firms (role of the management of human resources and of linkages within the firm), that produces both direct and indirect effects (such as increases in human capital) and that, above all, forms part of a wider but less clearly defined system of knowledge production. In attempting to extend this analysis, we might begin by asking how scientific and technical knowledge is used and/or absorbed by firms and how firms transform such knowledge into competences. It has been established that the processes of knowledge circulation are not linear (Kline and Rosenberg 1986) and that certain abilities are required in order to handle knowledge, which does not circulate in the same way as tangible goods (Cohen and Levinthal 1990).

In order to examine the organisation of R&D in multinational firms and assess its role in the structuring of technological cooperation, it is necessary to adopt a medium to long-term view of the development of competences (Hatchuel 1985). The focus of interest here is the construction of knowledge in firms viewed in the context of their approach to academic collaboration and against the background of transnational activities that bring into play local infrastructures for the diffusion of technologies. A distinction will be made between knowledge and competences. The knowledge in question here is scientific and technical in nature and is produced within universities and firms, as well as jointly. There may also be duplications of knowledge that go unrecorded. A firm setting up a knowledge management system has to put in place mechanisms that enable it to carry out regular inventories of the knowledge held. The term competences will be used to denote the aptitudes for achieving goals shown by the various employees within a firm; these aptitudes are distributed within a firm, with some having a collective dimension that makes it possible, for example, to implement knowledge management systems.

The sample of multinational firms we have selected in order to assess the strength of the relations between business and academia also enables us to take stock of the moves towards industrial rationalisation taken by firms seeking to develop their technological globalisation strategies by exploiting a diversity of cognitive resources. Such an evaluation can readily be extended to include an examination of the structures of R&D organisation and of the processes of resource construction. We begin this examination

by outlining its objectives and establishing the value of taking account of knowledge and competences in the management of innovation. This provides an opportunity to position our research vis-à-vis other studies of innovation and technological cooperation. The other two sections of the paper are given over to a presentation of the results of our study. In the second section, we analysis the role of the structures of R&D organisation in the globalisation of technology strategies. We deal jointly with the internal organisation of activities (role of innovation projects, human resource management) and with the external organisation of academic collaboration. The third section is given over to the role of the processes for the management of knowledge and individual expertise that constitute an autonomous framework for the construction of resources in the various R&D units.

Innovation, knowledge and competences

Innovation and co-ordination processes

Generally speaking, analyses of innovation processes focus on the factors structuring firms' activity from the point of view of resources and co-ordination. Such studies are concerned primarily with the internal organisation of such processes and seek to identify the factors determining the success or failure of innovation projects, with discussion revolving around the most effective ways of co-ordinating the resources deployed.

The main factors contributing to the success of innovation projects identified in these studies are the following:

- understanding clients' needs and taking them into account in the design of the new product;
- the quality of the communication and co-ordination between the technical, R&D and marketing functions;
- the efficiency of the technical and commercial development process.

Among these studies, Rothwell's contribution stands out by virtue of its originality (Rothwell 1994 ID: 344). He both highlights the importance of a good match between the competences available to the firm and those required for the project and attempts to construct an approach that links several levels of analysis (the project, the firm and the environment). The factors determining success reveal the role of the capacities or resources that firms possess, as well as that of the internal organisation of projects. The analysis suggests that a firm's capacities for internal co-ordination should be identified. It is true that the dynamic aspect, that is the management of a succession of innovations, is not really given systematic consideration in studies of specific projects. Innovation emerges in fact rather as a central function requiring adequate use of resources (talents, leaders) and processes (and in particular projects that the firm has to be able to evaluate, as well as measures to enhance motivation and communication).

While innovation requires co-ordination, it is becoming essential to understand the mechanisms that help to define it. What are the learning mechanisms through which the rules governing co-ordination (within projects and within firms) can be transformed or

stabilised? What is the role of cooperation among actors in supplementing co-ordination mechanisms that may on occasions prove inadequate as adjustments take place within organisations? Attempting to understand the modes of co-ordination not only within projects but also in the more general construction of competences would seem to be a particularly pertinent exercise.

Innovation and knowledge sources

A further objective of the survey is to elucidate the various modes of knowledge construction.

It is known that openness to the external environment is one of the main sources of innovation for firms. Carter and Williams (Carter and Williams 1957 ID: 329), in the case of England, and Myers and Marquis (Myers and Marquis 1969 ID: 345), in the case of United States, carried out quantitative studies showing that most innovations have their origin either in the adoption of a source external to the organisation or in market pressures exerted by demand or the competition. These findings are corroborated by a whole series of other studies.

Allen (Allen 1977 ID: 250) showed that a significant share of the messages transmitting ideas and solutions taken into account during a project come from personal contacts outside the firm. However, these interpersonal transactions are always extremely informal. Researchers respond to information needs in an ad hoc way, more or less as it suits them. Von Hippel (Von Hippel 1987 ID: 346) shows that individual researchers decide whether and how to comply with a request or to approach a particular partner. Thus firms take advantage of a phenomenon which they cannot dispense with but which they can neither really monitor nor control.

This raises the question of the choices firms make in opening up to the external environment. The objectives of inter-firm cooperation are examined in the literature. The main reasons for such cooperation seem to be, firstly, the opportunities for learning and appropriation created by gaining access to partners' competences and, secondly, the production of new competences (Nonaka 1994). However, firms can be driven to cooperate by a fairly diverse range of needs, or simply by a desire to open themselves up to the external environment. They might wish to:

- reduce the risks of technological choices made during the planning of research (that is very much upstream of any potential risk);
- promote innovation within their own organisations;
- diversify their competences and markets (the globalisation of competition, on the one hand, and the convergence of certain technologies towards the same application, on the other hand, encourage attempts to gain access to new competences);
- reduce their research capability in order to overcome problems caused by the inadequate capacity of their internal laboratories (competences, specific equipment);
- encourage the development of new ideas without reinventing the wheel;

- share risks.

From this point of view, cooperation has three fundamental attributes. It is

- a way of combining tacit or additional competences, or even an effective and efficient means of gaining access to information (Buckley and Casson 1988 ID: 328);
- an organisational mechanism for acquiring or exchanging such competences and information without entering into any irreversible commitments;
- a decision to create value and to hasten a firm's adaptation to its environment (Doz 1992 ID: 368).

Overall, therefore, a firm may very well be led to seek out partners on the basis of an inventory of its weaknesses (and not of its strong points) and to go it alone in producing knowledge in its strong areas. In such a situation, firms have to be able to choose from a range of different options and R&D has to be located sufficiently upstream for the partners to consider it worthwhile sharing the costs and risks, both financial and technological (Kogut and Zander 1993 ID: 359). The partners' involvement will be considerably greater if the results of the cooperation are strategically important, or if the distribution of the results seems equitable to all parties.

Innovation and knowledge

Thus the most advanced research on the management of innovation encourages us to focus on the circulation, transfer and accumulation of knowledge. The process of transforming concepts (whether technological or commercial in nature) into new products involves not only the exploitation of existing knowledge but also the creation of new knowledge. This process of creation takes place in several different time domains that have to be identified in the context of a study such as this. Since innovation projects have become a permanent way of life in certain industries, it seems appropriate to consider not only the management of innovation but also, and particularly, the permanent structures within which knowledge is managed. Thus, following Nonaka (Nonaka 1994), we refer to both the intention and the multiple processes of knowledge management that are at work within organisations. Within this framework, the firm is defined as a collection of segments of spaces or platforms for the creation of knowledge (see the concept of "Ba" developed by Nonaka (Nonaka and Konno 1998)). These spaces exist in several different dimensions in turn:

- physical: department within a firm, sphere of commercial influence, cooperation agreement;
- virtual : e-mail, teleconferencing;
- mental : shared experiences, professional interaction, shared ideas and attitudes.

Thus the firm is posited as a permanent locus for the creation of dispersed knowledge. It is management's task to facilitate the identification of these loci of production in order

to take advantage of them in a more collective way. Thus what we are developing here is an organisational approach to knowledge that seeks to go beyond a narrow focus on the inter-individual transfers of knowledge that may take place in ways that go unrecorded by firms. The management of knowledge is not new. What makes it an interesting field of study is the fact that it is explicit, routinised and brings into play the various "standard" management tools. It is interesting from two perspectives:

- from the point of view of the analysis of innovation processes, and
- in terms of explaining the linkage between the external and internal levels of the process whereby competences are constructed.

Thus we will posit that the management of knowledge is a precondition for the management of innovation.

Knowledge and competences

The firm is an institution that acquires new knowledge (through the recruitment of young graduates and professional from other firms or from the higher education system) and also creates knowledge over the course of its history. This knowledge is conceived as a resource that can be drawn on in the course of innovation projects. It is part of the firm's assets and has to be protected and used in accordance with the activities in which the firm engages. Knowledge can be defined as a stock that is the object of regular inventories in order to identify the potential for innovation (Pomian 1996). In this case, we are dealing more with declaratory knowledge, which exists independently of the actions likely to bring it into play, than with procedural knowledge, which is incorporated into the action. Above all, however, it is deployed within a process of production and use: it is produced by individuals through an effort of understanding that very frequently draws on a network of surrounding knowledge and is the result of an experience that may be individual or collective. The knowledge is then said to be contextualised (Vinck 1997). This distinction calls for further clarification of the links between knowledge and competence. We are in fact dealing here with a circularity that merits further explanation:

- the supplementary knowledge acquired by a firm's employees, the recruitment of new employees, the acquisition of a new company or even a merger may create the conditions for a gradual transformation of competences of the members of the organisation and, through a process of diffusion, those of the firm as a whole;
- the acquisition and absorption of new knowledge require specific investment as well as competences in co-ordinating with the external environment, in other words competences in assimilating new experiences.

There are indeed several types of competences, some individual, others collective, that play a more or less decisive role in structuring scientific and technological knowledge. Professional know-how links these forms of knowledge with procedural forms of knowledge. Firms develop competences in organising these various forms of know-how in order to identify knowledge and commit it to memory. They also develop

competences in co-ordination in order to diffuse that knowledge within its various departments and subsidiaries. Finally, a competence in collaboration is required in order to extract maximum benefit from the partners' resources. Any collaboration is in fact the object of a multiplicity of decisions taken by the partners, who have to decide on the forms the collaboration is to take and negotiate the terms of the transactions. We are dealing here with a circular process in which firms are seeking the knowledge they judge to be necessary and for which they have to equip themselves with certain capacities for acquisition and synthesis. This circularity can be summarised in a few propositions.

- Firms have to possess certain competences in order to access "external" knowledge (architectural competences such as those required for collaboration, as well as the competences required for the efficient production and mobilisation of resources).
- These competences are constructed in specific ways within the various units in firms (departments, subsidiaries in the case of multinationals). This raises the question of managing internal diversity.
- These competences play an important role in the production of knowledge, whether or not it is shared with partners. This raises the question of how to co-ordinate diverse sources of knowledge.
- The integration of new knowledge impacts on competences: experience acquired in the course of collaboration, enhancement of individual aptitudes through encounters with other professionals.

These competences in the development of new activities are defined in the literature¹³ as specific, tacit, intangible, accumulated over time, durable and scarce, and therefore difficult to imitate. It is interesting to link the various levels of competence by showing that there are systems within firms that combine aspects of knowledge management with aspects of human resource management. These systems are devised and implemented in a "multi-level" way: within firms, between firms and their academic and technological partners and globally in the case of the various sites operated by multinationals.

Diversity of resources and the organisation of R&D: the role of structures

Multinationals and technological globalisation

In organising their R&D activities, multinational groups actively seek out a diversity of resources. This diversity applies to the modes of product design, of technology construction and of client relations¹⁴. Similarly, there is a diversity of occupational and personal profiles. Finally, it applies both at multinational level (the main thrust of multinational strategy being to incorporate diversity rather than endure it) and in local

¹³ Many authors have contributed to the development of this theoretical school: Penrose 1959; Nelson and Winter 1982; Wernerfelt 1984; Teece 1988; Prahalad and Hamel 1990; Barney 1991; Leonard-Barton 1992; Amit and Schoemaker 1994.

¹⁴ We are not referring here to multinationals' location strategies, which involve either producing locally or adapting products to the market profile.

establishments: a single R&D unit usually draws on a number of different sources of knowledge (technological alliances, collaboration with universities and engineering schools that do not necessarily function institutionally in the same way).

The firms studied are attempting to endow themselves with this diversity through globalisation. They have embarked on this process from fairly different starting positions. A few of them are very diversified and wish to remain so, while others specialise or are seeking to specialise in a small number of areas. A large group of firms embarked on the globalisation process at an early stage, particularly in respect of production but also to a considerable extent in the R&D sphere. The search for diversity through the globalisation of R&D seems to be necessary in order to obtain a critical mass, in both financial and intellectual terms. Investment is concentrated essentially in the USA, Europe and Japan, although biotechnology and electronics companies have recently been showing some signs of expanding into Eastern Europe and Israel.

Consequently, there are fairly pronounced differences in most firms between the individual sites in terms of their relationship to R&D work, mobility within the company, attitudes to evaluation and the definition of research activities, on the one hand, and development activities, on the other. This explains the desire of corporate managers to put in place procedures intended to establish stable points of reference for the whole group. It is useful to note at this point that the management of innovation is an essentially antagonistic if not ambiguous process. Three major analyses of the process can be briefly sketched in here.

- Following Perrow (Perrow 1984; Perrow 1986), March (March 1991) and March and Sproull (March and Sproull 1990) define the characteristics of the organisation/innovation antagonism. This antagonism has its roots in different cycles of exploration and exploitation that do not draw on a firm's resources in the same way, particularly with regard to the uncertainty surrounding a technology or the nature of the work carried out. The authors show that a technology is generally adopted if a firm's technical and institutional dimensions are improved as a result.
- Thus it is not rare for the impression to arise of a certain degree of confusion within the organisation. Studies have shown that such confusion often arises out of the conjunction of two processes. The first is essentially bureaucratic in nature and tends to standardise organisational structures, while the other reflects processes that are uncertain in terms of both purposes and timing. Duncan (Duncan 1976) developed the notion of the dual structure in an attempt to account for this confusion and that of "organisational ambidexterity" in order to underline the need to combine the hierarchical principle with personal initiatives that take place outside the framework of standardised rules.
- Finally, Dougherty (Dougherty 1996) attempts to show that the main factor determining innovation is the striking of a balance in management practices between deterministic approaches to behaviour and the emerging modes of organisation that emphasise mutual adjustment.

From the point of view of both knowledge management in general and the management of collaboration in particular, the cases we have studied do indeed generate precisely

this feeling of confusion. The diversity of resources deployed (whether taken as found or deliberately sought out) serves only to sustain this impression. Policies and the corresponding management practices are being developed with a view either to making activities more visible or putting in place the means very actively to exploit diversity. Against this background, the locality issue (the siting of a subsidiary in a specific environment) is a basic given in the management of multinationals. Firms are more likely to set themselves apart from each other through their management styles, which reveal differences in their ability to establish continuity in the management of knowledge. To put in place a knowledge management system, by setting up a technological database or committees to review feedback, for example, is to contribute to the production of order: the firm's activities are being shaped by working on the "knowledge resource". This order is all the more necessary since there is considerable diversity within firms. In the case of multinationals, the objective is to co-ordinate the diversity of practices that exist in the various subsidiaries, which operate in societal and cultural contexts that are never homogeneous in their approaches to employment and economic activity. The construction of professional qualifications in the education and training system, the definition of employment rules, the management of competences and even the leadership of work teams differ from country to country (Whitley 1992). The standardisation of management methods and tools is one way of bringing the various practices in subsidiaries into line with each other. Laying down rules for launching and evaluating projects, irrespective of their nature, and the establishment of transnational technical databases are examples of this trend towards homogenisation. Although diversity is actively sought out by multinational companies, since it provides a wealth of different approaches to innovation, the conditions under which such diversity is implemented are also being adjusted in order to encourage the internal diffusion of experiences. Against this background, the management of knowledge is one of the issues at stake in attempts to strike a balance between organisational unity and diversity.

Structures better suited to technological globalisation

In all the firms studied, control of R&D is organised internationally. After several decades of experience with siting diversification, the questions of centralisation and decentralisation (or "hub" or "network" organisational forms (Boutellier, Gassman and Von Zedtwitz 1999)) are being stated differently at the beginning of the 21st century.

The majority of the firms have turned their subsidiaries into specialist units, following a decision-making process based on an assessment of local technological advantages. These now exist in sufficient concentration in the various zones of the "triad". The movement towards specialisation involves giving a particular site responsibility for the development of one or more technologies (at this level, firms tend to think in terms of technologies rather than specific products). This allocation of responsibilities has proceeded over the last decade against the background of the drive to rationalise operations. There are several aspects to this drive.

- The first involves the sale of assets that no longer fit with the firms' strategies for their core businesses. Firms specialising in the life sciences have divested themselves of their chemical operations, electronics companies investing in

telecommunications products have ceased production of passive components and firms specialising in the intensive provision of services have ceased production of operating equipment.

- The second involves mergers or the acquisition of companies of different sizes (from rival multinationals to start-ups) with the aim of strengthening the resources required for specialisation. These rationalisations obey decision-making criteria that are seldom easy to reconcile with each other: while mergers are a means of enlarging a group's financial structure, they do nothing at all to facilitate the organisation of newly available technological potential.
- The third involves the extension of the portfolio of technological alliances and collaborations. These various forms of cooperation are structured in very different ways: multinationals are now involved in the activities of most of the leading public research establishments in different countries while at the same time forging alliances with the major players in their own sectors and using the services of emerging companies in order to limit the risks inherent in technological exploration.

Multinationals are globalising their technology strategies by seeking once again to extend their asset base while at the same time developing their contractual activities. Despite this, there is little long-term mobility between the various R&D sites or between the various countries in which the multinationals operate. Nevertheless, such mobility could help to bring about a certain convergence of practices in the various locations. What tends to happen, rather, is that functional managers, whose task it is to relay central management policy, spend short periods of time at the various sites. In fact, the structures of R&D activities have gone through several phases of development over the past 20 years, which explains why the current structures combine a market-driven approach with networking practices.

- In the first phase, which took place during the 1980s, firms devolved their centralised R&D activities to the business units. Prior to this, multinationals had been globalising their activities while retaining the bulk of their R&D operations in the parent company's territory. R&D was organised centrally in order to achieve economies of scale in the context of industrial strategies defined on the basis of the technologies in the companies' possession. Thus a central laboratory was charged with the task of developing these technologies by shouldering most of responsibility for co-ordinating the various co-operative ventures with other firms and academia. The inadequate understanding of commercial constraints within the system was put forward in justification of the decentralisation of R&D resources to operational units charged with the task of developing product policy in a more focused way, driven by marketing considerations and the technological possibilities. R&D groups were established as a result of this desire to control technology policy through the market. This brought the actors involved in the design of new products closer together, with spectacular results in terms of reducing lead times. However, this specification of resources also contributed to the increased diversity within firms.
- In the second phase, which took place during the 1990s, this strategy appeared to drift somewhat. In some cases, the business units' decision-making autonomy now turned into technological independence from the multinational group. In

fact, various problems emerged. Since each R&D unit was being urged to meet the needs of its commercial controller, it was very difficult for it to justify its own independent exploratory and collaborative activities. On the other hand, none of the units had much opportunity to co-ordinate its activities with those of the others. Finally, there were certain inadequacies in the accumulation and diffusion of knowledge. In order to exert greater control over the diversity of results produced by innovation projects, managements redefined the centralisation of R&D. Since it was impossible to return to the previous situation, it was decided to put in place network-type organisational structures. And so "corporate labs" began to be set up, reflecting the need to separate short to medium-term activities from long-term activities and, in particular, to put in place knowledge accumulation systems. Although it is the task of these laboratories to centralise knowledge and to diffuse it to those units that express a need for it, they do not operate like the former central laboratories. Their physical and human resources are divided up among several subsidiaries and they are required to operate as part of a network. This second phase equates to the third-generation R&D examined in the literature (Reger and Von Wichert-Nick 1997).

In more or less formal ways, firms have adopted this organisational principle, which consists of separating long-term exploratory activities from development activities. Diversity is organised on these same two levels. The functions associated with the strategic development of technologies are concentrated on the first level, where responsibility for major academic collaborations and the dissemination of knowledge within the firm also lies. The second level draws on the first but is more closely linked to the market dynamic. This division of responsibilities is very well established in IT and telecommunications companies but less well established in pharmaceutical companies, in the sense that the first level is not yet functioning fully as a network since it is still to some extent centralised at a single site that retains overall control.

However, this new organisational structure is subject to co-ordination problems. Although the short-term secondment of functional managers makes it possible to establish consultation procedures that are very useful in advancing knowledge, each of the levels in fact develops its own preoccupations and academic contacts. The cases that best illustrate these difficulties are those of firms that have become highly specialised in service-based products.

This search for control of diversity has been accompanied by another major development in the guise of project-based management.

Project-based management: a results-driven mode of organising professional interactions

The new R&D structures lead to the various units becoming specialised in certain areas, while at the same laying down the principles governing the exchange of knowledge. They are also intended to lead to employees becoming specialists in specific R&D functions. As they carry out their activities, however, employees are at the heart of a

multiplicity of interactions with their colleagues that contribute to the construction of effective innovation processes. Professional interactions occur at all levels at all the sites operated by multinationals; they constitute the basis of R&D personnel's creativity. The same issues around the control of diversity are raised here too: differences in the progression of R&D activities from unit to unit, differing assessments of clients and of risks and of the need for co-ordination, even within the same design team. In this case, diversity is the object of very considerable attention on the part of R&D managers. The dominant approach to rationalising R&D activities is based on the spread of project-based management. Very little research work is currently being undertaken that is not organised in this way. It has a general effect on management tools and behaviour. The reasons for the adoption of project-based management are linked to the demands of competitiveness (innovation time, R&D budget, shared understanding of "needs"), which structure a large part of the design processes, from the project specification and the drawing up of the project budget to the organisation of creativity and the evaluation of the results.

The example of ICT 1 - The separation of research and development: the difficulties of cooperation

ICT 1 is a firm with more than 20,000 employees created out of the merger of several companies. In the mid-1990s, it changed its R&D structures by dividing up its R&D activities into smaller elements and devolving more power to the business units. The aim was to shift the company's operations towards telecommunications services, the design of corporate IT systems and the integration of communication systems. These activities represent short-term development projects of undoubted profitability that management thought could be structured by recombining existing knowledge. The company used to have a fairly powerful corporate R&D function that maintained highly structured links with university computer science departments. This function found itself downgraded until management became aware of the need to supply the business units with technological knowledge. The two areas of R&D activity were then redefined as follows. A central R&D function was set up to take charge of learning processes based on the recovery and re-use of existing technologies. It forges technological alliances and collaborates with university department with the aim of absorbing knowledge that is no longer being developed internally because of the strong focus on the "service" component of products. Finally, it seeks to diffuse useful knowledge to the business units. These latter are responsible for product development and design and also engage in service activities; they have, on the one hand, to take account of the needs of their professional clients and, on the other, to take the initiative in selecting their own collaborative ventures outside the firm. However, difficulties have been experienced in co-ordinating the activities of these two areas of R&D activity. The knowledge developed at each of the two levels is not of the same kind, and the two sets of actors do not really succeed in initiating discussion of common problems. The business units' customer orientation and the academic collaborations of the central laboratory cannot be combined seamlessly to advance the company's technological development. In order to get over these

difficulties, a system has just been set up that is intended to help engineers to establish their professional reference points ("professional communities"); it consists of identifying individuals' needs in this respect (in terms of professional activity and cooperation) and suggesting training programmes likely to strengthen professional links.

Project specification and budget formulation: the emergence of procedures and the need for justification

Project-based organisation involves bringing together several professional specialities and competences in order to work towards the same goal. How can a diverse set of R&D employees be mobilised to achieve the same objective? Although diversity may be necessary, it nevertheless needs to be controlled. Even within the same firm, a clear distinction is frequently made between the "German" concept of the R&D function and the "British" approach, with the former remaining very strongly attached to the autonomy of the R&D function vis-a-vis business units and the latter showing itself more receptive to short-term commercial concerns; the "French" approach tends to lie somewhere in the middle.

From this point of view, the preparation for a project is very significant. It is subject to a standard validation process that applies to all the subsidiaries in a multinational group. As part of this process, the autonomous actors in the subsidiaries are called on to justify their intentions and the means to be deployed in giving concrete form to those intentions within the framework of a very explicit monitoring programme that is activated prior to and during the project. For most firms, the presence of a company of North American origin has been decisive in determining the speed at which this type of management is adopted. Projects are specified in discussions between marketing and R&D managers. The discussions focus on the value of the project in the light of the subsidiary's particular remit and of an analysis of its costs and benefits. The actors putting forward the proposal must supply a detailed breakdown of the project, dividing it into various phases that will constitute a ready-made schedule for monitoring. The project is submitted to a committee of experts made up of financial managers, technological experts and representatives of the R&D co-ordination committee at multinational group level. This committee decides on the project launch and its budget allocation. The committee's decisions are taken within a budgetary framework allocated by head office to each of the sites on the basis of its previous results. Thus the project must be prepared with its overall coherence in mind: it must both justify the value added it may create and provide proof of the availability of the resources that will be deployed, both internally and in collaboration with external partners. In this way, interaction between the different professionals is encouraged in order to ensure that proposals link the needs that emerge from knowledge of clients with the resources created from the production of scientific and technical knowledge. The encouragement must be all the greater since the actors are urged to interact on the basis of very different relationships to time and to risk. Marketing professionals consider short-term risk in terms of the image they have of users, regard the duration of a project as a time frame imposed on them and expect their colleagues to provide solutions that are ready for use. This is why they have a preference for shorter projects that are finalised on the basis of a risk assessment. For

technology professionals, risk is an inherent part of exploration and of the unfolding of the project; from this point of view, it constitutes a variable linked to the competences of the researchers and engineers who make up the project team. Risk is not defined in the same way by all the actors: for technology professionals, a project represents an opportunity to construct new knowledge, while others see it as a means of attaining commercial targets. Nevertheless, we are not really dealing here with a "client-supplier" relationship, since the actors on both sides have scientific or technical competences that enable them to discuss in detail their needs and proposals. A certain degree of homogeneity in these technical competences, in some cases the fact of having taken the same course of education or training, combined with functional mobility among employees, may facilitate the discussions that lay the groundwork for a project. Thus cognitive proximity between the actors facilitates the preparatory stages of a project: they are marketing managers who usually have technical expertise and have worked in R&D departments or engineers who have experienced functional mobility and are therefore valued contributors to the discussions.

The example of Pharma 1 - Project-based management and the integration of diversified competences

Pharma 1 is a European pharmaceutical company that globalised its operations during the 1990s by extending its activities to the United States. Control of R&D is divided between France and United States, with the various sites specialising in particular therapeutic areas. The company has matrix organisational structures, and technology policy is decided by an executive committee that relies on strategic guidance forums. The French and American units are not endowed with the same resources. The former have a system of human resource management characterised by low turnover among the scientific staff and a fairly traditional system of evaluation and individual remuneration; they gain access to academic knowledge through relatively unwieldy programmes of collaboration in which the state plays a decisive regulatory role. The latter, in contrast, have higher levels of staff turnover and a remuneration system based on individual commitment and results; their collaborations are structured around a much more flexible network of relations. Project-based management was introduced into the company relatively recently with the aim of uniting specialists in different areas around a common goal, namely the design of new molecules. External resources are drawn on in the initial exploratory phase. Each project has a project leader, who embodies the scientific reference point (therapeutic concept), and a project manager in charge of day-to-day operations. Projects are evaluated each month in the same way at each of the sites. Project-based management tends to force professionals from different backgrounds to co-operate with each other and to take on board the views of those outside their professions, such as industrial and academic partners and managers.

This co-ordination is based in part on the business units, which are responsible for maintaining the company's competitive position. In this case, R&D is a resource, but at the same time one whose specificities are fully recognised. On the one hand, it is R&D that provides some of the business units' jobs. On the other hand, it is R&D managers who have the task of ensuring that the internal and external resources required to conduct projects are available. As a result, the process of laying the groundwork for projects is non-linear. This is self-evident to all the firms. This process may be based on more or less structured networking practices, which will be analysed subsequently.

The organisation of creativity and evaluation

The complexity of these professional interactions is also revealed as projects unfold. It has become commonplace to make a distinction between "cosmopolitan" and "local" attitudes among the actors involved in projects (Petz and Andrews 1976). The former, which are also described as "professional", guarantee access to useful knowledge through their involvement in scientific communities, while the latter, which are also described as "organisational", are more committed to the success of projects by virtue of their greater involvement in routines. In the absence of any real certainty about the different variables affecting a project, each actor is in fact led to produce hypotheses and demands to put to his or her colleagues. Depending on the situation, a biologist will sooner or later declare himself more confident than his colleagues about an experiment's chances of success, while a computer engineer will seek his colleagues' support for his ideas for future uses of the Internet. In this respect, the project manager cannot be said to control the interactions. In fact, it is known that the composition of teams must fulfil two major conditions: the actors must complement each other and their behaviour must be compatible (Hagedoorn and Schakenraad 1994). It is at this point that the dilemma of professional interactions is defined: cognitive as well as social proximity must be privileged without impairing the necessary diversity of approaches to both the forms and content of innovation. Thus here we have the problem relocated within the framework of the actors' autonomy and management's leadership practices. When a project is being completed, the interactions occupy a different strategic dimension. The aim at this point is to define the lessons that have been learnt. What individual learning processes have the actors been through? How can a consensus be reached in order to make official what has been learnt collectively? As the accumulated experience undergoes a process of objectification, the interactions produce agreements and differences of opinion. This raises an issue of knowledge management: who is going to accumulate the knowledge that has been acquired, and by what means? These questions are important ones from the point of view of giving renewed life to the project teams. If a project finishes by achieving its objective, the experience it has produced will be durable: the successes and failures experienced by team members shape their attitudes and necessarily affect each team member's involvement.

The organisation of creativity is left to the discretion of local project managers. However, it is monitored by evaluation procedures which, at regular intervals (every quarter or every month depending on the nature and duration of each individual project), determine each project's future. The evaluation is carried out by a functional project

director whose task it is to apply the rules laid down for the whole group to each of the R&D sites. The aim is to assess each project team's progress in terms of the objectives laid down at the outset : time allowed for each of the phases, adherence to the allocated budget, production of new knowledge, technical reliability and commercial relevance of the project output (prototypes, software, simulations). This type of evaluation has several further advantages for multinationals:

- the standardisation of project control despite the particularities and individual requirements of each project;
- the opportunity to compare projects (benchmarking), both within the firm and against those undertaken by competitors;
- the dissemination of an approach to evaluation to every level of the management hierarchy;
- the identification of which teams are quicker or better producers of knowledge than others.

Nevertheless, project evaluation does not eliminate diversity within firms; rather, it provide guidelines for controlling the distribution of resources (by giving management the means to halt a project in order to concentrate resources on another) and to identify to some extent the potential of individual teams.

Globalisation and the localised absorption of knowledge

Control procedures are also being standardised in order to manage the construction of the resources deployed at each site. Whether they are dealing with human resource management or strategies for collaboration with academia, multinationals are obliged to link diverse sets of practices in the areas of employment management and knowledge absorption. The structures put in place at this level clearly reflect a desire to manage competences in organisational contexts that retain the specificities of their construction.

Collaborating in order to recruit

Academic collaboration is viewed in two highly complementary ways. Firstly, it represents a reliable means of recruitment that is recognised by all the firms. Collaboration also exists, of course, for the purpose of carrying out joint research activities.

The importance of recruiting engineers and researchers is reflected in a lengthy period of preparation and the measures taken to ensure beyond doubt that the right candidates are selected. This process is based on the very widespread use of industrial placements, or similar arrangements¹⁵, which may last for between 6 months and 3 years. The pharmaceutical industry is something of an exception in this respect, since it seems to make less use of such arrangements. In their research activities, pharmaceutical companies collaborate more with universities, which make little use of industrial

¹⁵ This is a reference to PhD-type programmes managed jointly by a research laboratory and an R&D unit. France has won a certain renown for the reliability of its research-based training agreements (Conventions industriels de formation par la recherche - CIFRE) and its use of industrial placements.

placements, than with engineering schools. Stable links with a university, an engineering school or a research laboratory enable firms to draw on the services of regular batches of advanced students who may ultimately be offered jobs. Similarly, the academic establishments may put forward candidates, thereby acting as filters and minimising recruitment risks. This collaboration strategy is structured at the local level within the geographical sphere of influence of the R&D site in question or within the national network in which the personnel of the future are trained. This locational factor plays a major role in multinationals' decision-making. Academic collaboration can apparently be structured through various mechanisms depending on the firm's situation within the national space.

- Offering placements to students provides an opportunity to test individuals' capabilities while at the same time enabling potential future recruits to get to know the company. The students are allocated to R&D projects and placed under the supervision of a tutor, who is responsible for initiating them into the relevant working methods. Placements are in fact periods of observation for firms, which attach considerable importance to individuals' ability to make the necessary links between their competences and the situations in which they will be placed: understanding the needs expressed by the other actors in the innovation process, explaining the research issues (and not solely the available technologies), aptitude for management. For many firms, students on placements account for a significant proportion of recruitment.
- PhD programmes managed jointly by universities and industrial partners represent an extension of the placements principle. The aim here is to enter into a collaborative venture with an academic partner around a research or development project. For the vast majority of the firms, this aspect of collaboration is structured around doctoral students. This approach is inexpensive and is a means of objectifying the relationship between the two partners, since completion of the thesis is a goal shared by both parties. The doctoral student acts as an intermediary between the academic and industrial partners, affording each an insight into the expectations and practices of the other and thereby helping to bring the interests of the two parties closer together. Preparing for such a venture represents a considerable investment for the industrial partner, which stakes its reputation on a successful outcome and also has to deal with a risk of moral hazard comparable with that associated with recruitment situations. In fact, the industrial partner is doing more than selecting a doctoral candidate, since it is also choosing an academic medium that will contribute to the development of the doctoral student's work and provide the firm with new knowledge.

The example of ICT 2 - The development of external cooperation and the acquisition of competences

ICT 2 is a major manufacturer of communications network equipment that has recently decided to specialise in the complementary relationship between Internet-related technologies and services. The company's R&D activities are organised on two levels (research laboratories engaged in long-term projects and an R&D function that has been decentralised to the business units). The acquisition of external knowledge is an important part of company policy; it achieves its goal by operating a wide diversity of establishments (41 R&D units throughout the world), through the acquisition of start-up companies and through a recruitment policy based on its academic partnerships (placements provide 80% of new recruits). The most sought-after recruits are PhDs in software engineering whose talents combine technical expertise and an understanding of the future uses of the Internet. People with such profiles are fairly scarce because they are much coveted by firms that have been established in this particular niche for a longer time. In this case, academic collaboration is seen as a means of gaining access to emerging technologies. Ten universities have been selected in order to meet this objective. The company is funding professorial chairs and doctoral students and is donating equipment. The professors funded by the company provide more direct access to academic research networks, facilitate the selection of candidates for the joint PhD programmes and participate directly in this innovation of new knowledge by dividing their time between the R&D teams and the university. In this way, a stable network is established between the partners with the aim of permanently expanding the firm's technological choices.

- These opportunities go hand in hand with actions located further upstream, which involve establishing partnerships with a view to influencing curriculum design. Paying considerable attention to the mix of academic and national profiles (perceived as cultural profiles) likely to produce a diversity of approaches to innovation, firms select their academic partners with a view to participating in the joint development of graduates' training. For their part, the academic partners are undeniably motivated by the financial resources on offer, which take the form of equipment and contributions to operating costs, as well as by the prospect of gaining insights into the concerns of business and industry, which often provide valuable guidance for their scientific activities and the updating of teaching programmes. Firms try to obtain preferential status with a few universities or engineering schools. This practice is very highly developed among firms located in the UK and is beginning to emerge in France as well. It is undoubtedly more widespread in the UK because of a shortage of the competences sought by firms, particularly in IT and telecommunications.

This approach to collaboration is part of the more general trend towards the renewal of competences within R&D units. The preparation for recruitment is part of an approach to the management of employment and of human resources that is seeking to achieve greater synergy.

Human resource departments dedicated to R&D and the identification of competences

Consolidating the circulation of knowledge within R&D units, creating synergies between the various professional groups and making the individual units' capabilities more transparent are major preoccupations for firms unable to exploit very high levels of staff mobility. There are several reasons for the low level of mobility among R&D personnel: the nature of the activities involved, which require settled groups of researchers, particularly in view of the fact that the units are highly specialised, the explosion of long-distance communications and the costs and difficulties of expatriation for staff and their families. Short-term moves seem to be taking over, but these mainly involve managers rather than staff working on the content of projects. This lack of mobility may be accentuated in other cases by additional factors. It particularly affects firms that employ a wide range of occupational groups, as is the case in the European pharmaceutical industry, and particularly those French and German firms with roots in the chemical industry. The length of research projects and the nature of the links firms favour also play a role in determining the level of staff mobility. The propensity to mobility also varies by occupational group; it is higher among engineers, who can move into the manufacturing side, then among scientists. Short-term moves and local links seem to be replacing longer-term moves in the construction of knowledge. These are processes that will be examined in the next section.

More generally, it is in the area of human resource policy that the practices of multinational firms are most difficult to co-ordinate. National specificities in the construction of skills and qualifications and occupational reference systems and differences in the structuring of career management rules persist. Occupational reference systems are much stronger in Germany and France than in the United Kingdom, while the sharing of responsibilities for the definition of skills and qualifications between firms and the training system seems to be more advanced in Germany.

In order to manage these recruitment policies, and more generally to develop employment policy, the firms have set up, most of them fairly recently, human resource departments dealing specifically with R&D personnel. In some cases, "corporate" functions have been set up in order to bring recruitment and collaboration with universities (partnership, joint training programmes) under one umbrella. Charged with managing the careers of R&D personnel, the task of these departments ultimately is to support a part of firms' knowledge management systems. Their efforts are directed towards reducing the differences in personnel management between the various subsidiaries (particularly in matters of remuneration), developing tools for evaluating competences and harmonising the portfolio of internal and external training programmes, which developed in a fairly piecemeal fashion during the 1980s.

From this point of view, the management of competences is a major element of human resource management. It takes concrete form in:

- the compiling of documents listing the competences employees possess, with attempts being made to match these competences to jobs deemed essential (job chart) in the innovation chain. These documents are management tools that make it easier for managers to create the picture of their organisation they are trying hard to achieve. They provide a basis for making comparisons between the various units and help to some extent to produce common reference points for R&D jobs.
- annual or bi-annual evaluations of individual competences, often using the 360° method, in which an employee is evaluated by several people in his or her sphere of activity. The evaluation of R&D employees is carried out in different ways in different locations. While it seems to be common practice in English-speaking world, it has been introduced with a certain degree of caution in R&D departments operating in Germany and France. Nevertheless, American multinationals have succeeded in establishing this particular management practice in these countries without encountering any obstacles.

These practices are a response to two objectives that are high priorities for the firms. Firstly, the virtual absence of mobility between R&D units has to be managed by fostering the evolution of occupational profiles. Secondly, they are intended to support the establishment of technical communities or forward-planning committees with a diversity of occupational profiles. In this regard, the identification of competences is seen as a means of gathering together complementary cognitive and professional aptitudes. This second objective is not being met by all the firms. Only those that come close to the principles of "adhocracy" seem to succeed in making such communities or committees work properly (staff meet and produce documents or take some form of tangible action).

Knowledge management is an element in these practices. The identification of staff competences - not only their technical expertise but also their ability to work in a team, their ability to understand the contribution they are expected to make - shapes the action of human resource departments to a considerable degree. Knowledge management is composite in nature, linking areas of management that are not necessarily co-ordinated: evaluation in the course of projects/evaluation by human resources departments, identification of areas of expertise by those same departments/identification within internal communities. In this way, we can gauge the extent to which knowledge management strategies are conditioned by the contingencies of firms' organisational resources. The same phenomena emerge from analyses of academic collaborations.

An example of ICT 3 - Tools for managing the internal market in competences

ICT 3 is in the process of refocusing its activities on the telecommunications business. One of its divisions has 4500 employees, 57% of whom are *cadres*, i.e. managers and other professionals (75% of them are graduates of engineering schools, while 25% are university graduates who have done postgraduate work). The average age of these managers is 40 at one of the sites and 50 at another. The basic unit for R&D activities is the project. This mode of organisation gives rise to a middle management problem: it is difficult to find employees who are sufficiently young but who have acquired a certain level of experience, particularly to fill project manager posts or simply to fit into a team in an operational capacity. Since average pay levels in the telecommunications labour market have shot up rapidly, A can expand its recruitment programme only modestly if it is to keep its wages bill under control. Because of a certain degree of inertia in its internal labour market, the company has strengthened its management of competences by seeking to establish a stricter correspondence between employees' career paths and their actual competences and by facilitating internal mobility between the established units and recently acquired companies. The human resources department has developed an expert system for the management of competences and careers based on competence mapping: identification of basic competences, classification into "families" and evaluation of personal competences by means of individual assessments. A transitional matrix linking jobs and employees and jobs to jobs has been developed with a view to responding to future needs.

The rationalisation of academic collaborations: justifying and sustaining multinationals' cognitive networks

Academic collaboration is subject to the same constraints as the management of the competences of R&D personnel. Developed on a local basis by taking advantage of the opportunities of the moment, academic collaboration must now be justified to central management by local managers. The objective here is to make these collaborations transparent in order to assess their relevance and to provide co-ordinated guidance for firms' actions. This seems to be a particularly ambitious goal. On the one hand, it is not difficult to understand why firms engaged in technological globalisation should seek to put in place networks of contractual and relational resources. In the sense that it constitutes a potential source of new knowledge, collaboration must be able to be of benefit to any unit that feels the need for it. On the other hand, academic collaborations tend to follow patterns of development that cannot easily be generalised. Current approaches to the creation of shared knowledge emphasise several factors: regularity of contact between the partners, the type of relations fostered when projects are being specified and the fostering of relations that allow tacit knowledge to be brought into play and common practices to be gradually developed (Doz and Shuen 1995), (Inkpen 1996). It is also known that the joint production of knowledge and the absorption of academic knowledge depend on the local infrastructures for disseminating such knowledge.

Thus even when they are standardised to some extent, collaborations retain a strong personal dimension. They tend to give rise to fairly durable links and academic research laboratories seem to be very attached to them¹⁶. Multinationals' attempts to rationalise their academic collaborations in Europe can be summarised by outlining three significant developments.

- The first important development was the consolidation of the globalisation of collaboration strategies. As a result of the changes they had made to their own internal structures, firms had equipped themselves with the means to apprehend their portfolio of collaboration at the international level. The first direct expression of this was the establishment of global collaboration functions whose specific task it was to co-ordinate the academic relations of the various units. This transnational mode of organisation frees subsidiaries from the local constraints on collaboration. In principle, it should enable each subsidiary to forge links with the academic partner of its choice within the multinational's network. In fact, this organisational ideal is dependent on the functioning of internal information networks: everything depends on the quality of the co-ordination between local managers in charge of collaboration and the ability of project managers to adapt their practices to different contexts in order to absorb the knowledge. This development manifested itself in different ways in different sectors. In the pharmaceutical industry, it took place in two successive phases on the American and European continents. First, many German and French firms set themselves up in the United States in order to build up very quickly the collaborative links they needed to support their specialisation in bio-engineering. These foreign ventures gave a more global dimension to their traditional portfolio of collaboration during the 1980s. In the following decade, American firms made the trip in the opposite direction, forging closer links in Europe. Changes in the regulations on intellectual property rights have made them more favourable to universities and have in fact encouraged multinationals to increase their investments in European scientific networks. In the IT and telecommunications industries, the globalisation of collaboration took place earlier, particularly in non-European firms, firstly because of the shorter duration of R&D projects, which made it easier to establish a greater diversity of links, and secondly because of the quality of the partners: engineering schools adapt more easily to these relations than universities.
- The second development concerns the quality of the relationships between the partners. As in the case of the internal management of knowledge, collaboration has led to the introduction of various management mechanisms and has caused firms to give detailed consideration to the needs of their academic partners. These needs seem to play a major role in the negotiation of contracts between the partners. Universities have realised that the various types of collaboration

¹⁶ Going against the current of general writings on the relationships between academia and industry, several phenomena need to be highlighted. Firstly, such relationships have existed on a large scale for a long time, and in some cases they have been very intensive. Secondly, they have always been a matter of concern to industry, even in countries reckoned to be hesitant in this regard. Thirdly, it was scientific communities and not national entities that were very quick to seize on these relationships as a relevant space.

give rise to two effects that may jeopardise the development of their research activities. Firstly, the recruitment of students by firms - sometimes even before they have completed their degrees - may well lead to a shortage of candidates for publicly funded research posts. Secondly, by insisting that relations remain exclusive to some degree, firms risk segmenting the supply of academic scientific and technological knowledge. As a result, collaboration contracts are now explicitly taking greater account of the needs of academic partners, which is regarded by firms as a promise of trust. This acknowledgement of the needs of academic partners is also an attempt to respond to the aspirations of research organisations in respect of intellectual property rights, since the latter are showing themselves more demanding than in the past when it comes to the division of rights.

- A third, more recent development has seen a concentration of collaboration among a smaller number of partners and a greater insistence on exclusivity. It will be particularly interesting to observe the results of this strategy in the longer term. Multinationals are gambling on structuring scientific networks not on the basis of a collection of regional or national spaces, as has been the case hitherto, but rather at area level. The intention is clearly to secure a diversity of sources of knowledge and competences, in the European area for example, for the actors in telecommunications or life sciences. The exclusivity aspect of this strategy is not entirely consistent with the greater recognition being given to the needs of academic partners.

These developments manifest themselves in different ways depending on the technology policy being pursued.

- Those firms that have the most ambitious technological programmes and are seeking to be world leaders find themselves needing to combine several different levels of academic collaboration. On the one hand, they tend to establish long-term partnerships with a small number of research institutions operating in basic disciplines in order to maintain a supply of new research findings for their own long-term research activities. In this area, the firms tend to favour exclusive collaboration. On the other hand, they also collaborate with universities and research institutions on specific programmes geared to shorter-term technological developments, albeit also within the framework of long-term agreements. In general terms, firms in this category are seeking to consolidate and extend their technological base.
- Those firms that have positioned themselves in technological niches, those that concentrate on the "service" element of their output (we do not include the pharmaceutical industry here) and, finally, a few recently established subsidiaries of multinationals tend rather to use collaboration as a general source of technological knowledge and know-how. A division of labour seems to have emerged, with the R&D unit focusing on product design and the academic establishment providing very specific knowledge, industrial processes or technical tests, sometimes as an alternative to a commercial supplier.

Thus the nature of collaboration with academia seems to change as R&D organisations themselves evolve. However, the structures are not in themselves capable of supporting

innovation projects, so the various resources have to be allowed to develop as opportunities present themselves. From this point of view, it is very interesting to analyse the co-ordination processes that are emerging in R&D units with the aim of reconciling incorporation in globalised knowledge management structures with the more localised creation of competences.

The management of knowledge and competences: the role of processes

The various rationalisation programmes implemented by multinationals are intended to ensure a continuous supply of knowledge for innovation projects. The programmes are driven by two animating principles: the exploration of new resources to be used in projects and the exploitation of tried and tested solutions in matters of co-ordination. In the case of activities linked to exploration, firms have a certain range of possibilities at their disposal which they have to turn to the best possible advantage. Several processes are at work here: the choice of partners and technology transfer, networking practices and the management of competences.

The issues at stake in the joint production and transfer of knowledge

The choice of partners

In most cases, these collaborations take place under the terms of an administrative agreement between the firm and the laboratory's supervisory body (university, engineering school or research council). This agreement lays down the rules governing exchanges between the partners, including funding and intellectual property rights. Collaboration poses different problems for the two partners.

For the academic partners, there is a risk of being locked into a long-term relationship, particularly when the industrial partner keeps an eye out for the presence of potential entrants. However, a different risk - that of fluctuations in funding - serves to offset the first. This situation has reached a fairly critical level in the American universities, and is developing in Europe.

For the industrial partner, tensions emerge at different levels. Head office may be more or less mistrustful or suspicious of uncontrolled segments of the innovation chain, and may therefore intervene at inopportune moments in the collaboration. The research teams, and individual researchers in particular, may react in similar fashion to extra-mural activities that are regarded by their partners as core parts of their duties (this is particularly the case with pharmaceutical companies in Germany and France). All these constraints mean that firms are now inclined to define cooperation in more explicitly detailed terms.

In the past, it was common practice for firms implementing a technological advance to provide staff training programmes by enlisting the services of an academic partner. These practices were strengthened by establishing more sustained links within a wide-ranging process comprising several phases of adjustment between the partners.

- Making the capabilities and needs of the two partners more explicit allows both parties to evaluate the other's projects. In this way, the transfer of knowledge can operate in both directions. This is the case with French pharmaceutical firms that have entered into multiple collaborative relationships simultaneously by launching calls for tenders for projects on exploratory questions. The proposals submitted by public research laboratories were subjected to evaluation by a scientific committee made up of industrial and academic researchers. The evaluation and, subsequently, the selection of projects provided opportunities for scientific and technical exchanges between the various actors.
- Debate on the content of future graduates' education and training has led to change and, in return, the provision of technical assistance in the form of prototypes, software and databases. Such exchanges are now becoming more commonplace with IT and telecommunications multinationals, which are setting up e-learning systems for engineering school students. The scope of these systems extends beyond national boundaries.
- Criteria for the certification of knowledge have been defined by laying down deadlines for the production of patents and publications and the associated intellectual property rights. Although each country has its own legislation in this area, some firms are putting in place their own specific bargaining systems.

The objective of these various preparatory processes is to provide R&D units with networks that allow a certain room for manoeuvre and within which it is important to make explicit the various partners' points of view in order that lasting confidence can be established, which in turn is supposed to allow industrialists direct access to information. Thus the predominant aspect in the management of portfolios of industrial collaboration is the role of human, and therefore local, agents.

This is also why the vast majority of collaborative ventures in Europe adopt fairly similar organisational forms. On the basis of a long-established relationship, a permanent network of exchanges is put in place between the partners. In many cases, it is through this network that the twin objectives of research and recruitment are pursued. In some cases, the network is also open to a fairly wide range of other partners: firms, suppliers or representatives of a scientific community. From this point of view, the processes of collaboration take three main forms.

- Joint research units bring together the partners for a period of several years, fixed in advance, to explore questions of common interest. The public research laboratory is the physical space in which the collaboration takes place and it receives funding for equipment and operating costs. Such joint units are the most favoured option for collaboration on exploratory topics which, it is hoped, will produce results in the medium term; they also provide opportunities for knowledge diffusion through the provision of continuing training sessions for company personnel.
- The joint laboratory, "without walls" or incorporated into a network, constitutes an alternative form of collaboration. The two partners opt for greater interactivity by agreeing to combine their work teams to a greater extent. The presence in the laboratory of employees of the company allows for a more

continuous transfer of knowledge, although there is a risk of mixing people of somewhat different occupational statuses.

- In its most advanced manifestations, it takes a more highly structured form often denoted by the term "platform". This amounts to a coalition of technological interests endowed with physical resources and located within academic research institutions. In this case, the extent of the collaboration varies depending on the maturity of the technology. A very broadly based collaborative venture makes it possible to consolidate a "pre-market" agreement on questions of exploration. On the other hand, hopes that the technology can be exploited in the medium term usually create a preference for an exclusive agreement. IT and telecommunications firms make considerable use of these various forms of cooperation in several European countries, whereas in the pharmaceutical industry such practices are used mainly in Great Britain and the United States.

Collaboration in all its various forms always raises the question of the alternative uses to which the resources used by the academic partners might be put (may a laboratory use equipment provided by an industrial partner in the course of a collaborative venture with another, rival partner?). Although the message coming from corporate headquarters is clear enough in this respect, attempts to put it into practice at local level come up against real difficulties: the laboratories' supervisory bodies may indeed act to ensure their researchers' autonomy, and in any case the latter are free to explain their activities within their professional communities rather than reserving such explanations exclusively for such and such a company.

The example of ICT 4 - the wholesale externalisation of research

ICT 4 is a company that has externalised most of its R&D activities. In this sense, it constitutes an extreme case in the organisation of knowledge absorption. The company used to be a manufacturer of mainframe computer systems but has now diversified into services linked to the new communications technologies. Its R&D activities have been divided up: exploration of the potential of information technologies has been entrusted to large public research laboratories, while the design of products incorporating these technologies has been allocated to the company's various R&D departments. The absorption of new knowledge is guided by the needs of the business units, which identify the products of the future likely to be relevant to the company. Links with academic research laboratories are structured through an economic interest grouping, the terms of which are negotiated for a five-year period. A steering committee on which both parties are represented decides on the launch of new research projects, while an operational department is responsible for project management. Internal project coordination is the responsibility of experienced researchers employed by the company who divide their time between the two organisations. They have the task of translating the needs for new products into exploratory projects and of exploiting the commercial possibilities of new concepts developed independently by public-sector researchers. The transfer of knowledge from the laboratories to the firm has proved to be somewhat awkward in practice because of a certain incompatibility between the firm's traditional bureaucratic mode of organisation and the laboratory's "open knowledge" approach. Nevertheless, the

collaborative links between the two partners have created a space for exchanges that enables company staff to be in continuous contact with students (lectures given at the university, supervision of industrial placements and doctoral theses) and to be part of a scientific network described by the researchers as "virtual friends in computing".

Technology transfer

The aim of technology transfer is to consolidate innovation capacities. The translation of economic objectives into (internal or external) organisational mechanisms and then of scientific and technical results into resources that can be directly or indirectly incorporated into new products takes a variety of forms. The purpose of these various mode of translation is to establish continuity in the linkage between the internal and external levels of knowledge management. This continuity is subject to certain tensions that can explain the success or failure of technology transfer (Lambert 1993). Among the points most frequently identified, a distinction needs to be made between strategic dimensions and organisational dimensions (the links between the two being self-evident).

- the ability of the firm, and particularly of its senior managers, to develop clear ideas in two areas:
 - future technological opportunities;
 - commercial opportunities and customer preferences.
- the role of organisational mechanisms designed to support the various stages of the innovation process. The match between the degree of centralisation and organisation in the organisation and the type of technological problem and knowledge at issue seems to be a major factor in determining the effectiveness of the transfer process (there seems to be a strong need to develop "mutual adjustments" within and between teams, and a no less important need to identify a number of opportunities to accumulate experience).

Project-based management seems to be the current response to the challenges posed by the various forms (internal or external) of technology transfer. The attempt to manage creativity and the need to justify particular lines of research may indeed bring about a negotiated congruity between the objectives of R&D and the resources devoted to it. The adjustments constitute so many mechanisms for reducing the uncertainty surrounding technology transfer. However, a certain residual and irreducible uncertainty persists in respect of the direct incorporation of new knowledge into tangible goods. Ultimately, the input of R&D managers at these various levels consists of evaluating cognitive progress within their own workforce. This amounts to evaluation of the transfer. By virtue of the partners' virtual integration within the R&D project (or pilot study), the evaluation should preferably be carried out implicitly: the assessment criteria

are not made known to the academic partners, and it is rare for a programme to be halted before it is scheduled to finish (the usual duration is 3 to 4 years).

Networking practices

The co-ordination of the actors is a major element in successful innovation. Several different coordination situations can be identified: those that develop in the course of projects, those that make possible the linkage with external partners and those that occur during less constrained periods of activity, when projects are not running, which can be very useful for the accumulation of knowledge. From this point of view, the networks of relations that develop within R&D units and associated functions are accorded the same attention as the networks that develop out of academic collaboration. The general objective is to improve the flow of information within the R&D function. To this end, the availability of resources is promoted, i.e. those preparing a project are encouraged to consolidate their knowledge base. In more dynamic terms, it is a question of accumulating knowledge, not necessarily in a centralised location but rather by diffusing it to the units most directly concerned, because of the nature of their remit, with the nature of the technology or academic contact. The need in matrix organisational structures to strike a balance between the project-based approach to management and one based on technical functions makes itself felt very often in firms, as does the need to bring different professional profiles together. In other words, and this is an important point in knowledge management, the aim is not so much to establish international projects (of which there are very few, incidentally) as to facilitate cooperation across different R&D units. It is in this way that knowledge management seeks to be transnational. Nevertheless, firms' networking practices are also strongly contextualised. Such practices are always based on the individual involvement of researchers and engineers who feel the need to stabilise their cognitive environment. And even at local level, academic collaborations are constructed within networks whose form depends both on the institutional possibilities and on the visions of the various individuals in positions of responsibility.

These networking practices can be divided into two groups that do not obey the same rules with regard to the circulation of knowledge:

- essentially bureaucratic networks that seek primarily to codify knowledge and are geared to the identification of information;
- networks that synthesise the initiatives accumulated over time.

The first often take the form of knowledge management tools such as technical databases. These databases synthesise accumulated experience in the areas of product design, patents, design procedures and software and technical tests. In these various forms, knowledge is codified to quite a high degree, which makes it more worthwhile to accumulate it centrally and to diffuse it to the various units. The other, less codified forms, such as that relating to project management practices, are not yet being examined as frequently or on such a widespread basis, despite real concerns in this area. Nevertheless, there are signs that attempts are being made to combine the most objective data with feedback from experience. The limitations of such an exercise are

similar to those of project-based management: for lack not only of time but also of a properly defined collaborative space, knowledge is not being accumulated as extensively as it might be.

The second type of network tends to be structured more around the behaviour of R&D personnel. In their various ways, these networks are intended to create professional interactions to complement those that develop in the course of projects. It is indeed important to support innovation projects with procedures that make it possible to capitalise on feedback from experience, to accumulate knowledge and to identify not only the needs for technical training but also employees' expectations in terms of the direction of technology strategy. The originality of these procedures lies in the fact that they are based on networking practices that are independent of hierarchical organisations. These practices respond to the needs of the various professionals for reference points: presentation of findings, advancement of scientific and technical knowledge, clarification and diffusion of views on R&D activity. In some firms, these exchanges take place within technical communities that bring together researchers and engineers with a reputation for professional expertise. They operate by co-opting individuals who have both achieved recognition for their work within the company and acquired a scientific and technical reputation in the outside world. The community

The example of Pharma 2 - the internal codification of knowledge

Pharma 2 is a large multinational that has expanded vigorously over the last two decades through its policy of exogenous growth. It has its origins in the chemical industry, but has reoriented its investment towards the life sciences. Long established in Europe, it set up in the United States for commercial and, above all, technological reasons. Control of its R&D activities recently shifted to a centre in America, where the various procedures for launching and monetary projects are laid down in detail. In each of the subsidiaries, a project director is responsible for applying these procedures and disseminating the results obtained at each of the evaluation phases to his colleagues in the other subsidiaries. These results are gathered together in an electronic document compiled at central level in the United States and made available to the various directors. This centralisation makes it possible both to compare the efficiency of each project in terms of deadlines, cost and technical reliability and to identify the new knowledge produced within the company and to disseminate it to potential users. The nature of the knowledge circulating within the company tends to be codified, even though details of the experiments also figure in the documents.

The example of ICT 5 - the circulation of experiences and the building up of professional competences

ICT 5 is divided into divisions on the basis of technological competences. The number and scale of projects make the circulation of knowledge within divisions problematic. An intranet tool displaying the technical information in use in the various divisions has been in place since the 1990s. However, this tool is not considered adequate for the task of balancing individual initiative and team spirit in order to produce innovations driven by the needs of users of IT equipment. Several arrangements have been put in place in each business unit in order to promote the circulation of knowledge and of associated experiences. These arrangements include workshops and forums at which proposals for technological innovations and reports on experiences are presented. The proposals that are adopted receive support by being promoted among members of the business unit. The dissemination of the knowledge underpinning each proposal is intended not solely to launch an innovation project but also to strengthen the cohesion of each unit's internal network. One of the strategic objectives of the company's human resource department is to extend this dissemination of knowledge as part of its programme for developing each division's competences.

meets at least once a year at a conference and its members are in permanent contact with each other, exchanging the fruits of their research. Within the firm, central management consults its community in order to draw up long-term technology development programmes. In the shorter-term, members of the community are regularly consulted by project managers, either for their technical expertise or to facilitate access to the knowledge and competences of individual employees. Indeed, it is thanks to the experts who make up these communities that their company's technological memory is kept alive.

Drawing on these principles of autonomous organisation, corporate managements pay particular attention to any form of consultation that can help to concentrate the identification of information needs and to diffuse the benefits of experience on a large scale (i.e. throughout the multinational). Since the end of the 1990s, arrangements of the technological forum type have developed in this way.

As far as knowledge management is concerned, the principal finding is of a patchwork of different practices. Against the background of the rationalisation of academic collaboration, and given the focus on development activities structured around the learning that takes place at business unit level, those engaged in activities further upstream are being encouraged to make their capabilities more explicit and to explain the general direction of their work in more precise terms. Indeed, the business units base their knowledge management on their understanding and interpretation of the market. This process is brought into play by corporate managers who are very concerned with the quality of internal dialogue, particularly between researchers and business units. Under these conditions, networking practices sometimes have certain shortcomings when it comes to the identification of competences.

The management of competences

The processes by which resources such as internal networks are mobilised can provide support for the structural rationalisation programmes implemented by multinationals. However, a firm can never be sure that these networks produce more homogeneity than diversity when it comes to the circulation of knowledge. Indeed, the resources committed to these networks are a response to local initiatives rather than to the needs of transnational structuration. The management of knowledge is a particularly revealing example of this.

Competences as a means of accumulating knowledge

The validation of technical competences has emerged as a multi-dimensional issue. It is, of course, a more individualised means of personnel management. However, it is also an opportunity to evaluate the effects of exercises in the circulation of knowledge, such as technology transfers, between the partners in collaborative ventures. Moreover, the inherent limitations of the apparatus of evaluation notwithstanding, the management of competences can be a way of identifying the potential that exists within an internal network. Two observations should be made here:

- not all firms equip themselves with the means to identify in such a direct way the knowledge accumulated through individual competences;
- competences tend to be evaluated not so much by multinationals themselves but rather by individual R&D units, which feel a need to formalise the knowledge in the possession of their workforces.

Despite the fairly widespread existence of competence management policies within the R&D function, few firms manage to set up expert committees (made up of human resource, R&D and project managers) responsible for recognising cognitive gains. These committees examine the files of candidates for promotion up a technical career ladder. The files are analysed from several points of view and candidates are questioned on their aptitudes and sources of knowledge. While the outcome for candidates is a prospect of promotion, for the committees the procedure constitutes a space in which experiences can be compared and a record of technological management maintained.

The example of ICT 6 - a body of technology consultants engaged in identifying expertise

ICT 6 is a pioneer in the internal circulation of knowledge. Until the end of the 1980s, management limited its engineers' attendance at academic conferences in order to protect its stock of knowledge, which was reckoned to be far in advance of that in academia. The company's technical community is made up of 300 members working in several different subsidiaries. It is divided into spheres of technological competence in order to establish points of reference for each sphere and to ensure that they are diffused within the various divisions (information bulletins, internal seminars). The following criteria are used to select members: technical excellence (patents, publications), profile in the outside world (particularly in academia), ability to forge links with the socio-economic sphere (technological alliances, governments) and their "vision" of technological and commercial trends. The members of the community are consulted as a matter of course when innovation projects are being selected. They are also involved in the committees set up to evaluate staff competences. ICT 6 has developed a number of processes for the management of technical competences (recurrent training programmes, quarterly assessment interviews, internal social barometer in the subsidiaries, problem-solving and experience-swapping groups) by means of which knowledge can be accumulated. Over time, these processes have fostered a very strong attachment among the workforce to a certain technological image of the company.

The question of technology diffusion lies at the heart of this firm's development; for this reason, particular attention is paid to the evaluation of the transfers that take place following a collaborative venture. There are procedures for identifying technical expertise at European level across all the subsidiaries. Candidates for promotion compile dossiers detailing their experience. Each dossier is examined by a committee of experts drawn from several of the company's subsidiaries. This is a competence management device that imparts a certain dynamism to employees' careers. It also enables R&D managers to record employees' level of knowledge, to identify internal and external diffusion networks and to maintain a record of technological management that extends beyond the management of each unit.

Implemented in this way, the management of competences is not the sole responsibility of the human resources function but is also undertaken within an evaluation space divided between the projects and the various areas of technological expertise.

The problems of evaluation

Most firms have not sought to implement this type of competence identification procedures, perhaps because they can in fact become a new source of diversity. Multinationals already have to deal with the question of societal differentiation when putting in place knowledge management systems. The identification of various forms of technical expertise gives rise to a different kind of diversity in terms of where the responsibility for evaluation lies. Allocating responsibility to different individuals can

lead to confusion between the various areas of responsibility and in the long term to an increase in diversity at a time when management is trying to control it.

Part of this increased diversity is due to the existence of innovation projects, although a not inconsiderable share is explained by the needs of knowledge management. When project teams are being constituted, and when they are carrying out their assigned tasks, it is the technical managers and general management who assess the aptitudes of the various employees. At the point of recruitment, and over the course of individuals' careers, competences are evaluated by the human resources department. Finally, in the course of collaborative ventures with academic researchers and interactions within internal networks, the competences of existing and possible future employees are assessed by other functional managers, and these assessments have some influence on decision-making. This whole evaluation chain has many discontinuities that have not yet been brought under control by the managements of multinationals. These discontinuities stem from the object of evaluation (which changes with the function of the evaluator) and from the purpose of the evaluation (evaluations can be carried out for employment management purposes in order to determine pay, as well as to encourage creativity from the point of view of innovation management).

The processes of knowledge and individual competence management constitute a potentially rich source of innovation for firms that is not completely contained within the structures of R&D organisation. Controlling these processes requires the architectural competences that currently constitute a challenge for multinationals.

Conclusion

Through its structures and processes, the management of knowledge represents an attempt not only to take advantage of opportunities but also to resolve organisational problems. Knowledge is recognised as being a competitive issue as well as an organisational issue. The low level of mobility between subsidiaries and between research laboratories and business units does not aid the circulation of knowledge. The diversity of occupational profiles sought by multinationals can also lead to cognitive compartmentalisation. Finally, the introduction of project-based management makes it possible to organise R&D activities more efficiently while at the same time reducing the opportunities for knowledge accumulation. The practices put in place in order to overcome these difficulties show that several different paths can be taken. At the same time, they illustrate the changes firms are undergoing as technological globalisation advances. The various modes of knowledge management attach equal importance to the production and to the absorption of knowledge. Preparation for the recruitment and integration of young graduates and the forging of lasting relations between firms and their academic partners play crucial roles in the absorption of knowledge. As a result, they encourage the observer to examine very closely the institutional aspect of the multiplicity of environments within which the subsidiaries of the same multinational operate.

In other respects, there is much to be gained by analysing the production of knowledge against the background of organisational dynamics. In doing so, we have revealed the

procedural and incremental nature of knowledge-related processes in the organisation of R&D activities and, more broadly, at the level of the multinational. We have also determined the extent to which the management of competences influences this structuring of organisation, indicating in passing the prospects for joint investigation of the various management methods. From this point of view, the study of the management of knowledge and competences puts third-generation R&D into context. Relations with higher education and research establishments are in fact part of the decision-making systems of multinationals operating in a multidimensional environment. We have illustrated their immersion in this environment by examining their attempts to control diversity. We have also shown that these attempts give rise both to solutions and to new organisational problems. It would seem that we are dealing here with a necessary dynamic and a venture that has to be embarked on by firms aspiring to play a global role in the construction of technological capabilities. This is all the more true since, at the same time, the various national spaces are the framework within which academic collaborations with very similar objectives and modes of implementation take place. Thus several cases have to be examined in order to draw lessons for industrial strategy. The situation in the IT industry is a good example, since the major national firms in France and the UK are no longer leaders in technology. The same can be said of the fragile independence of the major European pharmaceutical firms.

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Subsection 2 - Science Industry Relationships : Collaboration and Intermediary Organisation in the Innovation's Perspective

The following two chapters concur in two ideas, firstly that the modes of production and regulation of the higher education and research system, on the one hand, and those of firms, on the other, differ profoundly¹⁷ (and, secondly, that relations between higher education and industry play a major role in the dynamics of innovation.

In the first chapter, these two systems are seen as having their origins in divergent, not to say antinomic principles, even though various areas of compatibility can be identified. In the second one, on the other hand, an "intermediate" innovation space is defined right at the outset as a set of interactions and mobility flows between the two systems. Both chapters make the point that collaboration is on the increase and agree on the need to go beyond mere acknowledgement of the heterogeneity of higher education-industry relations¹⁸. The view is taken that the partnership relation has to be apprehended in its totality (rather than focusing exclusively on the contractual form of the relation) in order to give meaning to the variety of possible arrangements and eventually to construct typologies.

With approaches rooted in two different disciplines, economics and sociology, these two chapters take different variables into account. Moreover, the first one confines itself to transfers of knowledge as it proceeds with the task of modelling industry-science relations, while the second is also concerned with the interactions through which the competences of the actors involved in innovation are produced.

The first analyses the relations examined in the company case studies carried out in the course of the SESI project in an attempt to ascertain whether the objectives of industrial and academic actors converge or diverge. Locating itself within the "new economics of science" approach (Dasgupta and David, op. cit.), it uses the notion of "research agenda" in order to explain the various forms of accommodation between the interests of the industrial and academic protagonists in these relations. Furthermore, this approach seeks to be a dynamic one in order to take into account the changes that have taken place in industry-science relations as the process of innovation itself has changed. Thus the relations are classified in accordance with these various objectives. The models and typologies thus produced are an attempt to define good practice in a way useful to public policymakers.

The second chapter extends the relation to encompass public actors; in doing so, it adopts the triple helix approach (Etskowitz and Leydesdorf 2000)¹⁹. It begins by

¹⁷ Dasgupta P., David P., 1994, "Towards a New Economics of Science", *Research Policy* 23 (5).

¹⁸ Cohen W.M., Héraud J.A., Goe W.R., 1994, "University Research Centers in the United States", Carnegie Mellon University.

¹⁹ Etskowitz H. and Leydesdorff L. (2000), *The dynamics of innovation: from National Systems and "Mode 2" to a triple helix of university-industry-government relations*, *Research Policy* 29, pp.109-123.

identifying a number of intermediate actors and relational principles at work between the three systems, the existence of which in turn reveals a number of different intermediate innovation spaces (Lanciano-Morandat et al., 1998)²⁰. This chapter presents a typology of these relational principles and of the actors involved in them that incorporates their trajectories, and in particular the transition between formal and informal relations. It then goes on to investigate the variables that structure these intermediate spaces, namely the (multinational) firm effect, the innovative milieu effect, the sectoral effect and the national effect, before finally putting forward a method for analysing the relations between the various actors.

²⁰ Lanciano-Morandat C., Maurice M., Nohara H., Silvestre JJ. (Eds) (1998), *Les acteurs de l'innovation*, Edition l'Harmattan.

Chapter 3 - Nicolas Carayol, "Research Agendas and Science Industry Relations "

Introduction

The last two decades have seen a considerable increase in collaborations between academic researchers in the broad sense of the term and firms. The empirical literature has repeatedly shown the importance of this phenomenon and has started to study its specific features (Cohen et al., 1994; Mowery, 1998; OECD, 2000; Caloghirou et al., 2000; Thursby et al., 2000; Hall et al., 2000). If this phenomenon has been further reinforced by the introduction of regulatory measures and incentive schemes (Geuna, 1998; Mowery, 1998), its present scope demonstrates that it has become relevant for firms to go beyond the simple position of awaiting the spill-over of knowledge created by public research. In this respect, Meyer-Krahmer and Schmoch (1998) demonstrate that the firms' basic objective in signing contracts with public research is now the acquisition of knowledge.

Numerous authors questioning the consequences of this phenomenon have sought to identify the benefits (Brooks, 1994) as well as the risks and costs (Blumenthal et al., 1997; Berens and Gray 2001) stemming from a large number of science-industry relations. Such relations are thus at the heart of a larger problematic posing the issue of how science and private research "fit together" which includes the question of the implications of science-industry relations on the returns from public research in both the short and long term? A survey of the specialised literature suggests that two main approaches may be used. We shall briefly describe them and examine how they approach this issue and what rationales they suggest.

The first of these two approaches, usually placed under the heading "new economics of science", was introduced by the seminal article by Dasgupta and David (1994). It focuses on the study of the intrinsic economic properties of open science by drawing on the analyses of Merton (1973) and notably brings out its properties of collective efficiency. For David et al. (1992), basic research (largely assimilated to academic research) should be conceived mainly as an informational or cognitive input for applied

research (assimilated to industrial research), thus permitting its returns to be improved²¹. However, the question of the design of this informational input into the applied research process is not really raised. For these authors, moreover, the problem lies elsewhere: the social division of research labour, assigning basic research to science and applied research to the companies, guarantees the existence of a "dynamic balance" between open science and industry in these two worlds. Such a balance comes about naturally and it should be maintained²². The only relevant public policy issue thus becomes better promotion of the dissemination of scientific knowledge from science towards the companies, without calling into question the intrinsic efficiency of open science in the collective production of knowledge. Science-industry relations are justified solely because they permit better transfer of tacit knowledge (David et al., 1995).

A second approach introduced by Gibbons et al. (1994) is widely known under the generic name of "Mode 2 of knowledge production". These authors stress interdisciplinarity, the co-production of research in networks of science-industry collaboration and the production of knowledge in the " context of application " (Foray and Gibbons, 1997). Their focus is radically orientated towards the distribution of knowledge and even more so towards the adaptation of the supply of public research to the companies' demand. It systematically highlights the fact that the relations between academic and corporate researchers may contribute to producing knowledge with more obvious potentiality for application. The fact that the application potential of collaborative research is more obvious or immediate does not, however, mean that the returns are systematically greater. David (2000) has thus assimilated this approach to a new version of a market-pull vision of scientific production. The essence of his criticism is that an overly "naïve" vision of the production of knowledge makes public researchers too dependent on market constraints, which would ultimately slow down the progress of knowledge since this can only come about with strict respect for the standards and incentives procured through open science.

Overall, these two approaches would seem to occupy separate and irreducible fields of analysis in numerous respects, notably in their prescriptions of public policies, since the "new economics of science" insists on the limitation of science-industry relations while the "Mode 2" authors emphasise (implicitly at least) their systematically beneficial nature. In order to bridge this theoretical gap, it is crucial to arrive at a better understanding of the microeconomic mechanisms simultaneously called into play within science and in the course of science-industry relations. While such an enterprise goes beyond the purpose of this paper, our aim here is to propose the use of the notion of "research agenda" as the "missing" concept which would allow the oppositions between the different approaches to be reduced and to provide a more in-depth treatment of the problematics of science-industry relations. These agendas are the research objectives that the agents set for themselves. We would argue that they are crucial both in the functioning of open science (in normative and positive terms) and for the establishment

21 This theoretical proposition is largely corroborated empirically by Hall (1993), who shows that the volume of public research leads to increased investment in corporate R&D (if the return on private applied research is higher, the same is true for its volume).

22 On this point, a heading from the article by Dasgupta and David (1994) is significant: "Policy changes: maintaining science and technology in dynamic balance" (emphasis added).

of science-industry relations and the participants' returns and ultimately on the way that science and markets fit together.

The empirical evidence on which we have based our analysis comes from original data collected within the framework of the SESI project²³. These take the form of fifty in-depth case studies of science-industry relations in six countries (Austria, Germany, France, Portugal, UK, US) with industrial partners in the sectors of information and telecommunications, pharmaceuticals or health-related biotechnologies. The variables surveyed mainly deal with knowledge, partner strategies, original organisational solutions adopted, cash flows and intellectual property agreements.

Our presentation is organised in the following manner: after examining how research agendas are at the very core of the functioning of open science (second section), we shall demonstrate how they allow a better understanding of the process of establishing relationships between public and private researchers (third section). In particular, the introduction of new variables such as the expected benefits from the exploitation of synergies with collaborative research efforts or the academic researchers opportunity cost borne by the partial diverting of their own research agendas because of the collaboration suggests that two opposing forms of relations can be distinguished in practice. On the basis of the empirical data, we shall propose a typology which brings out six coherent types of science-industry relations and then compare the data and typology to the theoretical propositions from the preceding section in order to show that they are consistent (fourth section). We shall argue that the relations generate dynamic effects which may be distinguished on the basis of the two kinds of collaborations and that they lead to two ideal-typical models of collaboration (called A and B), with distinct original properties stemming from the relationship created between open science and the markets (fifth section). The final section will conclude.

Open science and the determination of research agendas

Dasgupta and David (1994) show the importance of the "rule of priority" (only the initial discovery of knowledge is rewarded) and the "norm of disclosure" in the functioning of open science. These two practices encourage researchers to publish their results rapidly (Stephan, 1996) and in this way, largely tend to make open science a mode of production based on the disclosure of knowledge.

This means that scientists are "immersed" in a certain profusion of information available from multiple sources. As Simon (1997) asserts, however, "a wealth of information creates a poverty of attention". This idea is in fact two-faced. For the researchers, it means knowing how to collect relevant information in order to serve a given objective and above all knowing how to set a relevant objective in view of the available information and their own knowledge. If the first idea is rather well described in the literature dealing with the economics of science (Dasgupta and David, 1988) and other fields (Shapiro and Varian, 1999), the second is less often addressed²⁴. But it turns out

²³ SESI is a TSER (Targeted Socio-Economic Research) project funded by the European Commission's DG XII (contract SOE1-1054, project 1296).

²⁴ It is interesting that, for a variety of reasons, the properties of science are found in the new economy, which is based on the new information technologies.

to be crucial in science. Indeed, if knowledge is generally available (i.e., the frontiers of scientific knowledge are identified), the essential variable in the competition among researchers naturally becomes their ability to determine the meaning and objectives of their research. Thus, the researchers are confronted by what Ziman (1987) calls "the problem of problem choice" in order to determine their research agendas.

Peirce (1896) provides us with the first formal model, which is devoted to the issue of the optimal allocation of research between projects characterised by different levels of utility and risk²⁵. Polanyi (1962) goes beyond this analysis initially situated at the optimum by describing the way scientists, free to choose their research agendas, coordinate themselves in the advancement of scientific knowledge. He asserts that the scientists' decentralised choices, guided by a kind of "invisible hand for ideas creation", are in reality optimal: "[scientists'] decisions are designed to produce the highest possible result by the use of a limited stock of intellectual and material resources" (Polanyi, 1962).

Even if his position may be taken as the efficiency argument²⁶, the affirmation of the optimality of the agents' choices is difficult to accept, however²⁷. It then becomes necessary to study the scientists' choices of agendas more closely. On this point, we have several empirical studies (Rappa and Debackere, 1993; Debackere and Rappa, 1994) which have addressed the reasons behind the scientists agenda choices, and a theoretical model of such choices has been proposed by Carayol and Dalle (2000), who study the evolution of the knowledge of scientific disciplines in the context of a dynamic stochastic model.

The original reward mechanisms of open science, the peer review and citation system, create a specific incentive system which orientates the scientists agenda choices. The first mechanism offers an initial evaluation of the importance of the scientific contribution. The journals are ranked according to the quality of the scientific contributions they present. The researchers, seeking to enhance the status of their research, attempt to publish them in the best possible journals. In and of itself, however, this first evaluation mechanism is incomplete for several reasons²⁸. Notably, it does not take into consideration the fact that the value of scientific knowledge also lies in its ability to stimulate the creation of new knowledge. This aspect is then taken into account by the citation system. In general, when scientists describe their research results, they cite earlier discoveries which have fed their own creation. By counting the

²⁵ Echoes are also found in Cournot (1861) and Lakatos (1978).

²⁶ This amounts to a justification of the fact that the society, unable to determine which is the best use of the scientists' attention, allows them a certain freedom in the objectives of their research and limits itself to certain major decisions (notably the distribution of funds among disciplines). An overly hierarchical and administrative determination of the research agendas would result in an extremely inefficient collective dynamics. Mayntz (1998) shows us the disastrous effects of the finalisation of public research carried out in a centralised, bureaucratic manner in the Eastern bloc countries.

²⁷ The utility contained in a piece of knowledge does not directly enter into the agents' calculations (in fact it is impossible to determine with precision). In addition, as Dasgupta and Maskin (1987) have shown, the different agents' choices of agendas in a winner-take-all situation creates phenomena of over-investment in research projects and notably in similar ("correlated" in their terms) projects.

²⁸ Obviously, the contributions in a single journal are not all of the same importance.

number of citations, it then becomes possible to measure the impact of a given body of research.

Taken together, these two systems of recompense have several specific effects on the way scientists determine their agendas. First of all, they create an incentive for the interconnection of knowledge. Indeed, knowledge that lies outside the subjects of interest and the theoretical canons of the moment will have less likelihood of being published in a good journal and even less chance of being cited afterwards. In addition, there are incentives to produce more general knowledge: the more general it is, the greater the number of future research efforts that may be linked to it. Such an incentive luckily compensates for the high costs and uncertainty tied to this kind of research. The combination of the two effects tends to produce corpuses of knowledge, in the sense of bodies of knowledge related to each other by common generic principles. They favour the agents subsequent learning experiences (reinforcing the agents' absorption capacity) and thus decrease the cost of "cognitive mobility" between research fields.

At a second level of analysis, these two reward systems also create two dynamic phenomena which may be opposed. First of all; they give rise to a tendency towards the production of knowledge on the "knowledge highways" following a rationale of minimisation of production costs and risks. As a result, scientific knowledge is tending to be ever more hardy and better established. Second, they create an incentive for creativity: being a pioneer in an emerging field gives hope that a large number of future research projects in the same field will refer to the forerunners. Here, the hope of greater rewards can compensate for the higher production costs and degree of risk. On the collective level, this poses the problem of the right balance between incentives for creativity and hardiness within the disciplines²⁹.

It still remains, however, that on the individual level, the researcher (or research team) has to arbitrate between research projects which promise rewards which are extremely great but highly improbable and those where the rewards are of lesser importance but more probable. If it has a high level of excellence in a specific field, it also has considerable ability for generating promising new research agendas (in terms of rewards) in this field, so that it will tend to specialise in this field and thus the marginal price of abandoning these agendas will be higher. The existence of synergies between lines of research is also crucial for the academic researcher's strategies: if these are slight, he or she will benefit from diversification, otherwise the advantage lies in specialisation.

Research agendas and science-industry relations

Among the arguments developed in the last section which target the intrinsic efficiency of science, it should be noted that none of them directly considers the social utility of the knowledge thus created, but only their "value" as revealed solely by mechanisms within open science. In recent years, however, many scholars have focused their attention on the increase in spill-overs from public research, notably through the

²⁹ The risks for a scientific discipline are, on the one hand, to wallow in conformism or, on the other, to be subject to passing fads (Crane, 1969). For a more detailed study of these last aspects and the introduction of a third level of analysis describing and explaining the phenomena of waves and self-reinforcements, see Carayol and Dalle (2000).

improvement of the economic relevance of scientific research (Gibbons et al. 1994). Public policies in Europe and the United States have limited legal obstacles and adopted measures encouraging corporate funding of public research (Geuna, 1998; Mowery, 1998). The declared objective of these policies is precisely that the setting up of science-industry relations should increase the economic relevance of academic research by influencing their research agendas. Whether through dedicated production or the co-production of knowledge, science-industry relations are likely to orientate academic research towards fields and requirements more compatible with the needs of the industrial partners, who are supposed to transmit a more realistic appreciation of the utility of the knowledge.

If, in normative terms, we cannot ignore the intrinsically efficient properties of open science (Dasgupta and David, 1994), from a positive standpoint, it is also impossible to deny the importance that the determination of research agendas has for academic researchers given the incentive structure they encounter. Given that any research collaboration requires the definition of a common research topic, science-industry relations imply the existence of not insignificant costs and benefits for the partners. Academic researchers anticipating research agreements with an industrial partner integrate these aspects into their calculations. Thus, there is not simple deal for academic scientific knowledge because, at a given level of quality, the "price" (expressed in terms of cash flow and IPR) of research in collaboration is not the only dimension of the transaction for the academic researchers. Furthermore, the calculations of the industrial partners also take these issues into consideration relative to their own reward structures. Thus; the problematics of determining the agendas is central for matching up potential academic and industrial partners.

Scientists' research agendas and science-industry relations

For an academic researcher, a collaboration agreement with an industrial partner generally implies making concessions in terms of content, somehow changing the direction of its own research agendas. Indeed, the industrial partners most often want to explore questions that the academic researchers would probably have judged secondary and which, in any case, will probably be less promising from the standpoint of the scientific reward structure. By accepting to devote time and resources to different research objectives, the academic researchers thus renounce using them in a different way, which means that for them, science-industry relations constitute an opportunity cost reflecting the cost of abandoning the pursuit of their own research objectives³⁰. In that respect, the opportunity cost is an increasing function of the researchers' ability to set research agendas likely to generate significant recompense within the framework of the reward structure of open science.

A collaboration with an industrial partner should not only be considered a cost for the academic researchers, however. Indeed, they can exploit synergies between the collaborative research and that carried out in parallel in the strict respect of their own agendas. But the greater the distance between the academic researchers' subjects of interest and those of the industrial partner, the less important the synergies which the

³⁰ It may be noted that, even if his is not dealing directly with science-industry relations, Stephan (1996) refers to the "opportunity cost of agenda choices" in a footnote without developing this idea any further.

former can exploit³¹. In particular, the greater the distance between the level of excellence of the academic researcher and that of the industrial partner, the less the collaborative research will be likely to generate pertinent questions posed in advanced terms, the less the synergies which the academic partner will be likely to exploit will be significant and the less its desire to collaborate will be strong.

But this gap between the endowments of the two potential partners reveals only one aspect of the existence of synergies between collaborative research and the academic partner's research agendas. In fact, it is possible that this gap is slight and that the content of the collaborative research turns out to be of no interest for the latter: even if the question posed is pertinent, it is still necessary for the industrial partner to have the will to make a sufficient investment to address it completely and not settle for partial results. This last factor, a function of the industrial partner's strategic choices, requires us to consider the way the latter's own agenda is determined.

The industrial partners' agendas and science-industry relations

In deciding to finance a research project, the industrial partner establishes an estimate of the research costs, subsequent development costs, the return on the investment and the chances of success. The more the potential research partner's knowledge is remote from the industrial partner's own knowledge base, the more the latter will consider the decision to invest risky because of the limited ability to make efficient, rapid use of this knowledge (Cohen and Levinthal, 1989). Similarly, the more the collaborative research is located close to the frontiers of knowledge, the more it is objectively risky. Thus, in general, and all things being equal, the more the research is sophisticated according to academic standards, the more it is risky from the industrial partner's standpoint, even if the latter will tend to invest in such an asset.

The firms handle different research projects in parallel, however, like a portfolio of risky assets (Dasgupta and Maskin, 1987; Bhattacharya and Mookherjee, 1986). Even if their decision to commit themselves generally in projects which are more or less risky corresponds to the strategy they adopt given a certain economic structure (Loury, 1979), they will always tend towards the parallel management of research projects with different levels of risk, which are likely to give rise to product or process innovations in the more or less long term.

Thus, the firms envisage collaborations with a potential academic partner in the following way: with a constant volume of returns and costs, they try to minimise risks by choosing collaborative research projects close to what they already know how to handle. In order to preserve their ability to innovate in the future, and thus to sustain their flow of innovations, however, they also develop collaborative research projects which are risky. In this case, it is extremely important for them to find an academic partner offering the greatest excellence in the field.

³¹ This distance can be represented in terms of two dimensions: a horizontal dimension which describes the specialisation of the agents in particular fields and a vertical dimension which describes the agents' levels of advancement within a single field. Even if we are mainly dealing with the second dimension here, the first should not be forgotten.

Compatibility of research agendas

We shall briefly summarise the two potential partners' arrangements for collaborating with each other. The academic player has a desire to collaborate with an industrial partner which decreases in proportion to the level of academic excellence and the gap between their levels of advancement but increases in proportion to the industrial partner's desire to carry out fundamental, and thus risky research. The industrial player generally has a desire to collaborate with a given academic partner which decreases in proportion to the latter's level of advancement and the distance between their two levels of advancement. However, when the industrial partner wants to get involved with a risky, ambitious investment, the tendency will be to seek an academic partner with the highest possible level of excellence.

The compatibility between these two willingness' (i.e., by the compatibility of the research agendas) is thus crucial for the establishment of science-industry relations and coexists with the features and objectives of the academic and industrial partners. The "price" of the research is the adjustment variable between these two relative willingness'; it is expressed in terms of cash flows and IPR. Without going into the details of the way these two variables are handled or those of the complex process of establishing the initial connection, we may say that the price requested by the academic partner will increase as the willingness to collaborate decreases, and conversely, the price which the industrial partner is willing to accept will decrease as the latter's willingness decreases. It should be noted that this is an extreme case, where the industrial partner's preoccupations correspond exactly to the academic partner's research agendas. In this case, the latter's opportunity cost is nil and the synergies which can be exploited maximal. The academic partner will then have a strong desire to collaborate with this industrial partner and, at a given level of excellence, will be inclined to accept a relatively low billing price for the research.

It is useful to represent the space of compatibilities/non-compatibilities by means of two opposite cases for each kind of partners, thus giving rise to four configurations (Table 1). The industrial partner who wants to carry out a risky research project will prefer to collaborate with an academic partner of a high scientific level in the concerned domain (HH) and thus renounce any involvement with an academic partner below a certain level of excellence (HL). An academic partner at a high level of scientific excellence in a given domain will prefer to collaborate with an industrial partner who is ready to accept a higher level of risk (HH) and will renounce collaborating with an industrial partner below a certain level of commitment to it (LH). Last of all, an academic partner with a low level of excellence will be ready to accept doing research at a lesser level and may come to an agreement with an industrial partner who wants to get involved with a relatively low-risk research project (LL).

Table 1: the theoretical zones of compatibility between potential partners in LL and HH

| | | Academic player | |
|-------------------|-------------|-----------------------|------------------------|
| | | Lower academic reward | Higher academic reward |
| Industrial player | Lower risk | LL | LH |
| | Higher risk | HL | HH |

A typology of science-industry relations

The theoretical framework which we developed above for the reading of science-industry relations might seem somewhat one dimensional and reductive for the description of what is clearly an extremely complex reality. Indeed, any detailed case analysis of the science-industry relationship brings out strategic objectives, organisational solutions and institutional arrangements which are more precise. There is a great deal of diversity in science-industry relations and this is even more true at international level. In this respect, Mowery poses the problem quite clearly: "[Collaboration] covers a diverse array of programs, projects, and institutional actors. No single recipe for project design, program policies, or evaluation applies to all these disparate entities. Collaboration is a means, not an end" (Mowery, 1998).

In order to explain this heterogeneity, it is logical to turn to empirical studies. This implies having a sufficiently large number of cases where it is possible to connect the situations of the partners at the beginning of the relationship, the strategic objectives which have motivated their involvement, the broad outlines of the organisational solutions and the institutional arrangements (IPR, cash flow) on which they have agreed. On this basis, it becomes possible to establish a typology of science-industry relations, as is the aim of this section. We shall begin by presenting the data which we have used and then present the typology. Finally, we shall compare the empirical typology and the theoretical grid presented in the preceding section.

The data

In order to construct a typology of science-industry relations, we are using data collected in the context of the SESI project, covering a large number of case studies of science-industry relations in the six countries mentioned above. After visiting companies in the information and telecommunications, pharmaceuticals, and health-related biotechnology sectors, we identified and then interviewed their academic partners. This study thus potentially concerns all the scientific fields which have relations with these sectors (engineering sciences, applied math, physics, biotechnologies, organic chemistry, etc.). On the average, some fifteen interviews in average were carried out in each company (with heads of R&D, human resources and technical services and the researchers) and in the public laboratories involved. Such a

methodology based on case studies allows us to reconcile empirical wealth and comparability because of the substantial number of cases analysed within an integrated theoretical approach. In all, out of the twenty-seven firms visited and included in the study until now, we have identified and selected fifty cases of collaboration, including thirty-seven in the information and telecommunications sector and thirteen in the pharmaceutical and health-related biotechnologies sectors³². Eleven cases of collaborations directly involved several partners but our interviews were limited to the firm initially visited and the main academic partner. Six cases involve spin-offs³³.

The obvious advantage of international data is that they allow us to go beyond specific national features often resulting from the existence of particular institutional mechanisms and to focus attention on the variables essential to the collaboration. The cases are mainly defined by means of three series of critical variables. The first is related to knowledge: the agents' initial endowments in relation to the knowledge produced through the collaboration; these data permit an understanding of the agents' strategies and objectives, notably in the production and/or acquisition of knowledge. The second series of variables concerns cash flows and IRP agreements. The third series tells us about the way in which the relations are established, namely the original organisation solutions adopted for the production and transfer of this knowledge (duration, amount of research, organisation of the collaborative research and organisation of the partners vis-à-vis the relations).

Types of science-industry relations

Detailed study of the cases brings out certain regular features concerning these three series of variables. More precisely, we have been able to constitute six coherent types of science-industry relations, which we shall briefly summarise here. (The main contours of the typology are presented in Table 2, included in the Appendix.)

Type 1, which involves fourteen cases of science-industry relations, offers the most simple version of the collaborations. It illustrates a situation in which an academic player already has application potential, expertise or technology (because of the player's area of scientific specialisation). The marginal investment needed to develop it thus relatively slight and may be accomplished through a doctoral dissertation or even a master's thesis. The academic partner perceives the relation simultaneously in terms of a complementary development of its knowledge, an opportunity for student placement and the establishment of an industrial tie which can subsequently be strengthened. The industrial partner sees this relation as a means of creating ties with a potentially new academic partner and thus testing its capacities as well as an opportunity to benefit from

³² The firms visited include notably: Motorola, Hewlett Packard, Nortel Networks, Alcatel, Ericsson, Siemens, Canon, Racal, ICL, ICI, Pfizer, Aventis Pharma and Boehringer Ingelheim. Some of these were visited in several countries. The sample is not limited to large multinationals; it also includes several SMEs.

³³ For a more detailed analysis, see Carayol (2001) in the SESI project final report submitted to the European Commission.

knowledge at a relatively low cost, which it can absorb totally by purchasing the technology and/or hiring the PhD who has carried out the research.

Type 2, which involves ten cases of science-industry relations, consists of strategic bilateral relations most often based on framework agreements extending over several years and possibly covering a large volume of research³⁴. The academic partner is specialised in topics with a strong application potential; it tends to adopt a dedicated, integrated organisation in order to meet specific industry needs (respect of deadlines, responsiveness), to attract their collaboration budgets, (industrial partner clubs) and limit the costs of collaborative research. Industrial funding occupies an important share of their budget, which often compensates for difficulties in obtaining a sufficient level of supplementary public funding. By stabilising the funding from one or several major players in related sectors over several years, it thus stabilises its own funding in the future. The industrial partners offer a natural opening for their PhDs, who cannot all be absorbed by the academic labour market (which reinforces the ties even further over the long run because the PhDs become potential clients). The academic partner observes industry's needs and attempts to anticipate future demands, which allows it to select research directions which will turn out to be most fruitful in terms of science-industry relations. It also plays on synergies between lines of research and thus benefits from increasing returns.

The industrial partner outsources its research in this context mainly on the basis of a low-cost research offering (it could carry out the research itself but this would cost much more). The research is not at a very high level, entails relatively few risks and is likely to yield innovations in the short and middle term (6 months to 5 years). The industrial partner often hires the PhDs who have been directly involved in the research projects funded. As the partner has been able to observe their abilities over a relatively long period of time, there is less asymmetry of information and the work contract is generally more stable. By hiring the PhDs involved, the partner is sure of being able to absorb the knowledge produced (notably tacit knowledge) if this turns out to be useful. This permits the industrial partner to compensate for the risks of losing competences through the outsourcing of the research. The academic partner is responsive to its needs (as permitted by the establishment of considerable decentralised relations between engineers and academic researchers) and has appropriate organisational structures. In addition, the industrial partner may influence the academic research agendas and encourage specialisation in fields deemed promising in terms of its own research needs. In most instances, the industrial partner insists on maintaining the industrial property rights for the collaborative research because such research is generally rather close to development.

Type 3, which involves seven cases of science-industry relations, includes research consortia associating several research laboratories and several firms. These are most often set up on a national basis and benefit from considerable public funding. The broad objective common to academic and industrial partners is the building of bridges between their two worlds, thus permitting both the development of the interpersonal relations which will provide the basis for subsequent bilateral agreements and the joint creation of the cognitive bases for a shared research field. The academic partners have

³⁴ One case of a consortium has been included in this type because the collaboration involves only one academic partner and three industrial partners, one of which has a preponderant share.

many of the same features as those of type 2 and are in fact often involved in this kind of relations as well. The firms are interested in this kind of relations mainly because of the low costs: jointly produced knowledge and major investments are shared (in part or entirely) and there is generally additional public funding. The firms are most often required to make considerable concessions on research content, however, and the periods necessary for structuring the project can be long. There may also be significant problems with IPR and the sharing of technical knowledge because of the large number of partners, who may be direct competitors (while the research projects may be exploited rather quickly).

Type 4, which involves eleven cases of science-industry relations, bears on collaborations which are riskier than the preceding ones. They do not entail large amounts of funding. The academic partner is generally at a higher level of excellence, specialised in a narrow field of competence and less inclined to let itself be swayed from its research agendas. Its research projects have less potential for direct application than the previous types. The industrial funding thus almost exclusively supports lines of research deemed likely to earn recompense within the scientific community itself. The company takes a greater risk in funding this research than in the preceding types but it nonetheless commits itself to these collaborations because they should allow it to maintain its capacity for innovation in the middle and long term and/or get beyond a recurring technological obstacle. In this context, the industrial partner is less inclined to influence the academic partners' research agendas, precisely because, in its eyes, their interest lies mainly in their originality. This kind of relationship is most often spontaneously organised and flexible. *Type 4* also includes the endowment of university chairs (2 cases), the content of which is increasingly directed towards the development of original research projects on behalf of the industrial partner.

Type 5 involves only two original cases of science-industry relations. These occur within academic research funding programmes developed by European pharmaceutical companies, which use science-industry relations as leverage in the reorientation of pharmaceuticals towards biotechnologies. These programmes have allowed them to create numerous ties with academic laboratories which previously had little contact with the firms. In this situation, since the company's main objectives were to establish networks of collaboration and develop multiple learning situations, it did not seem relevant to orientate the academic partners' research topics but rather, to benefit directly from the most advance research in the scientific field. Thus, the academic partner profits from industrial funding in order advance lines of research which it had defined in accordance with its objectives for academic rewards. In this respect, this type shares many common features with *types 4* and *6*.

Type 6 involves six cases of science-industry relations which are distinguished by two main features. For one thing, the research content is at once of a high scientific level and risky for the firm; for another, it implies significant funding from the firm (unlike *type 4*). In the firm's eyes, these two points are compensated for because the anticipated returns in case of success are extremely high. It should be noted that all these cases of collaboration imply the development of emerging research paths (bioinformatics, gene sequencing, new path in electronics, new mathematical methods of telecommunications monitoring and management). These relations thus give academic researchers (and often

corporate researchers as well) opportunities for important discoveries and major recompenses as pioneers in emerging lines or fields of research. They do not consider themselves constrained in their choice of agendas; on the contrary, the relationship offers important leverage for the advancement of their lines of research, notably those which are not yet well received by the academic establishment. The organisational forms adopted are rather varied and adapt fairly easily to the objectives, with the common goal largely guaranteeing the partners' involvement. The participants are notably mixed laboratories and private research teams located in a scientific environment.

It should also be noted that nearly 70 percent of the cases concerning companies in the pharmaceutical and biotechnology sectors belong to the last three types (9 out of 13 cases), while more than 70 percent of the cases concerning firms in the information and telecommunications sectors belong to the first three types (27 out of 37 cases).

Four of the spin-offs in our sample are involved with software technologies (notably for the Internet) which represented a by-product of the research activity (most often PhD theses) conducted at a specialised research institute. They have thus been classified in *Type 1*. Two biotechnology spin-offs which were the subject of specific high-level research projects have been classified in *Type 4*.

Typology and compatibility of the agendas

Here we are comparing the theoretical grid and the typology derived from the empirical data. The typology clearly brings out the partners' strategic objectives in the collaboration. *Types 1, 2 and 3* describe situations where the academic partner's requirements concerning the expected rewards of the collaborative research are less significant than in *types 4, 5 and 6*. Similarly, the cases of the first three types clearly correspond to situations where the collaboration represents a less risky investment for the industrial partner than in the last three types. We are thus inclined to place the cases of the first three types in the LL section of Table 1 and those of the last three types in the HH section. After reconsidering each of the thirty-five cases of science-industry relations in our sample (spin-offs excluded), it may be stated that each case taken individually confirms this correspondence. Thus twenty-one (resp. 17 cases) of the cases studied show both a high (resp. lower) level of requirements on the part of the academic partner concerning the quality of collaborative research and a high (resp. lower) level of risk taken by the industrial partner.

We may thus conclude that the empirical data tend to confirm the theoretical grid. Certain limitations must be noted, however. First of all, the data only concern real cases of collaboration and we have not specifically studied relations which might not have been concretised, while the theoretical grid attempts to explain relations and non-relations alike. Second, measuring the scientific excellence of the research projects is also extremely difficult and partial and is not based on indisputable data. We would argue, however, that there is no irrefutable measurement system available and under the circumstances, an in-depth case analysis is always preferable.

Toward two models of science-industry relations

Compatibility of research agendas and dynamics of science-industry relations

Developing a typology and a static interpretative grid helps us to understand a complex reality at a given moment in time. The relationship itself must be seen, however, as a source of change insofar as it constitutes a resource for the partners. In order to grasp these dynamics, it must be seen that one of the consequences of establishing science-industry relations is precisely the establishment of new science-industry relations. In the context of the surveys carried out, there appear to be four main types of dynamic effects.

First of all, the creation of a science-industry relationship may lead to the creation of specific organisational mechanisms for the management and evaluation of the collaborations. Thus, the fact of having established or continuing to establish science-industry relations can reduce the costs generated by new collaborations.

Second, science-industry relations permit the creation of networks of interpersonal relations. Third, the partners arrive at a more in-depth understanding of their research practices and needs through the relations they form. The academic partner is better able to respond to the industrial partners' needs and the latter are more able to benefit from the competences of the former. These mutual learning experiences lead to the creation of knowledge which is, in various ways and to different degrees, conceived to be developed by the different partners. They thus increase their knowledge bases in the direction of greater compatibility between them. The relationship can, on the one hand, lead to greater economic relevance of the academic player's lines of research and, on the other, increase the industrial player's capacity to absorb and develop the scientific knowledge.

It should be noted that these different dynamic effects are far from "pure". For one thing, they are not independent of each other and are most often combined. For another, they can be more or less specific to the initial partner; for example, the third dynamic effect, which depends on the learning of reciprocal needs and competences, is generally more specific to the initial partner, or in other words, that it particularly increases the propensity to collaborate with the same partner. Finally, the national institutional structures may considerably influence the way in which these effects occur.

In any case, it is rather difficult to predict exactly what these dynamic effects will be and there is obviously also a random dimension. We would argue, however, that they way they come into play may be distinguished in terms of the two forms of relations (cf. Table 1) and that they are generally reinforcing. Indeed, the establishment of one of the two forms of relations seems to reinforce the features which predispose the agents to collaborate according to this same form and leads them to undertake quite specific strategies. This leads to two global forms of ideal-type co-operation which we shall call Model A and Model B (and which are briefly summarised in Table 3). These models of collaboration also include a certain normative dimension in that they seem to display properties which are distinct but economically and collectively pertinent and which emerge from the interrelation of the two worlds of open science and the markets³⁵.

³⁵ This does not mean, however, that there can be no coexistence between the two forms within a single discipline, sufficiently large research laboratories or university departments. In general, the effect of the collaboration is more apparent as the level of analysis descends from the laboratory or university

Model A: Cumulativeness and social demand

In Model A science-industry relations, the academic partner's overall strategy is to increase its volume of research, even if this means allowing itself to be distracted from its research agendas. To this end, this partner needs to adopt a specific organisation concerning science-industry relations (in order to increase its visibility and reduce its costs). It attempts to maintain relations with several industrial partners in the same sector for greater development of its research projects and to deepen existing relations with one or two strategic partners in order to stabilise funding. If the academic partner is ready to be distracted from its agendas, it must still preserve its internal thematic coherence in order to benefit from synergies between its lines of research. But this requirement is not incompatible with the relations it maintains with industrial partners; on the contrary, once it is keenly aware of the problems faced by industrial concerns in a given sector, it can benefit from specialising in the production of knowledge which is useful to them. It thus undertakes a kind of "cognitive Darwinism", selecting the lines of research which will be pertinent to industry in the future. It plays the role of pooling information on the needs of the industrial partners and codifying their technical problems in order to provide common scientific responses.

This does not mean that it detaches itself from the academic world (since public funding remains its main source of financing) but it maintains secrecy about technical data and especially the industrial partners' objectives and avoids publishing research results before patent applications have been made. In this respect, the academic partner is usually ready to sacrifice intellectual property rights on collaborative research in order to fulfil its strategy aimed at the increase in the volume of research, especially since the industrial partner is all the more concerned with maintaining the ownership of knowledge relatively close to development.

The low cost of the research carried out by the academic partner encourages the industrial partner to outsource research that was previously carried out for the most part in-house. The cost is further reduced when the relationship takes the form of a consortium. The outsourcing does not entail a loss of know-how because the industrial partner can hire the PhDs who have carried out the collaborative research. The establishment of decentralised, long-term interpersonal relations allows the development of research projects likely to find solutions for technical problems that have been set aside. It uses the leverage effect of funding to encourage the thematic specialisation of the academic partners and thus encourage the emergence of centres of competences useful in the long term.

As a result, the bilateral and multilateral collaboration networks are fairly dense. Relations can be quite intense in the form of strategic collaborations; these strong ties are developed over the long run with a self-reinforcing dynamics, more specifically with the initial partners (who have a mutual advantage in prolonging or even intensifying relations with the same partner).

department towards the research group itself. It is also possible that there is a certain interpenetration between the two forms but in our view this would be difficult.

The collective effect of this dynamics is a specialisation of research laboratories in fields which conceptualise the industrial partners' technical problems while largely maintaining the dissemination of knowledge. Thus, the properties of efficiency intrinsic to open science (based on the cumulateness of knowledge) are for the most part preserved while clearly integrating the industrial partners' needs. This idea largely overlaps that introduced by the authors of the so-called finalisation thesis (Böhme et al. 1983) who maintain that a discipline can be finalised in an "appropriate" way in its "post-paradigmatic phase" (i.e., when it reaches a certain level of maturity). In economic terms, an "appropriate" finalisation means that the orientation of the research agendas is collectively efficient. There is no longer any conflict between giving a research project applied objectives and undertaking fundamental interrogations. This idea is integrated into the notion of "basic oriented research" (developed by the finalisation thesis), which contests any systematic opposition between fundamental and applied research. This reading is consistent with the description of the engineering sciences proposed by Rosenberg and Nelson (1994) and Detrez and Grossetti (1998) or that of the transfer sciences proposed by Blume (1995) and corresponds at the level of collective efficiency to certain arguments developed by Romer (1993).

Model B: creativity and social demand

In Model B science-industry relations, the academic partner's main objective is to exploit the advantage offered by its scientific edge in a narrow field of excellence. Its funding sources are mainly public and its PhDs generally find career opportunities in the academic world. It only establishes relations with industrial partners when the collaborative research is likely to reinforce its own lines of research and are thus only perceived as sources of additional funding. It is little inclined to permit itself to be diverted from its research agendas; which may if need be suggest and provide information about medium- and long-term applications of its knowledge.

The industrial partner undertakes such risky collaborative research because it anticipates high returns in case of success. The partner is often quite advanced itself in the field of investigation involved, which is necessary for the absorption of the academic partner's knowledge and that produced in the course of the relationship. This relationship may allow it to expand its positions still further and gain a notable advance over its competitors in the mastery of promising fields.

The Model B relationship is thus more orientated towards increasing the excellence of the two partners' research in a narrow field. The resulting science-industry collaboration networks are less dense than those of Model A. The volume of collaborative research may be very high in certain cases but there are fewer science-industry relations and they are less stable over time.

If the collective outcomes of the Model A relations have already been explored in the literature, those of Model B are more difficult to grasp. We would suggest, however, that they play an important role in the emergence of new fields or lines of research radically influenced by the needs of industrial partners.

Indeed, the academic partners considered here are mainly seeking a form of scientific excellence which may consist in contributing to the emergence of new research fields (cf. section 2). These path-breaking research projects are precisely the ones which

industry is likely to fund because they suggest a large range of new applications. In particular, interdisciplinary research projects are of considerable interest for science-based technologies (Gibbons et al., 1994; Meyer-Krahmer, 1997). This suggestion is supported by the empirical evidence stemming from our data, notably the cases of science-industry relations corresponding to *types 4* and *6* of our typology (cf. 4.2.), namely those which are closest to our Model B. Type 6 relations involve all the research projects in emerging fields (e.g., bioinformatics, gene sequencing, gene therapy, new paths in electronics, new mathematical methods). *Type 4* relations, even if they are of a lower volume, generally also concern original research projects exploring brand new paths.

Table 1: the theoretical zones of compatibility between potential partners in LL and HH

| | | Strategies of the Academic players | |
|---|---|---|--|
| | | Increasing their volume of research by pooling information on needs and codifying solutions of industrial partners | Deepening their knowledge in a specific area of excellence by collaborating only within this field |
| Strategies of the Industrial players | Benefiting from research at a relatively low cost in an integrated, systematic and less risky way | Model A lower risk lower expected reward stronger ties dense networks Cumulativeness and social demand | |
| | Entering a research field by contributing to its emergence so as to benefit from an important advance on its competitors even if he has to bear greater risks | | Model B higher risk higher expected reward weaker ties bilateral relations Creativity and social demand |

Table 2 - the six types of relations between academic and industrial partners

| | Type 1 | Type 2 | Type 3 | Type 4 | Type 5 | Type 6 |
|--|---|---|---|---|---|---|
| General considerations on knowledge content of the relation | The academics has produced a knowledge that has a nearly direct potential of technology or expertise transfer | The less the knowledge differential between the firm and the academics, the less substantial is the marginal benefit but the easier the collaboration, the less risky the outcomes and the higher the synergies based on lowering research costs and co-specialization | The less the knowledge differential between the firm and the academics, the less substantial is the marginal benefit but the easier the collaboration, the less risky the outcomes and the higher the synergies based on lowering research costs especially in research consortia | The greater the knowledge differential between the firm and the academics, the greater its benefits, but the more the relations become difficult, expensive, time-consuming and risky | The knowledge differential between the firm and the academics is very high, but the firm knows that it has to invest the field, quickly and massively | The knowledge differential is low, but both the firm and the academics are advanced and find it convenient to break a scientific knowledge road-block |
| The academic partner characters | are more oriented towards industrial needs, belonging to less prestigious universities or to specialized research units which need a certain volume of research contracts with the industrial sector, without, on the other hand, abandoning all forms of more fundamental research using their own funds - in order to keep one step ahead of the industry | are more oriented towards industrial needs, belonging to less prestigious universities or to specialized research units which need a certain volume of research contracts with the industrial sector, without, on the other hand, abandoning all forms of more fundamental research using their own funds - in order to keep one step ahead of the industry | are more oriented towards industrial needs, belonging to less prestigious universities or to specialized research units which need a certain volume of research contracts with the industrial sector, without, on the other hand, abandoning all forms of more fundamental research using their own funds - in order to keep one step ahead of the industry | belonging to more prestigious universities, oriented more towards innovative research, and academic recognition neither allowing the industrial sector to set their research agendas, nor isolating themselves completely from industry | belonging to more prestigious universities, oriented more towards innovative research, and academic recognition | belonging to the most prestigious universities, oriented more towards innovative research |

**Table 2 - the six types of relations between academic and industrial partners
(continued)**

| | | | | | | |
|--|--|---|---|---|--|--|
| <p>The firms' strategic objectives in establishing science industry relations</p> | <p>The firm may be a SME or a spin-off if the industrial partner is absent especially if this solution appears tractable to the academics If it is a multinational firm, the relation is perceived as a trial, in order to test the quality of a potential new partner</p> | <p>Establishing stable long term partnership In order to cooperate with a reactive partner, aware of the firms' needs Performing research for innovations which are scheduled to come on line in 3-4 years, Relatively inexpensive research, Hiring of Ph.D.s To influence the definition of the research agendas the academic partners, toward specializing them on its specific goals</p> | <p>Establishing low cost research based on shared investments and usually State additional funding Permits to establish contacts with academics that may rise to long term stable partnerships To influence the definition of the research agendas of different academic partners in order to settle the cognitive basis of further cooperation Performing research for innovations which are scheduled to come on line in 3-4 years,</p> | <p>Taking advantage of the wider and deeper knowledge base, which should allow the company to "spring open the technological lock" by trying to gain from original research For projects involving a time perspective of greater than five years. It is not pertinent to try orienting the academics agenda</p> | <p>Invest a strategic field in which the firm doesn't know much. The relation is mostly perceived as the support of a learning process. The firm is trying to accumulate relevant and up to date knowledge</p> | <p>Invest in a strategic field in which the firm already knows much, but feels like still going ahead, which requires to contribute to the advance in fundamental knowledge. This operation is supposed to give to the firm an important strategic advance</p> |
|--|--|---|---|---|--|--|

**Table 2 - the six types of relations between academic and industrial partners
(continued)**

| | | | | | | |
|---|--|--|---|---|---|--|
| <p>The academics strategic objectives in collaborating with industry</p> | <p>The relation is perceived as the valorization of an already created knowledge</p> | <p>The academics can benefit from resources coming from industry, particularly in the case of those academics receiving less than adequate state funding. To find industrial openings for their doctoral students (in the context where opening in the academic milieu are scarce). The academics will try to increase the volume of its relations with industry, by maintaining stable relationships with a limited number of major actors in the sector, this way trying to link the main actors in the sector to the competences of the academics</p> | <p>The laboratories can benefit from resources coming from industry, particularly in the case of those academics receiving less than adequate state funding. To find industrial openings for their doctoral students (in the context where opening in the academic milieu are scarce) The academics will try to increase the volume of its relations with industry, by maintaining stable relationships with a limited number of major actors in the sector this way trying to link the main actors in the sector to the competences of the academics</p> | <p>Pursuing research on strategic and highly-focused themes Contracts with industry are perceived as complementary funding, helping to finance advanced lines of research. Contracts, from this perspective, should not detract researchers too much from their own research objectives, oriented mainly towards the international scientific community Concerning the Phd, the main objective of the academics is to insert them within the scientific community</p> | <p>Benefit from substantial financial support without modifying substantially the research agendas of the academics</p> | <p>To benefic from the firms subsidizes without any conflict with its research agenda setting process. The knowledge produced will be at the top according to the academic evaluation criteria The academics may also take a great advance against academic concurrency this way</p> |
|---|--|--|---|---|---|--|

**Table 2 - the six types of relations between academic and industrial partners
(continued)**

| | | | | | | |
|--|--|--|--|--|---|---|
| Research volume implied by the science industry relations | Very low | High volume of research, conducted with regular partners, increasing in importance up to the signature of a detailed Framework Agreement | The volume of research is globally high, but being shared by the partners, this becomes low for each | limited | It may be high | High volume of research conducted with one specific and strategic partner |
| IPR and other strategic assets (code for softwares) | Owned by the academic partner, if the industrial partner is a spin-off Owned by the firm if it is a multinational | Usually owned by the industrial partner | Usually owned by the consortium institution, or distributed to the industrial partners through specific rules based on the funding of each | More likely to be owned by the academic partner or shared | More likely to be owned by the academic partner or shared | More likely to be owned by the academic partner or shared |
| Organizational solutions of the collaboration | No specific | Bilateral Framework Agreement In a long term relation | Consortium | A short-term relationship for a specific project | A long-term relationship | A long-term relation Mixed academics or bilateral integrated agreement |
| Typical cases | 14 cases 1 pharma / bio-techs 13 IT 4 Spin offs | 10 cases 2 pharma / bio-techs 8 IT no Spin offs | 7 cases 1 pharma / bio-techs 6 IT no Spin offs | 11 cases 4 pharma / bio-techs 7 IT 2 Spin offs | 2 cases 2 pharma / bio-techs no IT no Spin offs | 6 cases 3 pharma / bio-techs 3 IT no Spin offs |

Conclusion

In this paper, we have focused on the notion of "research agenda" in the analysis of science-industry relations and have used it to interpret original data at our disposal. Our main empirical result, achieved through the construction of a typology, is the determination of six types of science-industry relations which are coherent in terms of the partners' objectives, strategies and features as well as the organisation, volume and duration of the relationship itself. By studying the dynamic effects affecting the relations, we then suggested that science-industry relations can evolve towards two ideal-type models whose features and properties we went on to discuss.

These analyses call for certain remarks in terms of policy issues. The typology per se could be useful for the management of public and private laboratories in order to link their objectives to best practices for co-operation. It might also be suggested to the directors of corporate R&D departments that they should not limit themselves to a single model but rather use both forms of co-operation, insofar as each model of science-industry relations offers distinct advantages for the firm.

At macro level, each model has distinct collective properties which cannot be classified and both have properties which are collectively functional. Thus, in terms of public policy, the issue is not finding the best way of organising the collaborations but rather, maintaining a certain equilibrium between the two models.

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Chapter 4 - Caroline Lanciano-Morandat, "Firms, higher education and research systems and public action: the principles animating the relationships between actors in the innovation process "

Introduction

The purpose of this paper is to apprehend, by adopting an actor-based approach, the diversity of interactions between innovation systems in firms and higher education and research systems (HERS).

Social scientists are divided in the way they apprehend the production of scientific and technical competences and knowledge. Some stress the difficulties caused by the fraught relationships between the two contradictory worlds of business and industry, on the one hand, and academic teaching and research, on the other. Others emphasise the "well-established cooperative links" between science and industry that contribute to innovation, in particular through the professionalisation of teaching and the establishment of socio-technical networks. Yet others claim that these two positions merely represent two separate historical phases.

We begin by locating this approach in the context of the literature (1). We then proceed to identify the various actors and the different principles animating the relationships between them and to construct the various possible couplings of relational principles and actors (2) in order, finally, to seek out the variables that structure these couplings at a more general level (3).

The relationships between actors in firms, actors in HERS units and public actors

Antinomic worlds

For a long time, social science researchers advanced a general model in which the weakness of the links between academia and industry was explained by the fact that the two belonged to two antinomic or contradictory worlds. Academic teaching and research were said to be closed in upon themselves, locked into a mode of structuring and organising power dominated by the academic community. Universities provided education, firms provided training: the knowledge and expertise dispensed by these two

institutions were said to be wholly different in nature. It was natural for academic science to develop independently of technology and of social needs.

From this perspective, the academic community is the key actor in higher education and academic research, with this "social circle", this "invisible college" (Crane, 1969) defining and limiting its own sphere of activity. The disciplinary matrix, the value and rule systems and the conflicts and controversies within the community in question (Lemaine and ii 1969 and 1983) constitute the principle by which this space exists. The members of this community share a common paradigm and are therefore able to subscribe to the same regulatory mechanisms and to construct common interests and beliefs. These are acquired through contact with other academics and the habits and customs of their particular disciplines. They are transmitted during the socialisation process and shape the behaviour and professional identity of individual academics. The knowledge and expertise that serve as a basis for these various learning processes are usually theoretical, generic and formalised within an academic discipline. Adherence to the rules, values and interests of the community, which is reinforced by the system of symbolic gratification and by control of the profession, contributes to the construction of the "academic citadel" (Merton 1973, Dasgupta and David 1994).

Firms, in contrast, are said to be characterised by a mode of operation shaped by the competition to which their products are exposed in the market place, by short-term profitability and a hierarchical mode of organisation geared to the fulfilment of specific strategic and financial objectives. The employees of these firms are said to be governed by explicit rules that are external to them and under the control of the owner of the capital or of his representative. The knowledge and expertise produced are applied to a given economic objective; they may be formalised but are often tacit and firm-specific.

This type of model is based on the trajectories not only of individual actors but also of collective entities (research organisations, firms, laboratories, teams) but takes no account of the interactions between actors and privileges certain occupational categories to the detriment of others. Nor does it take any account of the division of labour or of the way it is organised. On the one hand, it focuses on the links between researchers (and lecturer-researchers) that exist within the academic community but ignores the role of engineers and technicians as well as that of the various sources of funding (Callon 1994, Joly 1997). On the other hand, it restricts researchers' activities to those that the academic community recognises and legitimates, that is it fails to take into consideration the relationships that researchers, engineers, technicians, academic organisations, laboratories and research teams have with their environment, and particularly with firms (Latour 1996).

The actors in these two "worlds" are said to be sufficiently far apart from each other for relationships between them to be sporadic and fraught and to amount to little more than attempts by one to control the other (Moscovici 1967, Benusiglio 1966-67). Thus the academic community is said to be more or less incapable of understanding industry's needs, while fulfilling a commercial objective or meeting a specific social need is said to be incompatible with its fundamental task of producing knowledge. It responds to social demand, it is alleged, only because it is forced to do so, particularly as a result of cuts in public funding, which are said to have had a negative impact on the quality of its

output. Firms, for their part, are said to have no other objective than their own financial profitability and invest only in targeted research carried out externally. From this perspective, relationships between the two worlds are possible only through the intervention of "intermediaries" (individuals, organisations or institutions) capable of bridging the gap (Carlson, 1994; Bessant 1994; Dodgson and Bessant 1996) between firms and HERS. This model does not take into account the possibility that direct interactions between a firm and a HERS unit may lead to innovation.

Hybrid worlds

This model contrasts with another way of apprehending the links between academia and industry. This approach now unites many researchers in the social sciences who take the view that there are analogies between the academic world and industry. Markets and hierarchies, it is said, inform both systems, their objectives are compatible and often complementary and occupational identities in the two systems are closely related. It is therefore possible to establish networks of productive relationships between the two, linked either to the construction of competences or to that of knowledge and expertise. These networks are both a vehicle for information flows and the means by which the resources of all those involved in innovation are coordinated (Knorr-Cetina 1982; Laredo, Callon and Mustar, 1992). By controlling relations and creating trust between the partners, these research contracts make it possible to extend economic organisation beyond the firm (Cassier 1995, 1997, Estades 1995). Thus Aoki (1988) notes that the increasing co-operation on R&D both between firms and between firms and the higher education and research system in Japan may indicate that a new form of industrial organisation is emerging. This model emphasises the strength of the interactions between the initial socialisation and the construction of competences in firms. From this perspective, it is no longer relevant to think in terms of a clear distinction between the basic research carried out in academic institutions and the applied research carried out in firms. Any analysis must be holistic, taking account of the dynamic of the innovation cycle, the type of product that can be a vehicle for innovation, the competences, knowledge and expertise deployed and the various legitimisation and incentive systems mobilised in the innovation process. Some of these processes may, through a multiplicity of feedback loops, bring into play different functions within research organisations and firms (Kline and Rosenberg's chain-link model, see Kline and Rosenberg 1986 in Gaffard 1990). From this point of view, there are "*grey zones in which academia and industry interbreed*" (Callon and Foray 1997). This model has a tendency to downplay the incompatibilities between the systems and the possibility of tension and conflict between different norms and values.

Different historical phases

For more and more social science researchers, these two schools are not in conflict with each other but are merely dealing with different and successive historical phases (Gibbons 1994 and 1997; Pestre 1997). These different historical periods have their counterparts in different forms of innovation and human resource management in firms (Roussel/Saad/Erikson 1991). From this point of view, some firms and certain

approaches to the management of relations between firms and HERS are linked to modes of R&D organisation belonging to different generations (1st, 2nd and 3rd generations, Lam 2001).

The idea advanced in this paper is that these different models are necessary for any analysis of the relationships between innovation systems in firms and the HERS. The first gives pride of place to the historical trajectories of individual and collective actors in the R&D process (Joly 1997) and highlights the conflicts that might emerge between the two worlds. The second stresses the interactions between the actors in the innovation process and the need to apprehend both a process that extends beyond the boundaries of the firm or laboratory and the notion of hybridisation or interbreeding between the practices of the various actors. The third focuses on the historical evolution of these systems.

The "intermediate" innovation space as a basis for constructing relations

This paper is based essentially on two types of analysis, societal analysis and triple helix theory, but it also takes account of ideas and tools developed by sociologists at the Centre de Sociologie de l'Innovation at the Ecole des Mines in Paris. It focuses on the actors in innovation, on the emergence of new actors and on the type of organising principles produced when relationships are established.

1. The societal analysis of innovation (Lanciano-Morandat et al. 1997, 98) places the actors at the heart of the innovation process. They are not the agents of economic theory, nor mere individuals nor even Crozier and Friedberg's exclusively strategic actors. In societal analysis, the term *actor* "denotes any individual or collective entity having a capacity for socialisation or structuration" (Maurice, Sellier, Silvestre 1982). Thus it can be applied to individuals, to occupational categories, to an organisation or to an institution, depending on the level of analysis. At the microeconomic level, the interactions between actors will be primarily those between individuals or occupational categories, while at the macroeconomic level, the focus will be on the interactions between organisations and institutions. These actors have not only historical depth but also an ability to react to their environment, both of which help to shape their practices while at the same time enabling them to influence those practices in accordance with their immediate or long-term strategies. This tension between determination and autonomy is the source of both the stability of the principles animating their actions and their dynamic, that is the actors' ability to evolve. These animating principles unfurl within an institutional framework, the "innovation space".

The innovation space is, in the first instance, an occupational space (Maurice et al. 1982) and a locus of learning that is constructed in interaction with the actors who constitute it and with its environment (Lanciano-Morandat et al. 1998).

This is to say that it is structured through the interactions between the construction of competences and the actors' occupational and organisation practices. In this sense, this notion draws on both the contributions of the Chicago school of sociology (Hughes) ("opportunities space" Paradeise) and on those of the sociology of organisations

(Parsons). The actors/spaces dialectic has similarities in this respect with the notion of "embeddedness" (Polanyi 57, Granovetter 83, 85). Construction of the innovation space requires continuity (and hence serves to forge links) between institutional elements and occupational trajectories. These institutional elements are the policies pursued by public institutions and firms in the areas of training, occupational mobility, the hierarchisation of knowledge and know-how and organisation. Occupational trajectories (Tripièr 1992), on the other hand, are the processes of socialisation undergone by individual actors within the education and training system and in firms. Thus the innovation space is not synonymous with the national innovation system (Lundval 1988, 1992, Nelson, 1993, Edquist 1997) because it is a "social construct" that emerges out of the subtlest interactions between individual actors and occupational categories, interactions which are then structured and diffused within organisations and institutions. The learning processes involved are analysed by observing the work actually done by each employee in a specific productive context (workshop, technical unit etc.) and his/her "position" (Bourdieu 197) in a social field rather than by investigating a general process at the level of the organisations in question.

The research carried out in 1997 and 1998 by researchers in societal analysis placed the firm at the heart of the new productive system and took as its starting point the assumption that innovation was an inherent part of that system: firms cannot but innovate if they want to survive and develop. Innovation is perceived as both the production of resources (not only products but competences, knowledge and know-how as well) by the firms and the endogenisation and specification (Gaffard 1989, Moati, Mouloud 1993) of the generic resources produced by the environment, that is by the educational, R&D and industrial spaces.

2. Taking transfer mechanisms as their starting point, the **triple helix theorists** (Erzkovitz, Leydesdorf 2000 a and b) extend the analysis of the innovation dynamic to embrace not only the relations between firms and the HERS but also the state. Each of the three helices represents one of the systems and has its own internal coherence, dynamic, strategy and capacity for change. Thus in recent years firms have been busy forging strategic alliances among themselves. Higher education and research systems are not only producers of qualifications and knowledge but are also economic actors, as reflected in the emergence of the "entrepreneurial university". The state is opening up itself to various public actors (various groups and institutions) (Quéré 1996, Verdier 1999) characterised more by the production of public goods at different levels (local, regional) than by their participation in acts of government. Each time these various partners establish relations, the interaction between the different modes of coherence and dynamics produces a range of non-homogeneous and non-synchronised reactions that act upon and disrupt the principles animating the partners' actions (sub-dynamic). This disruption forces each of the partners to negotiate and put in place a series of "accommodations", both internally and vis-à-vis its partners. The helices are similar to the spaces of societal analysis in highlighting the varying degrees of compatibility between different dynamics but differ from them in not constructing their systemic coherence on the basis of the interdependence between actor and space.

3. We will take these various studies into account here and place the relational principles that emerge out of the interactions between, on the one hand, firms, higher

education and research systems and public action, on the one hand, and the actors involved in innovation, on the other, at the heart of current innovation systems. This coupling of relational principles and actors will be denoted by the acronym AFHEP (actors/firms, higher education and public action). A few years ago, the firm played a central role in the innovation space; today, at the beginning of the 21st century, it has moved aside in favour of the firms-HERS-public action "triad" (FHEP). This new innovation space, which will be described here as "**intermediate**", encompasses a variety of actors and relational principles.

The actors in the innovation process are no longer confined within the bounds of their respective systems and the relationships between them are mediated by "intermediate actors". The adjective "intermediate" (Callon 1991, Vinck 1999) refers only to the human actors involved. In our view, the non-human actors such as laws, technological artefacts, objects, competences and monetary incentives linked to the capacity to innovate are all elements in the process of constructing human actors identified by societal analysis. The relational principles linking the AFHEP coupling that structure this space can be distinguished from each other firstly by the degree of formalisation and secondly by the three different procedures for effecting the transition from one world to another. This first is a process of alignment (Callon 1994) among the actors themselves, the second a process of coordination among actors (Thévenot 1985) and the third involves the use of an organisation or institution to bridge the gap between the partners. Our notion of alignment process differs somewhat from that of Callon and denotes the actors' ability to draw on their previous "practical experience" in order to incorporate certain perceptions, knowledge and actions (Bourdieu 1974) into their behaviour patterns and thereby make certain adjustments to their practices. Thus irrespective of discipline and subsequent career trajectory, individuals who have completed a doctorate will have acquired the ability to work with others merely by virtue of that shared experience. They may well find it easier than others to align their different professional practices and adapt to new practices. The shared experience of having completed a doctorate makes them "compatible" actors.

However, the intermediate innovation space is also seen as a space in which actors operate amid the clashing and jostling of diverse sets of rules and values, giving rise to various tensions and conflicts. These tensions and conflicts may either represent an extension of the struggles taking place within each organisation or be a result of the relationships established between the actors or of the form those relationships take. They find expression in scientific and technological controversies and disputes arising out of social relations of domination and subordination at a more general level (Bourdieu 1976) or out of the hierarchical and professional relations within organisations that do not share the same rules and values.

The multiplicity of actors involved produces a diversity of relational principles, and vice versa. Their processes of permanent adaptation affect both the relationship itself and the helices (or spaces) that oblige the actors in the innovation process, the intermediate actors and the partners to negotiate and to jointly manage their relations. The intermediate innovation space thus delineated emerges as a tool that allows us to apprehend the actors, the relational principles and the way in which they are structured.

In the first part of this paper, we will attempt to identify and categorise the various actors in the trilateral relationship and the corresponding relational principles. In the second part, we will investigate the variables structuring the intermediate spaces.

The intermediate actors and the various relational principles

Analysis of the case studies reveals the existence of three types of actors involved in innovation: those in organisations, those in firms and those in HERS units.

Within this broad category, four main types of intermediate actors can be identified:

- those actors who are the medium for an economic relationship between the firm and the HERS;
- the "gatekeepers", who work for a firm or a HERS and whose function is to coordinate the two systems;
- the hybrid actors who, by virtue of having worked in both the firm and the HERS, have been through the process of aligning the practices, rules and values of their "home" system (industry or academia) with those of their partner;
- those actors who are involved in the trilateral network but are independent or on the road to being independent of the partners.

Various sets of relational principles are constructed around these actors. Each set of principles tends to privilege one type of actor rather than another. Similarly, a trilateral relationship between a firm and a HERS unit may possibly, though not necessarily, fall within the scope of several different sets of principles.

A distinction has to be made between those relational principles that are mediated mainly by relationships that fluctuate between the formal and the informal and those that are organised around relationships that are formalised in programmes of strategic cooperation.

The transitions between informal relational principles and formalised relational principles and vice versa

Many historical and sociological studies have shown how informal relations have led to the establishment of networks of relationships (Charpentier-Morize 1989). These relationships are frequently mediated by individual actors who have shared similar experiences during their university studies. These forms of relations are currently being brought into favour again, since they represent a particular phase in an historical process and may consequently evolve into more institutionalised relationships. They are also being taken into consideration because they remain productive when relations become subject to explicit organisation and management. In this way, informal relations may supplement relations that have been formalised in programmes of strategic cooperation. However, this type of principle is also favoured in its own right by small firms in circumstances in which there is considerable uncertainty about innovation networks (biotechnology networks) or the trajectories of firms and institutions. Despite their

strategic importance, these relations are not managed and controlled by senior management in firms or the HERS but are initiated at local level by actors within the units concerned or by individual "gatekeepers" who enjoy relatively little legitimacy. Nevertheless, these relations are implicitly accepted and given indirect support by the managements of the partner organisations (Kreiner, Schultz 1993, Hippel 1987).

Three of these sets of principles were observed at work in the course of the SESI field work.

Relational principle 1: the "*symbolic*" principle

In some of the SESI case studies, there are no or virtually no relations between firms and the HERS, except for the recruitment of university graduates (recruitment of a generic resource) and the provision of certain services. Nevertheless, the relationship is a symbolic notion that leaves its mark on firms.

Two cases were analysed:

A/ the firms investigated are technology companies with their own highly specific but hardly groundbreaking knowledge and expertise. They work exclusively for a clearly identified and narrow range of customers. They maintain very close links with this customer base, with suppliers and with the financial market. The actors involved in innovation within the firm are both the experts selling their technological competences to other firms and the managers and financiers contributing to the firm's development. Relations with HERS units are either nonexistent (UK-TEL3 and UK-IT3³⁶) or are of secondary importance compared with the partnership with suppliers (Austria-IT2). On the other hand, these firms explain their location on a campus by pointing to the advantages it offers in terms both of reputation and a network of potentially productive interpersonal relations. Their location has given rise to investments and although the advantages the firm seeks to derive from it are not formalised, it is none the less the case that certain indirect effects (externalities) are expected. There are no intermediate actors as such, apart from a few individuals providing one-off services. The principles driving this type of relation are linked to local social networks and interpersonal relations.

B/ The firms in question operate as subcontractors producing limited innovation, either as part of a large group or within the international division of labour. Their R&D effort is fragmented and confined within the firm. The actors involved in innovation are also located within the firm and have no explicit relations with the HERS, even though they are involved in multinational organisations that do maintain such relations. The principle at work here is that relations are initiated by the firms supplying the orders.

³⁶ The firms in question.

Relational principle 2: the "dormant" network

This network is **co-ordinated by informal gatekeepers within the firm** who are not, however, recognised as such by management, whose mandate they seldom have. Depending on the partners' needs, this network remains "dormant" or is activated by mobilising old or informal relationships, particularly among those actors who are the mediums for business relations (Portugal-Tel1, Portugal-IT2, Portugal P-2, Austria-Tel2). It is useful to the firm and the HERS unit involved both as a tool that can be deployed in order to take advantage of "overflows" (Callon 1994) in the environment, but it is not strategic.

The firms involved here are either dependent on the strategy of a multinational group or operating as subcontractors in the international division of labour. Their innovations are market-driven. The quality of their internal R&D effort and its links with the market are their top priority and explain the scale of their investment in this area. Their innovations are concentrated in specific segments of the production process or on specific products. The competences sought after by these firms have become those that combine market knowledge and a capacity for technological adaptation. They are intended to enable firms to conform to new technical or market norms (the technical norms specific to each country in the telecommunications sphere or the packaging of a medicine) or to improve their products (innovations in formulation, for example, make it possible to change the frequency with which a medicine has to be taken, thereby enhancing patients' comfort). They do not necessarily require relations with the HERS. On the other hand, alliances with other firms in the same sector are becoming of strategic importance. The HERS in question are those with which the firms already have links, either because of their previous practices or because of their geographical proximity. The public actor plays little role.

Two types of principles were encountered: those of the firms and HERS units engaged in constructing their relational capacities and those arising out of a change of trajectory within the firm (changeover from a organisation in which innovation was science-driven to a customer-driven organisation).

A/ In the first case, firms seek to identify the informal relations and to use them as a basis for constructing a "dormant" network that brings together actors capable of being the mediums for commercial relations while at the same facilitating the emergence of informal gatekeepers.

The mediums for commercial relations

These actors operate either in a firm or in a HERS and confine their activities to one or other of these systems. They are usually individuals or occupational categories that have some brief experience of working with the other partner: short training courses, engineers trained in the HERS, lecturers teaching on vocational or industrial training courses provided by universities, academic consultants working with firms or students forced by the absence of grants to fund their studies by taking temporary jobs. They may also be involved in supplying HERS services to firms; such service provision is usually treated like any other client-supply relation and is therefore very difficult to identify with the SESI research tools³⁷. These actors are strictly dependent on their employer's regulatory system, since it is that system that underpins their professional legitimacy. Nevertheless, while each individual experience might be brief, they can accumulate over time and thereby help to construct the professional identity of a gatekeeper or hybrid actor. These accumulated relationships may also provide firms and HERS units with opportunities for learning as they seek to become more flexible and to externalise certain resources.

B/ In the second case, firms try to change a relationship based on cooperation into a "dormant" network. Thus some firms that were involved in hybrid arrangements with the HERS have changed trajectory and externalised such activities (involving radical innovations) to the HERS while at the same time maintaining a privileged relationship with it.

When the network of relations was of strategic importance for the firm, hybrid actors were the medium for innovations in both the firm and the HERS unit. With the change of technological trajectory, a new configuration of internal actors, mediums and informal gatekeepers took their place. The hybrid actors, who were researchers of recognised scientific or technological expertise, have been obliged to change the direction of their professional trajectories, either to devote themselves exclusively to one innovation space - the firm or the HERS - or to become gatekeepers in one or the other organisation.

In the first case, some have gone down a path that enabled them to join the heart of their organisation. Those in industry have mainly had to acquire knowledge of the market and of users, while the academics have had to return to their basic knowledge, which has been problematic for both. Others from industry have chosen to move to the HERS unit with which they already had links in order to remain within their original area of specialisation. These moves were either an individual initiative or mediated through the emergence of an organised hybrid entity (France-IT2-Gie; UK-IT2/Brims).

³⁷ Indeed, the SESI research took as its starting point the bilateral relations between firms and the HERS and ignored the links that were not identified as such by company management.

In the second case, the gatekeepers in the firm were in a worse situation than their counterparts in the HERS. The former were disadvantaged by their remoteness from the core of the company, while the latter succeeded in attracting management's interest by virtue of their links with the company.

The notion of the "dormant network" encompasses a diverse set of relational principles, with various types of links interacting with each other, including informal relations constructed between individuals in their previous organisations (Austria-IT1) and explicit relations governed by an organised hybrid arrangement (France IT2/Gie; UK-IT2/Brims) or an independent institutionalised entity (Abili in the case of Portugal-Pharm1). It is also the object of various tensions and conflicts arising either out of contact with another world or the change in company strategy. This change displaces both the actors involved in innovation in the two systems and the intermediate actors, thereby blurring the reference points constructed in the previous phase: the "externalised" employers find themselves both distanced from their previous world, that of the firm, and competing with their colleagues in their new world (the HERS), particularly in matters of pay (France-IT2/Gie; UK-IT2/Brims).

Relational principle 3: the creation of a new intermediate actor

This principle is adopted when there is a gap (Carlson 1994; Bessant 1994; Dodgson and Bessant 1996) between firms' needs and the resources produced by the HERS and the explicit intervention of an intermediate actor ("the bridge") is required in order for the innovation process to be brought to a conclusion. It is based on the strength of **independent individual actors** ("notables", independent hybrid actors) and on **independent collective actors**. The interaction between them provides the impetus for the dynamic specific to this relational principle.

The example most frequently encountered in the SESI field work is the establishment of a spin-off from a HERS unit, although firms can also set up the same kind of entity under virtually identical conditions. When a research unit has "invented" a new product or process and has not found a company to develop and realise the innovation, it (or some of those working in it) takes the initiative and enters the marketplace directly by setting up a new actor involved in innovation in the shape of a spin-off.

This configuration is analysed as a transitional process, in which an actor within the HERS, frequently an individual, is transformed first into an organised hybrid entity and then into an institutionalised independent entity. Thus when it is first set up, the links with the HERS unit are very strong, the actors and their values are subject to the academic mode of regulation and the work is carried out jointly with the HERS unit. Then, by setting itself up as a spin-off, the technology company detaches itself from the parent unit; its activities begin to diverge from those of the HERS unit and it begins to acquire specific organisational structures (IT3-F). Gradually, this intermediate actor claims its independence, entering into relations with new partners, acquiring new knowledge, expertise and resources, establishing its own hierarchy and eventually becoming a company like any other. This process of institutionalisation, which also constitutes the transition from one world to another, is likely to be accompanied by

tensions, particularly those arising out of financial and legitimacy issues (the inventors not involved in the spin-off may be in dispute with the founders about payment for the invention or about publications), conflicts (transition from an organisation based on a coalition of independent employees to a hierarchical organisation) and a reclassification of the actors.

The HERS involved in such situations are already very technology-driven and frequently have organisations and tools that establish and maintain the academia-industry interface (internal organisations, incubators, nurseries or breeding grounds for new companies, links with business angels etc.). They have a reputation for excellence in very specific areas.

Public action is more likely to play a role in such spaces than in the other ones, with the objective of promoting relations between academia and industry at national level (in the absence of independent initiatives from industry and the HERS) and contributing to and participating in local development.

Gatekeepers in firms and HERS units

Gatekeepers act as go-betweens or mediators between their own organisations, the firm or the HERS unit, and its partner. They carry out their activities as intermediaries both at the interface of the HERS unit and the firm and within their own systems.

Their competences are constructed on the basis of their technological and scientific knowledge and expertise and their professional experience in both systems (mobility, post-doc fellowships³⁸; cf. UK-Pharm2, France-Pharm2, UK-Pharm1), which has given these actors the ability to coordinate internal and external teams and to facilitate the transfer of knowledge produced by the HERS to firms' R&D departments and to transfer problems raised in firms' research laboratories to the HERS. In order to be recognised as gatekeepers, however, these actors have also had to acquire organisational and management skills, knowledge of markets and of intellectual property rights and relational skills and expertise.

Depending on the individual case, these actors may be individuals or organised entities and their activities may be informal or explicitly defined by the firm or HERS unit involved.

Until a few years ago, this function was allotted to individuals whose professional identity meant that their ability to perform this role was acknowledged by the other internal and external actors involved in innovation process. The manager of the Taxotère projects in the France-Pharm2 company is one such figure. A former CNRS researcher, he was recruited by the company because of his leading-edge scientific knowledge; as a research biologist, he carried out a number of studies both within the company and in collaboration with HERS units. He subsequently took on a number of managerial functions within the firm's R&D department, but remained in close contact with academic research and was therefore able to seize the opportunity offered by the "discovery" of Taxol in the USA to put together a collaborative project with CNRS researchers, which led to the marketing of Taxotère. In the HERS, these gatekeepers exist at different levels; they may be the directors of certain public research institutions who have acquired competences in the management of

³⁸ In some cases, doctorates may also constitute professional experience in the academic world.

collaboration with industry and built up networks of individual relations or groups of researchers built up over time.

This role has since been recognised by the management of some large firms that have incorporated this function into their managerial hierarchies. UK-Pharm2's "resident engineer at IC-Park" and the University of Surrey professor whose chair is funded by UK-Tell are two such figures.

Since the mid-1990s, some firms have chosen to structure this role within an organised entity (HMR, RPR, Pfizer). In this case, one unit within the firm is given the task of identifying its internal needs and finding an external competence to meet them, of constructing the relation in both its scientific and legal dimensions, of monitoring and evaluating it and of disseminating the results within the firm, in conjunction with the patent rights departments. Employees in such entities also have a twofold competence that enables them to combine their knowledge of research, of management and of industrial property/patent rights. At the central level of the HERS, administrative structures have been set up in order to exploit academic knowledge and defend the individual and collective interests of HERS units.

This first group of relational principles highlights the complexity of the interactions between different systemic dynamics as well as the volatility of these relations over time when they are mediated by essentially individual actors. The second group, on the other hand, emphasises the stability and irreversibility of such relations when they are constructed collectively and strategically.

Relational principles formalised around strategic cooperation

These principles differ from the previous group because they are acknowledged as strategic and are structured and legitimated by the firm, by the HERS and by public action as part of a policy diffused by company management. From the firm's point of view, these trilateral relations make a direct contribution to its economic success; for the HERS, they help both to enhance its reputation and to boost its revenue; from the perspective of public action, they help to sustain the local and national economic fabric. They are mediated by management tools that have been harmonised and have a certain degree of continuity over time.

Relational principle 4: the actors as a portfolio of resources

This relational principle is based on explicit **co-ordination** between the partners based on the deployment of **gatekeepers** in both organisations. These new actors, which act as interfaces and "representatives", may be individuals or organised entities. They occupy a key position in the hierarchy of each of their organisations and have an acknowledged capacity for action. These "gatekeepers" operate both internally and externally: they have to respond to the needs of the R&D units, identify the competences located in the HERS and create the conditions for the endogenisation of the resource to be exchanged. They manage each of the relations with the aim of maximising the benefit to be derived from the best knowledge and competences available at any given time in their environment. In this way, they build up portfolios of relations that add to the value of

each of the organisations. These portfolios are very diverse. A gatekeeper in a firm may choose, for example, to concentrate on establishing hybrid actors with one foot in academia and another in industry or he may prefer to use an individual or collective independent actor.

The FHEP relations may be strategic but they do not radically alter the organisation of the firm or of the HERS. Each of these organisations remains independent of the others, with the gatekeepers managing joint operations (projects) by making a clear distinction between each organisation's contributions and constraints and maintaining a strict division of labour.

The firms concerned are part of large multinational groups but have retained a capacity for independent strategic action. They operate in areas that force them to implement radical innovations linked to new scientific and technological knowledge (research and development of new products or product ranges and new product concepts). Thus R&D is a strategic resource and a locus for intense competition between firms. Firms endow themselves with the resources to control their R&D output and to define what falls within the scope of their industrial property (the race to patent is very real phenomenon, as are the disputes relating to industrial property). As a result, R&D organisations employ considerable numbers of people and are able to draw on significant levels of investment; in most cases, they have little if any connection with production. The actors in the innovation process may be hybrid actors but most of them have been the mediums for business relationships. Most of them are researchers specialising in leading-edge disciplines and technologies. Their knowledge and expertise have been constructed within both the HERS and firms. Because of the high degree of specialisation, mobility within firms is low, but their close cognitive relationships with researchers in the HERS are of considerable importance. Furthermore, the reference systems of these industrial researchers mean that they accord high status to the norms and evaluations of the HERS. There are few direct alliances between firms.

The resources produced by the HERS are indispensable to the firms, either because they give them access to very scarce, high-level human resources or because they can benefit directly from costly knowledge and expertise. These resources are currently all the more essential to them since, for economic reasons linked to globalisation, most of them have minimal capacity for recruitment (Pharm1-F, Pharm2-F) and little scope for long-term investment. These resources are made up essentially of scientific and technological expertise. They must both complement and supplement firms' own resources, being rapidly exploitable in the first case and allowing the exploration of new knowledge and expertise in the second. Thus all types of relation are involved here, from informal relations and technological monitoring to service provision (in which case the HERS is treated as just another supplier) and more or less structured collaboration (hybrid entities). These resources are deployed mainly upstream of the innovation process but can also be used for specific purposes downstream of it.

The HERS units operating in these spaces are selected for their excellence in highly specialist areas of knowledge covering a very diverse range of disciplines and technologies. For example, the knowledge deployed in links with pharmaceutical companies starts with chemistry and ranges as far as computer science, via biology of

course. These units may equally well be part of the national HERS or of those of other countries. Their relations with firms serve to consolidate their scientific trajectories (legitimacy conferred by link with social needs) and may even go as far as the development of hybrid forms of knowledge and expertise and the emergence of new disciplines. More specifically, they represent a source of additional funding for these units. There are noticeable tensions with firms, since the actors involved in innovation in the HERS have the impression that their work is being instrumentalised in exchange for considerable amounts of money. Their keenness to publish bothers firms, who are also upset by the scale of disputes among academics.

The state used to be an actor in this space, which it helped to structure (*Contrat Bio-Avenir* in the case of Pharm2-F and intervention by the state and the armed forces in the case of Tell1-UK), but it has since withdrawn almost completely without really having been replaced by another public actor.

The dynamic of this relational principle is linked to that of the firm but mediated through an interface (and vice versa). It therefore retains a genuine capacity to adapt to change. Its mode of co-ordination by means of gatekeepers, and the independence of the organisations from each other, enable the internal actors involved in innovation to change partners without calling into question either internal strategies or the network of relations. In this way, a whole range of options regarding cooperation can be kept open (use of internal or external resources, types of competence/knowledge, choice of partners), making it possible to select the expertise most likely to overcome the rapid obsolescence of knowledge and know-how produced by the dynamic of innovation processes. This relational principle retains the same capacity for adaptation when the firm or HERS unit undergoes organisational changes or changes caused by sudden market constraints, such as mergers, which open up the possibility for a shift towards the "dormant network" principle. On the other hand, the non-alignment of the actors' practices and professional identities gives rise to tensions with the HERS units (conflicts of interests, differences in the time horizons of academic researchers and industrialists, etc.) which do not facilitate cooperation.

Hybrid actors:

Joint or hybrid actors are different from the other actors involved in innovation because their professional identities are constructed in both the HERS and in firms and because they are managed by the partnership for the duration of the relationship. Nevertheless, the influence of each "instituted" organisation (Lourau) remains considerable, and despite their affiliation to a joint entity, their referents in terms of rules and values remain close to those of their original occupational space. Their competence is essentially scientific or technological in nature and they are recognised both for their excellence in this sphere and for their general awareness of knowledge and practices throughout their sphere of activity (from academia to the market).

They are, firstly, individuals whose professional identities have been constructed simultaneously or successively in the academic and industrial spaces and who continue to have professional practices common to the two spaces. This shared history equips them with a cognitive background that gives them a distinct advantage in cooperative ventures. Administratively and hierarchically they belong either to the HERS or to industry. They may be university professors (Austria-Pharm2; France-Pharm2) working simultaneously and/or successively in the two worlds, long-term trainees, doctoral students funded by the firm or doing their doctoral research in the firm (France-Tel1 and 2; UK-Tel2), postdocs paid by the company but retaining strong links with the university or researchers seconded to the firm. However, they may also be engineers or researchers teaching in the HERS or spending time in academia in order to acquaint themselves more thoroughly with a leading-edge technology. These various actors, most of them with backgrounds in the HERS, are participants in the university's enterprise culture, in Etzkowitz's (1997) sense of the term.

They may also be organised entities set up by the partners to be the medium for the relationship. The purpose of these entities is to pool the competences of the firm and of the HERS for a limited period of time and for specific, jointly determined objectives. They may take the form of research contracts concluded within the framework of an overall agreement, mixed units, certain platforms developed around a particular instrument or spin-offs in a very early stage of development. The individuals who structure these entities are industrial and academic researchers, project managers involved in a collaboration contract and doctoral students or postdocs funded by industry who are taking part in joint projects. Researchers working in Brims, a unit managed jointly by UK-IT2 and the mathematics department of the University of Bristol, and in the France-Pharm2 unit at the Evry Génopôle (genetic research development site) are involved in this type of project.

Relational principle 5: the embeddedness principle

In some cases, and in contrast to the previous principle, the trilateral FHEP relations are embedded in the organisation and management of the two partners. This embeddedness is the result of the joint production of a hybrid actor, the engineer/PhD student (or trainee), and of the work done in the course of completing his thesis. This doctoral student is the basis of the relationship: he brings the partners together, links their organisations and contributes to the alignment of all the actors involved in innovation vis-à-vis the others. He is both a human resource constructed for the long term and a cognitive resource likely to produce immediate expertise.

Firms operating in this space have a capacity for strategic action at the international level, but innovation is more varied than in the previous case and may be both incremental and radical (improvement of products' competitiveness and of production processes, new products, new systems and concepts) and both market-driven and science-driven. It impacts on the whole of the production process. R&D is an integral part of the entire production process and is usually organised on the basis of a distribution of labour between specialist units located alongside the production units and a more generalist central unit responsible for co-ordinating the various forms of product knowledge. Intellectual property is managed as fastidiously as in the previous case and concerns the whole firm, not just the departments immediately affected. It may also give rise to disputes (Nortel) but is usually organised around a number of strategic alliances. Innovation within the firm is mediated through the figure of the engineer working in conjunction with that of the technician, albeit in ways that differ from country to country. This engineer, who may or may not have a PhD, has a capacity for mobility within the firm acquired during both his training and his professional career. Indeed, his professional identity was constructed on the basis of applied technological knowledge and expertise that are sufficiently general in nature to be deployed in a variety of posts and in different kinds of work. These actors in the innovation process subscribe to their firm's norm and value system.

On the other hand, these firms differ from those subject to relational principle (4) because their needs for the resources produced by the HERS are essentially exploratory in nature. Internal research-development-innovation (RDI Laredo 2000) fulfils its function and may need additional resources in order to innovate. Fewer services are provided than in the previous case³⁹.

The HERS units in question are close to the firm, both in terms of their location and their technological specialities. However, this proximity is often the result either of a deliberate choice by the firm (location decision, Canon-France) or the HERS (Alcatel-France) or of a joint process of construction (Motorola-France). This does not prevent these units being evaluated as some of the best in their field.

The state is not directly involved in this space, but it is the originator of some very active networks involving academia and industry (in the area of telecommunications). Local public actors are increasingly participating in this space, together with national governments and the European Commission.

The joint construction of this hybrid actor's competences represents a shared commitment to and a joint gamble on particular individuals, as well as a commitment to a long-term training process. The HERS unit selects students and is responsible for their academic training. The two partners then specify this training in accordance with the firm's "extended" needs. Finally, the firm offers jobs to the young PhDs or sponsors their entry into the labour market. This joint construction process not only sets in train the process of aligning the various actors involved in innovation but also gives rise to a very diverse network of collaboration between individual hybrid actors and to the

³⁹ What is required in particular is specific high-level human resources, already specified in part by the higher education system. These jointly constructed human resources are the medium through which a knowledge production network is constructed, on the basis of the proximity between partners.

establishment of various hybrid collective arrangements. These arrangements range from research contracts to the establishment of hybrid entities (joint France-Pharm3/CNRS unit, CNRS-France-Tel2 framework agreement) and include independent entities (joint platforms such as France-Tel2-GREMO and TéSA) or consortiums involving firms and HERS (UK-Tel2; France-Tel1 conglomerate).

This relational principle is characterised by the lasting nature of its relations, by the extent to which those relations are regulated and by the scope of the negotiations that proceed them. This has the effect both of minimising the tensions between the academic and industrial worlds and the disputes around IPR and of allowing the intermediate actors to benefit from the dynamic specific to each of the partners. However, the very embeddedness of these relations in the organisations involved blurs the boundaries between them and firmly links the trilateral FHEP relations to any internal changes taking place in the partner organisations. The irreversibilities thus produced reduce the capacity of the relations and of the actors to cause or initiate movement (Uzzi, B. 1997, Masson, Wagner 1999, Masson, Beltramo, Paul 2000) when economic circumstances or business strategies change, thereby making them less capable of evolving.

Relational principle 6: the use of a constituted intermediate actor

This principle is similar to principle 3 (establishment of a new intermediate actor), but in order to bridge the gap between them the firm or the HERS unit uses a collective actor that is already constituted or whose activities extend beyond acting as a bridge between the two organisations.

The independent actors

The independent intermediate actors operate independently of the partnership. They have been constructed by one of the partners or within the partnership and have managed to assert their independence from it. They are managed by norms and rules that are often specific to them but do not conflict with those of the partners. Their legitimacy is acquired within their own particular system.

Four types of independent actors have emerged from analysis of the case studies.

The "independent hybrids" are hybrids that have acquired a certain degree of independence from the partners and the partnership. Their autonomy reflects firms' need for labour market flexibility⁴⁰ or the type of recruitment characteristic of the academic labour markets in the various countries. For example, they may be students working on services supply contracts in order to fund their studies whose employment has not been organised by the HERS or pharmacy postdocs operating independently of the HERS who move between HERS units and firms as required and who are the medium through which many spin-offs are set up, both in the pharmaceuticals sector (France-Pharm2) and elsewhere (Portugal-IT2, UK-Tel3). They may also be aspiring academics in Germany, Great Britain or Austria who are obliged to take a variety of temporary posts before being appointed to permanent positions.

"Notables" are independent hybrids whose specificity is twofold. They have a hybrid work history, which has given them a certain reputation in both the scientific community and the industrial system. However, they are also extraordinary scientific "personalities" and entrepreneurs. Thus they have combined brilliant and widely recognised scientific careers in various leading-edge areas with considerable mobility at international level between the public and private sectors and experience of scientific and managerial risk-taking. They may have set up spin-offs or independent intermediate institutions, founded or managed incubators or been active as business angels. However, they may also be R&D managers in large firms, university professors or research directors. This type of personality is behind many of the operations investigated in the course of the SESI project: research directors at France-IT3 who have masterminded the establishment of spin-offs, the director of the joint CNRS/France-Pharm2 unit who has experience of biotechnologies in France and in the USA in the HERS and in start-ups, the founders of INESC and the "entrepreneurial scientist" in the computer science department at the University of Bristol in whom UK-IT2 are so interested.

Independent organised collective actors bring together not just two but several partners, whether they be firms or HERS units. Their activities and output are managed under the terms of a fixed-term agreement governing the rights and contributions of each partner, particularly in terms of IPR. They are consortiums, conglomerates or joint platforms (UK-Pharm1, VCEs and RFEEI of UK-Tel1, UK_Tel2, France Tel1 and 2). This type of organisation is usually supported by the European Community or by national or regional public actors.

Institutionalised collective actors may be both established organisations structured around their own particular rule and value systems (INESC, AIBILI, SCM) and permanent networks that have been in place for a long time, which has enabled them to put in place systems ensuring compatibility between diverse sets of rules and values (e.g. the networks of industrial firms and research centres in the telecommunications sphere in France and Great Britain). The direct intervention and participation of public actors play a decisive role in these institutionalised entities.

⁴⁰ Pharmaceutical companies experiencing difficulties with recruitment do not decide, for example, to offer permanent jobs to experts in a discipline or technology that they need only occasionally.

A/ This intermediary may be a **hybrid collective actor** acting as an intermediary between a firm and a HERS unit. In many cases, it has developed out of the firm (Austria-Pharma2, Austria-Tel2, Austria-IT2) even though it is a mixed public/private entity and enjoys a certain degree of autonomy. In this case, the firm's objective is to draw on university resources in order to supplement and/or complement its own without having to alter its strategy. The modes of organisation and regulation are those of the firm, but they are often mediated by hybrid or independent individual actors (university professors university professors, post-docs and PhD students), which forces the partners into permanent readjustments between different norm and value systems (particularly in respect of IPR) in order to allay tensions.

Relations between the two partners are exclusive, which limits the transfers of knowledge to these two entities. They are mediated by human resources or by cognitive resources. The knowledge transferred is linked to leading-edge scientific or technological themes.

B/ However, this intermediary may also be an institutionalised collective actor operating independently of the partners (INSC for Portugal-Tel1 and Marseille-Avenir for France-Tel3). In this case, it has its own particular status and value system. The partners may include several different firms and HERS units. Consequently, the relations managed by the intermediary are not exclusive, which makes it essential for it to ensure that the negotiated rules (particularly on IPR) are followed and monitored and that agreement is reached on certain shared values. In this case, the knowledge and expertise transferred extend beyond the technical sphere to include the organisational sphere or market knowledge. The individual actors involved in these relations have not necessarily been constructed as hybrids positioned between the partners; in particular their competences may be the product of their experience as public actors.

This relational principle is adopted by small firms seeking to forge links with the HERS as well as by large companies anxious not to put all their eggs in one basket when it comes to taking risks on external actors. The intermediate actor may become a specific platform resulting from an alliance between the HERS and several industrial actors. In many cases, such a platform represents the externalisation of the uncertainty inherent in innovation and gives the organisations involved some degree of flexibility in accessing human and cognitive resources. In return, the individual actors involved in these entities behave like freelancers, moving around the space in accordance with their own individual interests. Moreover, it provides a role for public actors and serves to consolidate local policies.

These three relational principles are all characterised by their stability and processes of institutionalisation but differ in their capacity to cause or initiate movement and in the extent of any irreversibilities. In the case of relational principle 6 (the use of a constituted intermediary), the risk inherent in the relationship is externalised, which allows each of the partners to evolve in accordance with their own partner without being imprisoned in the relationship. In the case of relational principle 4 (the "portfolio" of resources), the risk is taken on board but only at the boundaries of the organisations in question; it is therefore circumscribed, making it possible for the relational principle to

change. In the case of relational principle 5 (the "embeddedness" principle), which seems to be the most productive in terms of the knowledge and competences linked to it, the irreversibilities created between the partners reduce both parties' capacity to cause or initiate movement.

Thus in this first part we have defined six pairings of relational principles and actors. They are not ideal types in Weber's sense of the term. Rather, they reflect the diversity of practices and relational principles encountered in the course of the empirical studies carried out within the framework of the SESI contracts. Their relevance will have to be tested against various meso or macro-level economic analyses. Arranged in a variety of different ways, they will serve to make up the various intermediate innovation spaces.

In search of the variables structuring these intermediate innovation spaces

This typology of relational principles and intermediate actors has been drawn up on the basis of a concrete analysis of the relations between firms and HERS units. This raises the question of which factors linked to the partnerships or the macro-economic context within which those partnerships function influence this mode of classification. Do the practices of multinationals, those of innovative milieux or the relative significance of sectors or countries play a role in this typology? Our aim now is to understand the interdependencies between these different forms of stylising practices and thereby assess the relevance of the typology in a more global approach.

The multinational company effect?

Multinationals mainly, though not exclusively, adopt relational principles 4 and 5, and it is clear that their relationships with the HERS are not as homogenising as might have been expected (Mendez and ii 2000). Multinationals' practices in this area seem to be little influenced by the legal nationality of the holding company; rather they are shaped by many more varied factors, and in particular the position of the subsidiary/company in the international division of labour, and by the sectoral and national contexts.

All the holding companies have a strategy that seeks to maximise their subsidiaries' locational advantages. Of course they choose to establish or purchase subsidiaries in order to make good some of the inadequacies in their internal resources, but their locational decisions are very much determined by the opportunities for endogenising these high-quality external resources.

The SESI research shows that multinationals' practices in this area are twofold. In general terms, they establish relations with HERS units that have resources that are of interest to them at a given point in time and have been evaluated as the best available, irrespective of location (the development of ICTs has accelerated this process). At the same time, however, their policies are also very diversified and shaped to some extent by the national or local potential of each of their subsidiaries.

Thus the position of the Portuguese subsidiaries of large international groups in the innovation process is determined both by their ability to improve and develop products in specific technological niches and to produce small runs at low cost. These subsidiaries enjoy only very limited independence from the holding company. Their competence is reduced to the provision of a very clearly defined service that is part of a more global production system. Their efforts are directed towards maintaining their competitiveness in this segment and not on competing to produce more radical innovations. The Portuguese HERS is not attractive in itself but because it is able to supplement the resources of certain multinationals or countries by providing cheap, good quality labour. The position of the Siemens subsidiary in Austria seems to be similar, and its relations with the HERS are of the "dormant network" type.

On the other hand, other subsidiaries, such as Motorola-France and Pfizer-GB, enjoy a clearly defined and controlled autonomy within the group in terms of strategy and relations with the HERS. The size and industrial past of the firm explains this position to some extent, but the decisive factor seems to be its ability to produce competitive innovative products. The holding company defines each subsidiary's area of competence (a product range, a therapeutic target or a segment of the innovation process) on the basis of its internal capacities as well as its potential for endogenising high-quality external resources. The quality of relations with highly effective HERS units may then be a token of the subsidiary's autonomy. Thus multinationals in the pharmaceutical industry continue to locate their discovery phase in Europe in order to exploit the high-quality work produced by certain research centres and their links with universities. On the other hand, their development centres are located in the USA in order to exploit American expertise and a certain advantage in obtaining marketing authorisations. They also invest in the areas around American and British universities in order to use to their own advantage a high-skill labour force whose flexibility is unknown in Germany and France (role of postdocs).

Thus the multinationals' strategy is to develop a diversity of relations with the HERS; this strategy oscillates between characteristics specific to the group, to its sector and to the national space in which its subsidiaries are located. They would seem to adopt a wide range of different relational principles. Each multinational would seem to make specific strategic choices for each project and each subsidiary, favouring one country in some cases and another on different occasions. Consequently, it is not possible to fit each multinational neatly into our typology; rather, their practices need to be analysed by interweaving various different relational principles.

The innovative milieu effect?

Several practices described in the SESI case studies may be attributable to the influence of an innovative local milieu (Courlet, Pecqueur 1992) on relations between firms and HERS.

1. One initial divide linked to the role of public actors may be that between countries. In Great Britain, some firms have established a presence in the vicinity of universities with a tradition of links between academia and industry and a reputation for

excellence (Cambridge and Surrey). In the other countries, the public actors have either taken it upon themselves to open up campuses to firms in order to encourage the development of links between companies and HERS units (the Vienna campus in Austria) or set up science parks such as Sophia Antipolis and the Evry genetic research development site, which bring together universities and firms around a new technology.

2. Furthermore, three types of firms that have followed this line of development can be identified on the basis of their strategies and the type of relational principles (RP) they favour. The three types of firms in question are:

- subsidiaries of multinationals, which have adopted policies that seek to maximise the benefits from any possible externalities (RP 4 and 5);
- spin-offs from companies or universities (UK-Pharm2-Brims, Portugal-Tel1), which "naturally" establish themselves alongside the parent organisation (RP 3);
- firms without any direct relations with the HERS that are seeking to benefit from the "area reputation effect" (RP 1).

The benefits of such policies are debatable (Saxenian 1989) and the material gathered to date (we are still waiting for the American and German material) is not sufficient to give a definitive judgement on the value of such an approach. Nevertheless, three points can be made.

- While the "innovative milieu" effect has to date been exploited mainly by newly set-up small companies (e.g. Austria-Pharm2 and Austria-Tel2 on the Vienna campus), large firms are now altering their strategies in order to take account of it (establishment of the France-Pharm2 genomic centre on the Evry site, of France-Tel2 in Toulouse, UK-Tel1 in Surrey, UK-Tel2 in York, Austria-IT1 in Vienna).
- The role of the "reputation" these sites enjoy and of the production of "interpersonal" relations justifies the investments made by some companies that do not have relations with HERS units (RP 5).
- The importance of the quality of the actors in this type of configuration, particularly of the public actors and of the independent individual actors, the hybrids and the so-called "notables" (spin-offs from France-IT3; UK-IT1; DW; Portugal Tel1; Portugal IT2).

The classification in terms of relational principles/actors is compatible with an analysis in terms of "innovative milieu". It makes it possible to highlight, on the one hand, the variety of strategies deployed by firms and, on the other, the different ways in which the public actors intervene on these sites.

The sector effect?

The relational principles are not, a priori, specific to any one sector, and they may also be associated with a particular historic or economic context. Nevertheless, two of the principles analysed can be linked to a particular sector: RP 5 (the embeddedness

principle) could be said to apply to the ICT sector, while RP 4 (the portfolio of resources principle) could be said to be specific to the pharmaceuticals industry.

1. The state long had ascendancy over **the ICT sector**, either because of its strategic importance in the development of the national economy, because of its links with defence expenditure or because of its role as the industry's principal client. The role of the state has declined in significance, but public actors still play a not inconsiderable part as clients, as initiators of networks and alliances and as the producers of technical norms.

In this industry⁴¹, the research phases, firstly the theoretical research and the definition of a product concept and secondly the feasibility studies, are very closely linked to the development phase through a common object, **the prototype**, which is the pivot around which the whole process revolves. In this way, firms' expertise is concentrated on their architectural capacities, which enable them to gather various technologies and tools around the prototype and make them productive. Customer needs and the various consumer uses also shape the initial product design.

The world of the ICT industry is that of the **engineer and advanced technician** with sufficient technical and managerial abilities to combine a range of knowledge and expertise derived from different disciplines and various productive tools. There is currently a certain degree of tension in this type of labour market and firms are taking a number of steps to attract both occupational groups.

The organisation of Research-Development-Innovation is based on much the same principles as this type of production and is therefore very much integrated into the company. However, it must also have the ability to position itself in actual markets, to maintain productive relations with customers and to take account of the increasing importance of knowledge and expertise in the innovation process. These various constraints have led some large firms to re-engineer themselves, placing knowledge-based management at the heart of their organisational structures.

It is true that this organisational compactness has allowed firms in the sector to innovate internally in some technological segments. However, they need **additional resources** to carry out "pre-market" research and to appropriate specific research competences. As a result, technological alliances and relations with HERS have proliferated. These latter are chosen essentially in accordance with the strategies adopted by individual firms, but there is clearly a corporate preference for colleges and universities that specialise in applied technologies.

These relations are very diverse in nature, but they all involve the establishment of very close links between the vocational training of young people and the production of research, making it possible to align the occupational identities of the actors in the HERS and in firms and allowing them to engage in the joint construction of hybrid actors. In all the countries studied here, placements in firms now occupy a very important place in engineering and advanced technicians' courses. The joint production

⁴¹ Hardware and software alike.

of certain theses by firms and HERS units is increasingly becoming an integral part of researchers' vocational training.

The irreversibilities produced by the "embeddedness" of these various resources have positive effects on the production of new knowledge and competences, but they also have negative effects on organisations' ability to adapt. As a result, attempts to change strategy become difficult and conflictive because of the important role played by hybrid actors in the arrangement (RP 2). This is causing an increasing number of firms in the sector to become involved in the construction of FHEP platforms⁴² on their boundaries, thereby increasing their ability to produce or initiate movement (RP 6) and encouraging the establishment of start-ups and spin-offs.

2. In none of the countries investigated here has the state ever intervened directly **in the pharmaceutical industry**. On the other hand, the reimbursement of prescription charges, the price of medicines and the granting of marketing authorisations give rise to considerable interactions between several public actors.

The innovation process is a particularly lengthy one in this industry (currently between 8 and 12 years). Customer needs are more imagined than identified at the beginning of the process and the research phases are relatively independent of the development phases. Moreover, this process requires various functions and a wide diversity of knowledge, expertise and professionalities to be combined. Thus the research phase⁴³ covers the discovery of new therapeutic targets and of new molecules, pre-clinical trials, the development phase and clinical trials in humans. At each stage, knowledge, numerous specific tools (in particular the new genomic and information technologies) and actors are mobilised independently of each other. These actors come from very diverse professional backgrounds. They include university academics in various disciplines, chemists, biologists, pharmacists, veterinarians, doctors etc. The problem in the pharmaceutical industry is how to coordinate these different professional backgrounds within the innovation process.

In attempting to deal with this problem, firms in the sector have tended to place considerable emphasis on **'gatekeeping'** tasks. Thus project managers, whose role is often split in two, have the task of coordinating the various internal functions and liaising with management. Despite these policies, the multiplicity of professions and functions within RDI units has not only made internal mobility difficult but is also the reason why few people have acquired expertise in the new information technologies linked to the introduction of genomics.

The links between firms in the sector and the HERS have always played a key role strategically and organisationally and have always been very diverse (science-based industry). They involve the exchange of resources that can be directly **exploited** by the partners as well as exchanges of **exploratory** resources. The identification of a new therapeutic target or of a new molecule can lead to the marketing of a new product but

⁴² These relations are organised in such a way as to privilege proximity and regulated links (agreements, etc.) between the partners, which gives the independent collective actors an important place in the sector's relational principle.

⁴³ In most companies.

is also a subject of scientific inquiry. Collaborations between two partners leading to new products are a common occurrence. Highly specialised analytical work is often supported by services provided by certain university departments, while new medicines are developed in collaboration with hospital researchers. This type of relation usually involves just two partners, both of whom are extremely concerned to protect their respective contributions. Furthermore, the individual actors in these relations are often able to exploit the links developed during their training in HERS departments, which enables informal relationships to develop but also gives rise to tensions between different employment spaces and career profiles.

The introduction of new methods of producing medicines has forced firms to supplement this system with new types of relations. Firms need to call for very limited periods of time on the services of specialists with expertise in various combinations of new disciplines. To this end, they try to exploit the opportunities offered by labour market flexibility (postdocs) and the knowledge and expertise of spin-offs (RP 3). Since they are unable to acquire for themselves the new knowledge and tools of genomics, they have also begun to set up consortiums with other firms in the same sector or to locate themselves in innovative milieux. This type of strategy means they are currently able to react rapidly to the constraints of their economic environment, but in doing so they are exhausting the cognitive and human resources accumulated internally during earlier periods that are necessary for the endogenisation of external resources.

A sector effect is clearly identifiable through this typology. It enables the relational principles adopted by firms to be identified on the basis of their technological constraint, their markets and the occupational identities of the actors involved in innovation.

The national effect ?

The information contained in the national and sectoral summaries and the company case studies shows that some countries succeed better in certain sectors than in others. Moreover, the typology of relational principles shows that some countries make greater use of certain principles than of others

Thus the "portfolio" (4) and "embeddedness" (5) principles form the basis for relations observed mainly in Great Britain and France, while the "symbolic (1), "dormant network" (2) and "use of a constituted intermediary" (6) principles tend to underpin many of the relations observed in Portugal and Austria. Moreover, most of the relations in France are based on principles (5) and (4), while most of those in Great Britain are based on principles (2) and (4). These various forms of involvement are explained, firstly, by differences in historical period and economic context and, secondly, by the role of the public actors in the trilateral relations: their varying degrees of significance, their diversity and the interactions that exist between the HERS and the other national actors in the trilateral network.

State action traditionally focused on supporting and regulating the HERS but has extended to other areas as well. Thus in Great Britain and France, the state played the

dominant role in the post-war reconstruction process, taking it upon itself to perform a wide range of different functions as the holder of regulatory power, an industrial operator, the organiser of industrial restructuring, controller of the military and the sole decision-maker on education and public research policies.⁴⁴ Furthermore, it has upheld the value systems underlying higher education, which hierarchise the various forms of knowledge by systematically according higher status to the more general and more theoretical forms. The German system, on the other hand, has always recognised the importance of the application of knowledge in actual professional practices. This historical context is different from that in Austria and Portugal, where the state has hitherto played a part in the formulation of industrial policy and in efforts to match education policy to firms' needs. While the state in the first two countries is disengaging or altering the nature of its interventions, it is becoming aware in the other two of its ability to encourage and support innovation.

Thus the *dirigiste* approach was suddenly abandoned in Great Britain at the beginning of the 1980s, at the same time as public spending, both civil and military, was being drastically reduced. This policy manifested itself, on the one hand, in the privatisation of state-owned companies and research centres, the withdrawal of funding for certain university courses and the virtual elimination of student grants and, on the other hand, in the elimination of public-sector jobs in favour of possible rehiring in the private sector. The approach adopted in Great Britain followed the American principle of forcing public and private services to compete with each other in the marketplace. Thus most state activities falling within the scope of the market sector were privatised. These public-interest activities were handed over to various public actors drawn from the private sector (non-profit-making associations etc.). This policy led to many British companies being taken over by or merged with American and Japanese companies and greatly increased the openness of the British economy to international competition. It also "liberalised" exchanges within the HERS, forcing universities and research centres to manage themselves autonomously in order to offset the low level of public subsidy. As a result, they left the public sphere, positioning themselves as hybrid organisations between the public and private sectors in order to exploit the advantages of both systems.

The financial position of the HERS explains the large number of short courses and the small number of doctoral students. On the other hand, it has led to the creation of a pool of labour made up of students and young researchers without permanent contracts who are obliged to seek extra work in order to finance their studies. This pool of labour is available to firms, particularly in the sphere of RDI. Although the training of these young people is not designed and organised around alternating periods of academic study and work experience in industry, the lack of grants leads, nevertheless, to such a situation. At the same time, the doubt cast on the value of theoretical knowledge has led to an enhancement of the status of technical courses, as well as of those in law, economic and management, while research topics have tended to combine technology and social sciences. The emergence of technological companies and of independent institutions, such as the transformation of spin-offs into autonomous companies, has enhanced the development of such competences (RP (1), (3) and (6)). At the same time,

⁴⁴ Even though in England associations have always played a role in the regulation of occupations and professions that the state in France has always reserved for itself alone.

this new focus on the totality of firms' knowledge and expertise has opened up space for the introduction of a mode of human resource management based on RPs (2) and (4).

The authorities at local level were obliged to reconstruct themselves rapidly as an alternative to the central state. There was a tradition of autonomous higher education establishments able to manage, at local level, relations with the political and administrative authorities as well as with business and industry. This tradition facilitated the establishment of new intermediate institutions with links to the political authorities, to the universities and to private initiatives. Numerous independent actors (particularly "notables") emerged at local level. Some regions, which had long enjoyed certain advantages in terms of their industrial infrastructure and the excellence of the local universities, developed a highly competitive productive system by establishing extremely effective networks of public and private actors. These assets continue to be developed and are very productive.

The figure of the "innovator" is a very diverse one in Great Britain. It is based on composite individual trajectories: educational backgrounds are varied, in terms of both level and discipline, careers are very diverse, life histories very dense. This mode of construction prepares individual actors for risk-taking, new experiments and learning on the job. These actors have a greater capacity than the others to become individual actors, whether operating as gatekeepers or independently.

In general terms, the withdrawal of the British state has created space for the dynamism of private actors or of public actors drawn from the private sector. Positive results have been achieved in the pharmaceuticals sector and in the establishment of technology companies. On the other hand, the country is losing resources in ICTs and is experiencing difficulty in turning those firms that were the medium for innovation in the previous period over to a new type of production. The paradoxical effect of this policy is that, while the dynamic of the intermediate innovation space in Great Britain is modelled on the time horizons of firms (duration and discontinuity), it is those same firms that bemoan the deterioration of the higher education system and the lack of a research base.

In France, the state has remained a key actor in the innovation process, albeit in a more mediated way than previously. Its withdrawal was later, more gradual and less systematic than in Great Britain. It retains some degree of power over firms linked to defence spending (organisation of national telecommunications networks). It is still the main driving force in the education system, and in particular in its professionalisation, by contributing to the creation of a multitude of actors operating in situations characterised by "cooperation and competition" (Gérard-Varet 1996). It has retained direct control of national scientific objectives through its research organisations and is finding it difficult to allow local actors, whether public or private, the space they require to play an effective role in education/training and research. The proliferation of public actors at different levels (national, regional etc.) renders the public actors-HERS system even more opaque to firms, confirming them in their view of the state as centralising and omnipresent.

The higher education system is characterised in general terms by the high status accorded to the *grandes écoles* (the elite engineering and business schools) compared to the regular universities (Lanciano-Morandat, Nohara 2001). Graduates of the *grandes écoles* are virtually guaranteed managerial positions on completing their education, while young university graduates usually have to prove their worth in the labour market. This dichotomy is reinforced by the large number of PhDs, some of whom - engineers with doctorates - are naturally preferred by firms, while the others tend to go into the public service. Various other factors contribute to this absence of interaction between the academic and industrial labour markets (Tripier 1991): the funding of these doctoral programmes is organised (it is mediated either through public programmes or through an agreement negotiated between the national HERS and the firm in question), the state strictly regulates the labour market and lecturers and researchers are granted tenure in their posts at a very early stage in their careers, which reinforces the "embeddedness principle" (5).

Since public research is funded much more generously by the state than in Great Britain, academic research institutions have less incentive to enter into commercial relationships with firms. They are in a position to take the time to establish relations with local actors, taking as a starting point individual and collective hybrid actors produced jointly by the HERS and firms (the figure of the engineer with a PhD; RP 5).

The state recently started to put in place policies to encourage innovation in firms and HERS institutions (Lhuilery 1996), particularly with a view to facilitating company start-ups, which are fewer in number than in Great Britain. By enlisting the support of various public actors (research institutions and universities, support for local institutions), the state is seeking to direct both the emergence of financial capitalism (establishment of venture capital companies) and to establish innovative milieux (creation of incubators, either in particular disciplines or in particular localities, with a view to integrating SMEs and start-ups into local development dynamics).

In the wake of legislation on decentralisation⁴⁵, new hybrid or independent institutions (public/private) have emerged to support innovation in SMEs and to help them apply for national and European funds (Quééré 1996), to exploit local markets and to appropriate as effectively as possible the knowledge and expertise available in the region. The more established institutions (professional or consular organisations) have risen to these new challenges with renewed dynamism. Some state employees have turned themselves into regional actors, engaging in public-interest activities under the control of private associations while still being paid by the state.

Some regions with an industrial heritage have been able, through the combined actions of various local public actors, to promote themselves at international level. This is the case, for example, with the Toulouse region in the telecommunications sector. Thanks to its reputation, it has been able to attract new competences and firms, which has enabled the region to renew itself. With the assistance of dynamic local actors, other regions have supported their local industrial fabric with the aim of promoting job creation locally by setting up networks between firms and universities. These new

⁴⁵ Bernard Ganne, Place et évolution des systèmes industriels locaux en France : économie politique d'une transformation in Les régions qui gagnent, (PUF)

configurations of actors at regional and local level are a more recent phenomenon in France than in Great Britain. They are the medium for new forms of innovation (start-ups, spin-offs, technology companies) and have also enabled new forms of knowledge and competences to develop. However, they could not have flourished without the intervention of public actors.

In France, the figure of the "innovator" is linked to that of the engineer and his general and technical competences. It is constructed homogeneously along a highly organised, collective itinerary that stretches from the *grandes écoles* to firms. It encourages individuals to remain within a particular space and promotes continuity in relations between academia and industry. This mode of construction explains the use of hybrids and the low visibility of independent in trilateral relations.

The dynamic of the French intermediate space is still dominated by the activities of an extremely diverse set of public actors. Their involvement is a guarantee of the quality both of the professionalisation process and of the relations between firms and the HERS. Nevertheless, the excessive embeddedness of the trilateral EHP relations and of the human and cognitive resources gives rise to irreversibilities that prevent firms and HERS units to evolve and to adapt to new market conditions. In other respects, the overlapping of extremely differentiated labour markets and of antinomic value systems generates tensions that are not necessarily negative.

Since the revolution of April 1974, the **Portuguese** state has played the role adopted by the public authorities in Great Britain and France after the Second World War. The aim of its large-scale, direct interventions has been to accelerate the pace of the country's economic development (integration into the European Community). Thus a massive programme has been put in place to increase the number of university graduates, to structure university research and to set up public/private technology centres.

The industrial fabric has also been reshaped, taking as a starting point the stock of competences inherited from the past and the increasing involvement of multinationals in the country. The success of these efforts is due to the fact that Portuguese industry has strictly followed the role allocated to it in the international division of labour: high-level subcontracting operations within large groups or on a more independent basis and innovation in specific technological niches (RPs (1) and (2)).

This type of industrial system equips itself with competences and knowledge that are often produced by the English or American HERS and accommodates fewer university graduates than the country produces, which creates tensions in the labour market. Moreover, given the type of innovation allocated to it, it has less need of the knowledge produced in the HERS in order to innovate (RP 1).

Working jointly with the European Commission, the state encourages research institutions and firms to join international research networks with the aim of appropriating new knowledge and expertise and learning to work together. It is aware that Portugal does not yet have the resources to compete in the knowledge market. In

Portugal itself, the government has supported various individual initiatives that have led to the establishment of independent intermediate institutions (RP 6).

The figure of the innovator has a twofold aspect. On the one hand, there is the industrialist paying his part in the international division of labour and contributing to everyday economic development, on the other the academic/manager who, by virtue of his personal reputation, acquired abroad in many cases, and his networks, makes it possible for the Portuguese intermediate space to draw on competences and knowledge produced throughout the world. Since the revolution, Portugal has been able to construct its own independent intermediate actors, both collective and individual.

This intermediate space is constructed essentially around these personalities, with their wide-ranging experience, and the independent actors (intermediate spaces 4 and 5). Its dynamic is closely linked to the policies of multinationals and to those of the European Community.

The **Austrian** industrial fabric is long established. It is made up of SMEs, a few large national companies and a few subsidiaries of multinationals. Traditionally, these SMEs have not been convinced of the need to innovate in order to remain productive nor of the role played by graduates and knowledge in the new productive system ("dormant" RP 2).

Moreover, the higher education system has up to now produced high-quality graduates in a wide range of disciplines but has taken little account of the need expressed by industrialists. True, the public research system is integrated into European networks but it is concerned largely with its academic reputation and remains unconvinced of the value of entering into partnership with industry at national level.

At central level, the state has adopted a policy of constructing links between firms and the HERS. Drawing on the German model, it has proposed a reform of university curricula with a view to developing sandwich courses that would produce advanced technicians and engineers skilled in the new technologies. These new actors are intended to play a part in modernising the productive system and improving the balance between supply and demand in the training system (RP 5).

The state is also encouraging firms and universities to collaborate in developing technological platforms on university campuses. In this way, it is contributing to the emergence of hybrid or independent actors and to the emergence of type 3 and type 6 principles for the establishment or use of intermediate actors. Nevertheless, this type of approach currently seems feasible only in the Vienna region, where the university is particularly dynamic and the firms are large or medium-sized. In the rest of the country, the intermediate space is more or less disorganised and mediated largely through strictly economic relations.

The figure of the innovator has a twofold aspect. In the case of medium-sized firms in and around Vienna, the innovator is a hybrid actor, a university graduate (or doctoral student or postdoc) working temporarily in a public/private platform on campus. For

SMEs in the rest of the country, it may take the form of the new engineer or technician, who is primarily an actor in his firm's internal innovation processes.

To date, the construction of an intermediate space in Austria has not been recognised as a matter of concern for actors within firms and the HERS and it is the state that is seeking rapidly to impress the "bridging" RPs (3 and 6) on their minds with a view to combining the advantages of the British and French intermediate spaces (flexibility and solidity of production respectively).

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At national level, therefore, a specific set of innovative mechanisms is emerging out of interactions between actors involved in innovation in firms and in HERS units, intermediate actors and relational principles. This system, which equates to the innovation space of societal analysis, encompasses the trilateral network and is denoted by the term "intermediate innovation space". It stresses the role of public actors and the HERS, and the fact that it is constituted on the basis of the RP/A interdependence means that it can take account of the diversity of relations observed at the micro level in each historical and economic context.

Conclusion

At the outset, this paper had two linked objectives. The first was broadly theoretical in nature. An attempt was to be made, on the one hand, to apprehend FHEP relations in both their totality and their diversity while at the same time taking account of the different "social worlds" in which the actors in innovation operate and, on the other, to reintroduce public actors into innovation processes. The ultimate purpose here was to construct the intermediate innovation space and the actors involved in innovation (both those operating within the other spaces and those acting as intermediaries). The second was broadly methodological in nature but flowed directly from the first. The aim here was to construct a tool for analysing the relationships between spaces without defining, a priori, the relevant level and mode of coherence.

1. The multiplication of relations between firms and HERS units and the role they play in firms' strategies and in those of university managers and academic research centres mean they can no longer be analysed as if they were only one-to-one relations of minor importance. The firm no longer occupies as central a position as it used to. The higher education and research system and the public actors are also partners in innovation. However, it is the relations that firms draw on and endogenise in order to innovate that lie at the heart of the process. These arrangements - the intermediate innovation space and the various actors within it - have to be apprehended in their totality and overall coherence in order that they can then be apprehended in their diversity: the diversity of relations, of strategies, of rules and of values. This space is the locus for relational principles (modes of coherence) that bring the partners closer together or distance them from each other. It interacts with the actors in innovation within organisations and with those acting as "intermediaries" between them. These

intermediate actors play their roles as "interfaces", either through their ability to create alignments with spaces other than their own, through their mode of coordination or because they were established specifically in order to play such a role. The totality of these interactions justifies the description of this space as "intermediate".

This device allows us to compare the various modes of translation, the degrees of compatibility between the actors and the capacity for adaptation within the various intermediate spaces (cf. appendix 2). It serves to identify the advantages and disadvantages of the various relational principles: the "embedded principle" (5) maximises the compatibility between the actors but creates irreversibilities, whereas the "portfolio" principle is characterised by less productive FHEP relations (reduced compatibility) but greater capacity for adaptation than principle 5. Those principles based on mediation ("bridging") have good adaptive capacities but run the risk of reduced compatibility among the partners over time.

In contrast to the notion of innovation space, that of the **intermediate innovation space** places the trilateral relations between the state, the HERS and firms rather than firms themselves at the heart of the innovation process and also takes on board the possible contradictions and subjectivities that might form part of the interactions between the actors. In this sense, it constitutes an advance over earlier studies, since it apprehends the mode of innovation at a more general level while at the same time taking account of new contributions.

2. The method adopted here, which focuses the analysis on the relational principles/actors pairing, does not, a priori, define the level and mode of coherence to which it can be applied. Thus the intermediate innovation space can be used for firms (particularly multinationals), innovative milieux, sectors, regions and countries.

Each of these units of analysis is examined and then characterised by the specific overlap between different pairings of relational principles and actors. The framework used to construct the coherency of these pairings on the basis of various dimensions (cf. appendix 1) is one of the results of this paper. It characterises the partners, the resources exchanged, the type of intermediate actors involved and the relational principle governing the interaction of these various dimensions.

Depending on the level at which the intermediate space is analysed, one particular RP/A pairing will be more prominent than another. Thus in innovative milieux, the "symbolic", "creation of intermediate actor" and "use of intermediate actor" RP/A pairings, together with independent actors, tend to play a more prominent role than in the sector specified by the "portfolio" or "embedded" RP/A pairings and by gatekeepers and hybrid actors.

However, these RP/A pairings also constitute a tool for internal differentiation at each of these levels of analysis. Thus the pharmaceuticals sector is close to the "portfolio" RP/A pairing, while the "embedded" RP/A pairing tends to be more characteristic of the ICT sector. By multiplying interactions and comparisons in this way, it makes maximum use of the heuristic effect.

This tool can of course be used for international comparisons and to reveal any possible national effect, an effect that received particular attention in the SESI project. The analysis presented in this paper shows that this approach to constructing the national effect, which is characteristic of much of the economic literature, is not in itself sufficient. The societal effect cannot be apprehended directly at the national macroeconomic level but is constructed rather out of the multiple interactions between different levels (units, local, sectoral etc.) and in different historical and economic contexts. The notion of the intermediate innovation space takes into account both the different levels of analysis and the diversity of the trilateral relations.

Thus the French intermediate innovation space is characterised by the embeddedness of its trilateral relations, which privileges the ICT industries, the high level of dependency linking it to earlier modes of structuration, the weakness of the independent individual actors and the difficulties experienced in the establishment of local actors. The British intermediate space, on the other hand, has a considerable capacity for adaptation, which has enabled it to keep pace with technological and organisational developments in the pharmaceutical industry but has prevented it from preserving and renewing its stock of knowledge and expertise

APPENDIX 1

The dimensions of the analysis

The actors involved in innovation (within organisations or intermediaries) are constructed on the basis of the various cases studies carried out in the course of the SESI project, taking into account the partners involved, their "habitual" relational practices and the operations actually investigated.

Three analytical dimensions were used in order to identify several sets of relational principles and actors.

1. Identification of the partners and of the actors involved in innovation within each organisation:

1.1. The firm and its innovation strategy. This position is defined on the basis, firstly, of various characteristics of the firm in question (large company, SME, multinational) relative to the market in which it operates (market leader...) and, secondly, of its technological trajectory and innovation strategy (client-driven, technology-driven, nature of intervention in the process).

1.2. The partner HERS unit. The HERS unit is characterised by its sphere of activity (teaching and/or research; discipline-based/academic or technological/ multidisciplinary competence) and by the evaluation made of it (extent of recognition and scope of legitimacy; general or specific knowledge...).

1.3. The public actors (excluding HERS). Several types of public actors can be identified: the state and its various departments and services, various institutions (such as associations), which may be private or public bodies but respond to social demand at the national level, local public actors (local government, consular institutions), the European Commission etc.

2. Analysis of the resources exchanged and identification of the intermediate actors

2.1. The type of resources

2.1.1. The first distinction to be made here is that between relationships whose objective is a flow of knowledge and those intended to foster transfers of competences. This makes it possible to differentiate, on the one hand, those firms that retain a capacity to recruit from those that do not and, on the other, those that prefer to make long-term investments in human resources that are then integrated into the firm from those that choose to procure directly the knowledge they require.

2.1.2. The second distinction relates to the original objective of the relationship from the firm's point of view: either the firm is seeking to enter into a relationship in order to supplement its internal resources and to exploit them more effectively (in terms of knowledge or competence) with a view to putting them to better use for the purposes of innovation (incremental innovation) or its aim is to acquire resources (knowledge and/or actors) that it does not possess, that are to be found in the external environment and that are more linked to radical innovations and therefore constitute a new exploration (additional knowledge).

2.1.3. The third distinction seeks to identify whether the knowledge and competences exchanged are generic or highly specific, scientific, technological, organisational or related to customers' practices.

2.2. The nature and duration of the relationship

The following are separated out:

- 2.2.1.** Informal relations often linked to relationships between individuals.
- 2.2.2.** Formalised relations that are or more less dormant. These relations, which often form part of a network, tend to be "dormant", and can be activated for a specific purpose when the need arises for one of the partners.
- 2.2.3.** Service relationships/service provision, which reduce the link to one between client and supplier.
- 2.2.4.** Collaborative/cooperative relations that presuppose a joint activity involving the firm and an HERS unit; these relations may be more or less intensive and lead to organised research with shared objectives, organised separately or jointly.

2.3. The organisation of the relations is defined on the basis of three criteria:

- 2.3.1.** The type of relations that exist between the partners, whether direct or mediated by an actor from the HERS or from the firm, by a hybrid actor with a foot in both camps or by an actor independent of these partners. This categorisation does not remain unchanged over time, since the same relationship can move between the four categories depending on the phase of its intervention in the innovation process.
- 2.3.2.** The medium through which the relationship finds concrete expression within the firm and the HERS unit, whether it be an individual or collective actor (an occupational category, an organised or institutionalised⁴⁶ entity, whether linked to the partnership or independent of it).
- 2.3.3.** Whether or not the relationship has led to the reorganisation of the firm or of the HERS unit.

2. The construction of the relational logics

Two criteria are adopted:

- 3.3.** The mode of translation between the systems: the extent to which actors in one space align themselves with and adapt to those in another, the modes of co-ordination between actors, the use of an organised or institutionalised entity as a mediator and as a medium for the relationship.
- 3.4.** System compatibility: the question of whether one partner's rule or value system dominates the relationship raises other issues, such as the controversies and conflicts that might arise between differently constructed systems, how regulatory systems are negotiated and whether the partners are evaluated jointly or independently.

⁴⁶ In the sense of the institutionalisation of social systems (Neville 1968, Touraine 1973, Montuclard 1991, Maurice 1991).

APPENDIX 2

| Relational principles/Actors | Modes of translation | Compatibility between actors | Capacity for adaptation |
|--|-----------------------------|--|---|
| Symbolic principle/actors within the company | - | - | - |
| "Dormant" principle/informal gatekeepers | Co-ordination | Variable, depending on the history of the relationship | Intermediate space, in which change is difficult to initiate |
| The "creation" principle/Individuals, independents | Bridging | Declines over the course of the collaboration | Intermediate space in the process of construction |
| "Portfolio" principle/Gatekeepers | Co-ordination | Average | Adaptable intermediate space |
| "Embeddedness" principle/Individuals and hybrid entities | Alignment | Very good | Intermediate space shot through with strong irreversibilities |
| "Use" principle/Hybrid and independent entities | Bridging | Average | Very flexible intermediate space |

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PART 2

***SYSTEMS OF INNOVATION : AN
INTERNATIONAL PERSPECTIVE***

Introduction

Many studies have revealed "national profiles" of innovation structure that all stress the importance of the interactions between the various elements of the systems involved (public and private research bodies, higher education establishments, government policies, firms). First advanced in the mid-1980s by C. Freeman within a neo-Schumpeterian framework⁴⁷, the concept of the "national innovation system" was further developed and enriched by many authors, namely Lundvall, Nelson and Edquist⁴⁸. Although the various schools approach the notion differently, national innovation systems can be defined as networks of institutions operating in the public and private sectors whose activities and interactions generate, modify and diffuse new technological innovations. This approach stresses the specificity of the choices that shape the various national systems, in particular through public policies on education, academic research, legislation on intellectual property, the banking system and access to finance for emerging technologies. The resultant coherence between various institutional arrangements – or strategic institutional complementarities (Aoki⁴⁹) – tends to create a sort of irreversibility contained within "particular institutional infrastructures". Such institutional infrastructures correspond, therefore, to the incentive mechanisms through which the strategic behaviour of the various actors (firms, institutions and individuals etc.) is mediated. Thus firms are able to "exploit" the cognitive and institutional resources of their countries of origin in order to construct their competitiveness. In effect, once created, this coherence within a national system of innovation represents both a resource and a constraint for firms, since it tends to favour a certain way of innovation while at the same time precluding any deviation from a dominant pattern. This creates institutional inertia, a phenomenon known as "path dependency", which effectively defines national innovative trajectories over time.

However, the relevance of the notion of the "national" innovation system is now being seriously challenged both by recent developments and by new theoretical stances. It goes without saying that "globalisation" represents a radical change in the world economy, bringing with it increasing cross-border transfers of information and knowledge, the importance of research-related foreign direct investment, the explosion of international strategic alliances in science and technology and the "multinationalisation" of large firms. Such developments pose a serious threat to the importance of national R&D programmes, to the ability of nation states to protect their domestic markets and to the role of state in the management of scientific/technological

⁴⁷ See namely Freeman Ch., 1987, *Technology and Economic Performance, lessons from Japan*, Pinter Publishers, London.

⁴⁸ Lundvall B-A., 1992, *National Systems of Innovation, toward a theory of innovation and interactive learning*, Pinter Publishers, London.

Nelson R., 1993, *National Systems of Innovation : a comparative study*, Oxford University Press.

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⁴⁹ Aoki M.(1988), *Information, incentives and bargaining in the Japanese economy*. Cambridge, Cambridge University Press.

policy; in short, they threaten to weaken "national" borders, which to date have been considered as the natural framework for innovation systems.

The second part of the report seeks to address some of the key issues arising out of the vigorous debate on national diversity in innovation systems versus the "convergence" or "globalisation" of innovation systems.

This part has three chapters which, together, constitute an attempt to undertake an international comparison of science-industry relations. Each of them has a different theoretical background and methodological stance. However, they all seek to combine micro-level findings drawn from our empirical studies with institutional knowledge drawn from macro-level or statistical studies.

The first paper (chapter 5) begins by describing recent changes in the joint production of competences and high-level skills by academia and industry before going on to compare the recent evolution of the higher education and research system (HERS) in five countries.

The interaction between the HERS and companies, notably in the production of human resources, creates recurring actions that channel the various actors to a greater or lesser extent as their competences are shaped and their career paths developed. This repeated interaction plays an important role in the structuring and/or transformation of the 'intermediate innovation space', which is located at the interface between the HERS and industry. Examination of how graduates enter the labour market allows us to tackle issues around signalling, human capital and networks and to relate them to the emergence of a new form of labour market which combines the mechanisms of internal and external markets. These issues will be addressed in terms of actors' strategies and companies' sourcing and R&D policies. Our analysis will focus on the different dimensions of this interaction between the HERS and companies in the joint construction of competences and strategies for exploiting the various mechanisms of collaboration. The institutional arrangements governing these relations and the practices resulting from them may be quite different depending on the sector concerned, graduates' educational levels and the individual companies, whose R&D strategy may differ even within a single sector. In other words, the building of networks or the signalling mechanism remain subject to extremely varied local contexts. In spite of this diversity of practices, however, we maintain the hypothesis that it is possible to identify dominant forms of these relations which differ from one country to another.

The second paper (chapter 6) adopts an original approach in order to investigate the possible "Europeanisation" of national innovation systems. Indeed, it is interesting to enquire simultaneously into the various possible scenarios. Apart from the status quo in the form of specific national innovation systems (NIS), several possible development paths can be envisaged : the merger of each European country's NIS within a single integrative framework (the "Europeanisation" scenario), convergence towards the "American" model (the "Americanisation" scenario) and the creation of a new, integrated international system (the globalisation/standardisation scenario).

An author like D. Mowery⁵⁰ emphasises the fact that the various elements of the "American model" that developed in the forty years after the Second World War are

⁵⁰ Mowery D., 1996, "The US National Innovation System, Recent Developments in Structure and Knowledge Flows", OECD, October, 3, Paris.

currently undergoing significant changes that tend to point, he argues, in the direction of the globalisation scenario (emergence of a new, standard innovation system). Thus he rejects the "Americanisation scenario", thereby calling into doubt the very notion of NIS. Although there are many economic and technological factors that support his point of view, it would, nevertheless, that each nation has varying degrees of institutional inertia linked to "path dependency" effects.

The emphasis here is on the trends towards "Europeanisation", despite the fact that in reality there are complex, contradictory and non-linear elements within these trends. The main argument advanced draws on the notion that local factors play a structuring role, both in the organisation of science-industry relations and in the construction of foreign multinationals' ability to attract R&D resources. It is reasonable to suppose, moreover, that NIS will increasingly be based on a set (a network) of geographical centres with their own local, internal coherence and the ability to combine a variety of resources, both public and private. Thus it would seem that the supra-national and the sub-national dimensions are developing simultaneously and that this is one of the first elements of more wide-ranging processes of reconfiguration, either on a regional basis (i.e. encompassing several countries), or on a Europe-wide basis.

The third paper (chapter 7) seeks to develop a "transatlantic" approach by comparing the NIS of two countries, the United States – the inescapable reference point in matters of innovation – and Germany – whose institutional arrangements, currently undergoing profound change, can be seen as representative of the countries of Continental Europe. Based on a hundred interviews with actors involved in innovation in both firms and academic organisations, this approach uncovers both the similarities and the differences in science-industry relations between the two countries. On the one hand, these relations contain mechanisms that pit the world of science and that of industry against each other in terms of objectives, time horizons and incentive systems. The gap between the two worlds gives rise to the same type of problems, difficulties and dilemmas, that is "transfer gaps" that have to be bridged in one way or another. On the other hand, over the course of its history, each country has constructed a set of institutions, of legal and regulatory arrangements and organisations that are supposed to help bridge such transfer gaps.

Nevertheless, for various reasons, problems linked to intellectual property rights have emerged recently as core issues for science-industry relations in the two countries. Against the background of the increasing tensions between the existing rules and the changes being instigated by certain actors, they would seem to be emerging as the key element in these relations. The future evolution of NIS could depend on the way in which the protagonists in science-industry relations in each country succeed in negotiating solutions and putting in place new arrangements that strike a balance between public and private interests.

Chapter 5 - Hiroatsu Nohara, "Co-production of Competences between Academia and Industry: an emergent Bridging Institution"

Introduction

The aim of this study is to analyse innovation in terms of the ways in which competences are built. This topic necessarily raises questions about collaboration between the higher education and research system (HERS) and the companies. The HERS generates two kinds of resources favouring innovation in industry: one of these relates to scientific knowledge that is relatively formalised and transferable (via formulas, algorithms, software programmes, technical devices, documents, scholarly articles, or patents) and the other, to competences embodied in individuals. Notwithstanding the fact that these two resources are intimately interconnected, especially in the training of PhD candidates and the use of post-docs, we shall begin by analysing them separately (the integration of the two will follow), focusing on the development of the graduates' professional competences. We have chosen to proceed in this manner because the education and training aspects of the HERS has been relatively neglected in innovation literature on, even if it is generally recognised that the system's primary contribution to industry's dynamics of innovation is by far the production of inflows of well-educated graduates (OECD 2000).

In general, the ties between higher education, the labour market and the company are analysed in terms of human capital, signalling or networks. The first two approaches are strongly inspired by economic analyses, while the latter is more sociologically oriented. Given the inductive nature of our research, calls for favouring the phenomena of signalling and networks, with the first considered as a quasi-market mechanism and the second, a strategic construct based on interactions between the actors. An analysis based on these two mechanisms should allow us to reconcile the national institutional dimension (which can sometimes overpower the facts coming from observations in the field) with the micro dimension (which may appear to be too particular), in order to bridge the gap between micro and macro.

In classic innovation literature, the HERS and industry are held to be two autonomous, independent spaces for the production of knowledge and competences. They are clearly distinguished by the nature of the knowledge produced (scientific for the former and technological for the latter), by the nature of the communities of actors (scientists versus engineers), by the body of rules governing their careers (academic reputation or promotion/monetary gains) and by their functional opposition (producer of common or private goods). Such a conceptual separation is increasingly remote from reality, if it has in fact ever reflected relations between the HERS and industry. On the contrary, the

interaction between the HERS and the companies, notably where the production of human resources is concerned, creates recurring movements through which the different actors are to a greater or lesser extent channelled in the shaping of their competences and the development of their career paths. This repeated interaction plays an important role in the structuring and/or transformation of the 'intermediate space of innovation' which is located at the interface between the HERS and industry. Labour-market entry of graduates is one of the factors which allows us to introduce all the signalling/network problems mentioned above and relate them to the emergence of a new form of labour market in which the mechanisms of the internal and external markets are combined.

These problems will thus be addressed at once in terms of the actors' strategies, the companies' sourcing policy and ultimately, the latter's R&D policy. We shall centre our analysis on the different dimensions of this interaction between the HERS and the companies for the joint construction of competences and strategies for using various mechanisms of collaboration (internship, hiring, selection, industry fellowships, temporary use of post-docs, etc.). The institutional arrangements governing these relations and the practices resulting from them may be quite different depending on the sectors, the diploma levels of graduates or the individual companies, whose R&D strategy may differ even within a single sector. In other words, the building of networks or the signalling mechanism are subject to extremely varied local contexts. In spite of this diversity of practices, however, we maintain the hypothesis that it is possible to identify dominant forms of these relations which differ from one country to another.

In this study, we will begin by defining what we mean by innovation, which is something similar to the 'chain-linked' model developed by Kline and Rosenberg (1986). We shall attempt to improve (develop) the latter, however, by introducing certain elements from the societal approach. In the second section, we shall suggest national paradigms for the relations between the HERS and industry, based on the production of engineers/researchers, which closely reflect the national contexts to which the companies are subject (in varying degrees) in the sourcing of high-level human resources. Once the national institutional context of scientific/technical training has been defined, the third section will be devoted to the analysis and interpretation of the different case studies by sector and country. In our conclusion, we shall return briefly to the question of the analytical significance of "intermediate innovation space" which is emerging at the interface between the HERS and the companies.

The concept of innovation: The innovation space and the actors

Innovation as an iterative, cumulative process

For many years, and notwithstanding Schumpeter's pioneering studies, economic theory had to do without the notion of the innovative firm. Although in-house R&D laboratories continuously established their authority in the course of the century (Nelson and Rosenberg 1993) with the historic rise of the large corporation, the firm was long seen as an individual entrepreneur and scientific/technological knowledge as a variable emerging from generous environments. In such an academic context, the elaboration of evolutionary theory (Nelson and Winter 1982), arguing for the inevitable encounter of

the firm and innovation, constituted a major turning point in the economic theory of technological change. In schematic terms, the 'evolutionary' firm is composed of two complementary functions, the first related to production and the second to innovation, which is taken to be the firm's ability to make its production function evolve. These two functions correspond to opposing worlds: the production function is highly structured around the identical reproduction of gestures, decisions and competences in view of a productive efficiency based on repetition, collective frames of reference and mastery of a given competence⁵¹. The emblematic figure of this world is the 'routine', which serves not only as a basic tool of co-ordination but also as the repository of the company's organisational memory. By contrast, the innovation function creates a space in which actors can hesitate, discuss, disagree and advance by trial and error. It is quite difficult to rely on well-defined rules and objectives in order to co-ordinate their activities, the organisation of which remains largely uncertain. The emblematic figure of this world is the R&D department or the community of engineers/researchers, who are assigned the difficult task of exploring different technological paths and shaping the technical and cognitive resources that should be incorporated into the new products or productive activities of tomorrow. This world is eminently chaotic; innovation thus plays the primary role of incubating changes in the whole of the company's productive activity.

This shift from a theory of routine to a theory of innovation presumes that the problem of the absorption of technological or scientific knowledge is resolved. The evolutionary authors notably stress that absorbing science/technology requires the revision of the localised learning processes which shape specific productive resources. In this sense, they defend the idea that the processes of innovation taking place within the company basically correspond to processes of technological creation. One of the essential points confronting any theory of innovation is thus that of the dividing line between the outside and inside of the innovation process and the theorisation of that process. Indeed, every process of innovation draws its resources from its environment and proceeds, through a combination of assembly and creation, to adapt them to its needs.

The distinction between the notions of 'generic' and 'specific' resources is useful for describing the indispensable coming-and-going between the outside and inside of the innovation process. These two terms describe the separation of the two worlds and the transformation that necessarily occurs when the resources go from one to the other. Contrary to the 'diffusionist' theories (Artur 1988) which assume the homogeneity of the market, the situation of perfect information and automatic imitation by agents, the concept of technological creation based on the 'specification of generic resources' within the firms more successfully captures the complex realities of the innovative dynamics and idiosyncratic nature of locally produced knowledge and competences. Above all, it raises one of the thorny questions surrounding the 'absorptive capacity' of the firm (Cohen and Levinthal 1989).

Each of these questions has profound implications for our understanding of innovation. Given their scope, we shall limit ourselves here to proposing our own representation of the innovation process with the help of the 'chain-linked' model developed more than

⁵¹. The notion of the internal labour market, first developed by Piore (Piore and Doeringer 1971) and which implies a form of learning/on-the-job training that is fairly static or routine, reflects the way this world functions.

fifteen years ago (Kline and Rosenberg 1986). Indeed, this model coherently integrates the different dimensions of innovation and describes the information flows and learning dynamics, in contrast to the conventional linear model, where innovation is taken to proceed successively from science to technological development, to manufacturing and ultimately to marketing. In this alternative model of continual information loops, two mechanisms play the primordial role in organisational learning (Kline and Rosenberg, pp. 285-291):

- The first mechanism arises within the firm: the central 'chain of innovation' represents the main path of innovation along which the development of new products or technologies is organised from the initial phase of inventional/analytical design through the research, testing and manufacturing phases to the final phase of marketing. At the same time, there are two kinds of loops, one of which bears on the immediate return of information between successive phases (short feedback loop) and the other, on the return of information linking distant phases such as marketing and research, or client needs and design (long feedback loop). These feedback loops reflect the processes of trial and error, exchange of information between the different functions and accumulation of knowledge within the organisation. The presence of these different feedback channels thus allows the innovation processes to be interactive, iterative and filled with unexpected events. This uncertainty is precisely what creates opportunities for collective learning.
- The second mechanism, more relevant to our subject, is located at the intersection of the company and its environment, notably in the form of the institutions of training and scientific research. Throughout the process of innovation, the company maintains channels of formal or informal relations with different institutions possessing the needed expertise or scientific databases. Recourse to these resources continues not only to resolving certain technical problems but also to improving the supply of knowledge over time. Similarly, feedback loops between science and innovation permit radical innovations and, in return, help to stimulate scientific progress. What is important for our argument is that this interface between science and innovation is set up in each phase of development, from preliminary research to manufacturing, even if, to be sure, the kind of science required seems different for each phase: the further upstream the phase, the more it calls for basic scientific research (often synonymous with 'pure academic research'), while the manufacturing phase has greater need for knowledge coming from applied research or system science.

As we can see, the company is the locus of innovation where all the internal channels interact, in an integrated but not very co-ordinated way, to enrich the supply of knowledge and technical solutions which allow new cycles of technological development. At the same time, it also tends to integrate its scientific environment by deploying its own networks, which serve as a means of knowledge absorption. Innovation can no longer be conceived as a simple combination of information and standardised production facilities located in a neutral place. It corresponds, on the one hand, to a process of transforming generic knowledge coming from the outside into specific knowledge through development cycles carried out by the company and, on the

other, to the process of co-ordinating this locally produced knowledge with the help of different specific resources found within the company.

From innovation process to innovation space

This 'chain-linked' model helps to clarify the debate on the nature of innovation and the interaction between technology, organisation and environment (science and market) by identifying channels of information flows or defining the possible ties between co-operative connections. Notwithstanding this undeniable contribution to the conceptualisation of innovation, however, this model lacks institutional content. This lack is doubtless due to the fact that the authors treat the innovation process essentially as flows of information or knowledge. It is thus not easy to know what kinds of organisation or institutional architecture maintain these flows of knowledge. We may also ask ourselves who are interacting with each other, building the networks together and teaching each other.

Here we shall strictly limit ourselves to the science-industry interface⁵². Like so many other authors who stress the growing importance of academia-industry co-operation for company competitiveness (Cohen et al., 1994), the chain-linked model teaches us that the company increasingly absorbs its scientific environment by creating more or less formal ties that permit scientific knowledge or a series of technical solutions to be introduced into the innovation process. These ties range from the most formalised arrangements (mixed laboratory, research contract, research consortium) to those which have little visibility (consulting, loans of samples or machines, participation in seminars etc.). Such a linkage between the HERS and the companies emerges because of the limited appropriability of scientific knowledge, which--unlike information circulating on the market--has a considerable tacit dimension and implies appropriation costs that are far from negligible. Taking the intrinsic difficulty of appropriation into account opens a large field of investigation concerning contractual relations between the HERS and the companies. These co-operative relations have thus been analysed by economists in terms of production and the use of 'technological assets' which vary in their scarcity and the degree to which they can be replaced or appropriated. Without really belonging to this field of study, Williamson (1985) was the first to offer an interesting analysis of the institutional forms of co-ordination, with emphasis on the specific nature of the assets and the frequency of their exchange. According to the transactional approach, there are three types of co-ordination: market, vertical integration and 'hybrid' forms between the first two. In view of the nature of the output (knowledge or qualifications which entail both uncertainty and absorption costs), a wide range of co-operation between companies and the HERS corresponds to the hybrid form, which implies 'bilateral governance', an intermediate situation simultaneously regulated by market and organisation principles. Such a situation reflects the prior creation of contractual or permanent ties which allow the identification of the parties involved and their interests, and possibly the ex post facto resolution of unforeseen conflicts. If the nature of assets is considered, the co-operation can also be interpreted as a combination of

⁵² This "chain linked" model can also help us to investigate the inside of organisations or firm in terms of actors, actors' strategic games and so on. In this paper, we will not attempt to open this "black box", but restrict our attention to the interface problems.

complementary assets which makes it possible to boost the effects of synergy (Le Bas and Zuscovitch 1993). Furthermore, Aoki (1988) emphasises the importance of the 'relational quasi-rent' which is the fruit of mutual commitment to the accumulation of shared resources. He thus considers co-operation a source of profits for the two parties involved because it permits the establishment of rules of co-ordination and the accumulation over time of specific resources--scientific, cognitive and relational--through the mutual learning experience. These resources constitute a competitive advantage which the company could never acquire on the market. Co-operation thus appears as a form of compromise likely to alleviate the defects of the market (short-term optimisation behaviour or opportunism) and the negative effects of organisational rigidity (co-ordination costs and lack of adaptability to changes in the environment). A contractual relationship based on a certain stability allows a mutual adjustment of strategies--even if the objectives of the two parties are not identical, as is the case with co-operation between the HERS and industry--in order to optimise the yield of the 'relational quasi-rent'.

These different economic approaches shed light on the collaboration mechanisms forged at the interface between the HERS and the companies. Often associated with game theory, they thus provide tools for understanding certain empirical cases. But even if the benefits of co-operation are well understood at the 'normative' level, the conditions for the 'alignment' of respective interests are not automatic, since the objectives, incentives or evaluation procedures of each party remain quite different: in terms of the production and use of knowledge, the respective worlds of the company and the HERS are regulated by a group of rules which are often contradictory (Dasgupta and David 1994). Co-operation thus presumes institutional structures favourable to the matching of objectives or the institutional creation of such structures in terms of organisations and referents common to the actions. From this point of view, the different studies carried out in the context of 'national innovation systems' show that there are, at either regional or national level, different formal arrangements, often specific to the entities under consideration, which more or less permit a reduction of the cognitive distance or the costs of adjustment and thus facilitate linkages between the HERS and the companies.

For our part, we are proposing an institutional approach which would introduce the notions of space and actors in order to describe simultaneously the actors' strategies for action and the institutional framework within which these strategies are deployed. This 'societal' analysis attempts to grasp the innovation process as the result of interactions between 'societally constituted' actors, in the form of co-operations, conflicts or compartmentalisation, which may be combined and expressed in different ways specific to each society and each company within these societies⁵³.

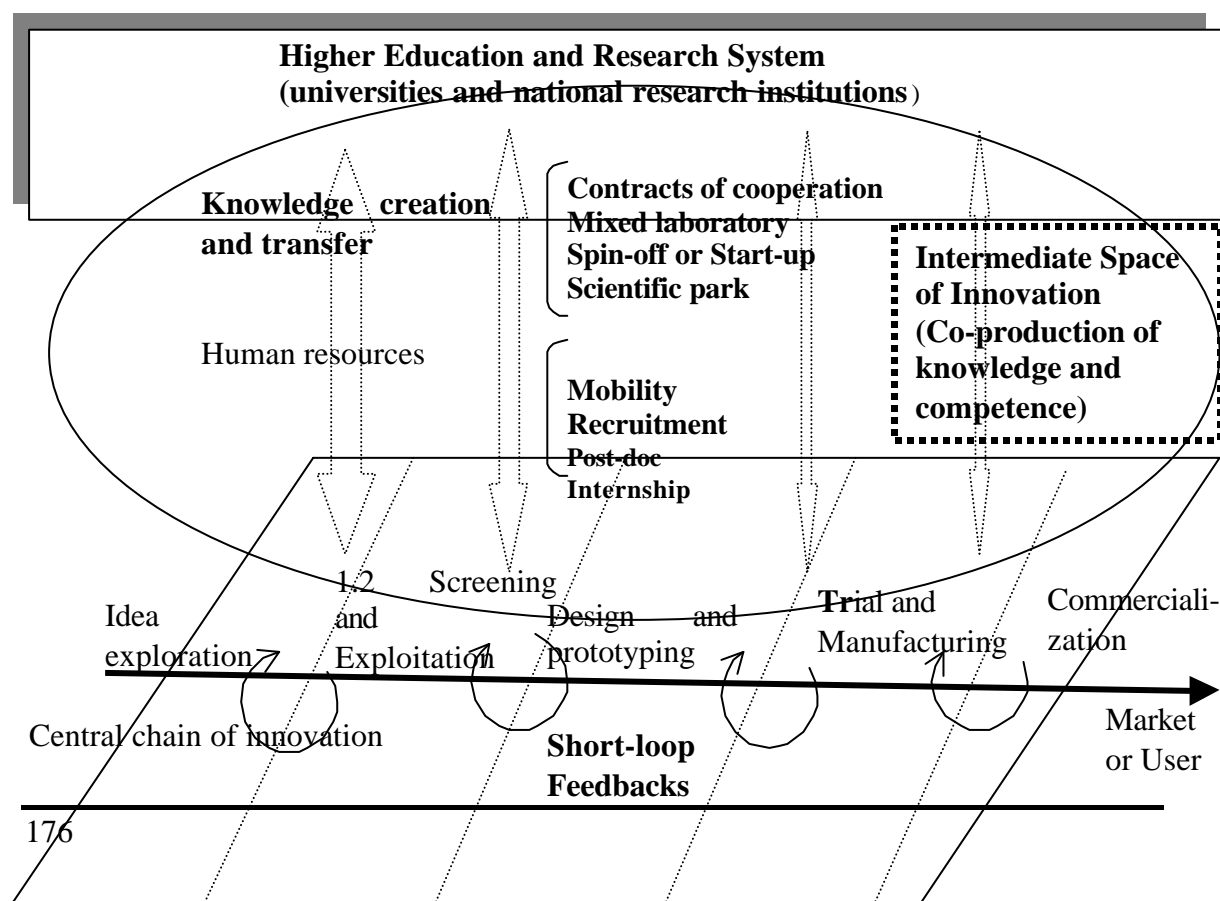
In our earlier studies bearing on the societal factors underlying the capacity for innovation, we presented the notion of the innovation space. Such a space is conceived as a site where the dynamics of learning--the company's absorption of resources--are forged by the interaction between factors of socialisation related to the building of the actors' professional know-how and factors of organisation reflecting both the division of

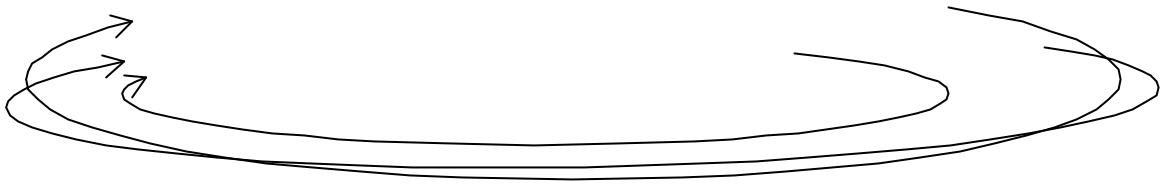
⁵³. As a socially constructed category, the 'actors' may include both individuals organised around a professional category such as engineers or researchers, and private or public enterprises, start-ups or public laboratories or agencies.

labour and inter-company relations. In other words, we were proposing to apprehend the company's innovation capacity in its surrounding societal context, namely in its relations with the educational and scientific spaces, but also with the different actors of industrial strategies or public policies, all of which contribute to defining the industrial space. Within the company, these three spaces correspond respectively to R&D strategy and organisation, to the relationship to the market, providers and users and to human-resources management, chains of authority and the division of labour. Our analysis is thus aimed at elucidating the processes, at national level, at company level, and between the two, which contribute to constructing the driving forces of innovation within the company by developing relationships of interdependence.

Such an approach based on the innovation space would seem to offer relevant problematics for the comprehension of technological innovation processes, on the condition that this theoretical framework is adapted to our specific subject, the interface between the company and the HERS. To this end, we shall introduce the notion of the 'intermediate space of innovation' which is directly derived from that of the innovation space. This new concept has a triple function (see Diagram 1). First, it permits a close alignment with the conceptual framework of the chain-linked model discussed above, which, although it is too functional as it stands, would be extremely pertinent if it were made more operational. Second, it allows us to delimit our field of investigation in terms of institutions, exchange flows, mobility or products of co-operation, which helps to define the contours of innovative 'milieu'. And last of all, it makes it possible to identify the actors' individual and collective interplays which, in spite of the weight of existing institutional forms, create a space for the co-production of competences and resources.

Diagram 1. Revised version of the Chain-Linked Model of Innovation (after Kline and Rosenberg 1986)





The mobility of manpower as a component of the intermediate innovation space

Organised around the companies, which are the main actors in innovation, this space contains various forms of institutions whose objectives are directly related to the production of scientific knowledge and resources/competences: individual entities such as universities, higher colleges, public, private or non-profit laboratories and hospitals; collective entities such as research consortiums, scientific parks or technology districts. In addition, there are institutions which mediate these co-operation relations, including various councils set up to manage higher training and research, public agencies for the transfer and dissemination of technology, research foundations, seed funds, offices for the handling and transfer of patents, professional associations, chambers of commerce and so on. Just below the surface, of course, are the public-policy dimensions, which may be more or less systematic but are in the last resort supervised by the State. Numerous studies show first of all that the overall configuration of these institutions varies greatly from one region or country to another in terms the weight, autonomy or function of each institution as well as of its legitimacy. These studies also demonstrate that the complex interactions between institutions contribute to the creation, at regional or societal level, of an institutional singularity often corresponding to the conglomeration of specific assets, the impact of which is expressed in the form of technological spill-over. Beyond these positive externalities, such institutions obviously interact with the company as well. For one thing, the companies incorporate the particular institutional features concerning them into their strategies as external givens, which allows them to profit from existing resources, often in the form of contracts. For another, in order to create new resources/competences, they jointly develop the various forms of collaborative relations resulting from compromises between each party's needs and aims. This process can take the form of research agreements, mixed laboratories, federative associations or networks of formal or informal contact which mediate the flows of knowledge and competences--back and forth--between the HERS and the companies. In order to circulate between the two worlds, these flows may assume the material form of scholarly articles, data, patents, technical devices, computer programmes, interns, engineers or post-docs. The particularity of this production lies in the fact that the knowledge is simultaneously constructed in the form of competences embodied in human actors. Insofar as knowledge is 'sticky' (Von Hippel 1990), it is not easily detached from the contexts or individuals who have generated it. Although we are not opposed to Callon's thesis (Callon 1989) that technical devices are also actors which transmit abilities and build networks, we accord a particular status to human actors such as engineers, researchers, technicians, professors, managers, experts, project leaders and so on: they are the privileged indicators concerning the structuring of this space. As

professional categories, these human actors are constituted through an interdependence between forms of socialisation forged by the university and research training systems and the companies' organisational behaviour structured by R&D practices and human-resources management. They are in some way products of this space, endowed with the institutions' operational strategies, often specific to a region or a country, and the linkages between the HERS and the companies. At the same time, these communities of actors contribute, on the basis of the cognitive resources at their disposal and their own strategies of professional functioning, to the specific nature of this space as well as to the construction of societal specialisations in the various technological domains. From this point of view, the academic spin-offs, which take very different forms from one country to another even if they constitute a phenomenon that may be observed everywhere, offer a good example of these interdependencies: they represent points of intersection between the institutional capacity of the 'societal' space of innovation and the individual capacity of the entrepreneurs and as such reflect both the professional strategy of the actors and the institutional strategy of science within a given society.

Thus, the introduction of the intermediate space of innovation allows us to situate the institutions at play, to highlight the main actors and observe the interactions. This overall reading of interdependencies between the space and the actor allows us to contextualise the different forms of collaborative arrangements at micro, meso (sectoral or local) and macro (societal) levels depending on the analytical options selected. It is aimed at revealing the strategies and quality of the relations thus established rather than quantifying them.

Given the emphasis placed on the human actors, we shall focus our analyses on the dimension of shaping/mobility of the competences which are embodied in the workforce. This dimension is traditionally treated by the labour economics specialists in terms of "school-to-work transition". This transition corresponds to a complex process which involves a set of co-ordination mechanisms allowing the companies to obtain the human resources, competences or expertise they need for innovation through the HERS. The mechanism regulating this transition goes beyond the general sense of the labour market as a system for the allocation of labour through prices. It reflects the interpenetration of market and organisation principles through a hybridisation of what economists generally call the 'external market', whose rapid adjustment is guaranteed by mobility flows (hiring and firing), and the 'internal market', where rules (incentive system) structure the development of long-term career paths. This hybrid space also reflects the mechanism of 'bilateral governance' which involves negotiating compromises between the respective strategies of the universities and the companies in order to determine common interests.

The hybrid character of this transitional space obliges us to clarify the mechanisms for certifying diplomas which are largely responsible for regulating the transition of recent graduates with scientific and technical qualifications (from high school+2 to the PhD or post-doc) from the HERS to professional activities. It leads us also to shed light on the networks and other mechanisms which, notably emerging in certain high-tech sectors and for the highest levels of schooling (high school+5/6 and over), tend to organise new kinds of relations at the company-HERS interface in the areas of selection, recruitment, training, mobility and so on. Such new types of relationships are contradictory: they are characterised, on the one hand, by the companies' increasingly intensive integration of

certain elements previously in the domain of the HERS (co-production of competences, industrial post-docs etc.) and, on the other, by an externalisation of certain R&D functions proper to the companies in the form of networks. The combination of these two trends increases what may be called the companies' 'flexibility of initiative' (Gaffard 1989), which amounts to profiting from stable relations based on networks, reputations or a succession of short-term agreements while maintaining the possibility of interrupting these relations (flexibility of choice). The emergence of a hybrid space of this kind, combining co-operation and flexibility, results from various changes which may be observed in the organisation of R&D in the companies as well as the conditions of the production of scientific knowledge:

- The companies are restructuring the organisation of their R&D activities to privilege a system of R&D management which is more decentralised, interdependent with other functions and interactive with the market. They tend to limit considerably the weight of the central laboratory, previously considered a source of generic technologies, while innovation in industry, at least in certain high-tech sectors, relies more and more directly on basic scientific knowledge. This double movement is leading to a modification in the boundaries between internal and external R&D activities, the portfolio of contractual activities and, above all, the nature of relations with academia in favour of more flexible forms of collaboration. From this point of view, the development of co-operative ties between companies and academic spin-offs marks the emergence of a new form of collaboration--one based on market regulation, and thus market flexibility, rather than negotiated flexibility tied to institutional arrangements.
- The companies are finding themselves in an economic environment that exacerbates tensions between objectives dependent on different time frames; they have to reconcile cash-flow requirements in the short term with the need to forge the core competence which is the source of their competitiveness in the long term. This trade-off between the two objectives is becoming increasingly difficult, owing to the fact that R&D in the new technological fields require ever more massive investments. Faced with the growing costs of R&D and increasingly uncertain results, the companies are seeking to share these risks through alliances with the others or outsourcing. Co-operation with the HERS falls within this trend, especially since the public research bodies and the universities, whose public funding is diminishing, are in need of other funding sources.
- Scientific progress is intensifying both the specialisation of knowledge in a given field and the need to recombine these ultra-specialised forms of knowledge (e.g., molecular chemistry, biochemistry). New areas of knowledge are emerging at the intersections between several disciplines (bioinformatics, genomics, network technologies, molecular computers etc.), where the simple addition of disciplinary knowledge is not enough to advance research. The increased capacity of computers also makes it possible to develop all kinds of digital modelling (molecular models, biological models) which can replace the work of instrumentation but which make the mastery of mathematical and computer tools indispensable. These different trends are complicating the sphere of scientific production and ties between research and university training, as well as their respective ties with industry. Two major problems thus arise (Lam

2000). The first concerns the spread of the new knowledge and competences which are just emerging and are little formalised, thus making it necessary to find adequate institutional structures for their transmission. The second concerns the erosion of the traditional disciplinary framework, which raises problems for the screening of students because existing certification no longer gives accurate indications of the quality of the candidates. In order to resolve these problems of dissemination and screening, an intermediate space is being created at the interface of the HERS and industry, with the dual aim of co-developing or co-producing the requisite knowledge and competences and co-constructing the new frames of reference for joint action.

Combined with positive business cycles marked by a shortage of skilled labour, these different trends are contributing to the emergence of a new form of labour market, albeit in different forms from one country to another, depending on their specific institutional infrastructures.

Institutional Infrastructures underlying the Relationships between HERS and Industry at the Competence Co-production level

Before proceeding to concretely analyse our case studies, we shall attempt to examine two institutional elements which seem to play, , an important role in each country in shaping the national capacity for supplying science and technology with manpower. The first refers to societal conventions which determine the configuration of actors such as research workers or engineers in a given socio-economic context. The second is related to the historical path by which a new discipline such as computer science or biotechnology have been legitimated within a national academic community.

The actors' cognitive and professional configuration: the societal linkage between the HERS and the actor figures

The interactions between the HERS and the companies consist, especially as far as the production of diplomas and competences is concerned, of repeated movements which ultimately generate routines, rules and practices. The different actors are in fact subject to a body of societal conventions which, to one degree or another, define the processes of socialisation, differentiation and hierarchical organisation of wage-earners. In other words, socio-occupational categories such as 'engineer', 'research worker' or 'technician' do not reflect a 'natural' order but rather, are social constructs. Thus, they can only be understood fully if we grasp the construction of their individual or collective abilities (or professional know-how), which are closely associated with forms of education, division of labour and hierarchical organisation of posts as well as professional mobility involving both industry and the HERS. This complex interaction results in a cognitive and professional configuration of the actors, crystallised around the figures of engineer or researcher. Such a configuration, which also differs from one country to another, remains more or less stable in the short/mid term but evolves over the long term because of path dependencies related to the national innovation systems. From this point of view, the notion of 'generic resources' used until now, and which has proven extremely

useful in economic analyses of innovation, should be reconsidered at a more sociological level. Indeed, generic human resources (graduates) are far from reflecting the natural state of resources; they are quite actively reworked by the institutions even before their appearance on the labour market. To be sure, they are the object of private and social investments as 'human capital', but are above all 'shaped' through institutional relationships which are very different from one country to another. The creation of generic human resources should thus be understood as arising from a process of investment on the one hand and a process of socialisation of the actors on the other. In this section, we shall draw on stylised facts in order to give a rough outline of the figures of the most significant actors in innovation, notably engineers and researchers, in five different countries: Great Britain, Germany, the United States, France and Japan.⁵⁴ These professional categories are considered as bearers of particular cognitive resources because they correspond to the crystallisation of certain institutional, scientific and professional rationales, but also as actors who are capable of playing social and strategic games. Our hypothesis is that this configuration of actors is one of the major elements structuring the collaborative ties between the HERS and industry and that, even if concrete arrangements between university and company always reflect certain specific local, sectoral or disciplinary features, it shapes new forms of co-ordination in a societal space in order to respond to the needs--and tensions--of the knowledge-based economy.

1/ The weakness of British engineers' professional identity due to conflict between science and technology

The case of Great Britain, the first country to have undergone massive industrialisation, is quite interesting. This country of small businessmen à la Marshall has not strived either to promote high-level technical education or to regulate access to the title of engineer through State control; indeed, the traditional figure of the engineer has been symbolised by self-made men (!) or engineers emerging from continuing education in the higher education colleges. A new figure is now based on a combination of Bachelors- and Masters-level training (3-year BEng degree : 4-year MEng degree) either in classic universities or polytechnics or in those resulting from the combination of the polytechnics (3 years) with several years of professional experience. This figure involves extremely specialised technical knowledge orientated towards application. University-type training, with a curriculum that is the shortest of all the countries considered here, places the emphasis on a strong disciplinary specialisation (curriculum content is concentrated on 3 or 4 subjects) and the applied aspects of technology. Engineering education in the university system appears to suffer from two weaknesses: the ambiguity of its status, which is considered less noble than that of science, and the low readability of the diplomas because of sharp disparities in the quality of the instruction, and thus the quality of the graduates, from one institution to another. After the Bachelors or Masters degree, access to the technical elite, in the form of the 'chartered engineer' status, requires a period of highly 'supervised' learning which combines in-company internships, additional university training and several years of

⁵⁴. In methodological terms, it must be specified that these figures of actors are ideal types in the Weberian sense. In addition to the national case studies provided by each team, the constructions are based on different international comparisons, notably the *The Research Foundations of Graduate Education*, co-ordinated by Barton Clark (1993).

work experience. The certification of this 'engineering' profession is carried out by the Engineering Council, which is composed of professional associations including the Institution of Electrical Engineers, the Institution of Mechanical Engineers and others; it thus differs sharply from practices in Continental Europe, which rely more on engineering diplomas issued by the public authorities. Even if this group of educational and regulatory mechanisms help to create the model of 'professionals' with technical expertise and professional autonomy, English engineers have never acquired an elevated social status or a strong identity. In practice, there is little difference between them and the 'technicians' holding a Higher National Certificate (HNC) or Higher National Diploma (HND), or 'sub-engineers' with part-time training, who have the possibility of gaining access to the engineers' function in the course of their careers through internal promotion. Thus, given the relative lack of status accorded to their position in the organisation, engineers have a high rate of turnover and above all seek to leave the technical function quickly by moving into management, which has much more status and is set off from other technical functions. This shift tends to introduce a certain discontinuity in their careers, as well as in their accumulation of expertise, which does not always strengthen the collective capacity for innovation within the company.

British research workers, meanwhile, do not enjoy the special status associated with the presence of powerful national research institutions, and as academics, they tend to be more university-oriented. They enjoy a higher status than engineers, however, because of the reputation of the historic universities (Cambridge, Oxford etc.), which have always favoured science over technique. Although the system of doctoral studies still remains marginal within the universities, its status and identity are more recognised--albeit to varying degrees from one discipline to another--because of the high quality of such programmes, which are characterised by their selectivity (small groups of doctoral students) and traditional pedagogy (tutorials). Mathematics, pharmacology, biology and veterinary science are, according to the Philadelphia citation index, the fields of English scientific excellence, thus reflecting a high correlation between academic excellence and the United Kingdom's industrial specialisation. Two new factors, however, are tending to alter the image of the English research worker. On the one hand, the decrease in the number of permanent posts because of the collapse of the national research institutes and the reform of the universities is sharpening competition on the academic market and worsening conditions of entry into tenured positions, with the result that a growing portion of PhDs are turning towards industry. On the other, since doctoral studies are increasingly financed by industry, the theses increasingly incorporate issues relating to the applied sciences. It remains to be seen how this shift of the figure of the researcher towards industry will be reconciled with the more classic engineers' low status and position within the organisation.

2/ German engineers and doctors as key figures of industrial foundation

The case of Germany lies at the opposite end of the spectrum from that of Great Britain. Indeed, Germany, like France moreover, has historically lagged behind Great Britain, which has led the two countries to undertake voluntarist measures for the development of higher technical education. In both Germany and France, the State intervenes in the training of engineers and above all in school-based certification, which is mainly intended to filter the access to the engineer title. Strongly legitimised in this way, the status of engineer enjoys considerable prestige in the society, corresponds to a high

level in the professional hierarchy (including the possibility of access to top management positions) and reflects the engineer's primordial role in the organisation of innovation. In spite of these resemblances in terms of formal structure, however, the figure of the German engineer is quite different from that of its French counterpart.

The German figure is based on two different curricula, that of the Fachhochschule (FH dipl.), which entails four years of study, and that of the Universität (Univ. dipl.), requiring five years of study in the sciences. These two programmes, which do not have the same academic content, channel the students towards distinctly different openings. The Fachhochschule, orientated towards applied technical knowledge, integrates a fair number of industrial internships into its curricula and trains engineers who are more capable of adapting to the SMEs or production functions, while the Universität has a much more academic curriculum (even if this is tempered by the Humboldt teaching method, which closely associates research activities with the instruction), and this means that it produces engineers with more of a 'researcher' profile or designers. In spite of this difference in schooling, Germany appears to be able to bring these two kinds of engineers together in co-operative work situations, thus shaping a central engineer figure rooted in a respect for technical culture and a clearly defined professional category. They share a common base, moreover, because of the fact that a majority of students entering these programmes come from apprenticeship: this is the case for 82 percent of the new students entering the Fachhochschulen and 52 percent in the Universitäten, which means that the majority of students enter higher technical and scientific education with real professional experience (2-3 years of apprenticeship) acquired after obtaining the Habitus at the age of 19. This kind of common base makes them attentive to industrial problems and, at the same time, prevents the creation of an insurmountable professional barrier between engineers having different diplomas.

The coherence of the profession, reinforced by the high level of technical training combined with industrial preoccupations, is favourable to innovation, notably in the 'middle technologies'. One disadvantage, however, lies in the fact that these engineers begin their formal careers relatively late: the university graduates obtain the engineering title at an average age of 29 and the Fachhochschule students at 31. If studies are pursued beyond the engineering diplomas, in a PhD programme, for example, the age of labour-market entry is even higher--between 30 and 35 years old--which obviously implies a greater maturity on the part of the PhD candidates but also the risk of limiting their mental horizons to pure research. Doctoral studies, which are not formalised like those in the United Kingdom (there is no clear division, for example, between undergraduates and graduates), prepare students above all for the academic labour markets, which are composed not only of universities but also of numerous public or semi-public research institutes (e.g., Max-Planck-Society, Fraunhofer Institute, Helmholtz Institute etc.). These features of the training of researchers, more orientated towards the consolidation of the traditional academic disciplines, do not seem very propitious for either the creation of new disciplines or radical innovation in state-of-the-art technologies. In sum, the German higher-education system supplies the market with high-level engineers who have a good operational capacity but it does not manage to fine-tune the production of researchers or 'innovators' who are really capable of making breakthrough innovations.

3/ French figure of engineer as a member of elite circles and the scientific excellence of the French engineering schools

As indicated above, France resembles the German case in that the State also organises the training of engineers and controls their access to the engineer title through a 'titles commission'. Apart from these administrative features, however, the figure of the French engineer is quite singular. The French educational system explicitly creates a many-levelled educational and professional hierarchy associated with the diploma pyramid, and this involves not only the length of schooling (high school+2, +4, +5 etc.) but also the institutional distinction between the universities and the elite institutions known as the 'Grandes Ecoles'. Notwithstanding the existence of technical or vocational streams, the selection for the 'Grandes Ecoles' is carried out on the basis of academic criteria. In particular, access to higher technical and scientific education is determined by knowledge of two core subjects, mathematics and physics. On the basis of these two disciplines, the 'Grandes Ecoles' for engineers, which are at the top of the hierarchy of educational institutions, thus train 'generalists' with multi-functional technical skills, even if these schools are variously specialised in a given technological field (telecommunications, aeronautics, civil engineering etc.). The best students coming out of these schools--in academic terms--will make their way into the State bureaucracy (corps d'Etat), which is responsible not only for industrial policy but also for major scientific programmes. This situation creates a certain familiarity between the State, the national research bodies and the industrial enterprises (often directed by engineering graduates coming from the same State bureaucracy); it has led to exceptional successes of 'mission-orientated policy' in the aeronautics, aerospace, nuclear or telecommunications fields but also to resounding failures in the computer or machine-tool industries.

Generally speaking, the engineering diploma (title) issued by these engineering schools gives their graduates the social and professional legitimacy which allows them access to 'manager' positions that are fully integrated into company management. Thus, there is no cleavage between managers and engineers as in the English case. But this phenomenon leads to another kind of hierarchical barrier in relation to other categories of technical employees such as the technicians, responsible for the practical knowledge used by the engineer-managers, whose basic competence lies in their capacity for scientific abstraction and human organisation. Nonetheless, this kind of barrier does not prevent a considerable flow of technicians who are promoted to technical supervisory posts in the course of their careers, thus creating another group of 'house engineers'--alongside the engineering graduates--whose highly 'practical' competence is difficult to transfer onto the labour market and whose identity remains weak. This co-existence of two kinds of engineers--who do not communicate easily with each other--in the French companies contrasts with the German situation, where the promotion of the better-certified technicians to engineering posts leads neither to the creation of 'sub-engineers' nor to an alteration in the engineer's status.

The status of the researchers, meanwhile, is characterised by three phenomena:

- As in other countries, PhDs are trained in the classic university programmes in order to reproduce the teaching corps and provide researchers for public research

bodies. Public-sector researchers, who are quantitatively the most important in the five countries studied, enjoy an extremely protected status, which tends to keep them in the academic field and eliminate any desire for mobility towards other sectors.

- Apart from a few industrial sectors such as chemicals or pharmaceuticals, the presence of university PhDs in the companies remains rather marginal, even if the State is attempting to develop mechanisms to facilitate their entry into industry. Alongside these academic PhDs, France also produces a specific category of research workers trained at the engineering schools: those with a 'doctorate in engineering'. Given their double training, those with 'engineering doctorates' are able to position themselves in the academic world and industry alike.
- Engineering graduates, who are trained in a high-level scientific culture, frequently encounter the research field at the beginning of their careers in the companies because they are assigned to R&D posts. These are often passing assignments, however--the situation varies from one sector to another--insofar as the engineers sooner or later move on to other technical or non-technical functions. Because of this inability to maintain engineers in the R&D function, the 'corporate researcher' identity is difficult to establish in the French case.

4/ Pragmatism of American universities and the powerful entrepreneur figure

The United States offers the case of a longstanding tradition of mass education at the higher technical and scientific level, which contrasts sharply with the history of the European systems. Notwithstanding the initial influence of the English model, the United States quickly broke away to create broad-based universities. At the same time, they managed to introduce engineering into the university landscape as a new discipline separate from the traditional natural sciences. This approach contributed to the massive dissemination of technical and scientific culture throughout the universities and the spread of engineer training. Paradoxically, however, the engineers' identity as a socio-professional group has still not been asserted in industry, even if there are regulatory bodies such as the professional associations (American Society for Engineering Education, National Academy of Engineers etc.) or the Accreditation Board for Engineering and Technology, which accredits 95 percent of the American engineering schools. Three explanations may be offered for the relative weakness of their identity. First, responsibility for curriculum development and diplomas remains in the hands of each engineering school and this extreme decentralisation, even with the presence of (private) accreditation bodies, does not permit any legitimation of diplomas at national level. Second, the boundaries between engineers and entrepreneurs have always been ambiguous--and largely remain so--because of mobilities between the two spheres, which explains the vitality of American spin-offs or the creation of risk-business by such engineer-entrepreneurs. Finally, the professional regulation of engineers is essentially based on labour-market competition, just as that of the universities is based on competition for reputations. This market-type regulation, combined with the decentralisation of the training institutions, does not seem to encourage the emergence of a unified professional identity.

Higher technical and scientific training of engineers is provided by community colleges on the one hand and universities on the other, with hierarchies based on both the level of the diplomas (Bachelors, Masters or Masters plus professional option, PhD) and the reputations that are essentially based on the scientific research carried out by the professors. This hierarchy serves to filter the possibilities of future engineers and the diplomas of a given university function as initial indicators of potentiality. Given the academic nature of the instruction, students come out of these schools with largely abstract knowledge which is disconnected from industrial applications and not immediately operational. Whatever their level of education, they are required to undergo on-the-job training in order to acquire both competence and legitimacy as engineers. Nonetheless, whereas their Japanese counterparts remain prisoners of the company where they develop their specific abilities (lifetime employment), American engineers are encouraged to take the initiative in building their careers through mobilities between companies. They forge their sense of 'professionalism' in the strict, American-style organisation of tasks and through a diversity of work experiences, sometimes combined with continuing training undertaken at their own initiative. Thus, the competitive games for career building seem relatively open and independent of the educational institutions where they were initially trained. Recently, however, young people have increasingly turned away from engineering, and thus from engineering schools, in favour of MBA programmes and this trend may weaken American industrial prospects.

The power of the American universities, and notably the research-based ones such as MIT, Stanford or Cornell (there are about one hundred of research universities according to the Carnegie classification), basically depends on the intensity of their scientific research activities. In addition to the level of public funding via the major scientific programmes (military, space, health etc.), the renown acquired by academic research can attract both federal research grants and considerable private financing in the form of contracts with individual companies. Such material resources allow certain of these universities to attract not only the cream of the American student population but also that of foreign countries: one-third of the PhD theses in the natural sciences are prepared by foreign students, and the same is true for over 40 percent of engineering theses. This means that the foreign contribution to the renown of American sciences is considerable. In this context, young PhDs or post-docs face extremely intense academic competition and sometimes undergo long periods of precariousness until they finally obtain a tenured position. This period of transition often reflects their double position between the academic and industrial worlds. Once they are tenured, they stabilise their academic careers through their scientific excellence, which, unlike the situation in the European countries, paves the way for careers in both university teaching and industry. Indeed, the status of university professor, based on well-established scientific legitimacy, allows cross-overs between research institutes, the university and industry through a variety of channels (contracts, joint research projects, consultancies, mobilities etc.).

5/ Predominance of corporate engineers and research workers in Japan

The Japanese case also shows a particular form of producing human resources with a high level of technical skills. The higher education system is characterised by the

preponderance of engineering schools over science faculties, by general technical training and by the hierarchy of universities. The different diploma levels, which are barely distinguished from one another and totally disconnected from the title of engineer, only allow access to the companies; there is a correspondence, more pronounced than in the American case, between the rank of the university and that of the company, which is based on social renown. The first job is particularly important because the majority of employees build their careers within one company (lifetime employment). The very notion of 'engineer' remains vague. Technical employees of different levels are often thrown together in a 'technical staff' category and develop their professional competences through on-the-job learning based on osmosis with their technico-organisational environments and mobility between various tasks which are not clearly delimited. Little differentiated at the outset, they have a certain professional coherence which favours co-operation between the different categories of employees, but a separation emerges at mid career between those who enter management and those who do not. Thus, recognition as an engineer is developed over time and within the company, a situation which does not give great visibility to the status of the profession, either socially or on the labour market. Similarly, the nature of the competences developed with time and oriented towards technological application is a good reflection of the cumulative nature of innovation.

Within the OCDE, Japan is one of the countries producing the smallest number of scientific theses relative to the size of the labour force. On the other hand, there is a sharp increase in Masters degrees (high school+6), now outnumbering the Bachelors degrees (high school+4) which were the traditional standard for engineers. The number of doctorates remains limited, especially since these are not required for access to university teaching, which is the main support for academic research. Thus, the professional identity of researchers is not established in the academic world. At present, however, there is a tendency for increasing numbers of engineers who have made their careers in the field of industrial R&D to prepare university theses: this is the case for half of the three thousand theses presented in engineering sciences (Ministry of Education, 1998 data). It may be asked whether a new category of 'company researcher', distinct from the engineers and with a new identity, is in the process of emerging.

Computer science training paths in some countries

The development of the capacity for supplying science graduates in some technological segments (computer science or biotechnology, gnomonic etc.) is not unrelated to the way the new discipline emerges within the HERS, is legitimated by the academic community and spreads throughout industry. The form of the intermediary labour market is not only highly determined by the discipline's history but also a determinant of it. More generally, the dialogue between the HERS and the companies over curriculum content constitutes one of the most important issues in the development of the HERS' capacity for innovation and by extension, that of the country as a whole.

With regard to the birth of computer science and its institutional materialisation in the form of the university computer science department, Mowery (Langlois and Mowery 1995) notes that in the late 1950s the United States benefited from favourable

conditions allowing pioneering universities such as MIT, Carnegie-Mellon, Stanford and others to quite rapidly create university programmes--first graduate and then undergraduate--in this field. What was involved was massive financial support through military and public research funds, co-operation with the computer manufacturers and the administrative flexibility of the American universities stemming at once from their decentralisation, faculty autonomy and the need to be self-supporting.⁵⁵ Through the mobility of their researchers or the hiring of their graduates, these pioneering universities expanded the number of computer science departments in other universities. The resulting university networks, functioning within an open research and operating environment, helped to train a large share of students who were to transfer both computer-science competences and the mentality of openness into the private sector. Thus, PhD graduates in computer science assumed important posts in emerging companies such as Silicon Graphics, Microsoft or Sun Microsystems. Similarly, many professors came in contact with these companies through formal or informal consulting relationships. The creation of this professional space, characterised by a certain continuity between campus and private sector, is credited with the cross-fertilisation of academic and market knowledge and the spread of innovation in a local, cognitive proximity (Saxenian 1994).

In contrast to the American situation, Japan completely missed the opportunity to develop computer science within the academic space. Several reasons may be cited: the rigidity of university administration, uncompromisingly supervised by the State, did not permit the creation of a new department based on the new discipline (programming is simply taught as a technique in the engineering schools or higher vocational institutions); the national priority given to hardware privileged programmes of study related to electronics, at the expense of software, which is at the core of computer science; a sharp division between academic training and on-the-job vocational training means that the companies have neither the reflexes nor the institutional channels to negotiate the teaching of computer science with the universities.

In the European countries as well, the training institutions also took a long time to react to the emergence of the new discipline. In Germany, Eulenhöfer states that the founders of computer science as an academic field did not include application problems in their concept of "Informatik" (Eulenhöfer 1998). From the early beginnings in the late 1960s, real-world, applied data processing was regarded non-scientific and was mainly excluded from teaching. Apparently, this tradition of computer science as a theoretical, mainly mathematical discipline has remained dominant during the past 30 years. English universities played an important role in the development of the first computers for military use but the discipline of computer science, basically associated with the field of mathematics and statistics rather than applied engineering, was to be orientated towards software theory rather than software application (Grindly 1995). Buried in university math departments until the 1980s, moreover, computer science failed to

⁵⁵. "There were virtually no formal programs in computer science in U.S. universities as of 1959. More than fifteen universities offered doctorates in computer science and seventeen offered bachelor's degrees by 1965. Federal R&D support aided the creation of the new academic discipline of computer science. But the creation and legitimation of a new academic discipline is itself not novel. Partly because of their decentralized structure and financing, US universities frequently have responded to the demands of industry by developing new academic departments and disciplines"(Langlois and Mowery 1995).

acquire its own disciplinary autonomy and academic legitimacy. Although a certain number of English universities enjoy world renown for their academic excellence in software theory, they have still not succeeded in setting up an adequate number of schools for applied training (software engineering). Notwithstanding a considerable effort in recent years (25 % increase in graduates between 1995 and 1999), this situation has created a certain bottleneck in the capacity to supply computer scientists.⁵⁶

France is one of the European countries where the State has maintained a voluntarist policy in all sectors of computer science, including university training, with the aim of catching up to the United States. In spite of the academism in a university community hostile, as in the United Kingdom, to the operational aspect of computer science, and in spite of the institutional division between universities, engineering schools and public research institutes (INRIA), State co-ordination has nonetheless permitted the constitution of the 'hybrid university space' (Grossetti 2000), notably around the less prestigious engineering schools which are integrated into the universities.⁵⁷ This space, which has emerged on the fringes of the university and "Grandes Ecoles" systems by mixing operational research and practical training, has been able to meet the needs of industry and the demand for computer science education, notably at local level. The development of this infrastructure, massively supported by the State, has created a large capacity for supplying high-level computer scientists.

This rapid survey of the case of computer science shows that the way a country builds the supply of new competences in the fields of emerging technologies depends on the interaction of multiple factors: the institutional interaction of different players at different national or local levels, the form of university management, the academic community's shared belief in the discipline or the behaviours of the companies in relation to the teaching programme.

It is probably also necessary to consider the nature of the discipline, which influences the institutional and cognitive arrangements of the 'hybrid university space': given that biotechnology has neither the same cognitive content nor the same organisational or institutional outlines as computer science, the players' strategies for action may differ considerably within a single country.

Empirical comments on the joint production of competences and some remarks suggested by the case analyses

Our survey is based on a sample which includes a variety of companies in terms of sector, size and nationality. This variety complicates our analysis by making the

⁵⁶. A recent OECD report places the shortage of IT workers around 80,000 in the UK, 75,000 in Germany and 25,000 in France (STI report 2000). The UK's capacity for annual student flows (first degree candidates) in the computer sciences was 10,400 in 1998, while France had an annual flow of 19,800 from computer science programmes in 1997 (Syntec-Informatique 1999).

⁵⁷. It is interesting to note that these engineering schools within the universities are located not in Paris, which is dominated by the most prestigious Grandes Ecoles but in the provinces, in Grenoble, Toulouse or Nancy. Since the 1970s, the first two cities house respectively Hewlett Packard and Motorola, and these two American multinationals specialised in CIT have quite actively collaborated with the universities.

situation of each company specific but we shall nonetheless privilege two entries: the national territory on which the companies operate and the sector to which they belong. Concerning the first, the companies remain subject to the different national conditions in the production of graduates, and this is true in spite of two newly emerging phenomena: the mobility of graduates beyond national frontiers is on the rise, especially in certain segments (computer scientists, post-docs in high-tech sectors etc.); a portion of the multinationals are often innovative in their relations with local university systems where they have operations. With regard to sectoral factors, it is possible to distinguish two technological regimes (Carlsson 1995) corresponding to the pharmaceutical sector and the information and communications technologies (ICT). Following the Kline and Rosenberg model, the first reflects the science-based sector which is at once in direct contact with academic science (research universities and public research institutes) and associated with the co-production of competences embodied in PhDs or high-level engineers. The second, more market-orientated, has a greater need for engineers capable of imagining technological applications adapted to the market/users. We shall attempt to address the functioning of the intermediary labour market through four aspects: co-operation between the HERS and the companies in the creation of supply capacity, the concept of practical training (student placement, internship), a typology of recruitment and the co-production of PhDs and academic spin-offs.

Interactions between companies and the HERS in the joint development of teaching programmes and the capacity for supplying new competences

The observation of our cases shows that in the United Kingdom and France alike, the national companies, representative of each sector, have contributed--and, to a lesser degree continue to do so--to the co-construction of the curriculum, certification or a given university establishment in order to develop the capacity for supplying new competences. The companies' involvement in the educational system occurs not only at formal levels but also at very informal ones, through, for example, participation in national bodies such as the Qualifications Commission which accredits engineering schools in France or the Engineer Council which supervises engineer training programmes in England, or participation in the board of directors of a certain university, or joint creation of specialised training streams, or informal participation--at very decentralised levels--in seminars, courses or mentoring of interns. These different levels of involvement in higher education are aimed at a group of very heterogeneous objectives ranging from increasing the company's visibility in the university environment or gaining access to the cream of the student population to explicitly creating competences for that particular company, not to mention responding to a 'social obligation'. For the majority of the national companies in France and the United Kingdom, these different participations, however dense and multi-dimensional they may be, do not seem to have been thought out in any systematic way or co-ordinated by an overall strategic approach. In the English case, this lack of coherence probably stems from the fact that the business units or subsidiaries are extremely autonomous and human-resources management is decentralised if not fragmented, which makes any overall co-ordination difficult at central level. In the French case, institutional relations have historically been constituted under State aegis between certain schools and companies held to be the 'national champions' in sectors such as telecommunications,

chemicals or computer science. Each major industrial programme systematically included scientific and educational sections covering the strengthening of the training capacity, improvement of the curriculum, exchanges of personnel and so on. These relations by osmosis created training programmes, particular curricula or networks for individual exchanges. But the fortunes of these results were subject to changes in political priorities and ties were sometimes frozen when the technologies, the market or the teaching programme evolved at different paces and sometimes in opposite directions. In this case, as if the companies were operating in stable cognitive environments with points of reference that were already known, their behaviour in relation to the HERS was marked by a kind of institutional automatism. Routinised over time, such automatic reflexes rigidified these ties and were hardly propitious for their regeneration, which was highly necessary at a time when, as in pharmaceuticals, the fields were undergoing rapid change.

On the other hand, the multinationals observed, notably North American, manifest a strategic desire to build a systematic, overall approach relative to their different commitments to the HERS. Their two strategic aims (and the resulting practices) are clearly distinguished from those of the 'national' companies. These two aims are not always in perfect harmony but reflect the presence of strategic co-ordination at a very high level of authority within these world-wide groups. On the one hand, there are the European ambitions which lead certain multinationals (Motorola, HP, pharma co. etc.) to place themselves immediately in the European space in order to seek out potential candidates for collaboration as broadly as possible, for example, by establishing a 'cartography of centres of excellence in Europe' or by casting a wide net over experienced engineers or researchers in the European labour market. On the other hand, they target what are sometimes called strategic partnerships, based on a lasting relationship with certain institutions of higher education. They thus develop a long-term, all-encompassing partnership with schools or universities, often those located nearby. What emerges, in the French case at least, is that the multinationals are not necessarily seeking to create partnerships with the 'best' schools or universities but rather to set up a dense network with local schools in order to constitute a veritable reservoir of new graduates. Such a partnership leads these firms to involve themselves systematically in very broad dimensions of the management of the universities/partners in order to influence the content of the academic curriculum as well as the engineers' professional profile and ultimately to attract the students best suited to their needs. In order to do so, some of these companies are members not only of the board of directors but also of the scientific board which determines the orientation of university research or various academic committees which define the teaching programmes. This participation in university governance is naturally accompanied by practical measures such as aid for courses, funding of facilities, organisation of internships for students and joint advising of doctoral theses or training of faculty. Beyond these classic means, which are used very systematically, they sometimes seek to influence pedagogical reform in the training of engineers by pleading in favour of teamwork and project-based learning, which make students aware of business environments. This kind of tight interweaving of company-university relations would ultimately seem to be aimed not so much at gaining access to the 'best talents' but at a more general revamping of the engineer/researcher profile in order to make it better adapted to changing technological and market conditions. According to the assessment of certain members of

management, the French-style hierarchy of schools, based on academic excellence and the capacity for theoretical abstraction, is not always relevant to industry, which is confronted with the rapidity of technological change. Thus, the strategic partnership deployed by these multinationals may gain ground in a system which has remained relatively homogeneous and alter the national framework for the training of engineers/scientists.

The notion of internships

In nearly all the case studies published, the students' internships in the company are thought to be one of the fundamental elements cementing HERS-company relations, even if this phenomenon often has little visibility. The flows of students repeatedly crossing the borders between the two worlds each year thus constitute the main networks structuring the labour market and feeding the intermediate space of innovation. Although it is difficult to measure, the effectiveness of the internship undeniably strengthens the companies' abilities to anchor themselves in the innovative environment, which is notably true for the SMEs. Furthermore, various observations show that the players (company, university, students) are practically unanimous in stressing the usefulness of the internships. There seem to be different reasons pushing the partners to dialogue and co-operate in this area, often going beyond considerations of the short-term cost/advantage calculation.

For the companies, the organisation of the internship may permit the creation of a pool of future hiring candidates or the observation and testing of the students' individual qualities beyond the formal signalling of their academic certification, or the assignment of an intermittent technical study or the gaining of advanced information or knowledge about certain technologies through the interns. These different motivations vary from one sector to another: the ICT companies often use interns as a supplementary workforce, while in pharmaceuticals it tends to serve as a hiring filtre. For the universities, the internship is one means of placing students in the labour market, gaining current information about the technological needs of a constantly changing industry and improving the quality of training or reorientating research through the resulting feedback. The graduate students, meanwhile, develop their professional ability by complementing their academic competence with practical work experiences aimed at solving concrete problems.

Beyond this 'universal' consensus over the usefulness of the internship, its status and significance differ according to the national (and sectoral) contexts of the training of engineers/scientists. Indeed, the in-company internship occupies a very different place in the programme depending on the degree of 'completeness' attributed to the engineers at the end of their formal training. Three country groups may be distinguished in this respect:

- **Germany** and **France** are the two countries where training institutions are assumed to supply the world of industry with engineers in the form of 'quasi-finished products', who are immediately operational and duly certified by a title based on the legitimacy of the State (Dipl. Ing. and Ingénieur Diplômé). In this case, the training institutions

necessarily integrate the internship periods into their programmes so that the students are alternately initiated to the acquisition of scientific knowledge and the learning of practical knowledge. Engineering schools in France generally organise two months of internships during the third and fourth years and four to six months during the fifth year, which culminates in an internship report. In Germany, the *Fachhochschulen* and the technological universities both organise four to eight months of in-company internships (*Praktikum*) during the programme, not counting the periods of vocational apprenticeship (2 to 3 years in the dual system) which the majority of students carry out before entering these institutions of higher education. Although both countries have a binary system--with institutions devoted to the training of engineers alongside more generalist universities--the practice of internships is also part of university training, which is more scientifically orientated. Local arrangements between companies and training institutions, as well as incentive systems at national level, are highly developed in order to encourage the co-ordination of internships. In spite of these similarities, given the very different profiles of the students in the two countries, the internships yield neither the same behavioural effects nor the same professional results. In particular, France is characterised by an approach based on a more multifunctional conception of the engineer's role (mixed profiles of technologist, scientist and manager) while the German approach is more orientated toward the technological profile.

- In the **United States** and **Japan**, the training of engineers occurs within a single university programme, in parallel with scientific training. Since the universities have neither the vocation to produce engineers nor the ability to certify them as such, they organise in-company internships only exceptionally (in Japan) or leave the initiative to the students themselves, through summer jobs (in the US). In neither case is the internship required within the university curriculum and engineers essentially rely on on-the-job training after graduation from the universities, on the basis of the technological competence acquired in an academic way. In terms of training at least, there is a complete break between the two worlds.

- The **United Kingdom** is an atypical case marked by the coexistence of the American-type university system where the internship is neither required nor integrated in the academic curriculum, the system of sandwich courses (one-third of recent engineering graduates), where paid--or fellowship--students alternate salaried employment and training, often in the polytechnics, and the continuing education system where a portion of those employed continue to study on a part-time basis. Two particular features of the UK case should be noted. First, a historical antagonism between theory and practice in the training of engineers results in the fact that the sandwich course is considered as a second choice, while, with the exception of disciplines such as chemistry or biology, the practical aspects are often neglected in the more classical universities. Second, the training institutions only grant students their academic diploma, which is separate from the title of engineer. New graduates coming from the most academic programme are thus considered 'half products', as is the case in the United States or Japan. After obtaining their diplomas (3 or 4 years of study at undergraduate level), the recent graduates have to complete at least two years in a formal training programme in the work situation and two years in a position of professional responsibility before being accredited as 'Chartered Engineer'. In such a context, even if the employers request more industrial placement and recognise its utility, the internship does not quite seem to

function as a mediator between the two worlds as is the case in the countries of Continental Europe.

Thus, the way internships are practised reflect both the companies' behaviours in the area of human-resources management and the conception of the engineers which the higher education institutions should to provide for the national economy. This means that they reflect as well the way the figure of the engineer is constructed in a societal context.

Inflows of graduates, recruitment practices; organisation of transition between academia and industry

Statistical comparison of inflows of graduates

Before analysing the recruitment policies observed in the case studies, we shall examine the general conditions of labour-market entry faced by new graduates in each country. The three tables which follow give a comparative overview of both the inflows of graduates and the stock of research scientists and engineers and their evolution from the early 1990s to 1997. Table I measures the density of production of graduates with four years of undergraduate study (except for the United Kingdom, where different 3-year programmes are included), relative to the labour force as a whole. Even if the exit levels and the significance of the diplomas are rather different between countries, these indicators show that it varies considerably from one country to another. In decreasing order, Japan, with an inflow of two graduates per thousand members of the labour force annually, is the most productive among the five countries considered, followed by France. The United States and probably the United Kingdom--if only post-graduates (more than four years after high school) are counted--occupy a median position while Germany arrives in last place, producing only one graduate per thousand members of the labour force, which amounts to half of Japan's production. By contrast, if we limit the population to doctorate-holders (Table II), three European countries are, in relative terms, the most productive of these titles, followed rather far behind by the United States, which nonetheless, in absolute terms, has a considerable inflow of new PhDs feeding the sizeable labour market for doctorate-holders.⁵⁸ Japan arrives far behind, showing an enormous deficiency in this area; along with the United States, it very clearly favours engineering PhDs, while the European countries, and notably France and Germany, where researchers from public research institutions play an important role, produce more PhDs in the natural sciences. In terms of the evolution during the 1990s, two observations may be made. The first is that in spite of the massive increase in the intake at most universities, the flows of new entrants into the science and engineering faculties vary from one country to another. Thus, Germany and the United States, for the late 1990s at least, show a drop in new inflows which allows us to expect a decline in their supply capacity for engineers, while the three other countries still show an

⁵⁸. It should be recalled, however, that in the United States, one-third of the doctoral theses in the natural sciences and over 40 percent in engineering are completed by foreign students. If we exclude these foreigners, the ratio of doctorate-holders in the US drops to the same level as Japan.

increase in new entrants into these disciplines.⁵⁹ The second point relates to the trend towards a rise in exit levels, notably at the Masters (6 years of study after high school) and PhD levels. Once again, however, the pace of growth varies depending on the country, going from quasi-stagnation in Germany to rapid growth in France and Japan (Table II, last line).

If we now look at the stock of research scientists and engineers (RSE), Japan and the United States show a density of RSE per thousand labour force which is considerably higher than that of the European countries. In particular, in the private sector, businesses employ twice as many RSE in Japan and the United States than in the three European countries. This term-by-term comparison only gives a vague indication, however, because the definition of RSE varies greatly from one country to another. On the other hand, the evolution of RSE over time is more pertinent: France and Japan are the two countries showing a growth dynamic for R&D staffs during the 1990s, and this growth reflects both the sharp pressure of graduate inflows, notably those of doctorate-holders in France and Masters (high school+6) in Japan. By contrast, the United Kingdom and Germany undergo a stagnation or even a decline in R&D staffs, notably in the private sector. This relative lifelessness of RSE demand seems to correspond to a weaker pressure from the supply of graduates. The United States occupies a median or even paradoxical situation insofar as it was, during the 1990s, the uncontested leader in scientific invention and technological innovation while its classic indicators of human capital (density of scientific/engineering graduates, PhDs, growth of R&D staffs) are relatively mediocre⁶⁰.

⁵⁹. For example, between 1993 and 1997, Germany already shows a drop in the number of graduates (Dipl.uni and Dipl.FHS) in the fields of electrical engineering, chemistry, biology and pharmacy, while the flow increases in computer science or math. The UK also shows an increase in the flows in computer science and biology but significant decreases in chemistry, physics etc.

⁶⁰. This situation shows that other, more organisational elements are probably more important for success in innovation, including, for example, the rapidity of disciplinary specialisation at the level of training and of industrial specialisation at the level of competition; sectoral mobilities of scientists/engineers, ability to attract foreign scientists or compatibility between human and financial capital.

Tableau 1
Inflow of university graduates with first degrees in natural science and engineering 1997

| | UK | Germany | France | Japan | USA |
|----------------------------------|----------|---------|--------|--------|--------|
| A) Labour force (1000 pers.) | 28552 | 39455 | 26404 | 67110 | 133943 |
| B) Graduates S/E (first degrees) | 68951(a) | 40134 | 46779 | 135278 | 199057 |
| B/A (ratio par .000) | 2.41 | 1.02 | 1.77 | 2.02 | 1.49 |
| New enrolment trend | + | - | + | + | - |

Source; calculated from NSF science & Engineering indicators and ILO year book

Nota (a) ; UK includes all qualifications of undergraduates (bac+3), except open university, while for other countries, the minimum is fixed at the level of (bac+4).

Tableau 2 - Doctoral degrees in natural science and engineering 1997

| | UK | Germany | France | Japan | USA |
|----------------------------------|------------|-------------|------------|------------|-------------|
| A)labour force (1000 pers.) | 28552 | 39455 | 26404 | 67110 | 133943 |
| B)PhD S and E | 6315 (100) | 9499 (100) | 7333 (100) | 5769 (100) | 19309 (100) |
| Of which PhD science | 3589 (57) | 5964 (63) | 4494 (61) | 1315 (23) | 10290 (53) |
| Of which PhD Engineering | 2726 (43) | 3535 (37) | 2939 (39) | 4454 (77) | 9019 (47) |
| A/B (ratio .000) | 0.22 | 0.24 | 0.28 | 0.09 | 0.14 |
| Ratio of progression (1989/1997) | 1.28 | 1.08 | 1.74 | 1.70 | 1.28 |
| | | (1990/1997) | | | |

Source; Idem.

Tableau 2 - Stock of research scientists and engineers in 1997

| | UK | Germany | France | Japan | USA (1995) |
|--|-------------------|-------------------|-------------------|-------------------|-------------------|
| A) Labour force (1000 pers.) | 28552 | 39455 | 26404 | 67110 | 133943 |
| B) Total scientists and engineers (1000 pers.) | 146 (133 in 1990) | 236 (242 in 1991) | 155 (130 in 1991) | 607 (505 in 1991) | 988 (924 in 1989) |
| C) Of which in business firms (1000 pers.) | 83 (83 in 1989) | 133 (141 in 1991) | 71 (60 in 1991) | 400 (331 in 1991) | 790 (733 in 1989) |
| B/A (.000) | 5.1 | 6.0 | 5.9 | 9.0 | 7.3 |
| C/A (.000) | 2.9 | 3.3 | 2.7 | 5.9 | 5.9 |
| Ratio of progression B | 1.10 | 0.98 | 1.19 | 1.20 | 1.07 |
| Ratio of progression C | 1.00 | 0.94 | 1.18 | 1.21 | 1.08 |

Source ; OECD, Main Science and Technology Indicators 2000

Practices for recruitment of new graduates

The sourcing of new graduates who are well trained and informed of the latest technological advances is one of the companies' main mechanisms for transferring knowledge and competences produced by the HERS. This kind of absorption of competences embodied in individuals is all the more necessary in view of the fact that the emerging kinds of knowledge are not easily transferable by more classical formalised means.

With regard to the recruitment practices for R&D staff, there is one constant which goes beyond the diversity observable at sectorial, national or inter-company level. Given that every act of recruitment is based on a gamble, the companies attempt to reduce the uncertainty surrounding the competence and behaviour of the person to be hired. One way of doing so involves evaluating these individuals--and their competences--on the basis of the signals they possess, such as diplomas, final educational institution, age, experience, professional specialisations, research subjects or laboratory affiliation (Spence 1973). These signals include certain elements which are more or less objectivised (such as the diploma, which corresponds to a form of 'certification' of the quality of the competence they have forged within the university system), and subjective elements which must be interpreted by the players and which yield a system of 'reputation'. In general, certification and reputation constitute two

major means of co-ordination which organise the matching of supply and demand on the labour market. Without minimising their 'universal' contribution to the reduction of uncertainty and the lowering of costs, however, we may consider that these means of co-ordination are also embedded in national institutional mechanisms and thus diversely regulated, with extremely variable functions and significance from one country to another, notably where the labour-market entry of recent graduates is concerned. To cite only one example, certification may depend on extremely different institutional arrangements. Furthermore, these classic means are no longer entirely satisfactory for regulating matching in many segments of R&D activity or in scientific specialities where the disciplinary corpus undergoes rapid evolution. In other words, the companies can no longer limit themselves to these means of regulation in order to select the appropriate specialised competences. They thus tend to set up, more or less explicitly, 'networks' which permit them not only to contact, inform themselves about, detect and select the talents corresponding to their particular needs but also and above all to co-produce them with the HERS. The discussion of the emergence of such networks thus goes beyond the issue of informational uncertainty surrounding hiring and addresses approach the wider issue of the building of new knowledge or competences in the intermediate innovation space. A combination of these three mechanisms, which yields different functional modes depending on the sector, region or country involved, seems to shape the form of interaction which develops between HERS and firms.

If we now consider the case studies in the United Kingdom and France, we see that the companies have recruitment practices which vary according to their size, local environment or sector but obey certain constants: the size of the company (or group), for example, shows a rather significant correlation with the local, national, European or world-wide levels of recruitment: the national companies are less focused on Europe than the multinationals; the pharmaceutical companies have a much greater demand for PhDs than those in ICT and so on. It is clear that between the various situations at hand and their specific needs, the companies develop their own sourcing strategies.

Nonetheless, the HERS institutional framework within a given country does not remain inactive; rather, it tends to introduce a certain number of specifically 'national' behaviours. Thus, the companies in France, in spite of acute local shortages, enjoy an overall situation where the supply of high-level recent graduates is relatively abundant (Table I) and above all, extremely well ranked by their diplomas. In particular, the engineering schools, which attract the cream of the crop from each generation, have a very visible certification, notwithstanding their internal hierarchy of schools. The engineering diploma, supervised by the State (Qualifications Commission) and supported by group of institutional measures, considerably diminishes the uncertainty related to hiring by guaranteeing the standard of technical quality that is required of the graduates. Combined with systematic in-house internships, the companies do not seem to have any particular difficulties in choosing among the candidates. This trust is consistent with the fact that French companies mainly employ recent graduates in R&D posts (training through research) before moving them into other functions, thus structuring the 'internal market'. This dominant pattern, tied to the figure of the French engineer, is above all applicable to the ICT sectors, whereas it remains relatively marginal in pharmaceuticals: since there is no engineering school for life sciences, the biologists and chemists in this sector, as well as the PhDs in pharmacy or medicine, mainly come from university programmes. But here, the majority of the new recruits are

PhDs who find their place in the networks of relations between the HERS and the industry monitoring their training.

By contrast, companies in the United Kingdom are confronted not only with a shortage seen as 'generalised' but with a confusion of signals transmitted by diplomas. In other words, and unlike countries such as France and Germany, where HERS certification provides a guarantee of the standard for engineers, the English diploma neither standardises nor stabilises levels of quality. The English university system clearly functions on the basis of reputation, as is the case in the United States and Japan: the new graduates are not 'qualified' as engineers but evaluated through the reputation associated with the institutions from which they come. This system, which is closer to a market mechanism, often leads to a sharp polarisation of quality levels: it tends to overrate the best graduates but does not always guarantee the minimum standard. Combined with a certain weakness in industrial internships, the hiring of recent graduates thus confronts employers with problems stemming from the non-legibility of their qualifications.⁶¹ In the English case, the certification procedure for chartered engineers increases this uncertainty since there is no guarantee that the companies can hold on to the young engineers once they are certified and thus recover their investment. Such uncertainty leads the companies either to create networks of trust guaranteeing the earliest possible access to the best candidates in certain targeted universities (strategic partnership) or to opt for experienced engineers who have already acquired the necessary competence--and professional reputation--on the external market. Most companies combine these two methods, but the national ones tend to opt more for the second and the multinationals for the first. In any case, the English situation reflects a greater use of the external market as a source of competence than is the case in France. It thus creates a form of intermediate space of innovation which is not exactly the same as that prevailing in France. The mobility of experienced engineers in the United Kingdom serves as a tool for knowledge spill-over between companies or sectors that is not simply technological but also, and above all, contextual, whereas in France the direct flows of recent graduates between the HERS and the companies tends to inject the latest scientific knowledge, thus reinforcing the technological database, but sometimes to the detriment of the accumulation of knowledge that is more tacit or oriented towards market needs.

The role of doctoral students and their labour-market entry

With regard to the role of doctoral students in the collaboration and more specifically their recruitment, all the companies use the networks which permit both the close monitoring of their scientific quality and the co-production of the new competences necessary for the development of R&D activities. In fact, the nature of the network is not quite the same as it has been in the past. In many cases, these networks have been pre-established in the course of research collaboration between the companies and the public or university laboratories. Their creation is based either on the mutual trust resulting from path dependency or on the system of reputation which permits the matching of supply and demand for the generation of new competences in a

⁶¹. The doubt expressed by the multinationals over the quality of certain segments of university education in England, along with the growing sourcing of engineers on the European continent, show that the problems are qualitative rather than quantitative.

very specialised field. Doctoral students are inserted into these networks and evaluated according to the reputation of the institution to which they belong, while at the same time constituting an essential link in the reproduction of these networks. The use of theses or doctoral students in collaborative research ties, through contracts or co-operation, is extremely common in certain sectors. The forms of such use differs, however, depending on the sectors or the countries, which have extremely varied doctoral training programmes.

The **United States** has the most widespread and systematised doctoral training, which makes it the international reference in this domain. This system produces just under twenty thousand new PhDs in science and engineering per year. Many of them receive financial aid from research funds, which are collected externally and managed directly by the universities (and the team) and allow the creation of teaching posts or research assistantships. Federal and state fellowships, on the other hand, are relatively little used. In other words, the quality--and reputation--of the team or the university depends heavily on its ability to attract funding--federal, military or private--which allows them to put the 'best' doctoral students to work on promising topics. Reputation thus plays an essential role in the matching of financial resources and 'young talents'. According to a National Science Foundation survey (NSF 1998), three years after obtaining their diplomas, just under two-thirds of doctoral students occupy university posts while one-quarter work in business firms. The majority of PhDs are still largely destined to enter academia. Nonetheless, the entry of PhDs into industry is increasing significantly, although this proportion varies with the business cycle and the discipline involved: in general, PhDs in engineering tend more towards industry than their counterparts in the sciences.⁶² Likewise, the proportion of post-docs, which occupy an intermediate position between the academic post, the status of trainee and industry, is rising rather sharply. This phenomenon is visible notably in the life-science sector, a pole of American scientific excellence: 60 percent of the new PhDs in life sciences enjoy this status and account for half of the total number of post-docs (5,600 out of 10,700). Combined with the influx of foreign post-docs attracted by the prospect of state-of-the-art training in biotechnology, this segment seems to represent a new kind of academico-industrial space where young high-level scientists on extremely flexible contracts migrate between research programmes, between temporary industrial and academic posts or between biotechnology start-ups. This fluidity has an impact on the trend among pharmaceutical companies towards the outsourcing of R&D activities, the start-up dynamic and the creation of an international space of mobility for certain 'hybrid' players--those who transcend the classic national and professional boundaries of the academic, the corporate researcher or the entrepreneur. Certain cases observed in our study clearly reflect this emerging space and its players.

Concerning the European countries, the forms of doctoral studies, much less systematised than in the United States, still reflect national institutional legacies (Burton Clark 1993). In recent years, **France** has undergone a reform of doctoral studies which has permitted a rapid increase in the number of PhDs; in particular, the "Grandes Ecoles" have strengthened their role in the production of PhDs by creating a new programme for *docteurs-ingénieurs*. The financing of theses is marked by the

⁶². According to another NSF survey, 57 percent of PhDs in engineering, 40 percent in computer science and 20 percent in life science were working in the private sector in 1997 (S&E Indicators 2000, NSF).

significant number of fellowships awarded by the different ministries, notably the Ministry of Education and Research (MENRT): among doctoral students in science and engineering, 85 to 95 percent, depending on the discipline, are funded by thesis fellowship schemes (Bourdon 1999). The distribution of these financial resources in the form of grants among research units or laboratories seems to be relatively stable, at least in the middle term. Similarly, grants from bodies such as the Armaments Division (DGA), the Centre for Atomic Research (CEA), the Centre for Space Research (CES) or France-Télécom are awarded in priority to laboratories with which they have already established relationships of trust. Unlike the United States, the funding of these is relatively separate from direct scientific competition and more subject to the administrative rationale (MENRT-type grants) or that of long-term partnership. In terms of labour-market entry, three years after obtaining their diplomas, slightly under two-thirds of French PhDs obtain posts in the public sector (higher education and public research) and one-third private-sector jobs (Martinelli 2000). As in the United States, academia, characterised here by a public status, remains the most important opening for PhDs. But in cases like the CIFRE fellowships, where doctoral students are jointly funded by industry and the MENRT, a large majority (78 %) enter the private sector (2000 data). In fact, the presence of PhDs in industry is extremely variable from one sector to another. The chemicals industry, for example, traditionally employs a non-negligible proportion of PhDs among the R&D staff (one-quarter) and half of the R&D staff in pharmaceuticals have PhDs (including medicine), but other sectors may have fewer than 5 percent among their R&D staffs (Beret 2000). This spectrum is indicative of the variation in cognitive proximity between the sector and the academic world depending on the nature of the scientific discipline (Lanciano 1997). Beyond this universal mechanism, three features seem to characterise the use of doctoral students in the university-industry collaboration in France. First of all, viewed by the companies as one of the least costly or risky means, the use of doctoral students in collaborations with the HERS is quite common and, because of its recurring nature, serves to cement the co-operative relationship. Second, doctoral students with industrial grants or CIFRE fellowships, who are de facto set apart from the others with more classical fellowships aimed at a future in academia, have a strong probability of entering the industrial environment or even the companies with which they have signed the contract.⁶³ These flows reinforce existing networks, thus yielding a kind of increasing return on custom. Third, the thesis, with an average time frame of three to four years, serves as a 'prospective' study on emerging fields or problems. This kind of technological gamble gives companies a margin of flexibility: the decision to internalise (or not) the co-produced knowledge or competences depends on the degree of potentiality indicated by the results. This rationale seems to be most present in the ICT sector, while the pharmaceutical companies consider the three-year waiting period too long and clearly prefer the use of the post-doc with a shorter-term contract which corresponds more closely to their R&D needs.

Doctoral studies are organised somewhat differently in the UK, due to the existence in this country of both full-time and part-time courses. In the autumn of 1995, there were 5180 newly enrolled full-time doctoral students in Science and Engineering in the UK, as compared with 1883 enrolled on a part-time basis. The latter group, which

⁶³. In the case of the CIFRE, 54 percent of the doctoral candidates remain in the partner companies with whom they have signed their contracts (Formation par la recherche 2000).

consisted mostly of mature students, accounted for a non-negligible proportion (more than one quarter) of all the doctoral students in the UK, whereas only young, full-time students tend to pursue doctoral studies in France. As far as the financing of these students' studies is concerned (as reflected in the source of tuition fee payment), 90% of the doctoral students in the UK benefit from some kind of financial aid: half of them receive grants from the Research Councils, 25% from the Universities, ministries and local governments, and the amount of industrial support with which doctoral students are provided is practically negligible (337 out of 5180 students) (SET Statistics for 2000). On the other hand, more than half of the part-time doctoral students pay their own way and few of these students receive either public (23%) or industrial grants (15%). There has been a general tendency for the State to gradually withdraw from its programme of support to PhD students, which has obliged the Research Councils to diversify their financial resources. Increasingly large numbers of doctoral theses are now being prepared in the framework of industrial partnerships, based on various combinations between several sources of support, as in the case of the CASE¹⁵ and PTP Programmes. The authors of a comparative study between France and the UK (Mason, Beltramo and Paul, 2000) have noted that PhD students seem to be much more frequently involved in industrial projects in the UK than in France, especially with SMEs in the electronic engineering sector. Apart from the fact that some part-time doctoral students have the status of employees, British firms are more willing than their French counterparts to include PhD graduates on their payrolls. A fairly large number of these graduates therefore turn to industry after completing their doctoral studies. According to a Research Council source (OST 2001), one third of all the doctoral graduates financed by the Research Councils find employment in the private sector as soon as they have completed their theses; whereas much fewer academic openings are now available, since University positions have become more scarce and the number of public research laboratories has been reduced. Many of those who opt for an academic career end up in fixed-term positions. As we have seen, the PhD labour market operates very differently from one country to another, depending on the institutional structures, the sector involved and the higher education and research policy adopted by the country in question.

Conclusion

After this brief analysis of how competences are co-produced at the interface between Academia and Industry, we shall now attempt to draw some initial conclusions. The first of these conclusions focuses on the use of the term "intermediate innovation space", and the second, on the heuristic uses of comparisons between Europe and the USA. Since this analysis is still extremely fragmentary at this stage, we have no intention of drawing hard and fast conclusions. We will attempt here simply to define the lines on which our own future studies might be conducted, with a view to extracting the essentials from the vast corpus of material collected so far.

First of all, the term "intermediate innovation space" is an analytical tool designed for detecting interactions between actors and organisations, restricting the field of investigation to the institutions, interchanges and networks involved, the patterns of personal mobility observed and the movements made by technical objects. The aim here

was to describe the innovative spheres within which both individual and collective players act, thus setting up a space where competences and resources are co-operatively produced at the interface between Academia and Industry. The introduction of this concept should therefore help us to determine which institutions are mainly involved, to identify the main participants and to observe their ongoing interactions as well as the processes of mutual edification which take place. This approach based on the interdependence which exists between the space and the players should help us to view the various types of collaborative arrangements in various contexts, i.e., on various scales, namely the micro, meso (sector-based or local) and macro (societal) scale with a view to detecting the logics and relationships at work. This "contextual" approach should then make it possible to carry out comparative qualitative assessments on the interactions between the various participants at the sectorial, national and other levels.

Although the concept of the innovation space still requires to be further developed, it is certainly a useful means of examining any innovative mediating interventions which occur. This is particularly true since this space - and these relationships - are becoming increasingly complex as the frontiers between organisations become increasingly indeterminate, mobile or permeable. In other words, the organisations involved (firms, universities and public research laboratories) are surrounding themselves with a hybrid space which serves to mediate the communications between those working on either side of it and to establish multiple co-operative links. If one describes them in this way, these expanding intermediate spaces can be said to fit the currently emerging "triple helix" theory (Etzkowitz and Leyesdorff, 2000) designed to model the relationships between the University, Industry and the Government. The recent "overlay of institutional spheres" is described by the authors of this theory in terms of a process of emergence of "tri-lateral networks and hybrid organisations". Although the triple helix theory focuses mainly on the macro-institutional level and tends to be public policy-oriented, many of the problems and concepts with which it deals are very similar to those addressed in societal analyses. It would therefore be worth engaging in some searching debates with representatives of this new school of thought and re-assessing the scientific relevance of our own approach, which we have described above in terms of the societal formation of actors, especially professional actors, and how they acquire their professional specificities.

The comparisons made in the present study between the ways in which competences are formed in Europe and the USA can be said to be fruitful, as long as we are able to look beyond the American model. In his recent book, Birton Clark has drawn a compelling picture of the powerful Graduate Schools which exist at the American Research Universities. These schools are characterised by their autonomy, their flexibility, their competitive spirit, and especially by their highly concentrated structure. This massive edifice is able to rationalise the academic curricula and the management of research funds, draining all kinds of financial resources, and creating conditions which are conducive to the production of scientific findings and PhDs based on economies of scale. The level of scientific excellence which results from the efficiency of the graduate schools might well account for the competitive edge held by the American economy, as well as the attraction it exerts on the brightest students from all over the world. There is no doubt that the American Research Universities are not only efficient and productive, but also more innovative (cf. the Entrepreneurial University) : this is a well tried and

tested machine which never stops generating new disciplines, new approaches and new talents.

However, a few figures, such as those indicating the output from the higher education system, show that as far as the training of graduates in Science and Technology is concerned, the situation of Europe on the whole stands comparison with that of America. Some European countries even have a competitive advantage due to their sometimes extremely elitist top streams, in which high-level scientific training is combined with the development of professional skills, as in the case of some engineer training systems. In addition, a number of higher educational institutions in Europe have either developed or are envisaging original modes of collaboration with firms, with a view to co-producing professional competences, which does not seem to be occurring to such an extent in the case of the American universities. In comparison with the American Graduate Schools, these European post-graduate educational institutions are nevertheless rather heterogeneous (in most countries, this is a bipartite system), show considerable institutional diversity from one country to another, and tend to be highly scattered, since the establishments are fairly small-sized. Although this diversity may be a potential source of wealth, Europe is not in a position to produce institutions rivalling in size and reputation with the American Graduate Schools. Improving the present state of "Balkanisation" would involve pooling the means and resources available in all the European countries and harmonising the practices adopted as regards vocational training, the way in which it is financed and certified, etc., without detracting from the specific role played by each institution at the regional or national level. This procedure would have to be based on an extremely thorough knowledge of the historical background in each of the member-countries of the European Union: the modes of academic governance adopted, the links between post-graduate training and the requirements of industry, State policy on the funding of research, post-graduates' career paths, etc. Further studies now require to be carried out on the lines indicated by this initial analysis, in order to throw some light on the questions raised.

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Chapter 6 - Alain Alcouffe, National Innovation Systems and Industry Science Relationships in Europe

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The "National System of Innovation" or "National Innovation System" concept was coined at the very beginning of the 90" by C. Freeman, B. Lundvall and represents probably a case of multiple discovery as hints are to be found in the 80' by several authors (Maurice & Silvestre)⁶⁴. It can be define as a network of institutions operating in the public and private sectors whose activities and interactions introduce, modify and diffuse the new technologies. This approach stresses the specificity of the choices that shape the various national systems, in particular through public policies on education, academic research, legislation on patents and intellectual property and access to finance for emerging technologies.

The result is a certain dynamic irreversibility contained within "particular institutional infrastructures" (see Nelson, 1993). Firms draw on the institutional resources of their countries of origin in order to construct their competitiveness and, more generally, to operate effectively in globalised markets. The interaction between firms and these institutions gives them access to more or less effective organisational and technological learning processes through which national industries acquire their particular configuration (Lundvall 1988).

In order to take a more operational approach, it is convenient to distinguish inside a country three fields more or less tightly related to the innovation process : training and education, research and production and stresses the importance of the flows which circulated between the summit of this triangle. These flows are manifold and include very different items : money, men, training, products, know how, knowledge. In the NIS definition, the assumed interdependence of these three fields justifies to speak of

*This paper tries to synthesise many firm or sector monographs which were circulated in the SESI project between 1998 and 2001. Stylized facts and examples which sustain the argument are directly drawn from these essays. The authors thank his partners in the SESI Networks especially Luisa Oliveira, Hirohatsu Nohara, Eric Verdier, Alice Lam, Saloua Bennaghmouch, Martin Unger and Kurt Mayer. He is responsible for the opinion expressed in the paper and of course for any mistake or errors.

⁶⁴ Cf Archibugi, et alii. "The 'system of innovation approach has developed and evolved since its initial appearance in the form of the national systems of innovation. (NSI) studies presented by Freeman, Lundvall and Nelson. Chris Freeman was among the first to use the concept to help describe and interpret the performance of Japan over the post-war period. He identified a number of vital and distinctive elements in its national system of innovation to which could be attributed its success in terms of innovation and economic growth. It has subsequently been applied to a number of different contexts, many of which has been outside the original focus of a national setting. Then, although the national focus remains strong and rightly so, it has been accompanied by studies seeking to analyse the notion of systems of innovation at an international (or pan-national) level and at a sub-national scale."

"system". The innovation system is further called "national" because it is asserted that for the intertwining of the three fields, national history, national features (etc.) matter. By some authors, the national character implies too that the bulk of the domestic flows which irrigate the different fields is "national", due to the limitation of human capital mobility, to the links between defense (i.e national) R&D and civilian R&D in some countries, more generally to the special part played by R&D in business and national strategies, etc.

"It is somewhat paradoxical that a concept relating performances to national features was elaborated and devoted much attention in the 90' while many observers stress the importance of "globalization". In direct connection with our topic, we can excerpt the following notes in the introduction of a OECD 1999 report : "The increasing pace of globalisation can be observed in the heightened importance of patenting by firms abroad; increases in the relative importance of both inward and outward research-related foreign direct investment; the explosion of international strategic alliances in science and technology; and increasing trade in technology." *The Letter of OST 2000* "The world economy is increasingly based on cross -border transfers of information and knowledge and the field of innovation can be considered as one of the best cases of globalisation"

Globalisation means radical changes in foreign affairs and consequently in tariffs. Domestic markets are no longer sanctuaries for big firms which are more and more multinational in their ownership, governance, scope and aims. Globalisation means too that corporate governance could no longer be protected by a secrecy wall and managers have to convince financial markets that they are "good". Consequently as nobody can believe that a firm can be efficient in many industries, conglomerates are no longer efficient way to follow and firms try to specialize and concentrate on their core competences. The same is true for states which could no longer follow the technical progress in all sectors even for large countries as the USA (see Crow and Bozeman). Moreover suspicion against the ability of governments to interfere with businesses strategies has grown and R&D public budgets are cut in many countries.

All these evolutions challenge the relevance of the "national" innovation system concept whereas American authors doubt if the American innovation system will be able to maintain its high level of performance. Mowery argues that virtually all of the central components of the innovation system that emerged in the postwar U.S. economy now are undergoing change. He The future U.S. innovation system is likely to be characterized by

- lower levels of overall federal R&D funding.
- lower levels of defense- related R&D funding and procurement activity.
- reduced military-civilian technological spillovers.
- a higher level of internationalization, both in terms of U.S. R&D investment in foreign economies and in terms of higher levels of non-U.S. R&D investment within the domestic U.S. economy.
- more stringent domestic and international protection of intellectual property rights.
- Less stringent domestic antitrust policy.
- higher levels of interfirm collaboration, university-industry collaboration, and collaboration between U.S. and foreign firms in R&D.

- greater efforts by U.S. universities to seek to protect and license the results of publicly and privately funded research.

The implications of these changes for the performance of the U.S. innovation system, and for the role of this system within the global science and technology system, are unclear. The effects of some of these changes, such as the efforts by U.S. universities to protect and market the results of their research, may be modest, because of the lower quality of much of these recent patents. In addition, the sporadic efforts by federal policymakers to limit the international dissemination of the results of publicly funded basic research and technology development programs have in many cases been frustrated by the ineffectiveness of these restrictions and by the actions of private firms in the United States and other industrial economies. But other structural changes, especially those affecting defence-related procurement, the role of universities, and intellectual property rights and antitrust policies, could reduce the importance of new firms in the commercialisation of new technologies and in the creation of new industries. The effects of these changes are mediated and possibly offset, however, by the abundance of venture capital for the foundation of new technology-intensive firms within the United States, as well as the relatively modest entry barriers in segments of such rapidly growing "new industries" as computer software and multimedia.

Structural change in the U.S. innovation system, of course, is not occurring in isolation from change in the structure of other industrial economies' innovation systems. Indeed, one of the defining characteristics of such structural change in the United States is increased links with non-U.S. firms and government-supported programs. Structural change in the U.S. and foreign nations' innovation systems nevertheless may well result in some "convergence" in structure.

Systems of innovation and social systems of innovation and production

Some authors have tried to enlarge the NIS approach which is for them too restricted to science and technology matters and refer to social systems of innovation and production (SSIP). By the way, they come very close to compare varieties of capitalism. Amable, Barré & Boyer 1997 distinguished four such SSIP: Firstly, one, market driven or "*Anglo-Saxon*", is exemplified by the USA, Australia, Canada, and in Europe by the UK. The second one, social democratic, encompasses the Scandinavian countries. The third one, *mesocorporatist* has an unique example, Japan. Features of the last one, "*European integration*" are to be found in Germany, France, Italy and the Netherlands. But even if SSIP are conceived more as ideal types than as categories of concrete national economies, a historical analysis of growth trajectories leads to a ranking of performances and authors cannot escape to benchmark these varieties. This approach rises then the question of a possible convergence towards the more efficient model of capitalism which appears to many observers to be the Anglo-Saxon one in the 1990's (Goyer 2001, Paillard & Amable 2000). Applying econometric models to a database including several variables referring to economic but also technological and scientific performances, Amable and Petit have compared 21 countries in the in the 1990's. They concluded that results from the more recent data do not differ strongly from those obtained for the 1980's by Amable, Barré, and Boyer (1997). They found that Norway has moved from the social democratic SSIP to the market driven one whereas Korea has now joined Japan in the *mesocorporatist* SSIP. As far as the European Integration

model is concerned, they augment it with two variants. To the countries included in the European SSIP in 1997, they join now, Belgium and Ireland whereas they include Italy in a Mediterranean variant with Spain, Greece and Portugal. Moreover they distinguish an "Alpine" variant formed by Austria and Switzerland.

Despite some interesting insights provided by this very large approach, the multiplication of variants recalls us that enlarging the scope is no guarantee for a better understanding, therefore we will focus on the systems of higher education and innovation.

The threats of globalisation on NIS

As formulated by D. Mowery, this convergence implies that the *raison d'être* of the NIS analysis could disappear. This theme has been addressed to by Jean Guinet in his report for OECD on Industry Science Relationships.. He remarks that ISRs have been structured around national research organisations and domestic firms at a time when the strategic interests of the different stakeholders converged easily towards national goals. Their international linkages were mainly through the scientific community that has a longstanding tradition of global networking. The situation has evolved gradually during the 1970s and 1980s with the intensification of government-sponsored international co-operation in technological development, especially within Europe. The globalisation of firms' R&D strategy and access to public research together with increased mobility of scarce highly qualified labour now lead to much more fundamental transformations:

Global Trends in Industry Science Relationships

- The hierarchical and centralised model of ISRs governance that still prevails in a majority of countries must leave way to a contractual and decentralised one. Within public/private partnerships the source of initiatives is shifting from government to firms, within governments from central to regional and local authorities, within public research from public labs to universities, and within public research organisations from central management to labs and research teams. Now that mission-oriented public research can no longer play a pivotal role within ISRs, new market-friendly co-ordination must be implemented, with greater involvement of the financial sector, especially venture capital.

- *Foreign firms makes often more intensive use of public research than domestic ones* and the efficiency of national support measures is enhanced when recipients are parts of dynamic international networks. Government must rethink how to maximise national benefits from ISRs that involve industrial participants taking a more global perspective. Building on globalisation to increase national benefits may require easier foreign access to national programmes and the relaxation of eligibility criteria regarding the location of publicly-funded research activities, as well as greater international co-operation among governments to avoid opportunistic behaviours and distortions of competition.

Globalisation prompts public funded organisations to reconsider their role in the economy. Some now enters into broad alliances with homologues or private firms in

order to create knowledge platforms, which could become key infrastructures of the "new economy".

The dynamics of evolution in ISR

But the pace of this evolution cannot be very rapid as the innovation system as the NIS analysis has repeatedly shows exhibits many path-dependencies. Chemical played a dominating rôle in the process of industrialization in Germany. The foundation for this can be found in the 19th century. Many of the German Competitive positions were created by the turn of the century, when Germany was characterized by a close connection between universities, Technischen Hochschulen and industrial firms. With the universities and Technischen Hochschulen, Germany has established a sophisticated system for education in scientific, technical and commercial matters, reaching from elementary schools to doctoral level. This system has had a significant influence on the structure of the German system as we know it today. And I. Drejer shows that the roots of German strong positions in chemicals are to be found in the beet-sugar industry of the late 19th century. (I. Drejer, p.383)

Consequently, Jean Guinet notes that if globalisation and the diffusion of best practice policies reduce differences between national systems of ISRs and may change their comparative advantages but cannot abolish the considerable diversity of existing models⁶⁵. The interactions between the public research sector and industry take various institutional forms and differ in nature and intensity by country reflecting national specificities in institutional set-ups, regulatory frameworks, research financing, intellectual property rights and in the status and mobility of researchers. Existing internationally comparable indicators capture some of these differences. Measurable national differences with implications for industry-science linkages include variations in: *i*) which institutions perform and which fund research development *ii*) trends driving the funding and performance patterns of R&D; and *iii*) specialisation in specific scientific disciplines.

Jean Guinet shows an extremely large dispersion of the rates of government funding. Following the OECD classification, the share of government in funding and performance can vary for low to very high through five step whereas the system can be based on universities or institute or combine the two institutions. Among the countries under review in the Sesi project, Portugal belongs to the countries with very high share of government in funding and performance. Austria and France to the countries with moderately high share of government in funding and performance, the United Kingdom and Germany to the countries with average share of government in funding and

⁶⁵ In the same sense see D Archibugi : "first, globalisation makes easier the transmission of best-techniques across countries. Semiconductors, antibiotics and new materials are based upon similar and shared knowledge across the globe." Of course, this does not imply an automatic process of acquisition of knowledge since learning is neither instant nor automatic. The tenants of the globalisation thesis themselves introduce a caveat : "While these general trends touch all OECD members, they present different challenges for individual countries -depending mostly on their industrial structure, the size and openness of their economy and the strength of their science and technology base. In fact, the globalisation process has not markedly diminished differences in innovation systems and may be accentuating the technological specialisation of firms in different regions.". This general stability does not prevent rather quick reversal as the ones experienced by the US semiconductor industry during the last decades. The decay during the 80's has been followed by a quick recovery in the 90's (see, Macher; Mowery; Hodges 1998)

performance; the United States to the countries with low share of government in funding and performance. The dispersion is almost equally important if we consider the three subcategories concerning the constellation of actors in the ISR : Austria, the United Kingdom, and the United States fall in the university based system, France, Germany, and Portugal in the broad-based system.

National innovation system and country size

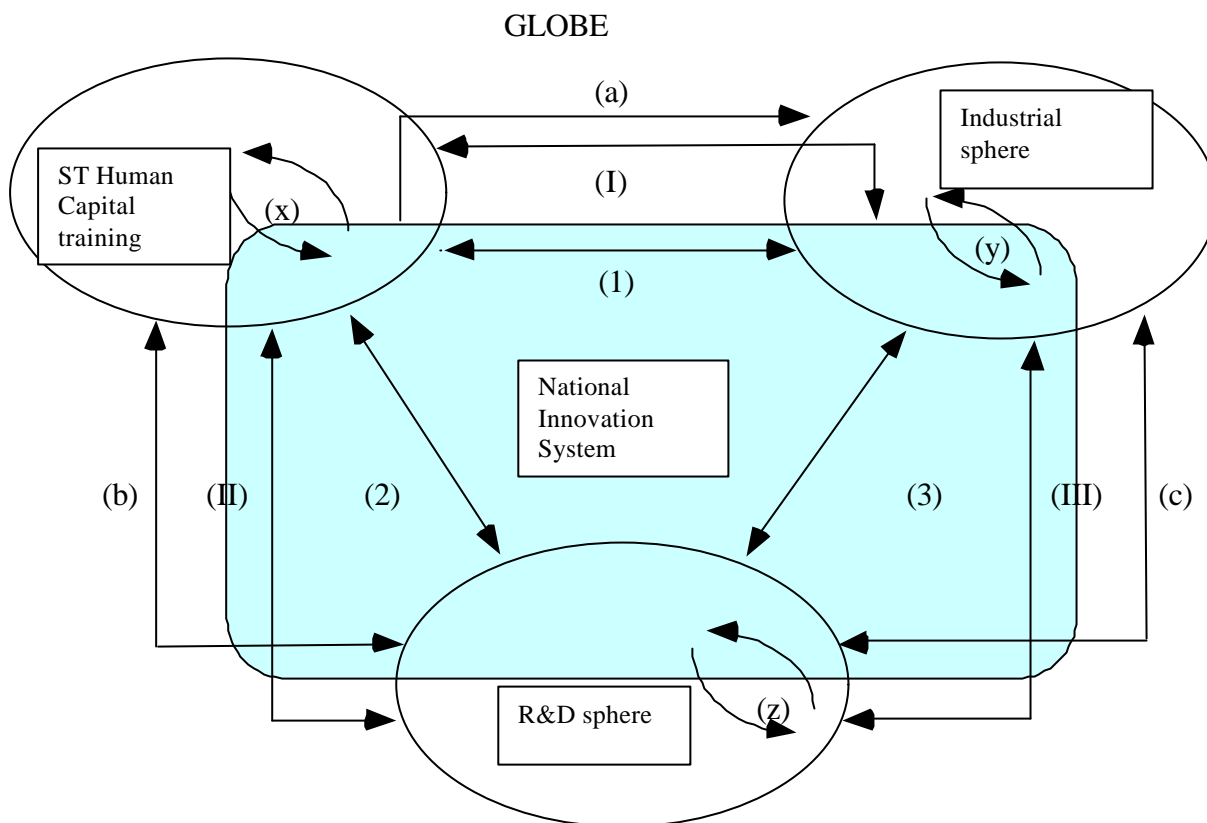
National science systems support innovation by generating themselves new relevant knowledge and by facilitating absorption of knowledge generated in foreign countries, the balance between these two functions varying with country size and S&T specialisation. Scientific specialisation profiles differ substantially across countries, are more contrasted in small than large countries, and tend to be quite stable over time. In small and medium-sized countries, scientific output in industry-relevant disciplines is well correlated with R&D intensity. Larger countries seem to enjoy economies of scale in translating scientific efforts into R&D, except the United Kingdom, where scientific output is inflated by prolific publications by the medical sector.

The evolution in the future depends also on some other features of their research system. The United Kingdom, and France have declining but still sizeable defence-related R&D investments.

National Systems of Innovation, Globalisation, and European Integration

In an European framework, consequently the question becomes twofold : on the one hand, it is worthwhile to analyze the evolution of the former nation-state innovation system, on the other one the possible emergence of an European innovation system. The concept of NIS has been elaborated to explain the different industrial and technological profile which are exhibited by countries and especially the persistence of areas of strength in national economies which are associated with specific institutional configurations for very long periods (Saviotti, p. 167).

Among these configurations the flows circulating between the three different spheres, industrial, human capital training, R&D, which can be distinguished in the national economies are of special interest. It is very obvious that any of these spheres is closed. It has been emphasised for long that the scientific sphere has always been borderless and the increase in exchanges between domestic and global spheres dominates the usual rhetoric about globalisation.



National Innovation System⁶⁶:

Johnson and Gregersen (1997) have discussed the various relations between economic integration and innovation. They distinguished four main types of integration according to the nature of arrangements and process (p.34).

Table 1 - Four main types of integration

| | Designed process | Self-grown process |
|-------------------------------------|------------------|--------------------|
| Formal institutional arrangements | I | II |
| Informal institutional arrangements | III | IV |

Source : Johnson and Gregersen (1997)

Actually these types are not clear-cut and more or less interdependent especially during innovation process. The digitalized pan-European mobile communication network, GSM, shows how integration processes may effect both knowledge production and knowledge distribution through formal and informal institutional arrangements. The GSM standardisation initiative triggered off a wave of concentration and co-operation agreements (for instance precompetitive development joint-ventures) in the industry (Johnson and Gregersen p. 36) . It initiated - partly as a designed process, partly as a self grown integration process - greater R&D-collaboration on both the national and the transnational level.

Summing up their discussion of the influence of integration on national systems of innovation, Johnson and Gregersen (1997) wrote that integration will affect innovation

⁶⁶ Source Alcouffe 1995. As the different subsystems inside the NIS are related to foreign counterparts, the arrows show the flows circulating inside and outside the NIS.

both because there is a tendency towards greater cross-border collaborative use of knowledge stocks and a tendency towards greater transdisciplinary complexity in technical innovation. They concluded that "the empirical evidence of what is happening to national systems of innovation as a consequence of the integration process is still rather weak. It is not yet possible to say if they are losing out to systems on the European and/or regional levels or not. Also the empirical evidence of an "autonomous" European system of innovation in a broad sense is still rudimentary". They found that "for the time being (1995-7) it is more reasonable to talk about an emerging European system of innovation in the narrow sense of the term".

But before addressing directly these questions, we have to take into account that NIS as the SSIP approach recalls are not separated of the economic production and exchanges processes therefore it is interesting to look more closely to globalisation. Recently Neil Fligstein and Frederic Merand have sustained a provocative thesis along which the evolution of the world economy since three decades is less characterized by globalisation than by "Europeanisation". "That is, a huge part of what is driving the increases in trade in the world economy is accounted for by the changes going on within Western Europe" whereas they see no evidence of a "single capitalist market". They argue that an integrated market requires a single system of rules of exchange, property rights, and rules of competition and co-operation. The EU has by and large also come to co-ordinate rules of competition and co-operation for firms involved in trade across borders and even if there has been thus far less convergence across Europe in property rights, the European Commission has recently proposed the creation of a common incorporation label, *société européenne*, that should eventually undermine the currently national systems of property rights⁶⁷.

Without following the detail of their argument, they show convincingly that (1) the importance of Western Europe in the world trade has not declined during the last decades, that (2) the concentration of EU trade towards Europe has substantially increased and that (3) for every country in the EU the concentration of trade towards Europe has continuously grown and substantially after entry for late comers.

Table 2 - Share of intra- and inter-regional trade flows in each regions merchandise exports, 1999

| | Destination | | | | |
|----------------|---------------|----------------|------|---------------|-------|
| | North America | Western Europe | Asia | Rest of World | Total |
| Origin | | | | | |
| North America | 39.9 | 19.4 | 21.1 | 20.6 | 100.0 |
| Western Europe | 9.9 | 69.1 | 7.5 | 13.5 | 100.0 |
| Asia | 26.3 | 18.1 | 46.6 | 9.0 | 100.0 |

Source : World Trade Organization, Annual Report, 2000, Table III.3 - quoted in Fliegstein Mérand, 2001

⁶⁷ Moreover on 1 August 2000, the Commission submitted a proposal for a Council Regulation on the Community patent. This proposal aims to create an single industrial title, a document which should be accessible and which should guarantee the legal certainty on a Community scale. Whereas the existing European patent, once delivered, is in practice a bundle of national patents, the Community patent would be a valid unit title immediately throughout the Community territory (http://europa.eu.int/comm/internal_market/).

Table 3 - Percentage of total manufacturing trade of EU countries with others in the European Union

| | Austria | Belgium | Finland | France | Germany | Ireland | Italy | Netherlands |
|------|---------|---------|---------|--------|---------|---------|-------|-------------|
| 1970 | 53 | 77 | 21 | 82 | 70 | 27 | 70 | 68 |
| 1980 | 65 | 86 | 35 | 84 | 75 | 61 | 61 | 69 |
| 1990 | 79 | 83 | 41 | 86 | 79 | 54 | 67 | 77 |
| 1997 | 78 | 89 | 51 | 90 | 81 | 42 | 70 | 77 |

Source: OECD Outlook #64, 1998, p. 154 - quoted in Fliegstein Mérand, 2001

On average, trade between European countries now accounts for approximately 40% of their GDP; indeed, 70% of their total exports are directed to one another. The main effect of the European integration has been to increase dramatically trade within Western Europe. European corporations have responded to these opportunities in several ways. First, they have undertaken mergers with their principal national competitors and many of their competitors across European borders. Second, European multinationals have become more Europe focused in their investment and sales activities. Non-European multinational corporations have also come to focus more of their activities in Europe.

If Fliegstein and Morand have very forcefully made the controversial point of "Europeanisation", it is worthwhile to note that many specialists of international trade have remarked the polarization of exchanges in the so called triad. The specificity of Fliegstein Morand is to emphasise the link between "Europeanisation" and political project on the one hand and strategic view of economic actors. Anyway there is a lot of evidence that in the industrial sphere, at least, national borders are no longer what they are used to be in Europe. Consequently Europe is by now an essential dimension of the markets for sellers and probably for producers too.

The national innovation systems and the dynamic of the global/local linkage

Even if we are to accept the Europeanisation thesis for trade and production, it does not follow that it holds for industry science relationships (ISR). Moreover in the EU, we have to take into account three levels in the focus when we are coming to ISR. (the regional, national and European levels). If they judge that the "national systems of innovation" are still valid and central to the European scene Lundvall and Boras found that there have been important trends towards decentralisation and Europeanisation. On the contrary, *the lettre de l'ost* (2001) sustains that in this field, globalisation strikes in pieces the previous progress in Europeanisation : "Since the 1990's an important and increasing number of internationally technology alliances has replaced earlier national or even European alliances [...] and European companies invest heavily in R&D in the USA (in particular in the life sciences). The significance of this evolution should not be underestimated ad ISRs have been structured around national research organisations and domestic firms at a time when the strategic interests of the different stakeholders converged easily towards national goals. The situation has evolved gradually during the 1970s and 1980s with the intensification of government-sponsored international co-

operation in technological development, especially within Europe". In our perspective, it is not easy to distinguish the possible emergence of an European innovation system from the pure geographical determination.

The geography of innovation

In the conclusion of a survey devoted to innovation geography, Massard states that, the efforts made to map innovation have shown the existence of local knowledge spillovers. These local features, however; are not necessarily the only way through which externalities are to be effective. They are combined with other; more overall geographical factors, as well as with sectoral and technological factors, as the result of complex processes.

The main question which arises therefore focuses less and less on the geographical element in externalities on the whole, and increasingly on specifying more clearly how these externalities are spreading and used to the full. Defining more clearly the complex modes whereby knowledge diffuses from one place to another is the main challenge to be met in order to understand the process of geographical polarisation which innovative activities have undergone, and above all, to assess the new trends occurring in this field. In addition, if the pattern of distribution of external resources shows the existence of significant differences between various geographical sites and countries, we will have to seek for new means of controlling the distribution of knowledge in space. Although the studies surveyed by Massard have yielded some partial results on these lines, further analyses are now badly needed to elucidate the following points in particular:

- the specific role of the players themselves and the direct contacts between them raise the question as to how much mobility is desirable for research scientists and high-skill jobs on the one hand and collaborative scientific projects on the other hand;
- the importance of the infrastructures conveying information and communications needs to be specified. Little attention has been paid so far to these infrastructures from the point of view of their effects on the spatial distribution of knowledge (by goods and persons in the case of transported knowledge, and more directly in the case ITC).

Although data on local R&D and innovation processes have been collected and carefully analysed in the SESI monographs as well in other surveys, we are still far to have at disposal proxies for knowledge flows⁶⁸.

The origins of the proximity effects

Nohara Verdier come to the same conclusion regarding the IT industry in France, especially as regards the Grenoble region. They insist that the region has a long tradition of co-operation between industry and higher education in innovation networks, which emerged in the electrical engineering industry in the 1930s. The exchange of know-how and local synergies was maintained in the electro-chemical industry until the advent of the micro-electronic industry in the 1970s. It is undeniable that the Grenoble region had

⁶⁸ John Lovering expresses a very skeptical view on the literature on innovation geography :He argues that "the restructuring of defense shows tendencies that run precisely counter to those that many economic geographers claim to have identified as the emergent paradigm of economic geography--namely the economic empowerment of "regions" [...] However, the regionalized versions of the NSI literature is much less substantial than its National elder brother. [...] There is virtually no empirical content to the claims of the RSI writers

already hosted co-operation between local productive actors which would justify the title of "technological district", or local innovation system.

Alice Lam remarks the same features in the UK IT sector. She insists that "Proximity is important for building trusting and stable relationship with external institutions. Innovation intensive multinational firms go for "global sourcing" of knowledge by locating their R&D activities in regions rich in knowledge and skills. Spatial distribution of learning activities is complemented by greater corporate co-ordination and control of knowledge transfer (Gerybadz and Reger 1999) (Lam Alice, Revuelta Félix, 2000, "Sector Report : the UK IT Industry", WP5, SESI Project, contract n° SOEI6CT 97-1054 Project n° 1297, 15).

"The evidence suggests that proximity to the University has facilitated the development of human resource links through student placement and recruitment, but not necessarily formal collaborative links. Given the characteristics of SMEs, students and graduate recruitment probably provide one of the most important mechanisms through which they absorb academic knowledge and new skills. SMEs often face recruitment difficulties and the shortages of qualified technical staff can inhibit growth and innovation (Senker 1996). Proximity to universities provides a recruitment advantage for them. For many SMEs, the importance of universities lies in their contribution to the formation of internal capabilities, and not necessarily formal knowledge transfer through research links. In fact, there are reasons to believe that formal research links might not be the most appropriate mechanism for knowledge transfer between universities and SMEs. Formal research links tend to be driven by the match of expertise and organisational objectives. Matching the needs between universities and SMEs is difficult because of the existence of a large gap between the type of research carried out in universities and the specific needs of SMEs. Knowledge transfer is a social process which requires social and organisational proximity" (ibid, 17).

Many studies have emphasized the proximity effect in the development of co-operation. For example, Brugarolas / Alcouffe conclude from their investigation in the data banks that proximity plays an important part in the cooperation between researchers and industrialists. Geographical concentration facilitates the propagation of non stabilized and tacit information. Success in cooperations depend heavily on tacit knowledge. Trust is based on elements which are very specific as "home made" know-hows which are not transferable and remain tacit. Geographical proximity facilitates local learning based on tacit knowledge, frequent contacts and it reduces the possibility of opportunistic behaviors. Our investigation on contracts involving engineering sciences has proved, on the one hand, that industrialists are more likely disposed to call laboratories close to their research centers (90% of the cases in Midi-Pyrénées) and this proximity facilitates business relations. On the other hand, 40% of the contracts between Midi Pyrénées laboratories contract with regional industrialists (the same holds in Grenoble).

It cannot be omitted that the incentive policies developed by the Government and the Regional Council are designed to preserve or to increase this proximity effect. Policies supporting local endogenous development or local productive systems or scientific parks concur to the same results. This microeconomic model clearly acknowledges and takes into account the importance of institutions which supply constraints and incentives and lead to institutional arrangements. (see Brugarolas Alcouffe1999).

Proximity and global strategies of MNC

As governments are mistrusting more and more general programmes and policies in industrial matters, they pay more attention to these local effects and support the formation of *Clusters*, defined as "geographic concentrations of interconnected companies, specialised suppliers, service providers, firms in related industries, and associated institutions (for example, universities, standards agencies, and trade associations) in particular fields that compete but also co-operate" (Porter, 1990).

For example, in the UK, it is not considered the Government's role to create clusters⁶⁹. Clusters must be business driven and they form due to a variety of reasons, e.g. specialised demand, prior existence of related industries or institutions, or historical accident. Quality of life and other non economic factors can be equally important in determining growth. Clusters arise from making the most of synergies across and between companies and academic and research based institutions. The government, however, seeks to create the conditions which encourage the formation and growth of clusters. This can mean, for example, ensuring both national and regional policies do not inadvertently place barriers to cluster development, catalysing the formation of social interactions and collaborations within a cluster, and ensuring research and innovation support programmes build on existing strengths so as to work with the grain of cluster development. Government support for clusters, it is argued, cannot constitute a complete industrial policy. Cluster policy should be part of a wider set of policies that include national and non-sectoral policies and programmes that support and enhance nation-wide innovation and competitiveness, unfortunately it is difficult to guess what kind of contour such policies could take.

Simultaneously, the multinationals observed, notably North American, manifest a strategic desire to build a systematic, overall approach relative to their different commitments to the HERS. Their two strategic aims (and the resulting practices) are clearly distinguished from those of the 'national' companies. These two aims are not always in perfect harmony but reflect the presence of strategic co-ordination at a very high level of authority within these world-wide groups. On the one hand, there are the European ambitions which lead certain multinationals (Motorola, HP, pharma co. etc.) to place themselves immediately in the European space in order to seek out potential candidates for collaboration as broadly as possible, for example, by establishing a 'cartography of centres of excellence in Europe' or by casting a wide net over experienced engineers or researchers in the European labour market. On the other hand, they target what are sometimes called strategic partnerships, based on a lasting relationship with certain institutions of higher education. They thus develop a long-term, all-encompassing partnership with schools or universities, often those located nearby. What emerges, in the French case at least, is that the multinationals are not necessarily seeking to create partnerships with the 'best' schools or universities but rather to set up a dense network with local schools in order to constitute a veritable

⁶⁹ See Alice Lam, July 2001. Related to clusters are science parks which are business and technology transfer initiatives that:

- encourage and supports the start up, incubation and development of innovation-led, high growth, knowledge based businesses.
- provide an environment where larger and international businesses can develop specific and close interactions with a particular centre of knowledge creation for their mutual benefit.
- have formal and operational links with centres of knowledge creation such as universities, higher education institutes and research organisations.

reservoir of new graduates. Such a partnership leads these firms to involve themselves systematically in very broad dimensions of the management of the universities/partners in order to influence the content of the academic curriculum as well as the engineers' professional profile and ultimately to attract the students best suited to their needs. In order to do so, some of these companies are members not only of the board of directors but also of the scientific board which determines the orientation of university research or various academic committees which define the teaching programmes. This participation in university governance is naturally accompanied by practical measures such as aid for courses, funding of facilities, organisation of internships for students and joint advising of doctoral theses or training of faculty. Beyond these classic means, which are used very systematically, they sometimes seek to influence pedagogical reform in the training of engineers by pleading in favour of teamwork and project-based learning, which make students aware of business environments. This kind of tight interweaving of company-university relations would ultimately seem to be aimed not so much at gaining access to the 'best talents' but at a more general revamping of the engineer/researcher profile in order to make it better adapted to changing technological and market conditions. According to the assessment of certain members of management, the French-style hierarchy of schools, based on academic excellence and the capacity for theoretical abstraction, is not always relevant to industry, which is confronted with the rapidity of technological change. Thus, the strategic partnership deployed by these multinationals may gain ground in a system which has remained relatively homogeneous and alter the national framework for the training of engineers/scientists.

"Pavitt and Patel provide significant evidence on three aspects of the innovative behaviour of large firms : first, multinational corporations are rather reluctant to locate technological activities in host countries. Core competences, including R&D and innovation centres, are still heavily concentrated in the companies' home countries. Second traditional industries are, in proportion, more internationalised than high-tech industries. The result is certainly significant since it indicates that knowledge-intensive productions are more dependent on territorially bounded competences. Third, when companies decide to move part of their R&D and innovation centres abroad, they generally select the fields of excellence of the host countries. In other word, companies are more likely to go abroad to exploit the national capabilities of other countries than to simply expand their own core competences."

But this concern with local externalities is not exclusive of global sourcing as the strategy of the European pharma firms shows⁷⁰ : In 1994, no less than 47 percent of the research conducted by the U.S. pharmaceutical industry was funded by U.S. affiliates of foreign companies. Examples of foreign companies that have made significant investments in U.S. companies include the following: Glaxo Wellcome (U.K.), SmithKline Beecham (U.K.), Rhone-Poulenc (France), and Pharmacia (Sweden).. Moreover according to the *NSF Science and Engineering Indicators 2000*, the funding of foreign-owned research facilities in the U.S. has grown substantially from 1987 to 1997: by an inflation-adjusted 10.9 percent per year, whereas the R&D funding of domestic firms in the same time period grew only by 3.9 percent per year (NSF 2000). In 1996, 10.4 percent of the R&D performance in the U.S. (\$15 bn) was funded by foreign firms, mostly from three countries: Germany, Switzerland and Britain. A part of

⁷⁰ See "Biotechnology Industry in the USA" Christoph Büchtemann, SESI Project WP 2.2

this foreign R&D engagement, the NSF concludes, stems from acquisitions of U.S. companies by foreign competitors.

The trend of increasing foreign funded research within the U.S. has accelerated significantly in the last eight years. According to a study by Dalton and Serapio in 1993 (cited after NSF 2000), of the 255 foreign-owned R&D facilities⁷¹ in the U.S., about half were established only in the last six years prior to the study. In 1996, an update of the study counted 715 foreign-owned R&D facilities operated by 375 firms. The number and the activities of these facilities are concentrated mainly on pharma and biotech (116), chemicals and rubber (115) and on computers and software, instruments and medical technologies, electronics and automotive applications.

Labour market mobility

The notions of "national innovation systems" and "firm-level innovation space" which are central in the SESI project carry with them the strong implication that firms' capacity to innovate is structured by their relation to society and is specific to the country in question. It is the outcome of various mediations constructed at national level. Among these various processes of mediation, higher education is assumed to play a fundamental role. Consequently it is very important to pay attention to the ability of international firms to monitor and assimilate the competences and knowledge produced in the various countries in which they operate. The findings of some previous research projects (albeit not very recent ones)⁷², "national technological systems" have remained relatively autonomous. Between 1981 and 1986, the basic research carried out in a given country continued to feed into a technological system largely under the control of national firms. In most countries, the links with foreign research and higher education systems established through personal contacts and recruitment remain relatively modest compared with national links. Nevertheless, our research has provided evidence that shortages of skills are leading to a more European recruitment by many firms.

In April 1997, 26.1 percent of holders of doctorates in S&E in the United States were foreign born. The lowest percentage of foreign-born doctorates was in psychology (7.2 percent) and the highest was in civil engineering (52.0 percent). Almost one-fifth (19.2 percent) of those with master's degree in S&E were foreign born. Even at the bachelor's degree level, 9.7 percent of those with S&E degrees were foreign born—with the greatest proportion in chemistry (15.9 percent), computer sciences (15.6 percent), and across all engineering fields (14.9 percent).

⁷¹ Defined as "free-standing" R&D structures outside of and separate from the parent company's other U.S. facilities. This means, R&D departments or sections within U.S. affiliates are excluded from the count.

⁷² We are referring here principally to the research carried out by Patel and Pavitt (1991) on patenting inside a country by firms foreign to that country. The main finding shows that large firms still play a relatively small part in national technological activities; only in Belgium, Canada and the UK do they account for more than 15% of the total. Patent applications lodged in the USA by American firms in respect of activities carried out in France, Germany, Japan and the UK account for the following shares of all patenting in the country: 2.4; 6.9; 3.2; 16.7. However, these data relate to the period 1981-1986.

**Table 4 - Number of foreign-born S&E degree holders,
by place of birth, 1997**

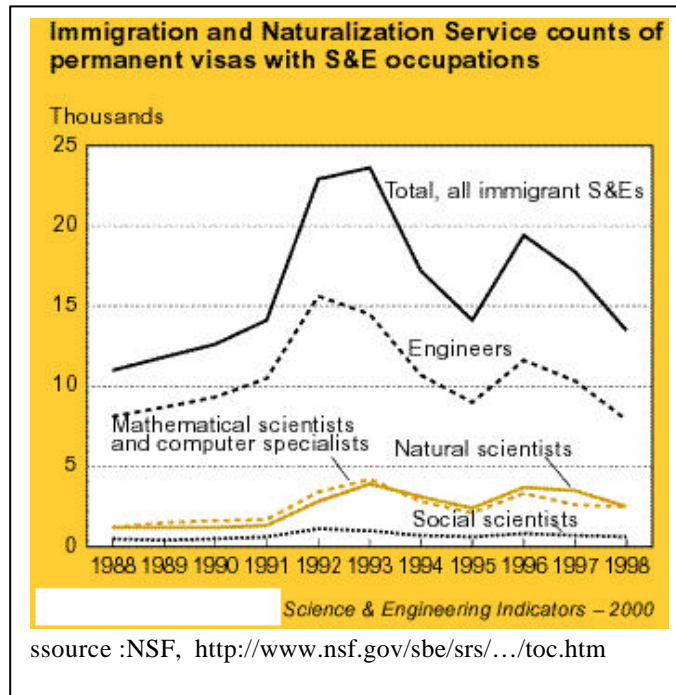
| Country of birth | Number | Country of birth | Number |
|------------------|---------|------------------------------|---------|
| India | 184 900 | Greece | 11 700 |
| China | 131 300 | Spain | 5 900 |
| Philippines | 92 800 | Austria | 5 400 |
| Germany | 84 100 | Ireland | 5 400 |
| United Kingdom | 74 600 | Sweden | 3 900 |
| Italy | 18 100 | European countries | 224 300 |
| France | 15 200 | Other foreign place of birth | 845 100 |

Source : NSF, <http://www.nsf.gov/sbe/srs/.../toc.htm>

As we analyze the relationship between industry and science it is interesting to note that a large part of the S&E foreign-born professionals have previously been students at graduate and postgraduate levels. According to a report by Finn (1999), 48 percent of 1992-93 U.S. S&E doctorate recipients with temporary visas were still in the United States in 1994. By field, this percentage ranged from 29 percent in the social sciences to 55 percent in physical sciences and mathematics. (See text table 3-25.) Within each discipline, the percentage of the Ph.D. graduation cohort found in the United States increases with years since degree, reaching 53 percent in 1997. The increase in the stay rate occurs despite considerable evidence from other sources that large numbers of foreign Ph.D. recipients with U.S. degrees leave the United States after completing a postdoc, or at later points in their careers. This suggests a very dynamic picture of the international migration of Ph.D. scientists—with some graduates of U.S. schools returning to the United States even as others leave. Sami Mahroum (1999) provides some data on European academics European doctoral graduates have a much higher stay rate in the US than their Korean and Japanese counterparts. The difference between Japan and Europe in the propensity to stay is large; only 8% of Japanese Ph.D. graduates stay. Graduates from the UK have the highest stay-rate in the US. Whereas, most German graduates go back (approx. 75%), only around 30% of UK graduates do. Greece lies somewhere in the middle between Germany and UK with a return rate of approximately 60%.

In the ISR perspective, it is interesting to note that in 1996 1000 of the Ph.D. graduates who started their own businesses in the US were Europeans (Mahroum 1999).

It is very clear that Europe is not attracting as many American scientists and engineers than the USA attract European ones. But these data should be used cautiously due to large incertitude. It seems that the emotion surrounding this topic has been enhanced by a burst at the beginning of the 90's whereas the trend seems to be declining :



Nevertheless it is remarkable that Europe (France, 171000, Germany 146000, United Kingdom 129000, Belgium, 35000, Swiss, 25000) attract 506000 foreign born students that is to say more than the USA (454000). From the French data, we know too that the percentage of these students who stay after their studies is roughly the same than the apparent figure for the USA (50%).

European countries are concerned by the shortage of skills and a possible braindrain by the USA. Because of their common language⁷³, it is not surprising that "concern in relation to the ability of companies in the UK to offer competitive benefit packages to attract leading people is high in the UK. Given the fact that leading researchers and managers are internationally mobile, and that there is a large demand for experienced managers, especially in biotechnology, it is considered imperative that more should be done to attract back some of the many managers and researchers who have gone to the US because of opportunities there. It is believed that an effective way of encouraging entrepreneurial spirit and attracting leading researchers and managers is through share options. In a government report it is explicitly stated that "the number of British entrepreneurs who have been attracted to work in the US biotechnology industry (...) is a trend we must reverse and ways must therefore be found to improve the attractiveness of share options" (DTI, 1999b:39). The decisions to provide incentives to enable companies to attract and retain the best staff, and the ability of growing companies to

⁷³ Concerning the role of space in ISR recent results (Schartinger et al. 2000b p.13) found that distance and language are major barriers for projects to take place. The probability of partnerships to be established is much higher if the native language of a country is German. This is valid for academic partners and as well for firms

offer key staff tax-advantaged options over shares is a measure introduced by government to help resolve this problem⁷⁴.

The issue of international labour mobility and the "brain drain" has received much attention in relation to science skills, this has especially been the case as the labour market for skilled scientists is becoming increasingly globalised both in terms of demand and supply. An Institute for Employment Studies research paper on "*Science Skills Issues*" commissioned by the Skills Task Force suggested that there has been "no serious evidence supporting the notion of a brain drain from the UK or its impact on the UK skills base" (Pearson *et al.*, 1999: 19). However, leading scientists such as Denis Noble, professor of cardiovascular physiology at Oxford, and one of the founders of *Save British Science*, (see <http://www.savebritishscience.org.uk/>), have argued that there may not be a net brain drain but that British science has been decapitated by two decades of under-funding. (Winton and Perry, 2000). Also, various academics responded to government measures as insufficient to reverse the brain drain (Farrar and Weiss, 2000). The flow of scientists to the United States, which has been studied by the European *Joint Research Centre*, can have positive effects if international experience and expertise gained by researchers enriches the scientific community in Europe on their return. This suggests that positive international mobility of researchers should be promoted if they can also be encouraged to return (RTD *info.* , 25). In a report on this topic, Mahroum (IPTS Report, no. 29) states that in order to encourage the return of researchers and leading scientists, the private sector should play a bigger role by creating research and engineering centres of excellence in joint ventures with the public sector. Also, in a study of the "inflows" of scientific personnel to UK academia, it has been argued that the increased foreign inflows reflect a decline of the local supply and increased demand for scientific expertise. It is cautioned that this increased supply of overseas scientists might make it less lucrative for local graduates to pursue an academic career in the UK, and that the benefits arising from the immigration of scientist are widely distributed in society, with the costs being borne by native scientists. Therefore, it is suggested that the availability of access to international pools of highly skilled personnel should not serve as a substitute for training and investment in the local labour force and improvement of employment conditions (Mahroum, 1999)" (Lam Alice and Nicolaides Andy, 2001, UK Policy Reforms on Academic-Industry Relationships: Challenges for Knowledge Transfer and Competencies Building, WP 6, SESI projetct contract N° SOEI - CT97-1054, Project n° 1297 pp. 26-27).

But as detailed data for other European countries are missing, it is interesting to use the SESI monographs in order to see if European recruitment at the firm levels are becoming more international and possibly more European.

⁷⁴ In France, Michel Charzat MP had been charged by the minister of economy, Laurent Fabius with a parliamentary mission about the measures which could improve French attractiveness. Indeed a report by Frédéric Lavenir, inspector of finances concluded that France has "a very bad image in the international executive circles" (see <http://www.finances.gouv.fr/minEFI/>). But the minister of economy has avoided to give any hint on either a possible tax exemptions for international executives working in France, or on possible measures improving firm creation. Michel Charzat in his final report (July 2001, recommends special income tax facilities for scientists and international executive in order to make France more attractive, but puts more originally a great emphasis on the European level (especially he suggests to decrease the cost of patenting and reinforcement of the EPO).

UK pharmaceuticals

Companies are increasingly recruiting Chemistry graduates in the wider European labour market. "Pfizer, for example, reckons that it has now established a very good medicinal chemistry network on the Continent, and in France in particular. The company's 1998 recruitment figure showed that the proportion of Continental recruits in Chemistry was as high as 40 per cent. Similar development can be seen at ICI Quest: the company is now recruiting more continental European chemistry graduates than those from the UK. An added factor is that Continental European universities, French universities in particular, are more active in encouraging student placement, an increasingly important channel for graduate recruitment" (Lam Alice, 2001, Sector report : The UK Pharmaceutical Industry", contract SOEI-CT97-1054, Project n° 1297, 6). .

"Pfizer is a global pharmaceutical company which has been experiencing rapid growth and expansion in the recent years" (ibid, 10) "The company has expressed concern about the quality and standards of graduates from UK universities, especially in Chemistry. Moreover, it was pointed out that the general lack of practical laboratory experience and problem-solving skills among the graduates had become more apparent because of the rapid advancement in research techniques and changing demands of jobs in research. In recent years, the company has increasingly looked for graduates from Continental European universities. It also favours recruiting graduates with laboratory (student placement) experience" (ibid, 11).

Similarly, "it is important to note that the development of strategic links with academic institutions is not restricted to the UK. Pfizer is increasingly casting its recruitment net wider by recruiting graduates from other European universities and forging research links with European centres of excellence. This is prompted by the need to search for the best quality scientists and to access a greater variety of knowledge sources. It is about a wider search for the 'potential of innovation' and the need to gain early access to 'new' and 'emergent' ideas" (ibid) .

The same observations can be drawn from ICI. "Over the past few years, ICI's graduate recruitment has become more Europeanised. This partly reflects the increased globalisation of its business activities, but more importantly, continental European graduates are considered to be more qualified than the British ones because of their broader and deeper portfolio of competence and linguistic skills. The general decline in the standard of British chemistry graduates appears to be another important factor prompting the company to look towards the continental European labour market" (ibid 15).

Even firms with a clear global scope are experimenting such an European recruitment . The example of UK-Pharma1 is especially highlighting. Central research at UK-Pharma1 is organised on a global basis. The research portfolio is co-ordinated globally, with a central committee overseeing the whole portfolio, covering the three main sites in the US, UK and Japan. Research teams and project managers located at different sites increasingly work in co-ordination with each other. The transfer of technology can be made to the operating divisions of any of the locations, not necessarily to the site where the drug was originally developed.

"With the rapid advancement in research techniques and changing demands of jobs in research, the deficiency in practical skills and problem solving abilities among graduates has become more apparent. On the whole, the company favours recruiting

graduates with laboratory (student placement) experience. In chemistry, the company increasingly looks for graduates from Continental European universities. A senior executive in Discovery reported that the company had now established "a very good" medicinal chemistry network on the Continent, France in particular. The 1998 recruitment figure showed that the proportion of Continental recruits in chemistry was as high as 40 per cent" (Lam Alice, Revuelta Félix, 2000, "UK Pharma 1, WP5, SESI Project, contract n° SOEI6CT 97-1054 Project n° 1297, 27).

But "this recruitment strategy is not only a response to labour shortage but clearly part and parcel of its competition and innovation strategies. It has recently started to generate a list of European centres of excellence by actively reading papers and identifying good research groups. The company is concerned about its relatively lack of a high profile in Europe. New initiatives such as organising postgraduate symposiums by inviting continental European scientists to present papers represents a first attempt to raise its European profile: The company is also keen to identify European funding for research as a means of building links with European research groups. It is increasingly aware of the importance of engaging in scientific dialogues with European research groups. The emphasis is on the importance of gaining *early access* to research outputs through networks of relationships" (ibid, 31):

"The company's interest in tapping into the European science base is a relatively recent development. At present it is not engaged in any major research collaborations with European research groups, but initiatives in this direction may well increase in the coming years. A note of caution here, evidence from an earlier study by Senker et al (1996) suggests that public research organisations in some of the European countries (e.g. France and Germany), were not prepared to deal with a foreign company. They saw it as their duty to give first preference to national firms" (ibid, 32).

The links between UK-Pharma1 and academic institutions in recruitment and education have already been discussed. This section focuses on the company's external research links with universities and biotechnology firms. "The company distinguishes two main categories of external collaboration: academic and corporate (i.e. biotechnology firms). In terms of the numbers of collaborative projects, the great majority are with academic institutions. However, in financial terms, 70 % of the budget is spent on biotechnology collaboration and the remaining 30% with academic institutions. For academic collaboration, about 70 % are with UK institutions and 30 % with those in the USA. In contrast, in the biotechnology area, the predominant majority of the collaborative ventures are with US firms. There is some emerging evidence that the situation might be shifting. A senior executive in Central Discovery believes that the ratio might be changing over time to be more European "as the science works through there". For example, interests in the German biotech scene is growing. The company has recently established a major collaboration with a German biotechnology company" (ibid, 37).

The small country case

Industry-Science Relationship in Austria

The Austrian industry is characterised by the overwhelming predominance of SMEs and a significant lack of big global companies. In this country R&D quota amounted to 1,79% in 2000, not comparable to remarkable achievement in the Scandinavian

countries. In comparison to the international average (EU with 1,83% in 1997 and OCDE with 2,21% in 1997), Austria remains unchanged behind. Austrian business perform a mere 56% of Austrian R&D (What is significantly under the European average); on the other hand, universities perform 35% of R&D what is tremendously high compared to other countries.

The Austrian research system still exhibits a strong fixation on the national territory and on national property on research projects and programmes. Internalisation and globalisation of the research system still remain at a low level. For the EU as a whole, the share of GERD funded from abroad was 6,5 percent in 1995. In Austria, the percentage of GERD funded from abroad was 2,5 percent in 1995, which is still well below both the EU average and that of other small open economies. The internationalisation of Austrian research, in particular that of the higher education sector, is still at a relatively low level. The Austrian participation in the European R&D programs is in most areas still under the European average. Schartinger et al. (2000) found that the Austrian university departments quantitatively prefer a type of interaction that do not necessarily include a recurring face-to-face contact between universities and industry. In this survey the joint supervision of PhDs and master thesis, lecturer by firm members at universities and contract research had the biggest share of responses" (Mayer Kurt, Sector report : Inudstry, Science Relationships in the Austrian ICT Industry, SESI Project, contract n° SOEI6CT 97-1054 Project n° 1297, 21). The geographical proximity has an important role in the knowledge transfer. Concerning the role of space in ISR recent results (Schartinger et al. 2000b) exhibit that almost three quarters of all project partners of Austrian universities come from European countries, the highest proportion of which, almost 40 per cent, come from Austria itself.

Concerning the role of space in ISR recent results (Schartinger et al. 2000b) found in a survey of 19.688 relations between an Austrian university department and a project partner that Project partners of Austrian university departments in the performance of research projects come from 87 countries of residence in total. They can be distributed in categories of distance along their location (Austria: 41% Neighbouring countries: 28% (among them Germany: 16%) rest of Europe: 17% Other countries: 14% (among them USA: 8%). National data as well as firm monographs show that the opening of the Austrian system of innovation is predominantly European, but with intended and significant linkages with the USA.

Austrian manufacturing mainly is engaged in rather traditional Fordist industrial sectors with a rather outdated production structure - characterised by being 'raw material heavy' - and has a major deficiency in the rather new technology supported sectors of the knowledge based economy. "The strong position of a sheltered public sector and nationalised companies guided more by political goals than by market principles reinforced the Austrian system of incremental innovation. According to Lundvall/ Nielsen (1998) a major factor influencing innovation trajectories can be found in the competiton regime: A strong exposure to competition and transformation pressure is tending towards triggering product innovations, stimulating organisational change, moving firms toward learning organisations and networking organisations and increasing the skill requirements in firms. Since wide areas of the Austrian economy have been sheltered from international competition this 'competition incentive' to innovation, up-grading of skills and co-operation did largely did not exist" (ibid, 26. Therefore innovation in Austria is a mainly driven phenomenon. It is not very research intensive, it rather means to adapt and adjust standardized products developed

somewhere else to requirements of Austrian customers. role. As a consequence the linkages and interaction of the higher education sector with the business enterprise sector are weak in terms of flows and funds.

"In 1989 Austria applied for membership in the EU, 1994 Austria joined the European Economic Area and in 1995 it was admitted with full membership in the EU. The biggest economic impact of EU membership was expected in strong transformation pressures on the sheltered sector in form of stepped up competition (Lauber 1996, 143). This process has been under way now since six years forcing Austria to revoke the sheltered sectors and to adopt European rules for market competition. With respect to competition Austria now has adjusted to European average" (ibid, 27). It is interesting to look at this adjustment in a particular sector as the ICT. The center of the Austrian production in the telecom-sector still consists of four companies: Siemens, Alcatel, Ericson/Schrack and Kapsch. For all this firms, the 1990s was a period of profound change with regards to academic institutions. Each of the case studies in the ICT sector is following an own specific course towards the knowledge based economy having a different focus on the possible strategies of knowledge sourcing and giving a different weight and a different moulding in that process.

Following the Austrian catching up, some concerns have appeared about skill shortages. Kurt Mayer tells the interesting story of Kapsch, an Austrian SME in the ICT sector. "In the second half of the 1990s the company hesitantly approached universities but only some minor agreements resulted from that activities (some diploma thesis, on PhD thesis, one small scale project having the nature of outsourcing a well defined problem to a university assistant). Nevertheless in the recruiting of human resources - especially faced by the ICT skill shortage since 1997 -- the company increased its activities to recruit graduates (with marketing events for graduates, participation on firm fairs at universities and by outsourcing R&D activities to newly established small competence centers in the environment of universities (eg. Graz or Budapest)" ibid, 33).

"Since other research reports point to similar problems (see ARCS/ IHS 2000) shortage of *qualified staff in the ICT* sector could be remedied by policy efforts in three directions:

1. to increase the number of graduates in the HES
2. to develop training courses to boost the number of qualified workers in the long term.
3. to open the borders for ICT professionals from abroad, especially from Eastern Europe" (ibid, 19).

The last point should be facilitated with the coming enlargement of Europe which will bring all part of the former Habsburgian Empire under the same roof, but to this point the economic needs are at variance with the credo of the FPÖ, the sulphurous partner of the ruling coalition in Vienna.

Industry-Science Relationship in Portugal

In the Portuguese case, globalisation or internationalisation cannot be said to destroy a national innovation system or to weaken national ties or links, because those ties have always been inexistent or weak. What we can say is that, in spite of all the public policies - including funding - to promote those ties, there is no system. This is because the industrial specialisation in traditional sectors, the international division of labour that maintains Portugal specialised in the manufacturing process and the weakness of science based sectors. In this context, European R&D programmes appear an

opportunity for Portugal and it is remarkable that Europe finances the most of the research made in consortium between firms and universities involving several European countries whereas transatlantic programmes do not exist in Portugal⁷⁵. More generally foreign firms are very important both as sources of innovation, clients and access to foreign markets. Training young recruits abroad is also important in the telecommunication sector for multinational firms operating in the country, namely Siemens and Alcatel. But this is mainly training in in-house laboratories located in France, Germany, etc.

There are examples of increasing recruitment from abroad in the IT sector (informatics and telecommunications), mainly from East European countries, to work in firms and some intermediate institutions⁷⁶. The main reason is the lack in the internal labour market (mainly due to the liberalisation of Telecommunication National operator and the emergence of new firms in this area) and the pressure on the increasing of wages.

Human Mobility does not concern only young recruits, but also people that is not yet in the labour market. For instance, science policies are particularly important, by financing scholarships abroad. This is one of the most important criteria of mobility and internationalisation of national research system (not innovation system), as it is questionable if we can talk about an innovation system in a country where the most of the firms do not use academic knowledge and we do not have headquarters of transnational firms).

But opening in the Portuguese case does not mean alliances. With a few possible exceptions, co-operation takes generally the form of dominance relations, depending on the "competitive platform firms are located"⁷⁷. Portuguese firms just sell, under certain conditions - defined by clients -, their knowledge. P1-Por monograph shows that the products are sold together with detailed technical reports, meaning that Portuguese firm has no property rights on that knowledge.

European S&T Policy and National Innovation System.

Government and foreign funding

The most notable trend among the G-7 countries, during the last decade, has been the relative decline in government R&D funding. Indeed, this pattern of reduced governmental R&D support is apparent throughout the OECD, and especially in European countries (Caracostas and Muldur 1998). In 1997, roughly one-third of all R&D funds were derived from government sources—down considerably from the 45 percent share reported 16 years earlier. Among all OECD countries, government accounts for the highest funding share in Portugal (68 percent of its 1997 R&D total)

⁷⁵ Some intermediate institutions, closely linked to universities (see INESC case in IT sector monograph to understand the meaning of an "intermediate institution" in the Portuguese case), are doing research (basic research) for American firms, due to the lack of interest of Portuguese firms in academic knowledge.

⁷⁶ Cf. Oliveira, Luisa, (2000), "Informatics and Telecommunication Monograph: the case of Portugal", in Verdier, Eric (coord), Innovation et Systèmes d'Enseignement Supérieur, project financed by TSER programme, DG XII, Brussels

⁷⁷ Cf. Oliveira, Luisa, (2000), "Informatics and Telecommunication Monograph: the case of Portugal", in Verdier, Eric (coord), Innovation et Systèmes d'Enseignement Supérieur, project financed by TSER programme, DG XII, Brussels

and the lowest share in Japan (19 percent in 1996). Part of the relative decline reflects the effects of budgetary constraints, economic pressures, and changing priorities in government funding (especially the relative reduction in defense R&D in several of the major R&D-performing countries—notably France, the United Kingdom, and the United States). Part reflects the absolute growth in industrial R&D funding as a response to increasing international competitive pressures in the marketplace, irrespective of government R&D spending patterns—thereby increasing the relative share of industry’s funding vis-à-vis government’s. Both of these considerations are reflected in funding patterns for industrial R&D performance alone: In 1981, government provided 23 percent of the funds used by industry in the conduct of R&D within OECD countries, whereas by 1997 government’s share of the industry R&D total had fallen by more than half, to 10 percent of the total. In most OECD countries (as in the U.S.), government support to business R&D is skewed toward large firms (OECD 1999a)⁷⁸.

The R&D funding share represented by funds from abroad ranged from as little as 0.1 percent in Japan to more than 16 percent in the United Kingdom. Foreign funding—predominantly from industry for R&D performed by industry—is an important and growing funding source in several countries and reflects the increasing globalization of industrial R&D activities overall. Although the growth pattern of foreign funding has seldom been smooth, it now accounts for more than 20 percent of industry’s domestic performance totals in Canada and the United Kingdom and approximately 10 percent of industry R&D performed in France and Italy. (See figure 2-32.) Such funding takes on even greater importance in many of the smaller OECD countries, as well as in less industrialized countries (OECD 1999d). In the United States, approximately 8 percent of funds spent on industry R&D performance in 1996 are estimated to have come from majority-owned affiliates of foreign firms investing domestically. This amount was considerably more than the 3 percent funding share provided by foreign firms in 1980.

The European IT and telecom case

The IT and telecom sector provide us with case studies in order to analyse the dynamic of European national systems of innovation and the effectiveness of European programmes in order to build up an European innovation system. Given the overwhelming force of the American IT industry, including in terms of software packages and IT services, Europe certainly seems to suffer from structural deficiencies inherited from past "national champion" policies. Despite these weaknesses, some European countries seem to be showing their capacity to resist the American offensive, drawing on knowledge, competences or positions linked to their own institutional set-ups. In particular, the case of France, which in the past systematically developed state policies in favour of IT, shows us how actors in the innovation process rely on existing institutions to revitalise their innovation activities.

⁷⁸ In transatlantic comparisons, it is frequent to complaint that European countries perform poorly in technological fields comparatively with scientific ones relatively to the USA. This should be related to the part of basic and applied research funded by governments. Basic research accounts for more than 20 percent of total R&D performance reported in Italy, France, and Germany when the United States expends only about 17 percent of its R&D on activities that performers classify as basic research.. (Data are not available for the United Kingdom).

After the relative failure of national policies, the European programme seemed to be an opportunity to challenge American pre-eminence. Despite these efforts, it may be noted that the Esprit series of European programmes had no effect on existing co-operative networks and did not replace them with new arrangements. Naturally, the Esprit projects in which Bull and Thomson, as well as many software and IT service companies and research institutions such as INRIA and university teams, were active participants, allowed research networks to be extended on a European scale and brought the various players in the European IT industry closer together. From the French perspective, however, the constitution of European networks has taken place within existing local and co-operative arrangements, notably those focused around regional centres. Being established in a locality does not, therefore, seem to conflict with the extension of co-operation between the industry, universities and public research to the European scale (Hiroatsu Nohara and Eric Verdier, 2001).

In 1983, the Commission of the European Communities undertook a vast programme of activities concerning telecommunications. This led to the publication of the 1987 Green Paper, followed by the liberalisation of the equipment and service markets. The principle of opening voice telephony to competition was adopted in 1993, with a calendar extending from 1998 to 2005 depending on the country.

The EEC's interest in questions related to the new information and communications technologies goes back to 1983, with the creation of a special task force on "Information and Telecommunications Technology". Three years later, this task force was merged with other departments to become the European Commission's DG XIII, responsible for telecommunications and the information industries. From 1984 to 1987, Community policy on telecommunications was organised around six kinds of actions:

- 1) co-ordinating the development of the supply of services;
- 2) developing a single market for terminals and equipment;
- 3) supporting the pre-competitive R&D programmes ESPRIT⁷⁹ (on information technologies) and RACE⁸⁰ (on broadband networks);
- 4) launching several programmes to encourage exchanges of information between European bodies and national government;
- 5) aiding the introduction and development of services and networks in outlying regions (STAR⁸¹);
- 6) adopting common technical specifications (GSM, MAC).

At the regulatory level, the Green Paper published by the Commission in 1987 set three objectives for 1992: total liberalisation of the terminals market, the possibility of interconnection for service providers according to "open" networks principles and the clear separation of regulatory and operation activities.

- 1) It is an industry that structures its environment because it provides equipment giving rise to new demands and new activities. It has gradually assumed a dominant position in the industrial fabric.
- 2) It is a high-tech industry that requires very costly R&D investments and a sufficient scale to cover such irreversible expenditures. It has already experienced a fundamental technological discontinuity with the shift to time switching, just as it has experienced rapid technological change with the importance of software in relation to hardware or

⁷⁹. European Strategic Programme for Research in Information Technologies.

⁸⁰. Research and Development in Advanced Communications Technologies.

⁸¹. Special Telecommunications Actions for Regional Development.

with the role of mobility for terminals, and it might be sharply destabilised by the accelerated development of optics.

3) Technological change in this industry leads to profound transformations in knowledge, skills and know-how that are essential to manufacturers. The boundaries with other industries are shifting and porous and often lead to new strategic positions for manufacturers seeking certain access to the latest key skills.

4) The environment of this industry is subject to the effects of the deregulation of telecommunications services, videocommunication cables and television.

5) Its strong national character is outmoded. Formerly multinational, it is becoming increasingly global, with a displacement of both geographic centres of growth and high-potential activities that reflects sharp international competition.

Major industrial battles are currently underway for the conquest of markets located at the juncture of the telecommunications, computer technology and audiovisual industries. Sector-based divisions seem to be flying into pieces from the pressure of the major players in each of these sectors seeking to enter the markets of the other two. Although the current recomposition, which is far from over, can be traced back to the 1980s, it has been sharply accelerated since the beginning of the 1990s. It is manifested by a strong interpenetration of players and actors from the three sectors, but the industrial organisation (i.e., the configuration of these players and markets) that may result from the breakdown of sectoral boundaries and market transformation is still largely undetermined. Amongst the possible configurations, the most frequently suggested is that of 'convergence'.⁸² Developing similar technologies, the main players in these sectors would be called upon to integrate the activities of audiovisual technology, computer technology and telecommunications. At the end of the process, we would have a few large firms intervening on a market that would indeed be differentiated but defined by a global need--that of access to information services whose previously separate forms of processing and communication (voice, image, text, data) would be integrated in a reunified communications process.⁸³

The 'convergence' thesis is illustrated by the circulation of a few vague metaphors such as "information highways" or "multimedia", which attest nonetheless to the way the players represent their actions. Rallet (1996) nuances this thesis by showing first of all that technological convergence is a differentiated movement that does not do away with the specific features of the skills on which the division of labour between the various types of players is based. He then brings out the relative indeterminacy of the possible trajectories for the industrial organisation of the three sectors.⁸⁴

Generally speaking, the telecommunications sector is organised in a context of uncertainty leading to what Badillo (1996) calls "technological and regulatory slack".⁸⁵

⁸². The question of convergence is not new; it was already raised in the early 1980s, although at that time it involved only two kinds of players, coming from the worlds of computer technology and telecommunications. Grand manoeuvres and battles were announced, notably between the two giants of American industry, ATT and IBM. Notwithstanding a few skirmishes, however, the battle did not take place. Ten years later, the question is raised once again, and the stakes related to the opening of the sectors are much more important. Two reasons may be cited: first of all, a third sector has come on the scene--that of audiovisual technology--and second, the deregulation movement that was just beginning in the early 1980s has since gained strength, which permits greater interaction between the sectors.

⁸³. Giving rise to what Badillo (1996) calls a "mega" communications industry.

⁸⁴. For further details, see Rallet (1996).

⁸⁵. The term *slack* is borrowed from organisation theory (Cyert, March and Williamson), but Badillo's concept of technological and regulatory slack is clearly somewhat removed from that of organisational

In such a context, the actors' strategies are preponderant and motivated by the prospects of high returns from the telecommunications market. It is doubtful that in such a framework public policies even at the European level could still play a structuring role in the future..

Concluding remarks

We started with some observations about the paradox represented by the success of the NIS concept in the face of globalisation. We discuss the phenomenon and distinguish between internationalisation per se and Europeanisation. This leads us to look after hints of a possibly emergent European system of innovation which could mirror the well documented European system of production which results from European integration. We found that labour mobility for scientists is rapidly increasing in Europe favoured by skill shortages. Nevertheless it is very clear that knowledge sourcing which is very important in firms' strategy, even at the SME levels is global and the picture we got is very different of an European fortress. To this point, we disregard an important phenomenon which is probably linked to the success of the NIS concept. Actually, new growth theories as well as policy inspirers emphasize the difference between social and private returns on R&D investments. Muldur argues in this vein that "the social return on R&D investment is not only very high, but it is also greater than its private return" (Muldur 2001, p. 120). The first part of the sentence is doubtful and it will be difficult to define a scale in order to measure these heights, but the second one will probably reach a large consensus among economists. If it is right, then we find a *raison d'être* for policies designed to reduce the gap between social and private returns. The indicators gathered by the European Commission produce convincing evidence that the top firms in the European Union are making R&D efforts very similar to their transatlantic counterparts whereas the European SME lag largely behind. The under-investment in R&D on the part of European industry compared with American industry is explained in the main by shortcomings in the lower stages of the industrial structures and not by a lack of investments on the part of large European companies. Muldur 2001 (p.150) argues that the under-investments by European SMEs in research and innovation could be explained by allocative inefficiency (the lack of access to national programmes for SMEs) as by organisational inefficiency (barriers to the start-up and development of new innovative enterprises, lack of cooperation with the universities). It is considered that a substantial increase in public and private funds for SME will achieve the desired results if this is accompanied by measures and dismantling the barriers to innovation, the business creation and the expansion of SMEs.

Nonetheless several SESI monographs show that European SMEs are not unable to engage in R&D and innovation. Unfortunately their linkages to the HES remain weak and could be one of the factors which prevent the European innovation system to develop and catch up the American one. Consequently among the policies designed to dismantle the barriers to innovation, the business creation and the expansion of SMEs, an important part should be devoted to develop the cooperation between HERS and SMEs.

slack. The parallel between the two is the following: just as there is company play within the company, the convergence of information technologies and the market organisation correlated to it takes place with a certain play, in conditions that are less than optimum. The distance between ideal and real organisation thus reflects the technological and regulatory 'slack'.

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Chapter 7 - Christoph Buechtemann and Hans Thie, "Industry-Science-Relationships in High-Tech Sectors: Comparison of Germany and United States"

The empirical basis of the following comparison of Germany and the United States are 24 companies/company sites in both countries participating in this study. Major multinational players as well as innovative start-up companies in the ICT and pharmaceutical / biotech industries were part of the sample. As cooperation partners of these firms, 36 universities and research institutes in the United States and Germany were also interviewed. Altogether, 175 interviews with 130 individuals in industry and academia were conducted between June 1999 and August 2000. The focus of the following sections is less on industry-specific differences and more on cross-country comparisons.

Differences and Complementarities in Industry-Science-Relationships

Today it is widely accepted that technology transfer is not a unidirectional process and is not limited to research results that can be clearly identified and transferred. In many cases it seems to be more appropriate to talk of technology and knowledge exchange, since interaction works best when partners cooperate in close and immediate contact in order to take commercial advantage of academic capabilities. Relationships between industry and science represent an institutionalised form of learning that provides a specific contribution to the stock of economically useful knowledge. Interaction should be evaluated not only as knowledge transfer but also in other capacities (e.g. building networks of innovative agents, increasing the scope of multidisciplinary experiments).

In our interviews it has been frequently noted that academic research and industrial R&D differ in many important dimensions. Academic research is curiosity-driven. Breakthrough discoveries are its principal goal. Down the road to applied research academics usually do not go beyond solutions-in-principle: solutions that work under well-defined experimental conditions. The time horizons in academic research tend to be long with an emphasis on depth and latitude leaving open the possibility of exploring both new paths and emerging fundamental questions along the way. Often energies of academic research are dispersed in many directions. Industrial R&D, by contrast, is purpose-driven and focused. Its principal goal is product development and incremental product improvement. In most cases industry does very little research proper and tries to refine prototypes and demonstrators to marketable products that work under varying market or customer-specific real-world conditions. Time horizons are much shorter than those of academic projects and energies are focused and bundled.

Our interview partners emphasized that these differences are a potential source of synergistic complementarities. Industry research needs the idea input from academic research and can take research results further than academia could (or would) ever do. Industry can provide funding for university research in novel topic areas that would not

attract public funding. Academic interviewees stressed that industry funding often has less bureaucratic strings attached compared to government research funding. Research money from industry can also compensate for declining public research support. In some cases industry gains access to the results of publicly sponsored research (e.g., NIH; DARPA in the United States; federally or EU sponsored projects in Germany) through collaboration. Access to specific technologies that individual companies would not invest in (e.g., special genomic test beds) is another reason for collaboration. Generally, collaboration lowers the cost of high-risk projects for industry.

Academics, on the other hand, often gain access to technologies, equipment or databases they could not afford themselves (e.g., genomic data bases; model organisms). Academia also obtains information about where industry's innovation activities are headed for and industry funding inflicts a sense of relevance into academic research. Collaborative research with industry can help coordinate and focus dispersed activities of university researchers (pooling of energies). Through industry collaboration academic researchers can learn to use resources more efficiently. To capitalize on these complementarities is a difficult process. Principal differences in goal orientation, mindset, governance and incentive structures are sources of an uneasy relationship and give rise to complaints on both sides. Industry demands that universities should become more business-like, more conscious of IPR matters, more focused on "relevant" research, and more like service providers. Academia complains about industry's short-term horizons, risk aversion, obsession with secrecy, timelines, and milestones. Coping with these mutual complaints is a delicate task.

The "Transfer Gap" in Industry-Science-Relationships

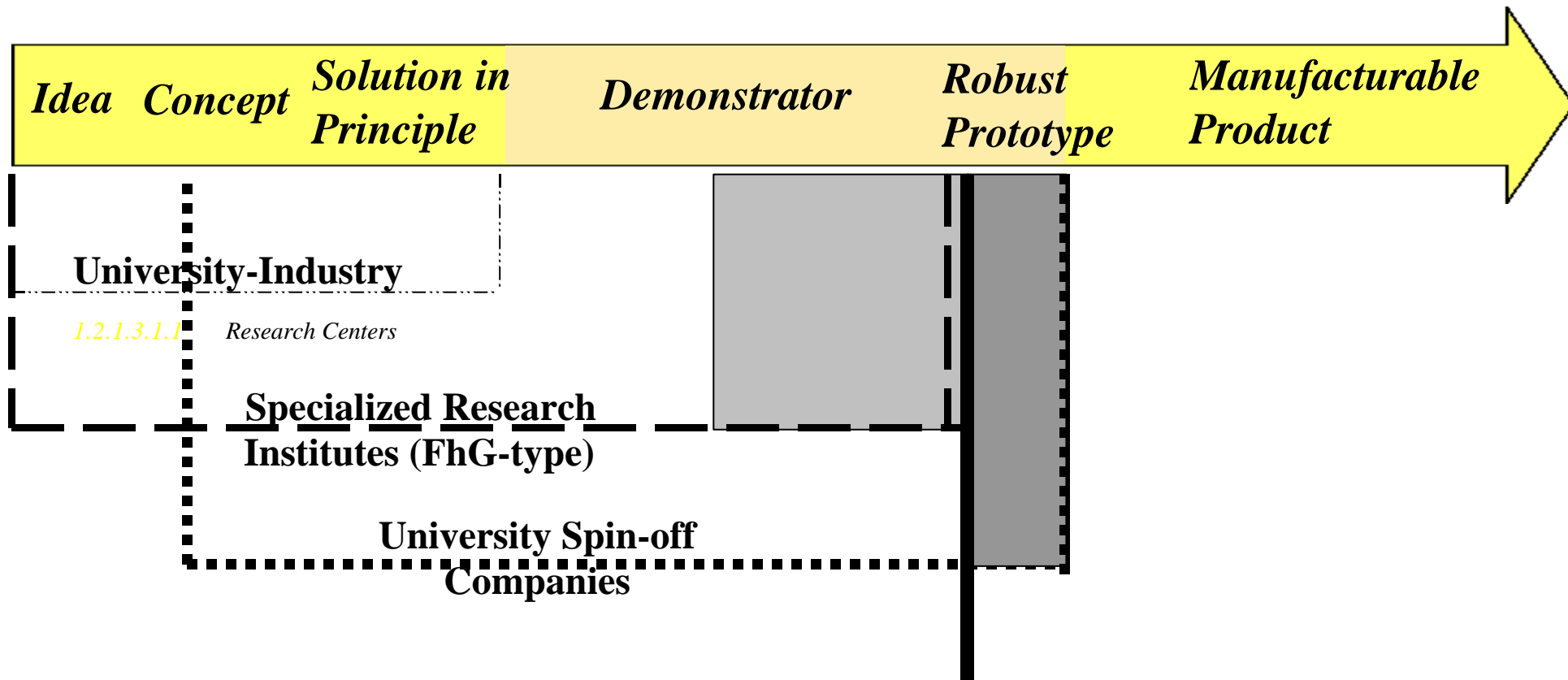
The principal problem of industry-science-relationships is what we may call the "transfer gap". The following diagram illustrates the role of and the primary focus of universities, intermediate institutions and industry on the road from "Idea" to "Marketable Product". Universities are usually miles away from what industry is interested in. They concentrate on research proper: on ideas, concepts and solutions-in-principle. Industry, on the other side, largely focuses on the final steps of the research and on the entire development process. Robust prototypes involving some research are often the starting-points for industry's main function: to develop products that work under varying real-world conditions. As such, universities and industry may have only links to collaborate on. Many corporate interviewees, especially those from ICT sectors, asked for the common ground, for the right starting-point to establish relationships with academia.

To bridge the gap between curiosity and purpose intermediaries have to step in. Their focus - represented by three typical institutions in the diagram - also varies considerably. American university-industry research centers hardly go beyond the narrow confines of the academic world. Specialized institutes, such as the German

The "Transfer Gap" in
Industry-Science-Relationships

University

Industry



Fraunhofer institutes, are an example of public research coming much closer to corporate industrial concerns. But these institutes barely touch the prototype stage. They can be interesting partners only for those companies that have at least some research of their own. Finally, university spin-offs usually cover a broad spectrum of the R&D process. They not only have to present interesting concepts, but they also have to demonstrate the feasibility and the practical utility of their research work.

National Frameworks for Bridging the Gap

United States

Beginning in the 1980s, a ground breaking series of new federal laws or amendments to existing laws were passed to adjust the U.S. economy to the pattern of accelerating global competition with other industrialized nations. Especially Japan and Western European countries were perceived, by U.S. lawmakers, as closing in on the, until then, undisputed market and technology leadership of U.S. industry. Most influential among these new national initiatives were changes in the copyright and patenting laws and a loosening of the prevailing 'Rooseveltian' antitrust doctrines to institutionalize tighter public-private collaborations and patent-protected technology transfers from the public to the private sector in the guise of 'pre-competitive' R&D partnerships.

This amounted to a broad-based redistribution and reallocation of federal grant moneys in the name of technology transfer in fields of perceived disadvantages versus international competitors and it was directed at 'targeted research' where the existing federal research institutions and laboratories were seen as inadequate or not sufficiently equipped to conduct the requested research by themselves.

The legislative overhaul included:

- the **Stevenson-Wydler Technology Innovation Act (1980)** which required federal laboratories to facilitate the transfer of federally owned and originated technology to state and local governments and to the private sector,
- the **Bayh-Dole University and Small Business Patent Act (1980)** which permitted government grantees and contractors to retain title to federally funded inventions and encouraged universities to license inventions to industry,
- the **Small Business Innovation Development Act (1982)** which established the Small Business Innovation Research (SBIR) Program within the major federal R&D agencies to increase government funding of research with commercialization potential within small, high-technology companies,
- the **National Cooperative Research Act (1984)** which encouraged U.S. firms to collaborate on generic, precompetitive research by establishing a rule of reason for evaluating the antitrust implications of research joint ventures. The Act was amended in 1993 by the National Cooperative Research and Production Act, which let companies collaborate on production as well as research activities,
- the **Federal Technology Transfer Act (1986)** which amended the Stevenson-Wydler Technology Innovation Act to authorize CRADAs

- (cooperative research and development agreements) between federal laboratories and other entities, including state agencies,
- the **Omnibus Trade and Competitiveness Act (1988)** which established the Competitiveness Policy Council to develop recommendations for national strategies and specific policies to enhance industrial competitiveness. The Act created the Advanced Technology Program and the Manufacturing Technology Centers to help U.S. companies become more competitive,
 - the **National Competitiveness Technology Transfer Act (1989)** which amended the Stevenson-Wydler Act to allow government-owned, contractor-operated laboratories to enter into cooperative R&D agreements,
 - the **National Cooperative Research and Production Act (1993)** which relaxed restrictions on cooperative production activities, enabling research joint venture (RJV) participants to work together in the application of technologies they jointly acquire.

Commercially structured and instituted technology transfer channels between universities and the private sector are, in the wake of the Bay-Dole Act (1980), of a more recent date. Nevertheless, they have proven to be effective tools in the dissemination of scientific academic knowledge that under an earlier doctrine of social return to the national community had been destined for the public good by releasing them directly into the public domain.

Since the passage of the Bayh-Dole Act, academic research has become a major source of technology licensing from public-sector entities to commercial enterprises. The Bayh-Dole Act expanded the range of government-funded research, whose experimental results universities, nonprofit research institutions and small businesses can utilize to apply for patents and exploit within their own intellectual property rights (IPR) regimes. The Bay-Dole Act allowed the granting of exclusive licenses on these patents on public research results to commercial enterprises or faculty members, which is a critical consideration for businesses risking time and money to develop technologies that may not succeed.

Since then, statistical data have revealed that the Bayh-Dole Act has significantly increased the patenting and licensing activities of U.S. universities. Before 1980, fewer than 250 patents were granted annually to U.S. universities, according to the Association of University Technology Managers (AUTM).⁸⁶ In 1996, a total of 2,095 patents were issued, and 2,741 licenses and options were negotiated.

As a result of all these structural and jurisdictional developments, cooperative research and development agreements (CRADA) between private-sector firms and federal laboratories grew a hundred-fold (from 34 in 1987 to 3,688 in 1996), and its number has hovered around this mark since then. Inventions stemming from such public-private collaborations have risen from 2,662 in 1987 to 4,213 in 1991 and 4,153 respectively in 1996. Likewise, patent applications have risen from 848 in 1987 to 1,900 in 1991, a level on which they have stayed since then. Licenses granted by public research institutions have risen from 128 in 1987 to 510 in 1998 (NSF 2000).

⁸⁶ Association of University Technology Managers, AUTM Licensing Survey 1998, Norwalk, Conn., 1998.

Licensing has long been a means for businesses to take full advantage of their technology portfolios. Since the Bayh-Dole Act, however, academia has also become a major source of technology licensing. The Bayh-Dole Act allows universities, nonprofit research institutions, and small businesses to own and patent inventions developed under federally funded research programs. The numbers cited above reveal that Bayh-Dole has been successful.

While U.S. universities themselves have not, for the most part, derived significant net revenues from licenses, their impact on the economy as a whole is large. AUTM estimates that sales of products developed from inventions made in the course of academic research and licensed to industry amounted to \$20.6 billion in 1996. That same year, licensee companies including 248 start-ups invested an estimated \$4.2 billion to bring early stage inventions to market. As indicated by TABLE 1, U.S. academic patenting and licensing continued to increase dramatically between 1995 and 1998. So did the formation of new company start-ups.

Table 1- U.S. Academic Patenting and Licensing Activity 1995-1998

| Activity | 1995 | 1998 | % change |
|--------------------------------|-------------|-------------|-----------------|
| invention disclosures | 9,789 | 11,784 | 20% |
| U.S. patent applications filed | 2,872 | 4,808 | 67% |
| U.S. patents issued | 1,837 | 3,224 | 76% |
| Licenses and options signed | 2,616 | 3,668 | 40% |
| New companies formed | 223 | 364 | 71% |

Source: Association of University Technology Managers, Annual Surveys

AUTM's 1996 survey reveals that academic licensing has been especially beneficial to the biotech industry. Of 12,951 active licenses, 67 percent drew on research in the biomedical and other life sciences. In return, biotech licenses provided 86 percent of all university license income. Thus, the increase in university licensing revenues was largely accounted for by structural factors, especially the emergence and rise of the biotech industry. An empirical study of three major U.S. universities points out that "the increased ability to patent research results in this and in other areas of expanded university research, probably (was) even more important than Bayh-Dole. Indeed, prior to Bayh-Dole judicial decisions had declared that "engineered molecules" were patentable, the U.S. Congress passed a series of laws strengthening intellectual property protection, and the U.S. government expanded its efforts to gain stronger international protection for intellectual property ... Even if there had been no Bayh-Dole one would have seen significant increases in university patenting and licensing. Nevertheless, Bayh-Dole was an important catalyst, and its provisions are interesting in their own right." (Mowery et al. 1999: 3)

The University of California at San Francisco (UCSF) is a case in point. In AUTM's survey, the nine-campus University of California System filed more patent applications (325), executed more licenses and options (137), and earned more gross license income (\$63.2 million) than any other US university. Of this total, inventions from the San Francisco campus, which focuses on healthcare, generate 75 to 80 percent. This implies that for many other universities the cost of patenting may have exceeded patent income.

Prior to the enactment of the international TRIPS (Trade Related Aspects of Intellectual Property) agreement, a U.S. patent was granted for 17 years following the date of issuance. In the pharma industry, an extension of a patent's term was possible under the Drug Price Competition and Patent Restoration Act of 1984 to compensate for delays in the pre-market regulatory approval process. As a result of domestic implementation of TRIPS, the U.S. patent laws have been modified to change the patent term to 20 years from the date of filing. However, because the processing of biotech patents is usually slower than that of the average patent, the 20-year period from the filing date actually shortens its effective term. In order to remedy this, the U.S. Patent and Trademark Office has been working with industry to continue to shorten the regulatory review of biotechnology patents. In addition, Congress is considering domestic amendments to the international patent regime that could add up to five years to the term where there were undue delays in the patent's issuance.

Since competition in the biotech industry is exceptionally dependent on drugs/therapeutics, diagnostics, and supporting technologies intellectual property issues have recently come to the forefront as documented by Cockburn (2000). There is a substantial increase in the number of biotechnological patents (as of 1998: close to 8000) as well as in the share of biotech patents in the total of all U.S. utility patents (as of 1998: six percent). This involves issues of the time span incurred for the examining of particular patents, which in general is considered much too long although it has come down to a mean time of about 10 months compared to over 80 months in 1975. And there is a fierce discussion about the height and breadth of biotech patents and about the length of patent protection, as well as about patentable subject matter (as far as information-dense genetic materials and in specific life forms are concerned), and about the scope of claims, their utility and unobviousness. The share of universities in biotech patents, as Cockburn points out, has risen from about three percent in 1976-78 to almost 20 percent in 1998 (see Cockburn 2000).

Germany

Research cooperation between industry and higher education has a long tradition in Germany. In 1967, about six per cent of university research was financed by private business (ISI, ifo, ZEW 2000: 3). During the late 1960s and 1970s linkages between industry and higher education experienced some decline due to an attitude among many students and faculty members that had grown hostile towards industry.

In the late 1970s efforts to bridge the gap between the academic sphere and the business world regained ground. At the time so-called technology transfer offices located on campus were seen as an appropriate means to improve the national innovation system.

These institutions designed to mobilize academic knowledge and research for the industrial innovation process increased strongly, from less than 100 at the beginning of the 1980s up to 1,038 in 1995 (ifo 1997: 107). Experts, however, agree that these efforts had only limited effects (ifo 1997: 53,60). To some degree, this is due to the fact, that „the activities of German research institutions are oriented primarily toward projects and less toward products, a situation that is unfavorable for technology transfer"(Abramson et al. 1997: 341). For this and other reasons, technology transfer institutions do not seem to have spurred significantly the innovation process of private business.

Germany's legal framework for intellectual property at universities and other public research institutions has changed little during past decades. Professors' privilege to take full advantage of their inventions had and still has countervailing consequences. On the one hand, private ownership of patents can be an incentive, if the invention is generated within the framework of existing ties to industry. In this case the patent is licensed or mostly directly transferred to the industrial partner, implying a generally moderate extra income for the professor. On the other hand, if no industrial partner is available, the professor has to pay the patent application fees which often exceed his financial means at his/her own risk and has to invest considerable time to find an appropriate industry partner to exploit the invention.

Most universities, as academic interviewees complained, do not have adequate capacities or sufficient funds for patenting, technology marketing and licensing activities. As a consequence, many inventions made at universities in Germany are not patented. Often university findings are given to industry considerably below their real market value. Generally, professors holding intellectual property lack the infrastructure to actively look for industry partners for their commercialisation. This situation may account for the fact that Germany is as good as the United States in terms of patents, but lagging in their commercialization.

This gap is one of the motivations driving current reform efforts designed to abolish the "free inventor" status of professors. In 1998 the Federal Ministry of Education and Research has also adopted new rules for intellectual property in federally sponsored research consortia. These rules have strongly improved the situation since they allow companies to retain exclusive IP if they are co-sponsoring projects.

Due to their specific mission, their fields of research and their organizational setup public research institutes vary in their ability to satisfy industry needs. Fraunhofer institutes, technical universities and technical colleges appear to be much more influenced by industry needs than universities and Max-Planck, Helmholtz and Leibnitz institutes. For the latter the science system itself is by far the most important point of reference for defining research topics, and publications in scientific journals continue to be regarded as the most important channel of knowledge dissemination and technology diffusion.

Nonetheless some researchers, in particular university researchers working on topics that are close to technology development, report that they regard knowledge transfer from industry as a very important by-product of cooperation with industry (see also ISI,

ifo, ZEW 2000: 111). In fact, there is a significant number of university institutes that have developed close relationships to industry and whose research budgets are financed by industry to 30 per cent and more (ISI, ifo, ZEW 2000: 108). In a survey conducted in 1997 university institutes reported the following average shares of research budgets financed by industry: production technology (24%), microelectronics (17%), chemistry (13%), biotechnology (12%), and software (12%). (see ISI, ifo, ZEW 2000: 106)

During the past decade universities and technical colleges have been steadily increasing their external, business-financed research budgets, up from about 153 million USD in 1987 to 334 million USD in 1997 (see TABLE 2). This expansion parallels the general trend of the business sector's increasing external R&D. The group of non-university public institutes, however, did not benefit from this shift. Their share of business's external R&D has been steadily declining.

TABLE 2 shows that public research financed by business is still rather modest compared to external R&D performed within the business sector itself. Compared to other major OECD countries, however, the proportion of business-financed R&D in the German higher education sector is rather high, reaching nearly ten per cent at the end of the 1990s (see ISI, ifo ZEW 2000: 55, 80 and OECD 2000b: 39).

Looking more closely at the information and communication technology sector, specific patterns of cooperation between industry and public research emerge. TABLE 3 compares internal and external R&D in ICT Fields to the total business sector. Whereas in 1995 the share of business research performed externally is similar to the total business sector, the ICT sector witnessed an absolute and relative decline of external research in 1997. IT hardware manufacturers, in particular, reduced both internal and external R&D strongly from 1995 to 1997. Although the magnitude of the decrease of R&D expenses is probably attributable to extraordinary factors, this development confirms many other findings indicating a weak performance of the German ICT hardware sector during the past decade.

Table 2 - Internal and External R&D of the German Business Sector, 1987-1997

| | 1987 | 1989 | 1991 | 1993 | 1995 | 1997 |
|--|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Total R&D (Mio. USD) 1987=100 | 20,86 7 100.0 | 23,56 8 112.9 | 26,38 4 126.4 | 26,22 4 125.7 | 27,10 4 129.9 | 29,51 3 141.4 |
| Internal R&D (Mio. USD) Share of Total R&D (%) 1987=100 | 19,00 9 91.1 100.0 | 21,26 4 90.2 111.9 | 23,61 0 89.5 124.2 | 22,78 6 86.9 119.9 | 24,16 3 89.2 127.1 | 25,23 1 85.5 132.7 |
| External R&D (Mio. USD) Share of Total R&D (%) 1987=100 | 1,858 8.9 100.0 | 2,304 9.8 124.0 | 2,774 10.5 149.3 | 3,438 13.1 185.0 | 2,941 10.8 158.3 | 4,282 14.4 230.5 |
| Business Sector (Mio. USD) Share of External R&D (%) 1987=100 | 1,274 68.5 100.0 | 1,513 65.6 118.8 | 1,787 64.4 140.3 | 2,292 66.7 179.9 | 1,815 61.7 142.5 | 2,788 65.1 218.9 |
| Universities / Technical Colleges (Mio. USD) Share of External R&D (%) 1987=100 | 153 8.2 100.0 | 166 7.2 108.2 | 229 8.2 149.3 | 254 7.4 166.0 | 312 10.6 203.6 | 334 7.8 218.3 |
| Other Public Institutes (Mio. USD) Share of External R&D (%) 1987=100 | 211 11.3 100.0 | 236 10.2 111.9 | 251 9.0 119.0 | 241 7.0 114.3 | 262 8.9 124.5 | 445 5.7 116.2 |
| Other Domestic External Research (Mio. USD) Share of External R&D (%) 1987=100 | 8 0.4 100.0 | 12 0.5 160.0 | 39 1.4 513.3 | 38 1.1 500.0 | 88 3.0 1173.3 | 82 1.9 1086.7 |
| External Research Abroad (Mio. USD) Share of External R&D (%) 1987=100 | 214 11.5 100.0 | 379 14.4 177.3 | 470 16.9 220.1 | 615 17.9 287.8 | 465 15.8 217.6 | 835 19.5 390.9 |

Source: ISI, ifo, ZEW 2000: 261

Table 3 - Internal and External R&D of the German Business Sector in ICT Fields, Mio. USD, 1995 and 1997

| | 1995 | | | | 1997 | | | |
|--|--------|----------|----------|----------|--------|----------|----------|--------|
| | Total | Internal | External | Ext. (%) | Total | Internal | External | Ext. % |
| Office, Accounting and Computing Machinery | 1,081 | 975 | 106 | 9,8 | 682 | 625 | 114 | 8,4 |
| Telecom, Television and Radio Equipment | 2,782 | 2,447 | 335 | 12,0 | 3,318 | 3,009 | 309 | 9,3 |
| Total Business Sector | 27,104 | 24,163 | 2,941 | 10,8 | 29,513 | 25,231 | 4,282 | 14,5 |

Source: ISI, ifo, ZEW 2000: 267

If external R&D of the ICT sector is broken down by partner institutions, non-university research institutes emerge as a very important actor. Both in the IT hardware and in the telecom, television and radio equipment subsectors, non-university public research is much more important than R&D performed by universities and technical colleges (see Table 4). Compared to the total business sector, non-university institutes perform an unusually large share of external research in the ICT sector.

Table 4 - External R&D of the German Business Sector in ICT Fields by Partner Institution, Mio. USD, 1995 and 1997

| | 1995 | | | | 1997 | | | |
|--|-----------------|----------------------------------|---------------------------|--------|-----------------|----------------------------------|---------------------------|--------|
| | Business Sector | Universities, Technical Colleges | Non-university Institutes | Abroad | Business Sector | Universities, Technical Colleges | Non-university Institutes | Abroad |
| Office, Accounting and Computing Machinery | 54 | 8 | 42 | 2 | 34 | 4 | 18 | 1 |
| Telecom, Television and Radio Equipment | 201 | 19 | 76 | 39 | 195 | 17 | 70 | 27 |
| Total Business Sector | 1,815 | 311 | 350 | 465 | 2,788 | 334 | 326 | 835 |

Source: ISI, ifo, ZEW 2000: 267

The prominence of non-university public research in the German ICT sector has been subject to political debate for some time. The principal issue has been the apparent gap between reasonably well developed capabilities of public institutes that existing firms (especially large firms) are eager to take advantage of and the weak record of starting new commercial ventures.

Taking both the Science Citation Index (SCI) and patents filed at the European Patent Office (EPA) as indicators of scientific specialization, a comprehensive study of knowledge and technology transfer shows that both telecommunications and data processing are fields that Germany has no specialization advantages in (ISI, ifo, ZEW 2000: 20ff.). Telecom specialization in particular is strongly negative. In data processing, however, there is striking difference between patents (strongly negative specialization index) and publications (only slightly negative specialization index). Apparently, Germany's weak competitive position in data processing cannot be accounted for by the level of scientific expertise. The study concludes that there is a high potential for the interaction between industry and science in the field of data processing and, similarly, in the field of optics (ISI, ifo, ZEW 2000: 23).

It has often been stated that Germany suffers from a „commercialization gap“: public research contributes too little to commercial innovations and reacts too slow to the requirements of technology transfer. This general statement seems to be true for biotechnology as well. A rapidly increasing, but still small sector of specialized biotech companies is contrasted by large-scale funding of public research. The record of the German pharmaceutical industry's external R&D also highlights the commercialization gap. As indicated by TABLE 5, the share of R&D performed by external partners is much larger in the pharmaceutical industry than in the total business sector. In 1997 pharmaceutical companies outsourced almost one third of their research and development. Apparently there are vast opportunities for public research to link up with private companies.

Table 5 - Internal and External R&D of the German Pharmaceutical Industry Compared to the Total Business Sector, in US-Dollar, 1995 and 1997

| | 1995 | | | | 1997 | | | |
|------------------------------|--------|----------|----------|--------|--------|----------|----------|--------|
| | Total | Internal | External | Ext. % | Total | Internal | External | Ext. % |
| Pharma Industry | 1.417 | 1.049 | 369 | 26,0 | 2.060 | 1.421 | 639 | 31,0 |
| Total Business Sector | 27.104 | 24.163 | 2.941 | 10,8 | 29.513 | 25.231 | 4.282 | 14,5 |

Source: ISI, ifo, ZEW 2000: 267

If the pharmaceuticals industry's external R&D is broken down by partner institutions, however, Germany's public research turns out to be of minor importance (see TABLE 6). Whereas universities and technical colleges hold shares of the pharma industry's external research which are very much in line with the entire business sector, non-university institutes have hardly acquired any research contracts from the pharma industry. Their share of pharma companies' external R&D was 2.1 percent in 1995 and 0.5 percent in 1997.

Table 6 - External R&D of the Pharma Industry by Partner Institution Compared to the Total Business Sector, in US-Dollar, 1995 and 1997

| | 1995 | | 1997 | |
|----------------------------------|-------|------------------------|-------|-------------------------|
| | USD | Percent of Extern. R&D | USD | tPercent of Extern. R&D |
| Pharma Industry | | | | |
| Business Sector | 174 | 47.3 | 430 | 67.4 |
| Universities, Technical Colleges | 37 | 10.1 | 46 | 7.2 |
| Non-University Institutes | 8 | 2.1 | 4 | 0.5 |
| Abroad | 149 | 40.5 | 159 | 24.9 |
| | | | | |
| Total Business Sector | | | | |
| Business Sector | 1.815 | 61.7 | 2.787 | 65.1 |
| Universities, Technical Colleges | 311 | 10.6 | 334 | 7.8 |
| Non-University Institutes | 350 | 11.9 | 326 | 7.6 |
| Abroad | 465 | 15.8 | 835 | 19.5 |

A second difference between the pharma industry and the business sector at large is the share of external R&D performed abroad. Considering big pharma's orientation towards research partners in the US and taking into account that Germany's biotech take-off happened only after 1995, it should not be surprising that pharma companies outsourced 40.5 percent of their total external R&D to foreign institutions and companies in 1995 whereas the respective share of the total business sector was only 15.8 percent. Two years later, however, the share of pharma R&D performed abroad had declined to 24.9 percent - still above the business sector's average of 19.5 percent, but much smaller than in 1995.

The most striking difference between those two years is the strong increase of R&D performed by German companies ("Business Sector" in TABLE 6) on behalf of the pharmaceutical industry: 430 million USD in 1997 compared to 174 million USD in 1995. This growing volume of research contracts between German firms seems to confirm that the mid-1990s have been the turning-point of commercial biotechnology in Germany.

In contrast to increasing interaction between German companies, public research has apparently remained a widely untapped resource for developing products and technologies. The misproportion between public biotech research working on a comparably high level and an underdeveloped sector of commercial biotechnology has been confirmed by a comparison of German biotech publications and German biotech patents. In contrast to publications Germany's biotech patent specialization index is strongly negative (ISI, ifo, ZEW 2000: 23). Therefore, interaction between science and industry should open up many opportunities for promising cooperative research projects.

At first glance, Germany seems to have a diversified public biotech research scene. But the impressive number of more than 500 institutions is misleading. The overwhelming majority of university institutes, for instance, is conducting research on a very small scale and is by no means comparable to biotech research conducted by many US universities. Most of the non-university institutes also have limited funds and do not seem to have a great impact on the industrial innovation process. As in other research fields, public biotech research is largely a domain of some large laboratories, receiving generous funds and establishing research relationships with "Big Pharma", but neglecting their own commercial potential.

In Germany, biotech patents are clearly dominated by large pharmaceutical companies. The public research sector, namely the Max-Planck-Society, plays only a minor role. Of course, patent statistics cannot be taken as a direct measure of research quality, since they also reflect differing attitudes and incentives towards the protection and the (potential) commercial value of research findings. Apparently, basic (often unpatented) research has remained the hallmark of Germany's large public research laboratories, whereas in the US „the emergence of a dynamic new sector based on small specialist research firms closely linked to academia has led to what can only be described as an "explosion" of the inter-related science and technology base"(Senker, Joly and Reinhard 1998: 110). Although informal networks between academic research and companies have been enlarged and strengthened in Germany as well, these interrelations are by no means comparable to the US scientific-industrial community.

Genome research and gene technology are a particular point in case. The so-called gene centers have been important as a source of qualified personnel for large companies, but did not succeed as a mediator between academic research and industry. To some degree this is certainly due to Germany's genome research lag.

Large German companies have tended to look to the US as the leading location of genome research. The German Human Genome Project began in 1995, five years after the start of the international human genome project. Besides the research lag, however, there are apparently other reasons why the gene centers did not fulfill their mediating function. For too long it was unattractive for academic scientists to secure commercial rights to their inventions and to exploit them. But the situation seems to change. Since June 1997, the German Human Genome Project is subject to a new model of technology transfer. Major elements are a patent and license office, a central data bank and clearly defined contractual relations between all participants including better conditions for start-ups.

Besides regulatory reform and support of national research projects, the federal government increased financial support for projects that promise to strengthen the commercialization of biotechnology. A large number of regional sponsorship programs is also underway. Regional coordinating centers, science and technology parks and the technology transfer organizations form an important part of the upcoming industrial-scientific network which is growing in Germany, but, compared to the US, still has a long way to go.

Prevailing Types of Collaboration

The institutional differences outlined above are reflected in our data on prevailing types of collaboration. In both countries the interviews included detailed stock-taking of individual cooperation cases under the aspects of both talent/knowledge sourcing and research cooperation.

Hiring of Graduates

In Germany the most frequent types of interaction are internships, cooperative master thesis and dissertation projects, which, from the companies' point of view, primarily serve the function of talent sourcing. In contrast to the past, companies have started to actively enlarge their contacts to academic partners in recent years, since the shortage of qualified IT and engineering personnel has become a severe limiting factor to German companies' innovation capabilities.

Thus far, human capital investment in Germany is largely firm- and industry-specific reducing employees' mobility between firms, between professions and between industries. In order to react quickly to industry's demands for more qualified personnel the Federal Government has started its much debated 'Green-Card-Initiative' in early 2000. According to new regulations up to 30,000 foreign IT specialists are eligible for work permits each limited to five years.

Unlike their competitors in many other countries German companies can rely on a diversified supply of engineering skills which includes engineers from the more theoretically and research-oriented programs offered by universities and engineers from the more practically and application-oriented technical colleges ("Fachhochschulen") who frequently have acquired hands-on skills during an industrial apprenticeship prior to enrolling in higher education. In the electrical engineering field, roughly two thirds of all new graduates belong to the second category of "applied engineers" from a technical college, whereas one third has graduated from a university.

Our interviews show that German employers appreciate the quality of graduates from both types of programs. Complaints by corporate executives about the quality of university graduates in technical fields have been rare. But interviewees have pointed to the fact that German engineering students lack entrepreneurial spirit. Commercial and economic issues receive little attention in university curricula. Specifically in universities (as opposed to the 'Fachhochschulen') technical programs appear to be strongly geared towards theoretical competences and reasoning rather than to application: a fact which has been cited as one reason for German engineers' highly deductive mind-set and specification-driven approach to real-life problems (see C*R*I*S International 1999).

Contract Research / Collaborative Research

Apart from hiring-oriented contacts the predominant channels of knowledge commercialisation in Germany are direct „contract research for industry, collaborative research with firms participating in the European programs framework; and, first of all, collaborative research with projects on behalf of the BMBF"(Abramson et al. 1997: 342). In a recent survey on "Public Private Partnership" Vogel and Stratmann confirmed that contract-based research cooperation is by far the most important channel of interaction in Germany (Vogel and Stratmann 2000: 25).

Focused contract research usually consists of industry-defined discrete, short-term projects (6-12 months) with clearly specified objectives, timelines, milestones, and deliverables. Intellectual property rests with the company. Emphasis is on applied research of the "high-risk/low budget" type. Academia is often seen as a low-cost service provider. "A typical contract between universities and industry in Germany is characterized by a limited time horizon of about two years and clearly defined - intermediate and final - deliverables. " (Schmoch 1999: 59) Publicly co-sponsored research consortia are longer-term, mostly industry-defined research collaborations uniting several academic and industry partners under the leadership of a major corporate player. Intellectual property is negotiated between partners.

In the United States there is little contract research and less collaboration overall. The most frequent form of research interaction are University - Industry Research Centers (UIRC's). These centers are usually based on university-initiated, renewable grants from one or more corporate sponsors. Compared to contract research in Germany there is much more basic research with broadly defined topics and few direct links to corporate R&D activities. Intellectual property usually rests with the university, the company having the "right of first refusal". Most UIRC's get government support and are financed by industry to about one third.

Drivers behind UIRC's are mostly university faculty members or university administrations. Mostly a group of professors, often from different neighbouring disciplines, develop a research program with a five-year time horizon and then go out to find corporate sponsors who are willing to contribute 30 percent of the cost. Most UIRC's are in the chemical / pharmaceutical as well as computer / electronic equipment industries. Advancing scientific / technological knowledge is the primary goal of UIRC's, followed by education and training, and by demonstrating the feasibility of a new technology. Transferring a particular technology to industry and/or improving industry's products and processes does not play a dominant role.

Besides UIRC's, endowment-type umbrella agreements have become a novel kind of cooperation. These agreements - sometimes aptly described as "Mega deals" - are multi-year, multi-million dollar research contracts between companies and university departments. Applied research projects are defined by university researchers and approved by joint research committees. Intellectual property usually rests with the university. The sponsoring company can negotiate exclusive licenses. Examples of "mega deals" in the U.S. are:

- **1982-2000** Hoechst - Massachusetts General Hospital (> \$100 m). Field: Molecular biology. Objective: corporate exposure and learning ("window function").
- **1992-2001** Sandoz (Novartis) - Dana Farber Cancer Institute / Harvard Medical School (\$ 100 m). Field: cancer drugs.
- **1998-2002** Rhône-Poulenc-Rorer - Stanford (\$ 10 m). Field: gene therapy.
- **1998-2002** Novartis / NADI - UC Berkeley (\$ 25 m). Field: plant & microbial biology. Objectives more closely geared to corporate R&D agenda.
- **2000-** Nanovations - M.I.T. : establishment of a \$ 90 m joint research center for research in the microphotonics area.

University Spin-offs

In the United States university spin-offs provide an outlet out of the collaboration blockage for both faculty and industry induced by issues of intellectual property: University faculty members found companies and obtain licences for using intellectual property generated in the university. Through spin-off companies, faculty can make deals with industry more freely. Companies prefer dealing with spin-offs because they can control intellectual property, sometimes by acquiring the spin-off company. Universities, in turn, support spin-off activities since, if successful, they promise future revenues while the risks are borne by founders and venture capitalists.

In Germany spin-off activities are gradually taking off in knowledge-intensive sectors (ICT and pharma / biotech). As yet there are only few restraints for university researchers on transferring knowledge generated in academia to their spin-off companies (universities are not charging royalties). In anticipation of imminent changes in universities' IP regimes, professors establish spin-off companies to be able to continue industry collaboration without IP restraints. The Max-Planck-Society and Fraunhofer institutes also have started to take stakes (shares) in spin-off companies evolving from them.

Creating ambiguity is one of the main disadvantages of spin-offs: University researchers' dual role as professors representing the university and entrepreneurs working for their own profit renders industry-science-relationships more difficult. Interviewees talk of the so-called "dual hat syndrome". The proliferating spin-off culture is in danger of skewing faculty's research orientations and basic research at the university towards commercially promising areas/topics.

Nonetheless university spin-off companies have become a powerful mechanism of knowledge transfer, specifically in the drugs and ICT industries. University spin-off companies provide a solution to the problem of bridging the gap between "solutions-in-principle" generated in academia and the "robust prototypes" needed by industry. For companies in science-intensive industries, the acquisition of spin-off companies has

become an important channel of knowledge sourcing. Major companies are complementing (partly replacing) their collaboration with academia by the systematic screening of the spin-off scene for promising acquisition candidates ("scouting").

Core Issues in Industry-Science-Relationships

The IPR deadlock

For very different reasons, one of the most controversial issues and concerns emerging from our interviews in both countries is the issue of Intellectual Property Rights, alluded to from both sides as the "sore point", the "roadblock", the "most sensitive nerve" in industry-science relationships. The IPR issue has turned out to be difficult to deal with in both countries despite the fact that Germany and the United States still have very distinct regimes governing IPR.

Germany used to have a "very comfortable situation" for companies in the past. Academic partners were not IPR-oriented, had little patenting expertise and universities were even not permitted to have licensing revenue. Professors ("free inventors") were willing to give away IPR in exchange for publication rights and consulting contracts. Only companies usually had the expertise and means to file patents.

Recently, however, IPR has become an issue. Universities are given more autonomy to explore new sources of revenue, including IPR and licensing. Political moves are intended to weaken the professors' "free inventor" status in favor of universities as their employer. Because of reduced public funding there are increasing pressures on public research institutes to raise more external funding from industry contracts. Currently, universities still have a very lax attitude towards and a lack of expertise in IPR matters. But the IPR regime governing industry-university-relations is seen as moving closer towards the U.S. model.

In IPR matters German public research institutes are facing a dilemma: They need to provide more pre-development type services for industry, involving stricter IPR claims from corporate partners and they also need to retain IPR in core areas of expertise in order to prevent a "bleeding out" and remain a partner for industry in the future. Similarly, universities face the problem of becoming a low-cost R&D provider for companies compromising their primary mission, i.e. the advancement of knowledge.

In the United States universities retain full IPR in most cases. Sponsoring companies usually have the "right of first refusal" (right to negotiate non-exclusive / exclusive licenses, sometimes with the obligation to develop a product). State laws have defined rigid IPR rules for industry-science-collaborations and prohibit universities from "selling out" their IPR to industry. The "one-size-fits-all" approach of the IPR regime, however, creates problems by ignoring differing industry conditions and needs (e.g., the pharmaceutical versus the ICT industries).

University faculty criticize the IPR regime as a "roadblock" to more collaboration. They advocate de-centralization with more discretion being given to professors. The U.S. IPR

regime has created a "schism" between industry, university faculty, and university administrations, with professors often viewing Tech Transfer Offices as their "foes" and industry viewing them as bureaucratic "obstructionists".

Only top universities are able to attract major industry funding. Several of the industry interviewees saw some universities increasingly taking too restrictive an approach to licensing and putting too high a value on their intellectual property contributions. Industry is increasingly seeking out second-tier U.S. universities and foreign universities for collaboration when they perceive first-tier universities to be too difficult to deal with. Some university boards of trustees may see technology transfer activities more as a revenue source than as a component of the university's public responsibility to assist in commercializing research results. This attitude can raise barriers to negotiations that actually reduce revenue over the long term.

Given that only a small percentage of university-generated inventions produce significant revenue, some participants likened the strong emphasis on protecting proprietary rights of some universities to "buying lottery tickets." Most of the discussion of this topic and suggestions from both industry and university participants focused on issues related to the university side of collaborations. There was also recognition, albeit with less detail and fewer examples, that the effectiveness of industry approaches also has a major impact.

Participants expressed a broad range of views on possible solutions to the IPR problem. It is important that faculty, as well as university and industry leaders understand that the role of intellectual property in the innovation process varies by field. Approaches that make sense in the biomedical field may not make sense in engineering and computer science.

Several participants suggested that universities consider forgoing all proprietary rights outside the biomedical area, essentially putting inventions in the public domain. Other participants responded that many universities do not seek patents on their inventions unless an industry licensee has been identified, and that this approach is more likely to facilitate commercialization than a blanket policy of not patenting inventions outside the life sciences.

To many participants, the main issue is whether universities manage their technology transfer roles to comply with the intent of the Bayh-Dole Act by enhancing the use of university-generated inventions. Several speakers believe that a well-run technology transfer operation governed by a realistic university policy can do this more effectively than a general policy of putting inventions in the public domain. In addition to university licensing policies, premature definition and valuation of intellectual property can become an obstacle at the initiation stage of a collaborative project. Granting the company the right of first refusal to negotiate an exclusive license is one commonly used practice to delay concrete negotiations until the commercial value of an invention is easier to assess.

In connection with intellectual property arrangements, many universities have created technology transfer offices to combine academic discovery with commercial promise.

Patent royalties are often shared with faculty. Participating companies seek different kinds of rights: first refusal to license, non-exclusive licenses, or exclusive licenses for a certain time. With respect to publishing restrictions, universities have accepted limitations on the publication of industrially sponsored research. Industry demands vary and can comprise no limits, advance notice, review and delay of up to a year.

The proper delineation of public and private interests

Because of the tighter linkage of industry and university research that has taken hold, questions are being raised regarding the proper delineation of public and private interests. To what extent have universities abandoned their goal of fostering development of human resources? At what point does the engagement of universities in short-term gain overshadow its core mission to conduct long-term research and to educate graduates who possess the breadth and depth of knowledge needed in all sectors?

The close connectedness of academic and industrial research as exemplified in the biotech and pharmaceutical industries is not without their inherent problems. First among these problems is the tradition of publishing research results of work in public research institutions and free access to the knowledge presented in such publications. However, a survey by Blumenthal and collaborators indicates that 82 percent of companies require academic researchers to keep information confidential to allow for the filing of a patent application, which typically can take two to three months or more. Almost half (47 percent) of firms report that their agreements occasionally require universities to keep results confidential even longer. The study concludes that participation with industry in the commercialization of research is "associated with both delays in publication and refusal to share research results upon request."⁸⁷

The dynamics of an internetworking knowledge universe are not without its strains on the traditional role of public-sector research as envisioned in a 1945 report by the 'founder' of the post-WWII U.S. national research enterprise, Vannevar Bush, which states that public universities "are charged with the responsibility of conserving the knowledge accumulated by the past, imparting the knowledge to students, and contributing to new knowledge of all kinds" so creating an 'intellectual commons' for society at large and obliging them to 'open science' (cited after Argyres et al. 1998: 429)⁸⁸.

As a conclusion, Argyres et al. note that the role of basic research that is awarded to research institutions such as public universities might interfere with the 'aggressive technology transfer programs' in basic research. Such programs have been pursued in

⁸⁷ Blumenthal, David et al., Withholding Research Results in Academic Life Sciences: Evidence from a National Survey of Faculty. In: *Journal of the American Medical Association*, vol. 277, April 16, 1997, p. 1224-1226. Blumenthal, David et al., Relationships between Academic Institutions and Industry in the Life Sciences: An Industry Survey. In: *New England Journal of Medicine*, vol. 334, no. 6, February 8, 1996, p. 368-373.

⁸⁸ Argyres, Nicolas and Liebeskind, Julia Porter, Privatizing the intellectual commons: Universities and the commercialization of biotechnology. In: *Journal of Economic Behavior & Organization*, vol. 35, 1998, p. 427-454.

the U.S. since the enactment, in the 1980s, of legislative reforms to favor the commercialization of basic research. This has especially benefited the emerging biotech industry. On the other hand, the authors regard this new research paradigm as a weakening of the traditional institutional mechanisms of public research.

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PART 3

POLICY CONCLUSIONS

Introduction

Drawing on the various chapters of the report and other deliverables produced in the course of the SESI project (in particular the national and sectoral reports in Work Package 6), this third and final part seeks to draw lessons and, if possible, recommendations for the policies adopted by the partners in industry-science relations.

In the first instance, the lessons and recommendations focus on the micro-economic aspects of these relations examined in the first part of the report. What forms does the coordination among the actors take? What institutional and organisational arrangements encourage effective relations? What are the consequences for each partner's internal organisations? What labour market regulations are, in principle at least, best suited to the current and future modes of these relations and will ensure that the protagonists have at their disposal the knowledge and competences they require?

The focus then switches to the institutional specificities highlighted by the analysis of innovation systems (cf. Part II of this report). The lessons and recommendations arise out of an interpretative approach to these specificities that combines three elements: the reforms implemented in recent years in the countries investigated, the trajectories followed by the various national institutional arrangements - convergence, increasing specialisation, adaptation of "traditional" characteristics" - and, finally, the development of initiatives likely to lead to the development of or to strengthen local innovation systems.

Finally, a "transatlantic comparison" of Germany and the USA provides a basis for enquiring into the major issues around intellectual property rights and, more broadly, the significance of the American experience.

Chapter 8 - Jean-Michel Plassard, Eric Verdier, Co-Ordination of actors and micro-economic incentives: high skills and knowledge transfers

Introduction : the scale and diversity of relations

The scale of the relations between scientific research and industry, and the vigour with which they have been pursued in recent years, are phenomena too significant to be regarded as merely contingent or accidental. On the contrary, they have to be viewed against the background of certain pronounced trends and developments in both the general economic and technological environment and in the processes of innovation themselves.

The structural changes that have taken place in the developed countries reflect the growing importance of the production, diffusion and application of knowledge. Science and technology are progressing ever more rapidly and the advances being made are permeating all areas of economic activity. The available statistics indicate that the structural bases of the knowledge economy are becoming increasingly significant and evident. The increasing level of investment in information and communications technologies (ICTs) as well as in intangible assets such as education, R&D and software, together with the expansion of knowledge-based industries, are important and widely acknowledged indicators of these developments.

However, these phenomena have not always evolved linearly, particularly when it comes to the overall volume of expenditure on R&D and the distribution of that expenditure between the private and public sectors. This type of variable has proved to be very sensitive to the influence of military expenditure, to attempts to stabilise budget deficits and to the general economic situation. Modes of funding are not neutral in their impact either, and they also tend to influence the direction of R&D in terms both of applied and basic research.

There are still very considerable differences between countries in respect of innovation, even though R&D and scientific research have become globalised. The findings of the SESI project, whose sphere of investigation encompasses the computer industry, telecommunications and pharmaceuticals, all of which are high-technology industries, confirm the existence of these differences in the sample of countries studied in the course of the project. The differences observed between Portugal, Austria, Germany, United Kingdom, France and the USA reveal in particular the role of national fields of specialisation, of a competitive base of national firms and of size of country (see Alcouffe, chapter 6 in this report).

It is nevertheless the case that innovation is now globalised to a much greater extent than in the past. This trend has to be viewed in the context of another recent development, namely the increasing amount of interaction between companies and the growth of network organisations, as evidenced by the expansion of foreign direct investment and the rapid proliferation of international alliances between firms (OECD 2000).

The changes are no less significant at the level of human resources, both in quantitative and qualitative terms. As measured by the flows of graduates leaving higher education systems, there has been a considerable expansion of education provision. Moreover, higher education has not developed solely by matching provision to the supply of public-sector and teaching jobs; it has also expanded in order to meet industry's demand for graduate engineers and researchers, which suggests that the various systems have in general been able to engage in a process of socialisation more in line with firms' expectations. The national reports compiled in the course of the SESI project may serve to put this statement into context in various respects by drawing attention to the possible existence of relative shortages, which are, incidentally, neither necessarily nor wholly attributable to the various national education systems (Nohara, chapter 5 in this report). It retains its validity, nevertheless, and even though there has been a certain decline in the popularity of science courses among high-school graduates, the example of France is fairly typical of the developments that have taken place over the past 15 years. In a country in which the humanities and social sciences have traditionally been very important, there has been a very real shift within the education system over that period towards science and technology (see Verdier 2001). Far upstream of the innovation process itself, this is one of the basic preconditions for a dynamic innovation system.

Moreover, it is now generally agreed that the performance of innovation systems depends more than in the past on the intensity and effectiveness of the interactions between scientific research and industry. Connections are made between this basic position and some of the key phenomena observed in innovation processes and their principal determinants.

The first of these phenomena relates to the research cycle rhythms that result from the various competitive regimes. Firms are increasingly using innovation as an instrument of competitiveness. Ever harsher competition is leading them to seek short-term competitiveness by accelerating the product development process. The shortening of technological cycles reflects a shift of emphasis in research towards a more applied approach more closely linked to corporate strategies, which brings with it a certain risk of "short-termism".

At the same time, many of the technologies that are transforming society are the result of basic scientific research. The links between innovation and the science base are closer than in the past. Particularly in key sectors such as information technologies and biotechnologies, innovation seems to be closely linked to advances in the basic sciences. These are sectors in which close links have developed between technologies, scientific publications and commercial successes.

Moreover, large-scale, complex developments linked to the expansion and application of knowledge are restructuring the space and architecture of knowledge itself. Knowledge is diversifying as a result of technological convergence at the same time as new disciplines are emerging. However, knowledge is also diversifying because the sources of knowledge are themselves becoming more diverse. Knowledge is generated by scientific research but also by clients. Thus the development of industry-science relations may be an instrument for reconciling requirements that seem, on the face of it, to be contradictory.

The scale of the links between industry and science goes hand in hand with a very considerable diversity of institutional forms and modes of coordination.

As far as the production of knowledge is concerned, the SESI research has uncovered a wide variety of mechanisms intended to establish cooperation. These mechanisms may be more or less formalised and range from joint laboratories to informal contacts within professional networks via spin-offs, the granting of licences, research contracts, researcher mobility, joint publications and specialist conferences, exhibitions, media etc.

It should be stressed that the formal mechanisms through which industry-science links are mediated constitute only the most visible and not necessarily always the most important part of these links. Many such links are mediated through informal, indirect channels.

Over and above their specific characteristics related to sector, size and national origin, virtually all the firms in the SESI sample take the view that the production of a flow of graduates channelled towards industry constitutes a particularly important, if not decisive, medium for science-industry links. The reasons generally adduced are already familiar. For firms, the principal objective is to have better access to better educated human resources. They also expect to gain access to new scientific knowledge, to established networks and to problem-solving capabilities. Thus the production of a flow of graduates must be understood in both quantitative and qualitative terms. In the latter respect, firms are seeking in particular to influence the contents of courses and training programmes, thereby giving themselves an opportunity to make their views heard in the debates that shape the construction of competences and knowledge.

Conversely, these collaborations can give higher education establishments an opportunity to facilitate their students' entry into the world of work and improve their job opportunities, to update their training programmes and to obtain financial support with a view to producing innovations. These links also raise their profile in the continuing education/training market, both for specific, short-term programmes aimed at company employees but also for longer-term arrangements in a context in which education and training over the life cycle is becoming a strategic issue.

The diversity of institutional and organisational arrangements makes it necessary to adopt a twofold approach, one that is both analytical and normative.

On the one hand, we need to investigate, from a positive perspective, the reasons that have prompted the actors to choose certain types of arrangements rather than others. The aim here will be to re-examine the actors' plans and objectives as responses to the challenges posed by the current environment or the changes that have taken place. On the other hand, this diversity can be given a more normative interpretation, in which the central issue at stake is the problem of efficient relations. These two perspectives come together fairly rapidly once the approach is located within the framework of a broadly based rationality and a concept of efficiency that revolves principally around the notion of congruity with the firm's environment.

However, the approach does not in any sense subscribe to the notion of "one first best way". The aim rather is to discuss and reveal the various possibilities for conflict resolution in terms of their advantages and disadvantages. In a context characterised by pronounced heterogeneities, joint actions must take account of diversity in order to determine what constitutes "good practice" and the measures best suited to the various institutional and organisational frameworks.

On the micro-economic or micro-social level, any analysis of cooperation between actors now begins with an investigation of the organisational principles at work. From this perspective, it is well known that problems of coordination and incentive occupy a central position.

The particular nature of the two actors involved in the relationship, who have their origins in two different worlds, naturally leads us to enquire into the organisational and institutional modalities through which effective collaborations can be mediated (1).

It also encourages us to investigate each partner's internal organisation and the possible reorganisations or restructurings that might facilitate appropriation of the results of the collaboration (2).

Finally, given that the key issue at stake in the relationship is the production of knowledge, it is advisable to tackle the question of whether the two actors succeed, through a process involving the co-production of competences and knowledge, in developing a joint response, which may involve the establishment of a high-level occupational market (3).

The organisational and institutional factors encouraging efficient collaboration

The multiplicity of apparently pertinent situations observed makes it virtually impossible to identify one single, simple form of efficient collaboration between partners. In fact, the determinants of a good relationship between industry and scientific research are to be found in various spheres and tend to take a variety of different forms. They include rules, incentives and the definition of property rights, as well as the hybrid or interface organisations.

A number of lessons can be learnt from the examples of successes and failures recorded in the case studies produced during the various phases of the SESI project. These lessons are located at the following three strategic levels:

- . that of the factors of risk and uncertainty,
- . that of the processes whereby interests converge and, finally,
- . that of the interfacing institutions, agencies and "bodies".

The hazards of innovation and of science-industry relations

Risk, uncertainty and the behaviour of the actors involved in innovation

It will come as no surprise to learn that risk or uncertainty is one of the elements shaping the actors' behaviour and decision-making.

By its very nature, innovation is a particularly risky investment activity. The time taken to produce a result, and hence the cost of obtaining that result, is uncertain. In addition to the technical uncertainty, the outcomes are also subject to the vagaries of the market, because of the behaviour of both consumers and competitors (Guellec and Van Pottelsberghe 2000).

In addition to the factors linked to demand and to the technology, two further factors make research a riskier activity than many others. The profits structure in innovative markets is asymmetrical, with high profits for the winners and considerable losses for the others. The literature on the rush to patent is based largely on the notion of a treasure hunt in which the winner takes all. Investment in research is largely irreversible. The specific nature of a research project's interim findings is linked to the fact that a large part of the knowledge accumulated by that stage is tacit and therefore non-transferable in the short term, which deprives it of any market value.

Thus cooperation between firms and higher education takes place in a context in which firms are seeking to minimise costs and diversify risks. At the same time, the specific forms of cooperation reflect judgments based on an assessment of the nature of the risks and uncertainty inherent in the relationship between partners from two different worlds.

The dominant approach to risk in the literature takes the firm as its initial reference point. The approach adopted in the SESI project, which puts the production of knowledge firmly in the spotlight, has proved to be more balanced. The firm is still a key actor, but account is also taken of the other partner and, in particular, of the risk that universities run in tailoring their research agenda to the specific needs of companies, thereby reducing the 'public good' element of their output, particularly if firms' needs are driven by short-term considerations.

Thus it seems particularly important to give equal weight to the two protagonists, their objectives and their behaviour in formulating policies and recommendations. This is the price that has to be paid in order to avoid the use of tools that cannot realistically contribute to a process of social optimisation.

Given these differences in objectives and behaviour, it is readily understandable that any collaborative venture between industry and higher education will pose particularly difficult challenges.

Greater involvement by firms in public research gives rise to costs and the possible loss of positive externalities for society as a whole. For example, if the norms of private appropriation replace the norm of total disclosure currently in force in open science, then the diffusion of knowledge may be slowed down as a result. Similarly, applied research may be privileged to the detriment of basic science, which may in the long term lead to a decline in social well-being.

This has implications for the criteria used to draw up regulations. The general regulations must take account of the interests of all the actors in the cooperative process. Policies must be targeted principally at supporting or achieving compromises.

Just like firms, universities are confronted with contradictory constraints to which they have to respond by reaching the most satisfactory compromise possible in the light of the human and financial resources at their disposal and the legal and regulatory frameworks within which they operate. Their principal concern here is to develop policies and procedures that allow them to avoid both the risk of subjugation to the needs of firms and that of becoming completely disconnected from social demand and the productive system.

Economic challenges, externalisation and the search for partnerships

From the point of view of firms and their expectations of what can be realistically achieved in the area of knowledge production, the importance and growth of science-industry links can be measured by the yardstick of the technical and organisational changes that have affected the manufacturing sector in particular. The rapidity of technical change, combined with the dismantling of the barriers to international trade, has helped to create new organisational and strategic opportunities.

The development of links with higher education is one consequence of the new strategic choices firms are making.

The economic environment tends to exacerbate the tensions between objectives attuned to different time horizons. Firms are constantly faced with the task of reconciling the need to balance income and expenditure over the short term with the long-term demands of forging their core competence on the basis of sustained competitiveness. Walking this tightrope is becoming increasingly difficult because of the importance of R&D work in the new technologies, which requires the investment of increasingly large sums of money.

Faced with rising costs and ever greater uncertainty as to the results of research, firms are seeking to share these risks and costs by forging alliances and networks or through externalisation. At global level in particular, strategic alliances of various types, particularly those intended to share the costs and risks of R&D in the field of

electronics, have become more crucial. The rise to prominence of such alliances has blurred firms' organisational boundaries and increased the need for coordination between market and non-market organisations. Cooperation between firms and higher education is part of this trend. However, the dynamic of cooperation also has to be viewed against the background of the budgetary restrictions that public research establishments and universities are increasingly facing; as a result of these constraints, they are being forced to seek other partners in order to diversify their portfolio of funding sources.

The shortening of technological cycles and new strategies in respect of knowledge

Recent years have seen a heightening of the challenges and points of tension as well as an increase in the opportunities for cooperation.

Thus technological cycles in leading-edge sectors have tended to become shorter because of the pressure of competition. As a result of this shift, which tends to favour short-term activities and which is further exacerbated by the application of more rigorous standards of corporate governance, firms have been forced to cut R&D costs while at the same time seeking rapid access to new knowledge. Higher education may well be the new source of knowledge firms require for their innovation activities.

This shortening of research cycles reflects an approach to research that is more directly linked to corporate strategies. The risk inherent in this approach is that too much emphasis will be placed on shortening R&D and product cycles, which might in turn lead to underinvestment in generic technologies and undermine the future prospects for technological progress and innovation.

However, the pace of technological progress has quickened and the market has developed in areas in which innovation is based directly on scientific activity, which increases the demand for links with the science base. Because of the long gestation periods, the high costs and the technical and financial uncertainty that go hand in hand with radical innovations, firms have entered into cooperation with each other and into partnerships with scientific institutions in a bid to reduce the costs and risks of innovation.

Similarly, the increasing diversity of the knowledge that has to be acquired is forcing firms into operating within networks and externalising certain functions in order to mitigate the technical and commercial risks. As competition and globalisation have intensified, the range of sources of new technologies and of innovative concepts has widened considerably, to the point where most firms are no longer able directly to control this diversity of knowledge.

The ranges of technologies required for innovation have also expanded as technological advances have pushed ever closer to the limits of scientific knowledge; moreover, each individual technology has become more complex because of the increasingly diverse knowledge on which it is based. Thus firms are no longer in a position to cover the whole range of useful scientific disciplines as some were able to do in the past.

Furthermore, monitoring other firms across the entire globe and in different markets seems to be a crucial factor in identifying sources of knowledge of relevance to firms' innovation drives.

Ensuring the convergence of interests

All cooperation presupposes the existence of institutional structures that favour the convergence of objectives or requires the creation of ad hoc institutions, both for organisational purposes and in order to provide common points of reference for the actions of the various protagonists. From this point of view, the studies of national innovation systems generally indicate the existence at regional or national level of jointly agreed arrangements specific to the organisations in question that aim to reduce cognitive gaps or adjustment costs in order to facilitate closer links between HERS and firms. The system of intellectual property rights, in all its various forms (duration, scope, conditions for the granting of rights, etc.), is not a neutral factor in this process of convergence.

The initial challenge : the cognitive and cultural "gaps" between "science" and "industry"

The literature provides many opportunities to identify the disparities between the two worlds of scientific research and industry, whose members pursue very different objectives, are motivated by very different forms of incentive and are subject to very different evaluation procedures.

In some cases, these two worlds that produce and utilise knowledge are even depicted as being governed by antinomic sets of rules (the "republic of sciences" and "the kingdom of technology"). The objective then becomes one of reducing or managing these differences by establishing rules intended to close the gap between the two worlds while at the same ensuring that this reduction of disparities does not diminish the mutual gains derived from collaboration, thereby seriously undermining the aims of the exercise.

However, differences in the actors' initial endowments in terms of knowledge levels can play a not insignificant role. Introducing the notion of the relationship between or the proximity of the actors' various spheres of research competences makes it possible to identify any horizontal cognitive gaps that might exist between the partners⁸⁹. Too great a horizontal gap undoubtedly increases transaction and coordination costs and thereby reduces the incentive to cooperate.

The simple notion of complementarity suggests that the vertical cognitive gaps⁹⁰ between the two partners should not be so great as to inhibit the development of the kind of synergies and problems likely to play a part in making significant advances. The notion of "gap" can be extended beyond the cognitive dimension to encompass more cultural aspects as well. The cognitive and cultural gaps between the two systems may

⁸⁹ The horizontal gap denotes the specialisation of the agents in particular fields.

⁹⁰ The vertical gap denotes the agents' levels of advancement within a single field.

be traceable back upstream to the output of the training and education system. The gaps may depend on the technological regimes and the various models of science-industry relations. Although a quantitatively and qualitatively adequate output from the higher education system is required in all cases, such an output is not a wholly sufficient condition, particularly in a system in which economic and technological competition is truly global. In this regard, the national systems still seem to be very different : the various national reports compiled in the course of the SESI project revealed the extent of the cognitive technical gap (with Portugal being the emblematic case) and certain heterogeneities with regard to social gaps, which are closely linked to the specificities of the various "national models", and in particular to the configuration of the engineering and research professions in each country (Nohara, chapter 5 in this report). It is very difficult, therefore, to draw any systematic lessons for firms, apart from the need to incorporate these particularities into their management processes.

It should be noted in this connection that the duality of the French higher education system is not without its consequences either. Thus the engineering school system provides a generic resource capable, by virtue of their dual training (and this applies particularly to engineers with PhDs), of positioning itself in both the academic world and in industry. On the other hand, there may be a cultural and cognitive gap between the teams working for the industrial partner, which are made up of graduates from the *Grandes écoles*, and the academic researchers, who tend to be graduates of the university system and have very academic CVs.

Two models of industry-science linkages

On the basis of the data gathered by the SESI teams, various "topological" divides were formed and used as a basis for putting together significant groupings. Several models of matches between the interests of the different actors coexist, each type having its advantages and disadvantages.

The complementarity of the actors' activities, both of whom are rooted in the production of knowledge, emerges as an important factor in securing relations between firms and universities. Nevertheless, it is still necessary to go beyond the tensions and to manage the risks, both of which arise out of the differences in the actors' agendas.

Nothing is being said at this stage about the mobilisation of human resources and the transfers of competences and knowledge through the flow of graduates from the university system to industry. They are the object of a separate study (see section 3 below).

The diversity of industry-science relations suggests typologies reflecting the actors' various strategic choices in respect of risk management. From a dynamic perspective, two polar models (Carayol, chapter 3 in this report) seem to emerge, in which the overall strategies of the academic and industrial actors tend to come together to produce a response to technological risk that is underpinned by a coherent set of functional and specialised principles.

In the first model, firms benefit from research at a relatively low cost and in an integrated and systematic way, while the academic partner's main concern is to maximise the volume of research. The latter pools information on firms' needs and codifies their technical problems in order to provide standard scientific responses. There is a relatively low level of technical risk here, and the commercial risk is mitigated by a close-knit collaborative network. This is a generalised version of Kline and Rosenberg's chain-link model or interactive chain-link model (Kline and Rosenberg 1986), in which the technology is no longer appropriated autonomously by the firm's research laboratory.

In terms of the practicalities of cooperation, the rules whereby cooperation is managed must enable the partners to face and respond effectively to the classic problems of balancing risks and incentives. To this end, the research establishment or university involved can help to spread the risk by adopting a form of contract that combines fixed payments with deferred payments that are dependent on the returns to the knowledge produced in the course of the collaboration.

In the second model, the academic partner's research agenda remains in place, the aim here being to advance knowledge in a clearly defined field of scientific excellence. As far as the industrial partner is concerned, the objective is to tackle a promising area of research in order to open up a significant lead over rivals. The much greater level of technical risk is mitigated by a "self-protective" approach, which reduces the probability of failure by making academic excellence the principal criterion for choosing academic partners.

This tendency towards bipolarisation among higher education establishments on the basis of their functional specialisation - with the leading establishments seeking to become major players in the "knowledge market" and the less prestigious ones providing support for firms and undertaking contract research, is not, however, inevitable or necessarily desirable.

It is encouraged by a system of financing that gives rise to intense competition for core funding, as the British case demonstrates (see Lam and Nicolaides, 2001).

However, the principle of risk diversification would suggest that several types of cooperation are possible, or even desirable. In order to diversify their portfolios of risk activities, companies' departmental managers can make use of the two polar forms of cooperation, since each model of industry-science relations has different advantages for firms. Public research institutions can also seek to diversify their activities by allocating their human resources to the various parts of their research programme. An excessively short-term approach can turn out to be disadvantageous in the longer term, since a research institute's applied research has to draw on a stock of more basic knowledge. Hybrid needs must be supported by hybrid solutions and pose the problem of the joint construction of occupational identities capable of sustaining these processes of cooperation (see 3 below).

A similar kind of problem, but related this time to firms' decisions as to whether or not to enter into collaboration with local university research institutes, also tends to make

itself felt particularly acutely. Increased globalisation brings with it greater opportunities for choice; nevertheless, changes in firms' strategies and choices that make academic excellence the sole criterion at the expense of the local dimension can give rise to unrecoverable costs, since past investments might well have served not only to establish lasting and productive relations but also to reduce the cognitive gaps between the partners.

However, it should be added that local centres of industry-science collaboration are all the more likely to develop or survive in the new global context if they have a significant competence base (that is an adequate range of disciplines and education and training provision and an innovative base alert to firms' needs and capable of reacting to them) and an adequate knowledge base (that is a potential panel of service providers open to both basic and applied research). The examples drawn from the case studies of multinational companies operating in France clearly reveal the importance of the transparency and complementarity of the diversified supplies of competences and knowledge that have been constructed in the various technological districts, such as Grenoble and Toulouse (Nohara and Verdier 2001). It is the role of the public authorities to put in place programmes that encourage the development of long-term synergies, thereby ensuring that these various types of knowledge and expertise are combined. Such programmes should both foster the formation of endogenous technological development capabilities and make the local area attractive to R&D investment by outside firms.

The issue of intellectual property rights

Intellectual property rights (IPR) are another important issue. The problem is made particularly complex by the instability of regimes over time and from one institution to another, even within the same national system. IPRs have led to significant changes and disruptions in the choices made by the various actors, particularly those between short and long-term considerations. On this latter point, it is clear from the surveys conducted in the course of the SESI project that this question of IPRs is one of the most contentious issues - given the extreme diversity of national rules in this area, this is a somewhat paradoxical finding.

The bipolar schema outlined above may shed some light on the choice of IPR regime. In the first model, the academic partner, whose primary concern is to increase the volume of research, is less preoccupied by the intellectual property rights relating to collaborative research, whereas the industrial partner is more concerned to retain ownership of knowledge that is fairly close to being developed. The lower level of technical risk makes it easier to enshrine in specified contracts commitments by means of which the problems of risk and incentive can be settled relatively effectively. On the other hand, too high a level of uncertainty - particularly one that is difficult to measure - may make it more difficult to draw up and specify contracts and brings the question of property rights into the spotlight.

However, there are other considerations to be taken into account as well, since giving priority to the academic partner is likely to give rise to patterns of management behaviour similar to those adopted by the private investor, i.e. ones that go beyond the mere use of royalties. This brings us to the question of academic entrepreneurship.

As far as this form of entrepreneurship is concerned, it might legitimately be asked whether certain incentive structures have not gone too far and threaten to undermine the production of generic competences and knowledge. From this point of view, the positive effects achieved in the short term may be merely illusory and the system would not be protected from a reversal of the trend in the longer term.

While most of the intellectual property rights regimes in force have their own particular advantages and disadvantages, the existence of a diversified assignment system within a single country depending on the nature of the research establishments involved is more puzzling. This merely increases complexity in an area that is already quite complex enough and may well damage both industry-science relations and cooperation among public research institutes. The lack of clarity and the transaction costs incurred by firms, particularly SMEs, engaged in cooperative ventures may well lead to a reduction in the commercialisation of research. More generally, it is likely that harmonisation at the European level would be an effective way of limiting opportunistic behaviour (on these issues, see Buechtemann and Thie, chapter 7 in part II).

Institutions, agencies and interface bodies

A distinction needs to be made between the actors involved in collaborations and the underlying institutional principles. Moreover, both have to be apprehended from a dynamic perspective : an interface actor's position can change considerably in a short space of time.

Taking account of the institutional diversity of industry-science relations

Examination of the relations between higher education and industry reveals that the types of relations are very diverse and that a large number of actors is involved. In this intense relational "magma", the informal aspects and individual relations prove to be of considerable significance. From the point of view of the actual actors involved, however, relations between the two worlds - in terms of the production of both knowledge and competences - are mediated through two main channels.

Individuals and social networks constitute the first vector, now well established, for industry-science relations. The doctoral student whose thesis is being jointly supervised or the post-doc researching a topic of mutual interest are the bridges and gateways through which knowledge flows between the two worlds. The informal networks that develop around lecturers and former students, those that develop around former researchers and their old research institute and the members of the business associations represented on department or university boards are some of the channels for the

exchange of knowledge between industry and public research. The new information and communications technologies cannot but strengthen the role of these social networks in industry-science relations.

The explicit organisational structures that constitute the second vector for industry-science relations also take a great variety of forms. They may be consortia of private and public partners, joint research units set up for a period of several years, joint laboratories "without walls" in which the links between public and private researchers are institutionalised, a joint technological "platform" supported by several university laboratories, etc. Spin-offs take several forms : i) firms founded by public-sector researchers, ii) start-ups that have licensed public-sector technologies and iii) firms in which a public institution has taken an equity stake or which have been set up by a public research institution. Spin-offs are the channel through which knowledge produced by public research is commercialised. Although the system is developing, it nevertheless remains small in quantitative terms.

The principles underlying industry-science linkages : the relative value of intermediate actors

The animating principles underlying industry-science links are diverse and increasingly targeted at specific objectives.

Usually, and particularly when they are perceived as strategic, the relations tend to be institutionalised in forms that reflect the underlying functional principles (Lanciano-Morandat, chapter 4 in this report).

The "portfolio management" principle leads the partners to look for a relatively simple organisational design in order to coordinate essentially bilateral relations between independent organisations. A high level of flexibility produces considerable capacities for adaptation, the task of coordination being entrusted to "gatekeepers", which makes it possible to absorb risk by confining it to the boundaries of each organisation.

The principle of "embedding" industry-science relations in the two partners' organisational and management structures has the effect of fostering the establishment of various hybrid entities, such as mixed research units, outline agreements, independent entities, joint platforms, consortia involving firms and higher education systems and conglomerates. This type of relation tends to minimise the tensions between the two worlds and gives rise to irreversibilities that impair each partner's ability to cause or initiate movement.

A third animating principle involves the use of an already constituted intermediate actor to fill the gap in knowledge levels and fields of specialisation that may separate the partners. It may lead ultimately to the creation of a hybrid collective actor or of an institutionalised collective actor independent of the partners. The fact of having an intermediate organisation subject to its own rule and value system leads to the externalisation of the risk inherent in the science-industry link. It is far from immune

from the possibility of failure, particularly because of excessively wide cognitive gaps and/or disparate animating principles.

These gaps, and the ensuing adjustment costs, can be reduced by exploiting the opportunities that exist for establishing "bridges" between the two worlds and by mobility of personnel. Such mobility helps to activate and strengthen complementarities between the actors and to diffuse knowledge and is an important channel for technology transfers. Thus the hybrid actors, the so-called "gatekeepers", facilitate the coordination of relations and the management of possible horizontal cognitive gaps by establishing continuity between the various forms of knowledge produced by the partners.

Challenges for the partners' internal organisational structures

Cooperation cannot in itself provide solutions to the various challenges faced by each of the categories of partners (firms and higher education institutions) unless the form it takes coheres with the partners' internal organisational choices. If there is a number of challenges specific to the different actors, effective joint responses are possible.

For firms, the main objective is to resolve the problems posed by the transition from knowledge to competences, whereas for the university involved, the major challenge revolves around the emergence of new disciplines and academic entrepreneurship.

The internal challenge for firms

From knowledge to competences

The conceptualisation of innovation processes in conjunction with the specific characteristics of the firms that implement them has evolved considerably over the last 30 years. The linear model led naturally to a concern with the factors determining firms' investment in R&D but did not reveal all the specificities. After all, investment in R&D produces learning in support of innovation (Cohen, Levinthal, 1989). This is a highly specific form of investment in the knowledge that firms can possess, acquire and produce, and it is one of the factors that serves to differentiate firms on the basis of their capacities for learning.

Account also has to be taken of the technological knowledge that firms derive from their environment. The notion of absorption capacity (Cohen, Levinthal 1990) can usefully be applied to the innovation process, since it suggests, on the one hand, that firms combine the knowledge they derive from their external environment with their own internal stock of knowledge and, on the other, that the knowledge that firms are able to assimilate from the external environment turns out in fact to be heavily constrained by their previously accumulated stock of knowledge.

Similarly, the complexity of the process frequently turns out to be better captured by explicit models with more than one principal line of action leading from invention to

market. In this respect, Kline and Rosenberg's chain-link model (Kline and Rosenberg 1986) may prove to be more realistic and relevant, in the sense that it acknowledges the multi-dimensional nature of the innovation process and of the numerous links and feedback processes between the various phases of product development and the sources of knowledge outside the firm. It also has the merit of drawing attention to a strengthening of the links with commercial activities. The twofold approach to analysis of the innovation process that focuses on both technical and commercial success is reinforced by the development of networking, cooperative ventures and alliances.

Innovation comprises, on the one hand, a process whereby externally derived generic knowledge is transformed into specific knowledge through the development cycles initiated by firms and, on the other, a process in which various resources are deployed in order to coordinate this locally produced knowledge. Certain modes of internal organisation tend to foster the development of absorption capacities as well as the ability profitably to manage knowledge derived from an increasingly diverse range of sources, including spin-offs, public research teams and firms' technological partners. At this stage, our analysis will focus solely on large multinational companies and will exclude small firms.

Internal organisation and project-based management

Project-based management is a form of organisation used by many of the large companies in the SESI sample and is intended to stimulate cooperation between the various occupational groups. This form of management leads firms to take on board the views of outside agents - those of industrial and academic partners and of management supervisors. Thus project-based management is a means of drawing together resources produced by scientific and technical partners, both inside and outside the firm; in this sense, it is a mode of organisation that goes beyond the boundaries of the individual firm.

In the case of Pharma 1 (see Paraponaris, chapter 2 in this report), each project has a *project leader* responsible for the scientific aspects and a *project manager* in charge of the operational aspects. In this way, the configuration of the two worlds is reproduced but within a unified whole.

Project-based management emerges, de facto, as an instrument for mastering diversity, since it fosters convergence. Thus a tool originally designed as an internal management instrument can become an effective form of interface organisation.

From the organisational point of view, network-type structures can be used to eliminate the divide between central laboratories and business units.

In recent years, there has been a general trend within large companies towards the transfer of corporate labs to the various business units. This is one important indicator of the emergence of a market-driven approach, with firms seeking to convert the fruits of research as effectively and efficiently as possible into successful products. At the

same time, this trend towards decentralised development has come up against problems of size, such as difficulties in coordination and inadequacies in the accumulation of knowledge that have weakened the knowledge dynamic.

The establishment of network-type organisational structures seems to be an effective compromise between the decentralisation and centralisation of research. This new way of operating makes it possible to decouple short and medium-term activities from long-term activities and falls within the scope of the third generation model of R&D (Reger and von Wickert 2000). Networks represent a viable compromise between centralisation and decentralisation, which itself encourages the development of local initiatives in respect of industry-science links.

The configuration, implementation and management of R&D activities: the need for specific competences

Individual competences are required to manage networks and the diversity of knowledge and sources of knowledge. Acquiring and maintaining these competences poses the problem of how they should be managed.

a) A firm must have in its workforce individuals with the 'absorptive' capacities and architectural competences required to act as 'gatekeepers'.

With regard to the changes taking place in R&D systems, there is a growing need for people with specialist skills in internal and external coordination and the transfer of knowledge across functional and organisational boundaries. An aptitude for collaboration and negotiation with external agents and for exploiting externally derived knowledge must be part of R&D workers' competence profiles. From this point of view, technical competences are of course required, but the full range of skills needed extends beyond them to encompass managerial and social competences.

In general terms, the competences required of R&D workers in leading-edge industries can be said to fall within the scope of the categories of competences identified by Lundvall and Johnson (1994):

- know what (substantive knowledge)
- know why (understanding of basic principles)
- know how (skills and competences necessary to act intelligently)
- know who (social capability to cooperate, to communicate and establish trust relationships).

In the new context that is emerging, the *know why* dimension may take precedence over the *know what* dimension because of the rapid obsolescence caused by technological change, with the last two dimensions playing an increasingly strategic role as "mode 2 knowledge" in Gibbons' sense of the term (Lam, chapter 1 in this report) establishes itself.

b) The extension and modification of the range of individual competences cannot but have an effect on the various modes of human resource management. The very notion of "management mode" suggests a cohesive system of more or less formalised practices in matters of pay, training and mobility, the effectiveness of which lies in their being used in conjunction with each other rather than in isolation (Holmstrom, Milgrom, 1994).

The management of research staff poses specific problems which are far from being always satisfactorily resolved. From the positive point view, this difficulty exists because approaches to the management of R&D personnel seem little different in practice from the general models of personnel management adopted by firms. Nevertheless, recent years have seen the emergence of a trend, driven by the globalisation of R&D, towards the development of dedicated human resource departments for R&D personnel. Particularly within the corporate labs, a process of homogenisation is under way with the aim of eliminating the pay gaps between subsidiaries in order to establish pay equity within companies and to make available tools for evaluating individual competences. In this respect, the management of competences becomes a crucial aspect of HRM, particularly through the generalised use of competence management tools (regularly updated charts of the competences of R&D personnel, periodic assessments of individual competences by means of formalised evaluation procedures).

These management tools constitute instruments that can be used to promote internal flexibility, with the evolution of job contents being regarded as a substitute for the generally very low levels of mobility among engineers, who find it easier than other scientific personnel to transfer to other functions within the firm. The use by ICT3's human resources department (see Paraponaris, chapter 2 in this report) of an expert system based on competence mapping for the management of competences and careers is a tool used for the dual purpose of managing the internal market and managing knowledge.

It should also be noted that research personnel are beginning to be distinguished from employees in other functions in terms not only of pay but also of career development (innovation bonuses, dual career ladder) (Lanciano-Morandat and Nohara, 2001).

c) As a general rule, recent developments tend to foreground the central issue of adapting a mode of management to its new context. It is known, for example (Caroli, 2000), that the construction of a firm's competence base can take place at two very different levels. It may be left to individuals or it may be the responsibility of the group, that is of the organisation as a whole. A firm's choices when it comes to internal or external flexibility are dependent on this knowledge base.

The highly tacit nature of the knowledge base (Lam, 2000) encourages internal flexibility, while external flexibility seems to be linked to the diffusion of new information and communication technologies. Whether innovations are incremental or radical also affects the choice of model, and judgements have to be made. In some cases, the existing stock of competences may not be suited to the adoption of far-reaching innovations, because of the risk of devaluing the firm's knowledge base and because of the existence of rigidities caused by lengthy careers. A similar phenomenon

became apparent as hardware companies were transforming themselves into IT service providers. Thus one of the telecommunications companies studied has been unable rapidly, in a context of very rapid internal change, to construct a base of operational competences (Lam, chapter 1 in this report and Verdier 2001).

Radical new technologies are not usually introduced by firms already operating in the industry in question, while most incremental innovations are introduced by already established firms (Henderson, 1993). Internal flexibility and incremental innovation are not necessarily contradictory. However, the management of long-term careers should not be regarded as a matter of concern for the R&D department alone.

Internal mobility flows between R&D departments and business units, and vice versa, and external mobility involving other constituent parts of the networks can make a useful contribution to the development of innovation processes, in that they can be a means of testing all the links and loops of the process.

All firms are experiencing difficulties in recruiting sufficient numbers of adequately skilled workers. The quantity problem may well be exacerbated in future by demographic developments, by the age pyramid in private and public-sector companies and by global scientific competition. It is further aggravated by the relatively low elasticity of the supply of scientific personnel.

The quality problem, and that of the extension of the range of competences required, will undoubtedly be resolved in part by a strengthening of the links with higher education. As Paraponaris (Chapter 2 in this report) suggests, firms collaborate with higher education in the first instance in order to recruit. In this respect, a client market is undoubtedly a more effective means of controlling quality than an anonymous market, even one controlled by signals, since it offers opportunities for testing candidates (through work placements, for example) and intervening upstream of the recruitment process itself in the production of education and training.

Taken as a whole, however, the complex judgements that have to be made require more general arrangements, such as the construction of a high-level occupational market (see section 3 below).

The internal challenge for academic organisations : new disciplines and the entrepreneurial university

Encouraging the emergence of new disciplines

The challenges posed by interdisciplinary education and research have undoubtedly become greater, for both the public and private sectors, even though curricula and education/training systems can be slow to adjust, particularly at PhD level, where programmes are still very specialised.

Nevertheless, this is a phenomenon that varies from country to country and from institution to institution, and in general education systems are proving to be considerably more sensitive than in the past to changes in economic demand. Nevertheless, it still has to find a guarantor within a sufficiently flexible university system.

Moreover, scientific progress has made knowledge in any given field more specialised (Nohara, chapter 5 in this report) and increased the need constantly to recombine these highly specialised areas of knowledge (see the examples of molecular chemistry and biochemistry). Indeed, new fields of knowledge are emerging at the point of overlap between different disciplines. Thus policies on education and the organisation of higher education have constantly to strike a balance between specialisation and the promotion of interdisciplinarity.

The ways in which ICTs have been diffused and applied in new fields of research illustrate these processes, which may be crucial to the production of new knowledge and its subsequent commercialisation. Bio-informatics is a good example in this regard : the increase in computers' processing power has made it possible to substitute digital modelling for instrumental analysis ; it suggests that researchers specialising in the biotechnologies will have to demonstrate increasing levels of competence in IT and expertise in the use of the corresponding computer tools in order to be able fully to exploit the available resources within their original area of specialisation (Nohara, *ibid.*).

If it is further assumed that non-technical competences are playing an increasingly significant role, PhD programmes, or at least an increasing proportion of them, will have to be expanded in order to facilitate the construction of the social and managerial competences required for integration into complex multi-disciplinary and multi-functional networks.

In general terms, it would certainly seem the right time to try to increase the reactivity of higher education institutions with regard to the development of new disciplines. Moreover, the various kinds of university and research establishments are not necessarily starting from the same point in this respect. Comparison of the *Fachhochschulen* in Germany (and now in Austria) and of the engineering schools in France, on the one hand, with conventional universities, on the other, would suggest that the former are much more likely than the latter to engage in this recombination of knowledge, which may eventually lead to the emergence of new disciplines. More generally, given their more flexible modes of governance and organisational structures more attuned to the demands of business and industry than the regular universities, these more specialist institutions seem to be able to react more quickly to these challenges than conventional, generalist universities.

Nevertheless, safeguards are necessary, even though they will necessarily have some rough edges because of the multitude of contradictory issues at stake. A system that tends to emphasise cost control logically restricts the preposterous demands that can be made but may unduly delay the emergence of new courses because of the corporatism of the established disciplines. This situation can prove to be particularly detrimental

when the phenomenon itself emerges in a context in which the traditional discipline is being eroded. This creates problems downstream for both basic research and firms when it comes to the selection of students, since formal qualifications no longer provide adequate signals as to the quality of candidates.

A regular audit of the relevance of university organisation might provide a minimum level of assurance in order to avert difficulties of this type, provided it is based on an accurate forecast of likely labour market opportunities and is carried out by an outside expert. Such an audit in no way reduced the need for an *ex post* evaluation of university systems.

Academic entrepreneurship - scope and limits

Teaching and research no longer adequately summarise the totality of a university's basic functions. The debates around the notion of the "service university" emphasises the diversity of functions undertaken by universities as a result of new circumstances and the internal and external consequences of these changes for institutions of higher education.

The notion of the entrepreneurial university has the merit of encompassing additional functions related to economic and social development and of being more explicitly aligned with the SESI project's sphere of investigation (Etzkowitz, 1998). However, there is no need to go as far as advocating changes to the current norms (as triple helix theorists do) to recognise that the changes in industry-science relations have given rise to a need for organisational change and for the introduction of incentive structures in order to take account of the new conditions under which knowledge is produced and to manage the transformation of that knowledge into effective economic activities (patents and spin-offs).

How can these activities be organised in order to reduce the conflicts of interest surrounding the income from IPRs? It is obvious that technology transfer and collaboration in research are heavily dependent on the regulations governing intellectual property rights. For universities and public research institutions, these rights are the main incentive they have to exploit research and knowledge with a view to producing innovation. National legislation differs considerably in this respect. It is undoubtedly the United States which, in passing the Bayh-Dole Act, has adopted the regime best suited to the changing requirements of public-private cooperation.

Intellectual property rights regimes are not neutral. The granting of property rights to establishments rather than to individual researchers tends to encourage non-exclusive licences. Public research institutions are inclined to favour non-exclusive licences since they ensure a wider diffusion of knowledge and broaden the sources of royalty revenues. Moreover, they do not entail any restrictions on the freedom to publish. On the other hand, problems of "exclusivity" arise in sectors where product development is very capital-intensive and lengthy. As a result, a balance has to be struck between the "open science" model and commercial risk. The granting of an exclusive licence for a

clearly defined period may in this case be an honourable compromise; the example of biotechnologies and the therapies derived from them is revealing in this respect. For all that, rigid rules governing the granting of licences might well produce perverse effects. They do not obviate the need to examine situations on a case-by-case basis. This "customised" mode of management means it is all the more important to make the appropriate choices when it comes to organising the commercialisation of research.

Indeed, it is important for research organisations to develop a policy on the commercialisation of their patents. They have two options. A company can be founded specifically for the purpose of commercialising research or a specialist department can be set up within the university. In the first case, the company set up to approach entrepreneurs may help universities, including the less well-known ones, systematically to develop their portfolios of "available" inventions. Nevertheless, a critical mass of patents is necessary for such a company to be viable. In the second case, a specialist technology transfer department located in publicly funded research organisations and universities may well help to reduce overheads and to ensure close links between commercialisation and basic research, with the latter having everything to gain by getting to grips with the problems identified by "users" of its results. However, there is a risk that on-site agencies may focus on existing relations with private partners rather than encouraging the establishment of new industry-science links and thereby encouraging more "radical" and profitable innovations, even though the risks incurred may be greater.

Another solution is to encourage the emergence of start-ups. Various forms of equity investments by universities in these start-ups are currently being discussed. Thus some universities are choosing to acquire holdings in the newly set-up companies in exchange for granting patent rights. In this way, universities can encourage commercial start-ups without incurring any additional costs in commercialising its research while at the same time having a stake in the results. Such arrangements can help to avoid any possible conflict between commercialisation and research. That said, however, setting up a number of companies can tie up funds that could otherwise be devoted to basic research and force the university to act as a shareholder, which is not necessarily within its province.

Responsibility for technology transfer and licensing could also be assigned to a public or private intermediary acting on behalf of those universities that do not have the critical mass (inadequate competence and customer base). This will often require public support. Another issue is the distance of such intermediaries from research institutions, which may limit their role in making researchers aware of the potential for commercialisation. To this end, specialist agencies can be set up to provide assistance, albeit at the risk of making the organisation of the commercialisation process excessively complicated. In any event, it is important to raise awareness among the various protagonists in industry-science relations of the competences of the various organisations involved in technology transfer, whatever their institutional positioning, and to evaluate their effectiveness on a very regular basis. It is important to prevent the imperatives of internal management taking precedence over the need for appropriate science-industry interactions around the commercialisation of basic research. One of the main criteria in this evaluation must

relate to the extent to which SMEs have access to the industry-science links engendered by these commercialisation processes.

In terms of governance, the establishment of entrepreneurial activities requires both the ability to devise a strategy for clearly identifying the principal functions and objectives of commercialisation and considerable development of the procedures for evaluating the organisations engaged in basic research. Greater autonomy for universities, a more competitive, performance-related system of funding and an increased role for universities in the commercialisation of publicly funded research are generally positive factors in industry-science cooperation, but on condition that these changes are accompanied by a strengthening of the mechanisms for evaluating publicly funded research.

Evaluation mechanisms must change for two reasons (OECD 2000, p. 205-205). Firstly, evaluation must be based on a sufficiently open concept of a researcher's activities that takes account not only of excellence in research but also of the quality of his or her activities in the training of graduates that help to encourage the application in industry of the results of academic research. Secondly, in the case of "applied research", it is necessary, when evaluating research for the purpose of obtaining core funding, to combine the traditional criteria with the ability to obtain funding from industry. Finally, the organisation of basic research must balance incentives for commercialisation and support for longer-term research in order to avoid an excessively entrepreneurial bias in basic research.

Towards an Occupational Labour Market at PhD level: a network of Innovation Communities ?

Processes of innovation are constantly being generated as stronger links between universities and firms are developing via contracts, joint research organizations, technology and knowledge transfer institutions and interfaces of all kinds.

These re-invented connections between academia and firms reflect a growing awareness that fundamental scientific knowledge is necessary to the production of innovation. Industrial firms and higher educational establishments are therefore becoming increasingly involved not only in the production of innovation itself, but also at a more upstream level, in defining the fundamental knowledge and skills which the actors of innovation need to possess.

The advent of these changes has not been entirely devoid of friction. Whether the processes of innovation are science based or market driven, they have to generate shorter technological cycles while mobilising highly specialised knowledge, which means that firms have had to greatly increase their capacity to absorb knowledge inputs. The need to combine flexibility with the long-term learning process is already giving rise to transformations which are tending to break down the barriers between firms and universities.

The innovators are therefore making tentative, sometimes rather haphazard efforts to invent new modes of co-ordination at both the conceptual and institutional levels in response to these new challenges.

Here we would like to suggest that these inventions show some of the characteristics of what has been classically described as the occupational labour market (OLM) in the literature. In view of the fragility of these institutional and conceptual (v. ante) constructs, it is surely worth enlisting some public, or at least collective support for these promising initiatives.

Occupational labour markets (see Eyraud, Marsden, Silvestre, 1990) are based on institutions which restrict the scope for opportunistic games and set qualitative training and competence standards in order to ensure that a suitable supply of human capital is available and ready to move from one employer to another at the lowest possible cost. The main advantage of a market of this kind is that it favours compromises between what the organisations require (people with the appropriate levels of skill who are also capable of flexibility) and individual interests (keeping some measure of professional independence while procuring some security). Apprenticeship training is the ideal mode for setting up the basic vocational skills which are necessary for a market of this kind to function properly. It requires a spirit of co-operation, or at least of compromise, between the various protagonists, i.e., between firms, young trainees, staff representatives and vocational training institutions. Germany is obviously the most outstanding example of a country where an institutional network of this kind has been set up, in the case of intermediate qualifications, i.e., those involving qualified workers and employees⁹¹.

Occupational labour markets, which can be said to resemble common goods or public goods, are a vulnerable form of regulation which can be destabilised at any moment by "poachers" from outside (Marsden, 1989). In the case of the high-skills market it is intended to set up here, this vulnerability will be all the greater, *a priori*, as the possibility of creating and running the market smoothly depends on interfaces and compromises between the profit-making and non profit-making organisations consisting of firms and universities: the former bodies involve private wage relations, and the latter, statutory conditions which are based to a variable extent on national regulations, depending on the country in question.

⁹¹ The following principles are recalled in connection with occupational labour markets (OLMs):

1. qualifications are transferable (they are either certified by diplomas or recognised via a process of peer assessment, based on the reputation of the diplomas), which leads to large workforce movements on local markets. This is where local innovation and research networks start up.
2. The following conditions must be fulfilled for qualifications to be transferable:
 - the content of jobs must be sufficiently standardised to ensure that new recruits are integrated at the least possible cost. At organisations which have adopted management by project methods, this process of integration occurs more smoothly;
 - there must be a sufficiently large supply of workers with certified qualifications available on the market: this is vital in the case of highly qualified candidates.

On OLMs, competence is associated with persons. Salaries depend on the recognition of this competence. The certification of vocational training which occurs on OLMs requires the participation of the trades associations and professional organisations in the creation of certificates and the regulation of workforce flows, and they must recognise the certification procedure.

This does not mean that vocational training should be rigidly organised, which would be in contradiction with the goals adopted.

Despite these potential difficulties, we would like to suggest that institutional developments of this kind are actually the fruit of spontaneous decisions made by those responsible for innovation. There is therefore no question of advocating strategies based on public interventions which do not spring directly from the ideas of those most closely involved in creating innovations. This would amount to imposing standards, which would be bound to have mainly unexpected, if not to say frankly undesirable effects.

Detecting embryonic OLMs at the PhD level

This re-thinking of the links between universities and firms is generating changes of two main kinds, which are liable to provide an institutional framework for creating occupational labour markets at the PhD level with:

- conceptual changes: the co-production of knowledge and skills
- organisational changes: creating networks between private and/or public protagonists.

However, these emerging modes have serious limitations which mean that the protagonists, especially recent PhD graduates and firms, are faced with some insecurity which can detract from their efficiency.

The co-production of competences and new occupations

The constitution of this common space is being accompanied by changes in the occupations involved and in the competences they require (see Nohara, Chapter 5 of the present report).

It emerges from what has been said above that the "new" occupational skills required in R&D departments tend to be based on the ability, at both the individual and collective levels, to combine academic knowledge with operational and applied skills so as to produce people who are able to both set and solve the problems which arise when customers' requirements have to be fulfilled and when dealing at a more general level with the other partners involved in the process of innovation.

Whatever the spheres from which they originate (university or firms), individuals are being increasingly expected to position themselves at the interfaces between disciplines and to respond to the conceptual needs which arise in the context of project-based management. This approach involves integrating objectives which seem to be contradictory *a priori* (organising project monitoring with short term perspectives *versus* producing basic knowledge).

From this point of view, some social skills have become increasingly valuable: "This means that the ability of R&D workers to collaborate and negotiate with external agents and to exploit external knowledge is becoming a necessary part of their competence

profiles. "Networking skills" and ability to "access and understand a much bigger data base" were frequently mentioned by many of the managers as something they look for amongst their R&D staff" (A. Lam, chapter 1 of this report). Now it is difficult to acquire skills of this kind while following a purely academic curriculum; they require familiarity with the way businesses are organised, and company culture of this kind can best be acquired via alternance training or during regular periods of placement or internship.

At a more general level, at the firms where surveys were carried out by our teams in the framework of the present SESI project (especially in the computer engineering and telecommunications sector), employers were found to be increasingly reluctant to engage young graduates who have not acquired a minimum amount of professional experience, at least in the form of short periods of placement. "The placement period also allows the company to have a long period of screening and probation. It serves both the training and recruitment functions. It amounts to a kind of "informal apprenticeship" which gives the companies an opportunity to instil the specific competence and tacit knowledge for the type of work for which they are recruiting" (Lam, *ibid.*).

The stakes involved are all the higher since there has been a sharp increase in the proportions of doctoral graduates joining firms in all the countries under consideration, including even those such as France, where the cleavage between academic training and industry has always been particularly pronounced. At the present time, nearly one third of all doctoral graduates join the private sector, and this proportion is as high as 80 % in the case of those whose doctoral theses have been financed jointly by industry and the system of higher education and research. These jointly sponsored doctorates are of course less numerous than those of the purely academic kind, but they are becoming much more frequent in all the countries of interest here (Lanciano-Morandat, Nohara, 2001). These institutional formulae are necessarily based on the building of new relations between firms and universities, and the latter are therefore now tending to include the financing of doctoral training projects among the terms of their co-operative contracts.

Local networks providing knowledge and skills

In response to these challenges, there has been a strong tendency for R&D networks (see Lundvall and Borrás, 1997)⁹² to develop which span the two spheres. These networks take various forms, which sometimes at least partly overlap:

- Technological partnerships between firms with a view to forming "pre-competitive" alliances on matters relating to research.
- Consortia formed between research groups from the public and private sectors for the purpose of defining and solving key problems in the field of industrial research and conducting applied research on specific topics.

⁹² "In relation to this phenomenon, a large variety of public programmes to support these networks have been launched in the last decades with the purpose to stimulate interactive learning through enhancing the linkages between firms and between firms and the R&D infrastructure" (chapter 7 "Creating networks and stimulating interactive learning", 73).

- Technological districts based on networks formed between public and private research groups, SMEs and large firms, which focus on creating new activities in specific technological fields.

Firms and academic research units are therefore using network contacts to recruit doctoral graduates and to guide them during their training so as to ensure that they have the appropriate scientific knowledge, and are thus co-producing the new competences required for R&D activities to be able to develop on new lines (de Lassale, Maillard, Martinelli, Paul et Perret, Document Céreq, 1999).

Social relationships of this kind, which are often rooted in the fabric of local social networks, do not serve only to facilitate the training of young doctoral graduates and their subsequent integration into firms. They also enable firms to take part in shaping the training courses for future research scientists and engineers, at both the PhD and post-doc levels: "By becoming a trusted partner in the academic community, companies are not only in a better position to catch the best students early but also have an opportunity to influence the education and training of the graduates and future researchers. Activities such as giving seminars at universities and supervising student projects are often used to cement relationships with particular institutions and raise the industrial awareness of students" (Lam, *ibid.*).

However, the stability of these relationships and their ultimate efficiency at the output end depend strongly on the quality of the co-operative links forged, which depends in turn on whether there is a spirit of mutual trust between the partners. Now the lack of certainty which surrounds innovative processes and the way high tech markets operate, whether one is looking at products or competences, tend to put a strain on this trusting relationship and force the partners into adopting more opportunistic strategies.

Precarious relations fraught with uncertainty :

The uncertainties of various kinds to which employment relations are subject make it difficult to achieve a delicate balance between the wage-earners' expectations and the flexibility sought by the firms.

Consequently, "a fundamental dilemma facing many firms is the growing difficulty in attracting and retaining the best researchers, many of whom are reluctant to pursue a career in an industrial environment where firms can no longer provide stable research careers. Firms will have to devise new strategies to tackle the problem of 'intellectual resource immobility'" (Lam, *ibid.*).

The wide statutory gap which has been deliberately maintained in many countries between universities and firms, especially in countries such as France, where most research scientists have civil servant status, has restricted the opportunities for moving from the one sphere to the other. Although a move has been taking place for a long time in some disciplines, such as chemistry, to promote the co-production of knowledge and skills and to encourage mixed careers between the public and private sectors, the labour market for scientists is still basically "split up between two distinct entries, the one

leading to industrial careers (in the private sector) and the other to academic careers (in the public sector), with little real mobility going on between the two" (Lanciano-Morandat, Nohara, *ibid.*). In addition, the instability of the high tech industries, especially during the emergence phase, does not make it easy to reach the firm compromise between flexibility and co-operation on which the regulation of occupational labour markets is based.

In addition, the doubts companies may have as to what abilities and skills specialists with a purely academic background may have (see Lam, *op.cit.*) may lead both firms and universities to over-develop temporary forms of employment for young scientists to such an extent that they are prevented from putting the capital of knowledge they have acquired to good use. "Between firms and higher education and research units, completely precarious forms of employment and extremely short-term contracts are emerging. In France, the public sector is tending to use non-binding contracts which are renewable on a month-to-month basis and the private sector is also (ok using short-term contracts which are valid for periods of less than 3 months as a means of having the work of technicians carried out (much more cheaply) by students. This enables those who join the "open external market" to complement their meagre grants (which have not kept up with the cost of living) and thus to earn their living during their studies (...). [What is more,] post-doc contracts are now becoming common practice. As a result, industrial managers benefit from a highly qualified workforce...without having to make any commitments" (Lanciano-Morandat, Nohara, *ibid.*). As we can see, it is no longer an occupational market but a secondary labour market which seems likely to become the main stage on which the conditions of employment of highly qualified R&D workers will henceforth be negotiated.

From the structural point of view, however, the fact that "knowledge moves too fast in high technology activities to be codified into institutionalised occupations or professions, and the same would be true of the media industries" (Marsden, 2000) argues against the idea that an occupational labour market (OLM) is likely to develop at PhD level. The ways in which individual competences are conventionally signalled on OLMs will therefore no longer be relevant, especially as "Codification is too slow a process for the transmission of rapidly evolving tacit knowledge" (Lam, *ibid.*). Now, as mentioned above, one of the conditions on which the stability of an OLM depends is that there must be some standardisation of occupational functions. In this case, when there is no efficient system of institutional regulation, there is bound to be a tendency for competences to be internalised, and hence there will be less scope for mobility, as Osterman (1984) has pointed out in the case of computer engineers. Might there exist, then, a viable alternative space somewhere in between the competitive mechanisms at work on a secondary labour market for young graduates and the internalising forces which tend to absorb new competences to the advantage of large firms and to the detriment of SMEs, although the latter contribute such a vital contribution to the dynamics of innovation?

Conditions for establishing an OLM at PhD level: a draft project

In the professional space where links between high technology firms and universities are forged, some contradictory tendencies are therefore at work. On the one hand, structural mutations of a conceptual and organisational nature seem to be working towards the creation of an OLM, and on the other hand, the instability which is persisting and possibly even increasing seems to run counter to this possibility.

The stakes are non negligible. It is a question of finding a practicable alternative to the following two scenarios :

- a high level of compartmentation (and hence a wide skills gap) between firms and universities, although this is no longer consistent with the fact that increasing proportions of all the research graduates (Masters and PhD graduates) leaving higher educational establishments will inevitably become employed by firms, whereas these numbers used to be low or extremely low, especially in the Continental European countries, apart from the fields of engineering and chemistry.
- the emergence of a market for doctoral students and graduates where the only regulatory mechanism at work is the insecurity resulting from competition, which leads to increasingly stringent requirements, due in particular to the prospective employers' lack of information. This situation is resulting in precarious conditions of employment, in the form of short term post-doc contracts which are not in the least favourable to the development and full professional deployment of individuals' intellectual capital. In addition, this step-by-step method of enrolment may well turn out to be relatively expensive and anti-productive for firms in the long run.

In the latter scenario, the savings made by firms in terms of wages will depend strongly on the rate of influx occurring on this particular segment of the labour market. In the United States, for example, in addition to the influx of post-doc graduates from other countries who are attracted by the prospect of undergoing state-of-the-art training in biotechnology, this segment shows considerable mobility at various levels. It seems to constitute a new kind of academic-cum-industrial space where highly qualified young scientists on extremely flexible contracts are able to migrate between research programmes, temporary industrial and academic posts and biotechnology start-ups. In the USA, this method of regulating the labour market for post-doc graduates is based on a permanent flow of young doctoral graduates from other countries. Europe is hardly likely to be able to drain outside resources on this scale, In European countries, a mobile pattern of this kind would therefore probably collapse within a very short time without reaching an equilibrium. But in Europe, opportunism works in favour of the large companies, since the medium and small-sized ones often have difficulty in gaining access to the competences provided by those with doctoral degrees. In Europe, the main channel of opportunist behaviour is always the local system of market regulation.

The OLM space at PhD level: local institutions have priority

It is something of a paradox that in this era of globalisation, an occupational market for people with the highest qualifications should take root in local spaces. As suggested above, an OLM for PhD graduates, viewed as an alternative to a purely competitive system of regulation, is unlikely to succeed in being established in the framework of a top- down organisational approach, via a set of centralised public measures. It is necessary, on the contrary, for the process of institutionalisation to take place on very similar decentralised lines to those sketched out by the protagonists of innovation. This is why it seems appropriate to speak about occupational labour markets (in the plural) rooted in the local innovation communities.

In this connection, many studies have focused on the importance of a community-based occupational labour market as a means of providing the social infrastructure and the institutional framework required to be able to create and sustain the high-skills sector (Lam, *ibid.*). The case of Silicon Valley, which has been analysed by Saxenian (1994), is an outstanding example of local high technology structures based on personal networks set up "by occupational or industrial affiliation" (Marsden 2000).

However, structures of this kind based on local networks and having links with innovation would be all the more powerful if they had national backing in the form of incentives to encourage local actors to promote the local exploitation of resources. This has actually occurred in France in the case of the CIFRE programme and in Britain, in that of the CASE⁹³ and PTPS programmes (see Alice Lam, Chapter 1 of the present report).

The existence of national programmes can provide more than simply a financial and procedural basis, but can also favour the forging of links between the various occupational markets located in specific technological districts and milieus, in each of which the universities, hybrid and interface organisations and firms, especially SME, are involved. The example of the internet shows how it is possible for national schemes and "globalised" partners such as the subsidiaries of multinational firms to promote connections between the various localised OLMs and to stimulate the circulation of some of the human resources. Although the subsidiaries of multinational firms may have sprung from "a local atmosphere", they can subsequently advertise the knowledge and skills formed at the local engineering college by making them known throughout the world-wide space occupied by the firm

These possibilities for broadening their horizons do not mean that markets of this kind have no limitations, however. It is true that many highly qualified jobs - both purely academic positions and those which come under the heading of "classical" internal labour markets - will continue to escape regulatory systems of this kind. This applies particularly in the case of all the jobs which belong to the context resulting from the

⁹³ Like the CIFRE programme in France, the CASE programme is used to employ doctoral students, whose research projects are then directed jointly by university lecturers and industrial managers (for further details, see Alice Lam, Chapter 1 of the present report).

interplay between various links and interfaces which mediates the process of innovation, as we have seen throughout this report.

The organisation and regulation of OLMs for PhD graduates

Educational backgrounds contribute importantly to sustaining the processes involved in mobility, which in turn favour the constitution of the common professional codes) without which no creative social networks can emerge: "The experience of Silicon Valley suggests that the social solidarity which grows out of shared professional experiences and common educational backgrounds is an important precondition for flexible economic relations, and that such trust in turn is best sustained through the constant interaction allowed by geographic proximity" (Saxenian, 1994).

Generally speaking, the quality of the competences and qualifications produced by universities involved in local innovation networks is one of the raw materials of which OLMs of this kind and their regulatory mechanisms are made: as Marsden (2000) has put it, "the university's reputation too provides a form of quality control at least in terms of the workers' capabilities if not over their output. Thus, systems of boundaryless careers contain mechanisms analogous to those of occupational markets in many respects, and although less codified than those of blue collar crafts and established white collar professions, they are dependent upon institutional structures to cope with the many problems of opportunism that would otherwise beset them" (see Saxenian, 1996).

Based on the information collected at many of the firms studied in the SESI project, it seems likely that far from simply producing a flow of graduates which the firms absorb depending on their needs, the universities will play a decisive role in regulating high-level occupational labour markets. With their various councils, the universities can provide a space for discussing what sets of competences should be developed in the various curricula subscribing to the process of innovation, and these interactions can help to overcome the uncertainties which result from the speed at which information and know-how are developing in the high technology fields. The joint supervision of doctoral theses by academic and industrial partners is one of the ways in which knowledge can be regularly updated, and another way consists of organising regular periods of internship as part of university curricula. Exchanges of this kind may thus come to replace one of the basic ingredients of occupational markets, i.e., the high level of occupational standardisation which is necessary for mobility to be possible. Standardisation is in fact very difficult to achieve when knowledge is constantly expanding, as it is in the high technology sector.

Furthermore, the constant updating of curricular contents - which contributes to reducing what have been referred to as "vertical cognitive gaps" (cf. Carayol, chapter 3 in the present report) - in which public and private partners are jointly engaged on the PhD-level OLMs is consistent with the management by projects approach, which is becoming the standard form of co-ordination both inside firms and between firms and the outside world (Paraponaris, Chapter 2). One might even go so far as to say that this mode of management, which is being increasingly applied in co-operative projects

between firms and universities, is contributing to produce exactly the standard organisational framework which is a prerequisite for competences to be able to circulate freely on the market, and which makes for greater flexibility at the boundaries between various careers and functions (cf. "the systems of boundaryless careers" described by Marsden).

Lastly, the studies carried out by the participants in the SESI project have shown that specific modes of management and pay are gradually developing in the field of R&D in the form of stock options or employees' savings plans, which to some extent counterbalance the risks to which workers in this branch of the high tech sector are exposed as the result of the high rate of professional mobility.

All in all, these various proposals are in line with some of the objectives of the Extended Internal Labour Markets (EILMs) defined by Alice Lam: "The build up of social networks through EILMs serves three important functions: a) as a recruitment channel; b) as an informal "apprenticeship" system; and c) as a mechanism for sustaining boundary-spanning knowledge networks"⁹⁴

Conclusion

In the field of research and innovation, the development of occupational markets is bound to mainly involve specific experiments - particularly at the local level - and the specific application of national standards and incentives.

The advantages which firms, especially very small ones, stand to gain from occupational markets are well known: they enable small-scale employers to have easier access to a suitably trained workforce. This should therefore make it possible to prevent the imbalance which sometimes occurs on many local highly qualified labour markets, which benefit large firms to the detriment of small ones (cf. the example of Siemens' Vienna branch faced with a shortage of IT engineers, quoted in Mayer 2001). Once again, occupational markets can be seen to potentially provide a protective mechanism against the opportunism of the protagonists who presumably occupy the most favourable position on the labour market.

By promoting the circulation of knowledge which has been jointly recognised and codified, these markets help to reduce the previous conceptual gaps and to promote the creation of greater absorptive capacities at firms, as well as sustaining the spirit of mutual trust and reciprocity in which these networks were founded.

From the individual point of view, doctoral candidates stand to obtain the following advantages:

. highly specialised technical know-how;

⁹⁴ Manwaring, who was the first to argue in favour of EILMs, stated that their emergence depends on social networks in local communities. Here we have preferred to talk about occupational rather than internal markets, so as to stress the transversal nature of mobility between occupational functions, which reflects the flexibility of the networks underlying local occupational labour markets.

. and the social skills which can be acquired via exposure to the complex multi-disciplinary and multi-functional patterns of organisation generated by the management by projects approach. These patterns of organisation tend increasingly to involve partnerships between public and private instances and lead enable their participants to join local innovation networks.

By alternating research work at firms and advanced pluridisciplinary training, we have created a learning process which is reminiscent, at a much higher level, of the well-known method of apprenticeship used in the German trades and occupations ("Ausbildungsberuf")⁹⁵. There are other points in common with the German system of occupational markets, since the latter are based on a fundamental component which is also at the basis of the regulatory system underlying OLMs at the PhD level: the reputation of the qualifications acquired both at educational establishments and with firms⁹⁶.

The institutional links involved are forged at several levels:

- the setting of curricula: firms and universities at the national or regional level must be able to have a say in the content (here there is a risk that the definition of the basic competences in question might become too restricted or too highly specified)⁹⁷;
- financing doctoral training (mainly during the preparation of their thesis), possibly in the form of an ad hoc work contract (cf. the example of CIFRE grants in France);
- organising curricula (periods of internship in a cross-functional perspective);
- joint recognition of the validity of the knowledge and skills acquired by candidates, resulting in certification. The status of this certification will depend strongly on the reputations of the two protagonists responsible;
- a compulsory levy, or preferably, incentive measures.

The principle of alternance training is therefore present at two basic levels in the innovative system of vocational training we have described here:

⁹⁵ The concept of a job which provides training ("Ausbildungsberuf") differs fundamentally from that of training on the job. A job which provides training does not consist simply of repeating isolated tasks until one has mastered them completely. It focuses rather on teaching young people to perform a whole coherent set of occupational activities so that they learn an overall approach and gain understanding of a whole industrial context. According to this concept, the qualifications and competences acquired during vocational training of this kind equip the candidates to carry out jobs of various kinds.

Qualifications can therefore be defined as follows:

- the ability to handle new work situations.

⁹⁶ "One important feature of the German apprenticeship system has been the way firms' reputation for training helps maintain both the quantity and quality of training places. The peer pressures of the chambers of industry and commerce may well function because they provide strong social networks among employers along which reputation for good or bad behaviour may pass, and which help to certify it because one knows the source from which it comes" (Marsden, 2000).

⁹⁷ The fact that the most general rules and regulations can integrate the specific features of individual contexts of application in their underlying principle is a decisive factor in creating an institutional process that thus escapes being a constraint (which often becomes inoperative). Genuine commitments can be made, in particular, because each actor involved can give a meaning to this "common law" that accords with his respective approaches.

- it combines two complementary components: general and specific training (codified / tacit knowledge) ;
 - it involves a relevant matching process between the youngster and the firm.
- This process is assessed at two levels, in terms of the certification to which it leads and in terms of the reputation of the course (especially as regards the training dispensed by the university in partnership with firms).

There exist two main institutional modes liable to mediate the emergence of labour markets of this kind:

- the main mode is the "Bottom Up" mode, which starts with local structures consisting of innovation networks and competences. This requires the existence of some fairly formally structured spaces for discussing possible responses to the challenge in terms of competences, curricula and certification.
- the second mode is a "Top Down " process whereby local OLMs are provided with financial resources as part of national incentive schemes such as the CASE programme in the United Kingdom and the CIFRE programme in France.

These forms of institutionalisation will naturally each have their own historical background and therefore take various forms, depending on the specificities of the national and local contexts.

Local occupational markets of the kind we have been talking about will obviously be most unlikely to spring up if the penury or at least the shortage of suitable competences and qualifications is too great: the baseline output of scientific qualifications must be sufficiently high, otherwise opportunism is bound to gain the upper hand, unless there is a permanent influx of graduates from other places, as in the case of the American model.

From this point of view, the existence of links between the local and national public instances is of vital importance.

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Chapter 9 - Eric Verdier, "National Public Policies : Challenges for effective Knowledge and Competence Transfers in the high tech Industries"

In the previous chapter, it was attempted to describe the characteristics of a general model for the relations between firms and academia which might serve to improve the efficiency of the exchanges between these institutions. The aim of this model, which was mainly based on the results of the monographs drawn up on individual firms in the framework of the present project, was to identify goals and modes of action. What should the priorities be for the public policy-makers responsible for building and circulating knowledge (tacit and codified, as well as generic and applied knowledge) and the competences and skills embodied in persons.

On the whole, this approach is in line with the triple helix model (Etzkowitz 2000) for the interactions between science/industry/public authorities. In addition to being extremely general, one of the great advantages the latter approach is that it gives the public authorities a leading role in the relations between Science and Industry in terms of both the analyses and the standards they are required to produce. Public incitements are bound to influence the decisions and attitudes of individual actors in one way or another, and can have either positive or negative effects from the point of view of economic and social welfare.

Looking at the problem in question in terms of the production of standards and analyses seems to be a promising approach, all the more so as the Triple Helix model was not designed just to analyse the interactions between the three categories of protagonists. It also takes into consideration the internal transformations which each of the protagonists undergoes as the result of their relations being redefined. Here there is a shift of emphasis towards the increasing tendency for overlaps to occur between the three types of partner, and more importantly, for hybrid structures to emerge, as exemplified by the "entrepreneurial universities", which are having direct effects at the regional and local levels. Three-part initiatives classically involve agreements which can take various institutional forms, but which in addition, tend to generate common structures, such as the spin-offs which are frequently being given as an example these days (see Chapter 4 by Caroline Lanciano-Morandat in the present report).

Apart from these general considerations, it is proposed to deal in the present chapter with the institutional specificities of the countries studied, with a view to drawing up some recommendations without losing sight of the specific national contexts. These recommendations are mainly based on the monographs in which firms were re-analysed with a view to drawing some initial conclusions which might be of use to public

authorities. Taking as a starting-point the idea that relations between firms and universities are rooted in configurations of actors and the rules of the game, many of which are dictated by the given national context, it is proposed to deal with each country separately in turn. This does not mean that the effects of globalisation and/or Europeanisation (see Chapter 6 of the present report by Alain Alcouffe) are held to be negligible or secondary. The contrary is the case, since our country-by-country approach also makes it necessary to look at the overall tendencies from three different angles.

- To what extent are the overall policy statements, such as those produced by the OECD (OECD 2000) in the form of regular recommendations strongly inspired by the American model, adopted and implemented in the various countries?
- How do public and private actors adapt their national systems of innovation to converge with other countries, or on the contrary, to accentuate the differences?
- Is the national level still that to which the coherence of the systems of innovation is built first and foremost?

It is not within the scope of this chapter on recommendations to public actors to attempt to answer these three questions in detail. For a closer analysis, readers are referred to the reports, especially the national ones (WP6), in which all these aspects have been covered⁹⁸. Here the same national reports will be used as a basis to define possible orientations and suggestions for public policy-makers, focusing in particular on the high tech, ICT and pharmaceutical sectors (in the latter case, especially as far as biotechnology issues are concerned).

In the case of each country, our analysis will therefore focus on the combined effects of the three-fold instances mentioned above :

- What lessons can be learned from the reforms introduced during the last few years with a view to making the relations between Science and Industry and R&D policies in general more efficient? To determine what the general sources of inspiration have been, it is worth consulting the recommendations on

⁹⁸ CRIS International, 2001, Biotechnology : Industry-Science Relationships in Germany, WP 2.2., SESI PROJECT CONTRACT N° SOE1 - CT97-1054 Project n° 1297.

CRIS International, 2001, Information and Communication Technology: Industry-Science Relationships in Germany, WP 2.2., SESI PROJECT CONTRACT N° SOE1 - CT97-1054 Project n° 1297.

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We used here many sentences and analysis of these different national reports. But The author of this chapter is responsible for the proposals and recommendations and of course for any misunderstanding.

research, development and technology (RDT) policies made by the OECD. These recommendations recently served as a reference frame for adopting the reforms recommended by the OECD experts (OECD 2000) in the various countries. They can be summarized as follows:



Source: OECD, 2000

- the modes and possibilities for developing the national institutional framework . These are "path dependent ". Casper (1999) has suggested that there exist three basic scenarios which can be used to interpret patterns of institutional reform:

. a process of *convergence* towards an American oriented Framework, which means making radical structural transformations in R&D policies of the European mainland countries such as Germany and France;

. a process of *specialisation*, which means reinforcing the specific national frameworks and approaches to the globalisation of Research, Development and Technology;

. a process of *adjustment* of the present institutional frameworks in France and Germany, for example, to make room for at least minimal forms of entrepreneurial science-based innovation without undermining the country's particular achievements in the field of Innovation.

- the development of infra-national initiatives liable to yield increasingly diverse sets of local innovations and relationships between Science and Industry in particular. The national institutional frameworks should not indeed be viewed simply as constraints weighing on the decisions of the micro-economic actors, but rather as examples of decisions in which such and such an economic or technological factor was given priority. The National Institutional Framework can influence these strategies by determining the relative cost of building the organisational competences they require; for example "a company management faced with international competition can survey the spectrum of possible organisational arrangements prevalent within their [national] industry, and attempt to shape a coherent strategy" (Casper, *ibid*, 6). Public policies may influence the conclusions of this "survey", and hence the choice of strategy made by the firms and individuals, but only within certain limits.

This non-deterministic approach, which nevertheless takes the path determinants (dependency) into account, is all the more useful as the dynamism of innovation systems is resulting increasingly from the emergence of innovation networks within which tacit forms of knowledge are circulating, and which involve various institutional arrangements, from clusters of technological districts to more widespread innovative milieus (cf. the previous chapter). This is in fact what public policy-makers have been striving to achieve by encouraging local initiatives on these lines (Lundvall and Borras, 1997).

Based on the systems of classification proposed Amable, Barré and Boyer (1997) and by Casper (*ibid.*), the lessons learned by public policy makers will be dealt with here in the following order:

- the United Kingdom, where the policies and regulations are typically market oriented and the orientation adopted as far as science, technology and innovation are concerned is undergoing a process of specialisation.
- France and Germany, where the relations between Science and Industry are facing fairly similar challenges, especially in comparison with those being met on the other side of the Channel, and where the scenario tends to alternate between radical change and a process of accommodation.
- Austria and Portugal, which have rather different technological and industrial structures, but are both facing the special challenge of adapting the small-scale national systems of innovation to the European Union and world-wide competition in general.

The UK: maintaining specialisation in a context of academic excellence

The United Kingdom is uncontestedly the European country - at least among all those studied in the present project - which is nearest to the reaching the standards recommended by the OECD: the history of the UK has been strongly science-oriented and it was predicted in the study by the OECD's Economic Development and Review Committee (EDRC) that the UK would be faced with relatively few major policy changes (OECD, 1998). However, industry's ability to take advantage of the research being carried out in the UK is on the decrease. It should be pointed out, however, in this connection that any excessively heavy orientation on these matters might detract from the strong point on which Britain has relied for its success, the level of scientific excellence in many fields, from which the emergent bio-technology sector⁹⁹ is now benefiting, as the pharmaceutical industry did in the past. The risk arising here are all the greater as the previous Conservative governments did very little to reinforce the basic infrastructures of fundamental research.

Preventing both public and private sectors from under-investing in R&D

At higher education institutions, the increasing "professionalisation" of technology transfer carries the risk of academic research becoming over-commercialised. This might have the undesirable effect of changing the "blue sky" basis of academic research. This shift of agenda might mean that focusing on readily exploitable research might erode the traditional basis, along with the advantages previously inherent to academia. In addition, enhancing of the spin-off process might promote the creation of companies with no sound technological basis, and might stimulate synergies within the walls of academic research spheres.

Although the UK is noted for its high intellectual standards of biomedical research, the scale of investment in science might not be large enough to create an adequate supply of highly trained scientists and entrepreneurial managers for the pharmaceutical sector and specialised biotechnology firms. Moreover, in recent years, the focus of government policy has been aimed towards commercialising science and integrating fundamental and applied research. One potential risk inherent this approach is that the basis of science itself may be weakened. Casper and Kettler have argued that the main long-term problem facing the UK biotechnology sector might be a problem of scale: that of producing a sufficiently large, high quality science base to generate the scientific and managerial expertise required.

This does not mean that the private sector is devoid of the risks surrounding output-oriented, short term strategies. Also, as the SESI case studies have shown, the amount of R&D conducted by the commercial sector in the UK has significantly decreased during recent years, which has weakened the industry's ability to make good use of scientific research. This under-investment in R&D by UK industry has strongly affected the absorption capacity of firms, and thus reduces the effectiveness of government policies designed to promote links between academia and industry. The 'disconnection problems' in knowledge transfer experienced by many of the ICT firms included our study clearly

⁹⁹ Cf. WP6 Alice Lam op.cit. and Appendix 4 to the present report for information about the main indicators.

illustrate this point. Public investment in research can possibly serve as a complement to private investment, but it certainly cannot be a substitute.

Avoiding too much focusing of financings in the "top universities"

The standard of fundamental research in Britain is largely due to the excellence of the leading universities, such as Oxford, Cambridge and Imperial College. Scientific policy in Britain involves extremely selective patterns of funding which favour the top universities (Evidence of this is provided by the fact that in the UK, 33 per cent of all the university research funds originating from industry went to only 6 per cent of all the existing institutions (seven institutions) in 1996-97; in line with the current assessment procedures, this public policy trend is liable to lead to the distribution of both public and private funds being far too strongly concentrated on the top universities. Firms do in fact tend to follow the signals emitted by public policy and focus their co-operative arrangements with the higher educational system on these universities, which is liable to have non negligible undesirable effects..

First, "this tendency can result in new scientists working at low graded institutions being prevented from developing their potential. Secondly, researcher workers at institutions with low resources will not be given much incentive to carry out fundamental research and may become stale or obsolete. Thirdly, universities may not be prepared to meet the real opportunity costs which might arise if they invest their low resources in contract research for industry. This could result in contract research for industry becoming a form of public subsidy to particular industries for the type of research that firms would otherwise have had to finance themselves on a full-cost basis. Considering the under-investment of UK firms in R&D, and the previous lack of application of the UK science base, this would seem to be another strong indictment of the current government research funding policies.

The increase in competitive university research funding may further exacerbate the cumulative self-reinforcing effects undermining the process of scientific production. This might result in the so-called "Matthew effect" (Merton, 1968)" (Lam, National report, WP6).

Now developing a "science based economy" requires a higher educational system with a much wider knowledge production base than that which can be obtained by concentrating the means available on a few universities, however efficient these may be, especially if the chosen few are accustomed to working with large companies with substantial R&D funds at their disposal. SMEs might have no access to these resources, which is contrary to the aims pursued by the authorities in promoting technology transfers towards smaller companies. If nothing is done to stop this two-fold selective process, public programmes such as The University Challenge Competition and the Science Enterprise Challenge, that can be said to be incentives promoting long-term research projects, might strengthen the "Mathieu effect" even further. Means of counteracting these tendencies need to be found.. *Ex-post* assessments of university research performances (via the RAE, for example) can lead, for example, to focusing on an institution's recent quantifiable outputs without taking into account the work in progress at less prestigious younger universities or their plans for long-term projects.

All in all, there are two aspects to the challenge with which public policy in Britain is now faced: finding ways of preventing the undesirable effects of the tendency for public research to become more market-based at the expense of its long-term investments; and ensuring that the funding of public research does not result in the pattern described as "the Mathieu effect". This leaves very little scope for what is known in the United Kingdom, when talking about STI policies, as "the third stream of funding" to foster knowledge transfer. This stream has provided financial support for increasing the links between research institutes "and companies and has taken the form of competitive funding under the University Challenge (UC), Science Enterprise Challenge (SEC) and Higher Education Innovation Fund (HEIF)¹⁰⁰ schemes" (ibid.).

Optimising technology transfer and networking policies

The promotion of innovation networks is one of the possible means available for efficiently bridging the gap between universities and industry and encouraging the industrial use of research. Although this programme may be destined to become the normal way of conducting research, it raises problems as to how the future collaborative research projects should be co-ordinated.

Networks of two kinds supported by public programmes were investigated in the framework of the SESI project:

- *Informal and social networks.* These make an important contribution to the innovation process, because much of the knowledge transferred via personal networks is tacit and personal interaction is needed for tacit knowledge to be transferred. These are deliberately designed virtual research networks with public and industrial funding, in which consortia of universities and companies work together on areas of technology identified as priorities by the Foresight Communications Panel. What are the main challenges for these networks and the relevant public policies? One of the main problems appears to be intellectual property rights arrangements. The range of agendas covered by the innovation networks plays also helps to determine programmes of common interest. There is a risk that larger companies may have a greater say than smaller ones in choosing areas of research and controlling intellectual property ownership rights. Another more fundamental problem is the failure of these innovation networks to attract SMEs and sustain their participation.
- Another form of innovation network supported by government policy is that called *Clusters* (Porter, 1990). It is not thought to be part of the Government's role to create clusters. The Government seeks, however, to create conditions which are favourable to the formation and growth of clusters. This can mean, for example, ensuring that neither national nor regional policies inadvertently impede the development of clusters, catalysing the formation of social interactions and collaborative projects within a cluster, and providing research

¹⁰⁰ The objectives of these funding schemes are to encourage: systematic and sustainable changes within institutions in their relations with businesses, and especially changes in the institutional and academic approaches; more widespread and rapid transfer of new ideas, products and processes generated within the research base to businesses; entrepreneurial activities; the incorporation of business courses into science and engineering curricula; contributing to the economic development of the nation.

and innovation with support programmes based on existing strengths so as to work in line with the grain of cluster development.

The main challenge in the future will be to strengthen the participation of the universities in local initiatives of this kind, on the lines adopted in science parks, for example, to ensure that SMEs participate more fully and satisfactorily than they have been doing so far. Here the relationships must not depend entirely on formal arrangements, which are often not very appropriate for purposes of this kind, but rather on personal and social links. Links of this kind are necessary, in fact, for the absorption capacity of small firms to be enlarged and improved.

Generally speaking, most of the policies designed to promote these networks so far have come up against one of the potential pitfalls surrounding attempts to make universities more entrepreneurial. The problem here centres on the management of intellectual property rights (IPR), which has to be given a more formal structure in this context. Policies adopted at British universities can inhibit the transmission of the knowledge necessary for innovation to occur. Although the devolution of IPR to universities is a potentially positive step, it has caused many universities to concentrate on drawing up formal rights, and this has set obstacles to the innovative flexibility of new technology-based firms. In addition, as many of our case studies have shown, IPR negotiations have become laborious as the result of the universities' increased awareness of the IP ownership issues.

Pursuing promising reforms designed to fill the "skills gap"

The 'skills gap' problem is strongly linked to the limitations of conventional academic specialisation as a means of preparing the next generation of scientists and engineers to participate efficiently in the new mode of R&D and innovation (see Alice Lam, chapter 1) : "The type of skills and competence profiles required of R&D workers are now more demanding in multiple dimensions, particularly in the combination of technical disciplinary expertise with a broad range of business, management and social skills. The effectiveness of R&D workers depends on their ability to apply scientific and technological expertise in shifting problem contexts, to operate in inter-disciplinary¹⁰¹ and trans-disciplinary environments and to sharpen their project management skills".

The gap was particularly wide in the United Kingdom because of the predominant status of academic learning in this country. This explains why another major thrust of government policies is towards the education and training of science and technology students in business management and entrepreneurship. This innovation was instigated via the Science Enterprise Centres and the Teaching Company Scheme, CASE

¹⁰¹ From this point of view, public policy-makers should take care to ensure that the *system of assessment* should not be particularly unfavourable to interdisciplinary research. It might be argued that interdisciplinary research has become crucial because the traditional academic disciplinary divides have become too rigid. As shown by our case studies, the potential to generate "disruptive" technologies which go beyond traditional disciplines is vital to find the radically new ideas on which industrial activities thrive.

studentships and Postgraduate Training Partnerships.¹⁰² The purpose of these initiatives is to adapt teaching curricula to meet industry's needs for skilled graduates in new technologies and fill the "skills gaps" which have obviously occurred.

These programmes have made it possible to carry out some particularly promising experiments which it is intended to apply systematically in forms which have been specially adapted to the various sectors.

The stakes are particularly high in the ICT Industry :

- The first point at stake is the types of skills and competence profiles required of the R&D workers in response to the shift in R&D organisation and the changing nature of innovation activities. The requirements are now more demanding in many respects, particularly as regards the need "to combine technical disciplinary expertise with a broad range of business, management and social skills. R&D and innovation activities are no longer confined to the R&D labs but are widely distributed and dispersed throughout the entire business firm" (Alice Lam, National Report op.cit.).
- The second point is the mismatch between the expectations and of graduate engineers and the realities of the work roles they are expected to play. Engineers from universities have the impression that that they have been trained to "make things", whereas the reality is that a large proportion of them will not be "making things" but will end up in a "service" environment dealing very closely with the customers and markets. This reflects a general shift of the IT industry towards the service sector
- The third point is the increasingly distributed and network-oriented form of R&D activities. Along with the fast increase in technological progress, this development means that the careers and work roles of R&D staff will be increasingly characterised by volatility and diversity. "Their knowledge and skills are being deployed and continuously reconfigured in flexible and transient forms of organisation" (Lam, *ibid.*). An increasing number of these employees will be deployed outside the traditional R&D framework. One of the main challenges to be met by educational institutions is to parallel the diversity of the career paths in their curriculum design.

This also requires firms to be much more committed to training future R&D workers than they are today, especially in the form of joint vocational training courses: according to Mason (1999), only 38 % of the firms consulted had provided training

¹⁰² The **Science Enterprise Centres** were established in 2000 to increase the awareness of the importance of business enterprises at all levels at universities, and to justify commercial activities as a valid aspect of academic life. Each centre has a business plan to ensure these activities will become self sustaining within five years. The **Teaching Company Scheme** was launched in 1975 to improve economic performances via links between university and industry. Academics have been working with companies on various technical and managerial projects and the work of groups of young undergraduates has been jointly supervised, and university syllabuses have thus been made more relevant to industry. The **CASE scholarships** (Co-operative Awards in Science and Engineering) are intended to support research students on projects which are jointly devised and supervised by academic departments in co-operation with representatives of industrial and commercial organisations. **Postgraduate Training Partnerships** involve collaborative research between selected universities and Research and Technology Organisations (RTOs), where students carry out research at the RTOs while still under the supervision of the university.

courses. A much greater level of involvement of industry in the education and training of the next generation of scientists and engineers must therefore become an increasing feature of the collaborative landscape between universities and industry.

In the pharmaceutical industry, what is at stake is for Britain to keep its leading position in the field of biotechnology in Europe. With this aim in mind, filling the skills gap will involve meeting the following three challenges:

- providing relevant competences and qualifications in new disciplines such as genomics;
- improving the standard of UK graduates in Chemistry. One of industry's serious concerns is the general lack of practical laboratory experience and problem-solving skills among the graduates. Companies have responded by recruiting Chemistry graduates from the wider European market (which shows that the British system of innovation at least has the structural ability to widen its horizons beyond the strictly national scene, although this quality can be counter-productive¹⁰³ if it is too pronounced);
- promoting the recruitment of PhD graduates: this is a vital mechanism for maintaining firms' absorption capacities and for mediating the transfer of knowledge from academia to industry.

In addition, the British pharmaceutical industry is facing a "brain drain threat". The risk of losing its resources must be turned to advantage by taking innovating measures in this sector, especially in the bio-technological field: the flow of scientists to the United States, which has reached quite large proportions, can have positive effects if the international experience and expertise gained by researchers enriches the scientific community in Europe on their return. These advantages suggest that international mobility among research workers should be promoted if they can also be encouraged to return.

Encouraging the entrepreneurial university

All the national policies on RDT matters have tended to encourage university graduates and research workers to show greater mobility towards industry. It turns out that despite the financial incitements proposed for this purpose, the employment contracts signed by UK academics are not actually flexible enough for them to be able to take temporary leave or accept part-time positions in industry while still keeping their university appointments and advantages. As noted in a Pharmaceutical case-study, it is still very much the case that a scientist is engaged in either academic research *or* an industrial firm, but not both together. Acknowledging the possibility of combinations and

¹⁰³ We have been warned that this increase in the supply of overseas scientists might make it less lucrative for local graduates to pursue an academic career in the UK, since the benefits resulting from importing scientists from abroad are widely distributed among society, whereas the costs are borne by the native scientists. It was therefore suggested that the availability of international pools of highly skilled graduates should not be allowed serve as a substitute for training and investment in the local labour force and improving the conditions of employment (Mahroum, 1999).

encouraging academics to create links with business firms and engage in entrepreneurial activities while still depending on their universities would seem to be a more reasonable attitude and one which would probably more effectively induce greater mobility between academia and industry. The current move to give scientists and technologists more education and training in management and business related skills would seem to be an attempt to rectify this situation, but it is not easy to make academic careers more flexible, and a change in the whole spirit of academic research may also be required.

In the long run, public policy-makers are having to make a rather delicate compromise between promoting the marketing of scientific results and continuing to excel in the production of generic knowledge by maintaining the centres which excel at fundamental research by allocating most of the research funds to just a few universities. What is more, the higher educational system has started to reform the basic training curricula in order to close up the "skills gap" resulting from having adopted a too narrowly academic vocational training model. The process of compromise and reform which has been initiated and now requires to be extended means that the British system of innovation will have to make adjustments which run counter to the traditional logic of specialisation in some of the sectors and disciplines renowned for their academic excellence.

The French and German cases¹⁰⁴: between accommodation and bifurcation

Based on some new legislative measures, the French and German systems have been undergoing some important institutional reforms during the last few years. In both cases, il efforts have been made to implant rules inspired by what has been happening on the other side of the Atlantic into the national systems of innovation, which incidentally differ fundamentally from each other. One of the problems which needs to be solved is to decide whether the future coherence of these systems can be achieved by making structural changes, or whether it will simply require adapting the new rules to the existing system.

The French higher education and research system in the perspective of innovation: a political turning point ?

Contrary to what has happened in Britain, the French system has had to make some complete institutional and organisational changes in response to the recommendations of the OECD. The first step in this direction was the law of 12 July 1999 on innovation¹⁰⁵, as the result of which the OECD (2000) gave France quite good marks.

¹⁰⁴ Since we have more information about the French case, we will focus mainly on this case here.

¹⁰⁵ The parliamentary report, meanwhile, which is devoted more specifically to the organisation of public research (Cohen and Le Déaut 1999), takes up the OECD's recommendations in order to emphasize the fact that the quality of a system of innovation depends on the intensity and fruitfulness of relations between its various constituents—companies, universities and research institutes. As a result, the public authorities should adopt a regulatory role, and even more so, one of co-ordination "to reduce the obstacles which prevent the formation of networks and see to it that the public research infrastructure functions in close collaboration with the business sector" (Cohen and

However, it is still too early to be able to judge whether the results obtained will be satisfactory in the long term.

At the official level, ministerial statements and parliamentary reports introducing the legislative debates have taken care to set the new measures in the context of the 1982 law on research and that of 1984 on higher education. This rhetoric of continuity has been part of the civic justification of reforms which constitutes a kind of "societal benchmarking": this procedure, was very directly inspired by the American example of start-ups and spin-offs referred to by the OECD. In other words, this was a kind of "translation", into the French context, of procedures making the borders between market and non-market spheres more permeable. The intention was to create a legitimate compromise between a "mutation" (to borrow the term used by the OECD in 1999 to qualify the French reforms and schemes) and the official French policy-makers' ideas about the independence of science in relation to the world of business. This is why the term "turning point" seems to be a fairly appropriate way of describing the "gentle and gradual break" which has been made with the previous course of events, a kind of bifurcation in the evolutionary sense of the term. The implementation of the spirit of the law is based here on a series of directives adopted by a meeting of the French interministerial board on scientific and technical research in June 1999.

Handling the shift from a mission oriented policy to a diffusion oriented policy

All the official reports (such as that by Guillaume, 1998, which has been given the most publicity) argue for a shift from the model based on the "major technological programme" involving a public agency, a research institution and a large industrial group, to that based on an interactive network where the players gain organisational experience via a process of co-operation the change was therefore from a top-down policy to a bottom-up policy. when confronted with the need to accelerate modernisation in order to catch up with rival countries, the French State privileged public co-ordination via the intermediary of "major programmes" up to the nineties. This is a top-down form of innovation "adapted to the complex technology used for major public infrastructures, as opposed to the bottom-up model for innovation via market selection, which is suitable for mass markets and, it must be said, for producing endless hybrid versions of today's technologies, as well as for the general trend towards market deregulation on the international scale and the process of globalisation in general" (Barré and Papon 2000). As this quotation suggests, these "major programmes" have led to outstanding achievements in the fields of rail transport, telephone communications and the nuclear and aerospace industries.

There has been a significant shift towards public interventions designed to further the spread of technologies; these interventions have included new incentives for research workers to develop their work at both the technological and industrial levels. They have also involved schemes encouraging companies and public research groups to set up networks for the production of knowledge and the creation of start-ups.

Le Déaut, 39, citing the article in the OECD journal entitled "Promoting scientific and technological progress".

To shift in this way from a policy of one kind to another, several prerequisites are necessary.

Simplifying public interventions designed for SMEs to make them more efficient

The multiple forms of public action which occur in response to the complex regulations and schemes devised are often reduced to perpetuating forms of management which follow the current, without any capacity for analysing, much less assessing, the overall coherence. As a result, every new problem or objective leads to the creation of an additional organisation or aid scheme. We thus end up with the well-known French paradox, which can be summarised as follows: the predominance of "public matters" (*res publica*) over "private matters" has led to the proliferation of public and para-public bodies. Their missions intersect, if not overlap, to the point of creating sharp inter-institutional competition instead of the co-operation and complementarity which should prevail if the final recipients of public aid schemes (i.e., the companies, especially the SMEs, and research scientists) are to benefit from a coherent group of services and incentives which are complementary rather than redundant. Ultimately, the State and the public authorities in general are at once omnipresent and rather powerless, or in any case handicapped.

In this institutional context, the mechanisms promoting the transfer and spread of knowledge (as distinct from the production of applied research) are overly complex due to the multiplicity of the players, including certification structures at the main institutions and universities, CRITT, SRC, industrial parks, industrial technical centres (CTI), technology distribution networks and so on.¹⁰⁶ These mechanisms have a very low level of legibility for the SMEs, especially at the regional level, where "the multiplicity of players is experienced . . . as the consequence of a stratification over time of measures and schemes which survive independently of any evaluation" (Guillaume 1998, 22). Contractual agreements (between the State and the regions, the main organisations, the universities, etc.) defining common objectives and drawing on common resources are a very poor substitute for the lack of co-ordination and in any case, contribute to preserving the former forms of intervention.

¹⁰⁶ CRITT: regional centres for innovation and technology transfer, "created in response to the Regions' desire to take charge of the management and structure their own research potential, in parallel with their concern for making the more traditional SMEs aware of technology and R&D". These centres have suffered, however, from the multiplicity of the statuses and missions, which are overly diversified and constitute "an extremely confused panorama" (Guillaume 1998, 97).

SRC: contractual research companies having industrial R&D as their main activity. These companies facilitate intersectoral transfer and the access of industry to top-rate technologies by providing firms with scientific and technical knowledge integrated into operational solutions. They have been certified by the ANVAR, and fall into three legal categories.

CTI: 18 centres involving 115,000 industrial concerns and 1,700,000 employees. These centres include some 4,000 staff members (1,800 of whom work for the Institut français du pétrole) and 36 plants and laboratories. Their missions include "marketing analyses of industry's needs", largely through technological intelligence, and "setting up collective activities (standardisation, quality assurance, etc.)".

RDT: the technology distribution network is designed to co-ordinate the technology transfer among the main public players working in the field. It was created in response to the excessively complex interface mechanisms and the resulting need for co-ordination.

It is therefore not hard to imagine what far-reaching reforms will be required before a "bottom up" policy structure is installed. This will involve revising not only the legal texts and incitement schemes, but also the everyday working habits of the French administrative departments, at both national and regional levels.

Reaching a temporary compromise between mission and diffusion oriented policies

What has occurred in the case of bio-technology and especially that of genomics exemplify this particularly delicate transformation which the public authorities are having to undergo. In this respect, the national and local public partners, private firms and non profit-making organizations have the same system of reference, which can be summarised as follows: the aim of the links created between the public and private sectors is "to create an innovative environment including firms which have sprung from universities of research laboratories (spin-offs), tripartite initiatives (cf. the triple helix model) for economic development based on knowledge, strategic alliances between firms of various sizes, using variably advanced technologies, public laboratories and university research groups. These institutional arrangements are often encouraged by incitement schemes without being government-controlled, or only indirectly via the new "rules of the game", as well as benefiting from direct and indirect forms of aid and the support of institutions create to promote innovation". However, at the same time, the real-life experiment which the launching of the Evry genopole can be said to constitute shows that complete departures from "mission oriented" forms of public action can be extremely dangerous, since it is necessary to catch up with the outside competitors in Britain and the USA, as well as those in Germany. Having to make up for lost time tends to incite the players to hand onto the advantages associated with mobilising sufficiently large resources under the auspices of the State to be able to reach an irreversible situation which is also positive. Studies on this local processes have shown that they are in fact at the crossroads between two strategies, one of which is mission-oriented (a national tradition which helps to catch up at the international level) and the other, diffusion-oriented (based on local co-operative arrangements within a network) (Branciard 2001). The problems associated with "making up for lost time" are leading to the development of a voluntarist type of activity, where efforts on hierarchical co-ordination lines prevail over co-operative attempts to carry out collective learning experiments at a pace which is not necessarily dictated by the need to overtake competitors.

The above example suggest that it might in fact be dangerous to completely relinquish the advantages of mission oriented policy. As Amable, Barré et Boyer (1997) have pointed out, the French system based on a set of major programmes - which these authors describe as a component of a model for European integration based on public interventions - "finds complete logical at those times when a backward country is trying to set up the institutions it needs to make up for its technological handicap".

French-style public intervention does not have much scope for action here, as we have already been taught by the difficulties encountered when attempting to reconvert the "military-cum-industrial complex, as it has been called. For the moment, France is

indeed way behind Britain and the United States, as far as setting up dual research structures is concerned (it was Clinton who launched the idea of combining civil and military structures, which resulted in "financial incitement programmes designed to promote the development of technologies which meet both national defence requirements and market demands" OCDE, 1999)

Higher education and the production of skills : consolidating what has been achieved by the reforms

The key themes here are the mechanisms for guiding the decisions of secondary school-leavers, the content of doctoral training curricula, and the ability to produce the skills required in generic disciplines and technological fields (ICT, biotechnology).

Ensuring that the numbers of science graduates continue to increase

During the most favourable period for the development of higher education (1984-1995), the numbers enrolled in the second and third study cycles in science increased much more rapidly than that in the arts, social sciences and economics on the whole, although the latter courses were considerably less expensive and their entrance policies were less selective. The same is true, moreover, of the most selective colleges of all in France, namely the "Grandes Ecoles", while the number of engineering school graduates increased more than two-fold (+150 % from 1984 to 1996) at a rate which was slightly greater, and above all more regular, than at the business schools. The increase in the number of industrial vocational diplomas (BTS-DUT, two-year post-*baccalauréat* higher technician training programmes for industry) was less conspicuous, but it should be mentioned that the expansion of this programme occurred earlier than in the case of full-time higher education. A real tendency therefore occurred at that time for the various higher education systems to be fairly science- and technology-oriented. The ability of the French system to produce graduates equipped with the basic knowledge required has not yet been put to the test. New reasons for future concern have arisen, however, due to the apparent loss of interest in university science programmes shown by science *baccalauréat*-holders since 1995. This trend is becoming so pronounced that some universities are now trying to reform these studies in order to stem the decrease in the numbers of students enrolled.

How to make the private sector recognize the value of doctoral training (the PhD)

Apart from Pharmacy and Chemistry, the doctoral training undergone by PhD graduates is not properly recognized at firms.

In the business world, the societal image of the engineer trained at a specialised college still prevails and constitutes the main mode of access to R&D positions. In the large companies, the engineering diplomas give access to a space of internal mobility which leads to other functions. This space is less easily accessible to those with purely academic PhDs; and this is one reason for developing a model for innovation based on a

high degree of human circulation and the production of hybrid knowledge acquired by combining research activities and other more practical functions¹⁰⁷.

It is partly thanks to engineering diplomas, moreover, that the doctoral thesis has obtained some recognition on the labour market. Graduates with PhDs in engineering benefit from noticeably more favourable conditions of labour-market entry than other doctoral graduates, and those with CIFRE engineering PhDs enjoy outstanding conditions of entry into working life.

That much said, the increase in the number of CIFRE fellowships, nearly 80 percent of whose holders then go into the private sector, shows that a joint company/higher education space is probably emerging around the thesis. The process is tricky to handle, however, because the quality of the relations between laboratories and companies, the PhD's determination to acquire professional experience and the company's long-term investment in the field of knowledge covered by the doctoral research seem to be decisive (Perret and Paul 1999).

Along with the ever-present competition between engineering colleges and university, these features show the limits of political voluntarism in these matters, as the authors of the report on the parliamentary mission on research priorities implicitly recognise: "The research sector, for reasons of French company culture, recruits less than 20 percent of the PhDs trained in our universities. . . . It is clear that concrete proposals for increasing the recruitment of PhDs in the private sector are indispensable (Cohen and Le Déaut 1999, 24). Indeed, according to the same source, although a large majority of these graduates want an academic career, "out of 11,000 PhDs, fewer than 4,000 will become research scientists or senior lecturers".

It is farther upstream, at the new doctoral colleges, that vocational training modules could be introduced which include periods of placement with firms, during which doctoral students could be trained to carry out managerial tasks or to take business decisions, which would constitute an extension of what is learned in the framework of the CIFRE fellowships.

Here again, there is a long road to be covered before the SME begin to take a sufficient amount of interest in the doctoral pool of resources. It is nevertheless essential that they should do so in order to significantly increase their knowledge absorption capacities.

Overcoming the problems involved in producing skills in some key sectors

The skills needed in the emerging field of genomics, such as bio-computing skills, have given rise to some controversy between biologists and computer specialists. While this type of conflict may be productive for research, it delays the creation of new academic disciplines at the universities, and the creating of a new system of teaching in general

¹⁰⁷ The reason why the computer engineering services sector is flourishing in France is mainly societal. French computer engineering services firms are creaming off a significant proportion of the newly qualified engineers from the "Grandes Ecoles", which the supply of human resources with the highest social status. The mutual attraction exerted between these firms and the "best engineers" is certainly one of the strengths of the French IT services sector.

which is conducive to the production of highly sought after new types of university graduates.

In the pharmaceutical sector, one of the problems encountered by firms in the management of their human R&D resources is due to the heavy compartmentation occurring between the academic and professional specialities of pharmacologists, biologists, veterinary surgeons, physicians, physicists, chemists, etc. Each of these specialised departments has its own internal regulations, its own knowledge base and applied competences, and its own institutions. Although each of these professional training paths compares very favourably with other training programmes available at the European level, the isolation of these professions is one of the reasons why relatively few changes have occurred at human resources departments in the French pharmaceutical industry. Although industry needs co-ordinated competences and compatibilities between various different highly specialised spheres of knowledge, the system of higher education is continuing to produce qualifications which show relatively little awareness of either the intellectual environment or matters relating to industry.

In the telecommunications sector, the combined effects of deregulation and the withdrawal of the major French programmes might disrupt the historic "telecommunications circle" which has created strong ties between science and industry by forging links between various players, including the Ministry of Telecommunications, France Télécom (the French telephone company, which was recently privatised), the Centre national des études en télécommunications (National Centre for Telecommunications Research, CNET) and the three national telecommunications engineering colleges. These colleges are attended by some two thousand engineering students as well as four hundred doctoral candidates and four hundred research professors working at approximately a hundred laboratories.

Improving the running of the public higher education and research system

In the Attali Report (1998), the higher education system was referred to as "Gulliver tied up in knots": an often inefficient "university government" caught between ministerial supervision which is much more extensive than the autonomy theoretically accorded to the university presidents and the feudalism of the long-standing but old-fashioned training and research units, which resist the idea of participating in co-operative projects of any kind. This is especially true because, behind the national standardisation of university rules and diplomas, "an implicit hierarchy of universities has emerged. Their size and their means vary considerably from one university to another" (Cohen and Le Déhaut, 12). In addition, some of them are multidisciplinary, while others are divided into groups of disciplines. And because of the excellence of their curricula, a number of "Grandes Ecoles" jealously cling to their individual prerogatives, which only accentuates the Balkanisation of the system, while it is far from certain that in the future these schools will have the necessary critical mass, notably in the area of research. The system as a whole is therefore difficult to comprehend, for foreign and private partners in particular, and it is highly resistant to reform.

Developing a system of assessment based on the results achieved in the field of teaching, fundamental research and the ability to communicate and co-operate with firms.

Considerable progress still needs to be made so that the various disciplines are organised and run more flexibly with a view to improving the relations between academia and firms. In the case of the life sciences, for instance, the lag in the development of links between the public and private sectors has been aggravated by the fact that the institutional landscape is even more complex than in the case of chemistry. Publicly-funded chemical research in France is co-ordinated by a single institution (the CNRS), whereas research in biology and medicine is funded by various bodies (the CNRS and the universities are responsible for fundamental research, the French national health and medical research institute, for research in the framework of the university/hospital system, and the National applied research institute, for other types of applied research). All the funding organizations have different missions, and there is relatively little co-ordination between them. This does not facilitate co-operating with industry. Nor do these institutions do not have any common policies as to how to protect their intellectual property rights when dealing with business enterprises.

Lastly, it is difficult for new disciplines to emerge and achieve recognition in a system which is both atomised and lacks flexibility because of the national legislation, which leaves the universities little scope to handle their own affairs, if only by creating new positions corresponding to the requirements of the latest disciplines.

Main stakes in the German ICT and Bio-technology industries

As suggested by Casper (1999, op.cit.), in Germany it is a question of continuing on the lines whereby the already more entrepreneurial regulations and incitements are adjusted to fit the existing institutional framework. This process has contributed to the outstanding technological and commercial success achieved by several industries producing consumer goods for households and firms.

ICT: higher educational reforms to remove the barriers to innovation

Making university training and organisations less strictly academic is incontestably one of the main challenges to be met in the key sector of ICT.

Coping with a shortage of qualifications

One of the main problems encountered by German firms in this sector is due to the lack of trained computer engineers and information technology specialists in general. During the latter half of the 1990s, the German ICT sector, especially the software sector, which has won several important industrial battles, has increased its demand for higher

education graduates. The shortage of qualified IT and engineering specialists has become a severely limiting factor preventing the full deployment of Germany's capacity for innovation. Since this shortage reflects some of the main features of the German system of higher education (a strong tendency towards specialization, and career paths which depend on the cyclical hiring patterns of firms), it should provide the movement of reform with considerable momentum: towards broad, non-specific skills and towards long-run educational goals. Human capital investment in Germany has been largely firm- and industry-specific so far, and employees have had little opportunity for mobility between firms, professions and industries. In order to respond *quickly to* industry's demands for more qualified personnel, the Federal Government launched its much debated 'Green-Card-Initiative' early in 2000.

Reducing the academism of university training courses

Commercial and economic issues feature very little in university curricula. Especially at universities (as opposed to the 'Fachhochschulen'), technical programmes appear to be strongly geared towards theoretical competences and reasoning rather than to applications, and this has been cited as one of the reasons for German engineers' highly deductive brain-set and their specification-driven approach to real-life problems. Graduates complain that they lack interdisciplinary knowledge as well as communication and business administration skills. The failure to integrate practical experience into the education process seems to be one of its main weaknesses. Against this background, it is not surprising that only a small fraction of engineers take the risk of becoming self-employed after they have graduated.

In his account of the discipline's history in Germany, Eulenhöfer states that the founders of computer science as an academic field did not include applied problems in their teaching of the principles of "Informatik" (Eulenhöfer 1998: 265). From the early beginnings in the late 1960s, real-world, applied data processing was thought to be non-scientific and was practically excluded from teaching. This tradition picture of computer science as a theoretical, mainly mathematical discipline has apparently prevailed for the past 30 years. Wherever computer science has been more application-oriented, however, it has focused on the large-firm sector. The latter sector has been reinforced by the leading information technology research and transfer institutions (Gesellschaft für Mathematik und Datenverarbeitung - GMD - and the IT institutes of the Fraunhofer-Gesellschaft -FhG), which are large-scale research institutions largely geared towards heavy industry and in addition, have diverted many resources (financial means and human capital) away from more entrepreneurial activities and fields.

The German Computer Science Society recommends reforming computer science education on the following lines: more applied knowledge and more integration of practical tasks, participation of the students in two long study projects each lasting about twelve months, teaching social and business skills. Numerous efforts have been made recently to change existing curricula on these lines and to create entirely new degrees, including computer science master courses run in English and other new courses providing growing markets, such as the multimedia and telecommunications markets, with qualified personnel.

Developing the spirit of enterprise at university in order to make better use of the scientific potential

As in France, the performances of the universities were found to be satisfactory as far as strictly scientific matters were concerned, but little was being done to make industrial use of scientific findings. For instance, Germany's weak competitive position in data processing cannot apparently be accounted for by the country's level of scientific expertise. An official report has concluded that there is a high potential for interactions between industry and science in the field of data processing and likewise, in the field of optics (ISI, Ifo, ZEW 2000: 23).

However, contrary to what is happening on the opposite side of the Rhine the question which arises is not so much how to improve technology transfers towards the SMEs, thanks to the excellent work carried out by the Fraunhofer Gesellschaft, but how the research scientists themselves might apply their results.

The recent upheavals on the capital markets are certainly one of the main reasons why there is such a small number of New Technology Firms in Germany. In addition, the organizational patterns and the non-competitive funding of many academic and other public research institutions seem to prevent the spirit of innovation from developing. In comparison with the USA, German public research institutions are less numerous, larger and tend to be more homogeneous in their size, the administration on which they depend, and their methods of management as well as in the overall scope of their research projects.

Favouring the development of clusters in the field of ICT

Although German firms have had a resounding success with their software programs, the results obtained on the hardware side have been much more disappointing. One of the reasons for this weakness seems to have been the lack of strong regional clusters of IT expertise. This has made it difficult for the German hardware industry to take advantage of the economies which can be achieved by agglomerating. This may be a crucial factor, because it remains to be seen whether the transition towards a knowledge-based economy can be successful without having significant indigenous IT hardware strengths.

Biotechnology: marching on from strength to strength

The number of small research-oriented biotech firms increased from 75 in 1995 to 279 at the end of 1999 (Schitag Ernst & Young 1998, Ernst & Young 2000). As several observers and many politicians have proclaimed, Germany has surpassed the United Kingdom as Europe's leading biotech country in terms of the number of core biotech companies.

The sustainability of this take-off, still remains to be proved, however, during the years to come. New companies have not yet passed the real test of the market, which will

require sustained growth, high-level research alliances, developing their own technologies and products and floating the company successfully on the stock market. The main question which arises is whether German biotech companies will be able to generate novel proprietary technologies and patented products, and in particular, to find some promising new candidate drugs.

Ensuring that an appropriate supply of skills is available

In quantitative terms, providing a sufficiently large supply of qualified specialists has not been a major problem, but this may prove to be a limiting factor in the near future, especially if Germany's biotechnology industry continues to grow as fast as it did during the past five years.

A much more critical issue, however, is the biotech sector's ability to attract graduates and experienced researchers who excel in their field of research as well as being commercially oriented. During the 1980s and on an even larger scale in the 1990s, many of the most talented German life-science researcher workers went to the United States for post-doc training and stayed on there, working either in public research or in private companies. If more of the German scientists who have accumulated scientific as well as management know-how in the United States returned, Germany's young biotech sector would be greatly boosted.

German biotech companies suffer from the 'technophile' attitude of German university graduates. They tend to be highly qualified in their respective specialized fields, but business-like thinking and management skills are still quite rare phenomena among natural scientists.

Nor does Germany's public research sector, which consists of university centres and large public laboratories, have a particularly strong marketing record. There do exist institutional and in many cases, personal ties between those working for established companies and the generously funded public research institutes. Yet before it can establish anything at all comparable to the US industrial and scientific community, Germany still has a long way to go.

Promoting the emergence of new disciplines

In the long run, the German system of higher education itself has to prove its ability to adapt to the demands of the modern biotechnology business. As acknowledged by many observers and recently confirmed by a survey of German post-doc graduates working in the USA, the quality of life-science education at German universities is still excellent as far as the basics and the principles of the disciplines are concerned. What is lacking on all sides, however, is the ability to quickly integrate new fields of research into university curricula and the willingness to cut across conventional discipline demarcations¹⁰⁸.

One exception is the University of Heidelberg's new "Biobusiness" curriculum developed in co-operation with the University of Mannheim and industrial partners: this course was designed to provide life scientists with business skills.

Sustaining the dynamism of local innovation networks

In addition to the co-ordinating centers in the BioRegions, science and technology parks and technology transfer organizations form a large part of the upcoming industrial and scientific network which is developing in Germany, but in comparison with the USA, this country still has a long way to go.

What Germany has achieved in the field of Biotechnology might serve as an example to countries such as France: this shows how a country with a 'top-down' type of public structure, by consistently persevering with a series of relevant interventions, can generate a 'bottom-up' process of technological and industrial creation which fits in with the previously existing structures.

Austria and Portugal: the lessons taught by smaller members the European Union

Although Austria and Portugal have completely different, not to say opposite political, economic and scientific histories, it can be highly instructive to examine the experience acquired by countries where the national systems of innovation are bound to be extremely incomplete, open to the outside world, and subject to the influence of large multinational firms originating from elsewhere.

Austria: from industrial dynamics based on incremental innovation towards a knowledge based society

As far as knowledge sourcing is concerned in Austrian business companies, the HERS plays a fairly subordinate role in this country. Consequently, the linkages and interactions between the higher education sector and the business sector are weak in terms of flows and funds. The typical innovation model adopted in Austrian companies is based on the continuing improvement of their products and processes and therefore on a process of very gradual innovation. This strategy is rather a ginger one, but it promises to pay off in the end. Austria's business firms have therefore launched many small-scale; low-cost innovation projects. This further shows how cautiously they proceed whenever it comes to introducing technology which is new to a market." (based on ART 1999, p.21). The outcome has in fact been a successful process of gradual innovation with rather low R&D quotas, although the system has recently had some difficulty in finding its feet in the 'New Economy' business world.

Most entrepreneurs have been pursuing a recruitment strategy whereby preference is given to graduates from vocational/ technical secondary schools and post-secondary vocational courses over university graduates. Engineers with this educational background are cheaper to hire on the one hand, and less ambitious to take over the leading managerial role of the entrepreneur on the other hand (who typically has no academic degree either). Nevertheless, these recruitment strategies are thought to have been interacting with innovation trajectories: technological process innovation and

gradual network innovation were shaping the innovation process at the expense of product innovation and "radical" innovation.

Dissatisfaction with this situation – producing theorists and generalists at the universities on the one hand and vocational engineers at technical and vocational secondary schools on the other hand – and the conviction that many undergraduates at universities would be better off attending a more vocational course, has led the Austrian Government to enrich the HERS with ten experimental *Fachhochschulen* (FHS) in 1994. The FHS were intended to provide a more flexible and practical alternative to academic university studies. Eight of them specialise in fields relating directly to the ICT sector, and most of them have one or more curricular modules devoted to information technology.

Confirming the relevance of network and consortia policies to stimulate innovative SMEs

Several measurements have been implemented in Austria to strengthen the relationships between research institutions (mainly universities) and enterprises. The most important programme is the K-plus programme. The K-plus Competence Centre Program was launched in 1998 to promote long-term co-operation between innovative enterprises and top-level research groups in order to contribute to a lasting improvement in the co-operation between science and industry. One of the key prerequisites for a Competence Centre to be established and able to function is that it must be able to enlist the long-term participation of research institutions and at least five enterprises. At the moment, 12 K-Plus Centres have been established and 9 further applications are currently being assessed.

the K+ initiative might certainly be the best possible practice in terms of the goals of the SESI project because it has generated *two ideal models* for the knowledge based economy, the success of which was based on developing work process knowledge and sound technological knowledge.

These two models (both of which are set in the ICT context) again illustrate the two-fold process of adjustment and bifurcation which seems to underly the transformations undergone (with success) by most of the European systems of innovation involving a renovation of the relations between Science and Industry:

The *Kapsch 'risk avoiding close to market model of knowledge sourcing'* can be viewed as an upgraded extension of the traditional Austrian trajectory mainly continuing on similar lines to the Austrian model.

· The *AT&S 'network-based just in time model of knowledge sourcing'* can be seen as a major departure from the traditional Austrian model. First, due to the firm and ambitious decision to move towards a technological leader and secondly, due the new strategies dedicated to building links between the various actors in the economic process (firm departments, suppliers, customer, universities, etc.) with a view to establishing a *tacit knowledge base in the area of scientific and* theoretical knowledge. The tacit knowledge base relating to the work process and other fairly practical considerations

has therefore now been combined with a new tacit knowledge base at the more theoretical scientific level. The problem of the firms' absorption capacity has been solved by setting up of small – but top-flight – R&D departments initiating, steering and managing the ISR and as well the other knowledge intensive network and relationships.

In terms of lessons for policy, the AT&S case is clearly the most interesting because sophisticated work process knowledge seems to be an asset which many Austrian companies have. But the second step, that of combining process knowledge with academic knowledge, is one which only a few companies are able to take. Consequently, the question has to be raised as to how can those companies might be assisted with taking the second step?

Stimulating the formation of the appropriate skills for a knowledge based economy

The implementation of the 'Fachhochschulen' in 1993 could be seen as an appropriate answer of the Austrian system of skills supply to assist the *Kapsch 'risk avoiding close to market model of knowledge sourcing'* in the road towards the knowledge based economy. Since the 'Fachhochschule' courses provide students with a vocationally and technically oriented educational programme at higher educational level, they perfectly fit a model where the aim is to continually upgrade a sound technological knowledge base mainly including upper secondary technical school skills so as to be able to face new competitive and innovative forces developing outside. And indeed the Austrian technologically oriented businesses are scrambling for 'Fachhochschule' graduates¹⁰⁹.

Doctoral training could be adapted in the case of some PhD courses to the Occupational Labour Market. To become a research scientist at a pharmaceutical company, a PhD is useful if not a pre-requisite, but young PhD graduates are not regarded as having finished their education. Only Post-doc graduates with several years of practical experience (preferably in a foreign country) are regarded as "trained" (although the position of a PhD graduate in a pharmaceutical research group is somehow different from an internship.).

An occupational labour market for PhDs may emerge in the fields of Science that are relevant to pharmaceutical research as well as other fields such as physics (e.g. chip-design) or even mathematics. In the ICT sector (with the exception of the above-mentioned hardware areas), however, PhD diplomas are thought of as being too scientific and too theoretical..

¹⁰⁹ The following quote by Dr. Kapsch (the CEO of Kapsch), who really welcomes the "Fachhochschulen" but is sceptical about the universities, is an illuminating illustration. "I feel the *upper secondary technical schools* we have constitute a very good system. However, the problem is that in these schools, not much store is set on general education issues, and hence the new "*Fachhochschulen*" are idea. they are very valuable. we strongly support the "Fachhochschule" system...in my opinion, our *universities* have some serious shortcomings".

Reforming the science base: how compatible would this be with the roots of the Austrian system of innovation ?

There have been several trends which show that attempts have been made in Austria to make greater commercial and industrial use of the country's scientific potential by taking more market-oriented options. The question now arises as to whether this orientation is compatible with the traditional basis of the Austrian system of innovation, which has achieved considerable industrial success, mainly thanks to the gradual pace at which innovation was introduced.

Measures of two kinds have been adopted to make the system more flexible: the first focus on the way in which university workers' status and careers are managed; and the second, on the development of venture capital:

In May 2001, the government and union representatives signed an agreement on the legal reform of the status of civil service university employees. This reform means that people working at Austrian universities will no longer have civil servant status. The other aims of the reform include increasing the permeability of academic positions, opening the universities to larger numbers of young research scientists and the abolishing the research supervision diploma as a pre-requisite for a professorship. This reform was hotly debated, and the university staff threatened to go on strike at the end of May. Several of the issues that the new government is currently discussing in the education and higher education sectors are viewed by many critics within the institutions in question as liable to weaken rather than strengthen the long term research basis. The main points at issue are the financial problems associated with the new government's promise to wipe out the deficit in the national budget from 2002 onwards.

.Many measures have been taken to increase the amount of venture capital made available by public and private sources in Austria. The lack of capital was one of the main criticisms put forward in the discussion about new firms, spill-overs and the fear of a technological relapse in Austria. Now several observers have stated that sufficiently large funds are available, although firms, founders and research workers are still claiming that there is a lack of venture capital. Several initiatives and consulting institutions and associations have also been established to facilitate the establishment of companies. All the necessary information is now easily accessible.

Portuguese paradoxes

There exist some strong Portuguese specificities which explain why the path taken here has differed considerably from those described in the case of Austria, Britain, France and Germany.

The competitive Portuguese model has been called the "**Portuguese paradox**" in the sense that "...in macroeconomic terms, the country has had a remarkable performance, namely after the adherence to E.U., in 1986, but has been unable to change the

competitive pattern, which is almost the same since the 70s..." (Lança, 1999:317). This satisfactory performance can be judged, for instance, by the way the *per capita* income has caught up with the average European figures, which increased from 55.1% in 1983 to 68.4% in 1995. Since the beginning of the seventies, the OECD member countries have reinforced their investment in science-based industries, which increased the contribution of the corresponding products to the export rates from 9% to 13% between 1970 and 1993. Portugal not only has a different pattern of specialization, but it has developed quite differently during the same period by reinforcing the labour-intensive industries and decreasing the science-based industries. One might add that a relatively low proportion of the total DTID expenditure in Portugal goes to industrial R&D, which accounts for only about one third of the European average.

Limited scope for the high tech industries

By studying the history of firms and sectors, it is possible to determine whether they are on an upward or downward competitive and innovation trajectory. As far as Portugal is concerned, we can conclude that:

- The pharmaceutical sector is obviously undergoing a downward phase as far as competition and innovation and the process of de-industrialisation are concerned. These firms do not need academic knowledge, and the recruitment rates of graduates are very low. These graduates are recruited mainly by the traditional chemical sectors.
- The telecommunications sector – i.e., software design for telecommunications – has been in an upward phase, but is highly dependent on the strategies adopted by multinational firms established in the country. In these cases, flows of knowledge occur in a closed circuit inside the industrial group, and this explains the weakness of relationships with the national HERS.
- The software industry is on the rise, especially the "Basic software industry". The weak point is that this segment consists almost entirely of start-ups. Academic knowledge is needed and if engineers and PhDs trained abroad could be recruited, it would certainly help this segment to expand.

The weakness of the intermediate institutions: can they be relied on ?

Some of the interfacing organizations are in a very unfavourable financial situation not far from bankruptcy, because after receiving public funds to implement and develop their infrastructures, they were supposed to work for industry in a market oriented spirit. However the demands of industry have been very low. This seems to be a case where the distance between the two spheres is too great.

In this case, rather than looking to HERS for a solution, the recommendation was to look to industry for a solution. This is the main specificity of the Portuguese situation, as far as the topic of the present SESI project is concerned. The need for institutions and organisations to solve the problems of intermediate institutions are an unexpected form of failure. Important lessons could be learned from these cases if we could identify the reasons for failures, implement solutions and prevent similar experiences from occurring in other countries, namely the East European countries which in some cases, such as Slovenia, have similar industrial structures.

Entrepreneurial universities: the main challenges

In Portugal, PhD graduates working at universities or other laboratories need to be encouraged to identify business opportunities for applying their knowledge, and the number of high tech firms needs to increase, as mentioned in the OECD report. Venture capital and regulation barriers are important, but these are not the only problem. And we cannot expect the same person to be highly specialized in a specific scientific area and at the same time to be a competent marketing specialist and a manager, etc. These new professions are the keys to promoting high tech business, however.

Since the Portuguese industrial firms are not dealing much with science based products, their absorption capacities for generic knowledge are low. Given these structural conditions, one of the possible ways of setting up a knowledge based economy in Portugal might consist of developing a strong spirit of business enterprise at the universities. The upstream condition which needs to be met for this project to be possible is that the research groups must be producing work of a sufficiently high standard to constitute potentially marketable material.

Conclusion

The handful of European countries studied here with a view to defining what needs be done at the public policy level differ considerably from each other, as we have seen. It is not surprising that in the various typologies drawn up so far, they have usually all been allocated to different categories in terms of their systems of innovation.

Yet each of these countries, with the possible exception of Portugal, will have to make compromises between divergent if not contradictory pathways for organising and regulating their national research and innovation structures. The future competitiveness of each institutional system will in fact probably depend on the quality of these compromises.

The compromises are first and foremost a question of how "top down" policies link up with interventions designed to promote "bottom up" processes, or, if we take the French context as an example, how "mission oriented" policies are made to fit in with "diffusion oriented" ones¹¹⁰. Whenever there is a competitive lag to make up for, the fast mobilisation of large-scale resources tends to require the intervention of the State, but this may tend to clash or at least fail to fit in with incitement policies intended to promote the creation of new high tech companies. What has occurred in the field of biotechnology shows how difficult it can be to achieve this co-ordination.

¹¹⁰ As suggested by Pavitt (2000, 4), this is a field where the European countries have a lot to learn from the experience acquired by the USA: "a tendency to underplay the role of the US Federal Government in contemporary US successes in biotechnology and ICT is leading some foreign governments (particularly in Europe) to learn the wrong lessons from the US experience".

Secondly, all the countries in question have been introducing measures for marketing the results of public and private research institutions and making them more widely known. There is a risk that this might encourage research organisations and firms to take a short term view instead of accumulating generic knowledge as they have done in the past. The blurring of the roles of universities and private industry might lead to the loss of research workers to industry and to fewer fundamental scientific discoveries being made by the universities, which would be detrimental to their status as places of research. This in turn would mean that university research careers would begin to seem less distinctive and appealing. Powell and Owen-Smith (1998) have also mentioned the risk that changes entailing the use of market-based criteria (such as more focus on patenting and licensing) to assess the merits of research may, in unanticipated ways, demolish the mission of research universities by undercutting public trust in these institutions. However, as shown by the evidence obtained in the present case studies, the situation is far more complex than simply the issue as to whether universities or industry should control IPR.

In the last resort, successive waves of new approaches may end up by creating irreversible situations on the institutional scene and give rise to bifurcations on the road to innovation on which the systems of innovation involved in these reforms have been launched. In Germany, for example, the emergence of the new bio-technology sector has led to a whole series of sudden changes on market oriented lines. This does not necessarily mean that convergence towards the American model is the only possible issue. On the contrary, each institutional system is engaged in a continuous process of appropriation and adaptation between the rules inherited from the past and the various incitements to pursue the reforms initiated. Some original new institutional lessons will probably soon be learned, which will have effects on society as a whole.

In most of the countries studied here, the reforms have tended to be based on common frames of reference with a view to finding more useful applications for the results of research, creating more space for introducing the university entrepreneurship, and supporting local and regional initiatives in which both public and private research partners are involved. This change of approach is mediated in all these countries by the innovation networks which have developed either spontaneously or otherwise. The creation of these networks is decisive, since it gives SMEs access to the basic scientific and technological resources available.

The local mechanisms whereby skills and knowledge are produced and made to circulate are gradually diversifying the individual national systems of innovation. Both the national and European policies will have to gradually become less like prescriptions and more like reference frames providing a setting for the activities of the actors on the micro-economic scene (possibly forming clusters involved in networks and local initiatives). The success of scenarios of this kind depends greatly on how clearly the public authorities' incitements and modes of organisation are perceived. It is no doubt at this level (whether one is talking about transferring technology to firms or organising university curricula which lend themselves to the appropriation and adaptation of scientific knowledge) that the most radical changes will have to be made in the various European countries. This is an essential aspect, as it will determine the ability of the

various actors involved in innovation to absorb generic knowledge in a knowledge based economy.

The points in common should not be allowed to make us overlook the great institutional diversity shown by the various European countries we have been looking at. Lundvall and Borrás (1997, 109) have suggested "that the capacity of institutional learning depends at least partly on the diversity of its knowledge base ". One might be tempted to say at first sight that the British practices as far as biotechnology is concerned could serve as a guide, that the German methods of transferring technology towards SMEs are an example to be followed, that the training courses for engineers run at the French elite institutions could serve as an inspiration to other countries, and that the Viennese ICT innovation networks are particularly promising ... But it has become rather fashionable to say that institutional borrowing of this kind has definite limits, as foreign institutions are difficult to transfer to a different context from that in which they were created (see Lundvall and Borrás, 1997). Nevertheless, any solutions designed to reduce the academism of university curricula and develop new modes of alternance training in collaboration with firms with a view to promoting the emergence of occupational labour markets at PhD level or creating carefully controlled forms of entrepreneurial activity will help to construct bridges which will make it possible to move away from institutional borrowing and to start a new process of institutional learning.

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APPENDIXES

Appendix 1

The SESI teams

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Appendix 2

Participating companies

Multinational Firms with foreign origins

Multinational Firms with national origins

Small Firms or new Firms

| Countries / Sectors | Computer (Industry and services) | Telecommunication | Pharmacy |
|---------------------|---|--|--|
| Austria | Siemens <i>AT&S</i> | Ericsson <u>Kapsch</u> | <i>IGENEON</i> <i>IMP Bender</i> |
| Germany | Agilent Technology <u>SAP</u> | Lucent Technologies Nortel Dasa Alcatel Research Center | <u>HMRAventis</u> Merck KgaA <i>Atugen Berlin</i> |
| France | <u>Canon</u> Bull <i>Inria Spin offs</i> | Motorola <u>Alcatel Space</u> <i>SCM</i> | Hoecht, Marion, Roussel (Aventis) <u>Rhône Poulenc Rorer</u> <i>(Aventis)</i> <i>Fabre</i> |
| Portugal | <i>Neuronio</i> <i>Critical Software</i> | Alcatel <i>EID ENT</i> | Jaba <i>Horvione</i> |
| UK | <u>ICL</u> Hewlett Packard <i>Signal</i> | <u>Racal Electronics</u> Nortel <i>Science Park</i> | Pfizer <u>ICI</u> <i>Oxford Glyosciences</i> |
| USA | SAP Labs <u>Agilent Technologies</u> <u>and Labs</u> <i>Force Computers</i> | <u>Lucent</u> <u>Technologies/Bell</u> <u>Labs</u> Alcatel USA Nortel Networks | Aventis <i>Atugen</i> <i>Sugen Inc</i> <i>RPI Inc</i> <i>Lexigen Inc</i> |

Appendix 3

Interview guide proposal/Firms

The following proposal expresses the points of interest that we feel are useful. The questions formulated below are simply suggestions, and the proposal itself is meant to be only the first step in writing interview guides that should maintain a certain uniformity. We think that following such a procedure can save us some time.

1 /Review of the general procedure

The principal research objective is to explicitly clarify the role of relationships between the research and education system (RES) and firms for developing innovation capacities in firms. The general orientation of the research is especially intended to formulate recommendations for public policies.

The questionnaire should be adapted to every sector and every company category (multinationals of foreign origin, multinationals of national origin and small and medium sized firms).

2 /In-company surveys

In-company surveys are intended:

- To identify the flow of general and technical knowledge between the RES and firms (in both directions),
- And to understand how firms can organise themselves to take best advantage of both kinds of knowledge and to incorporate them into innovating behaviour.

We are attempting to set up investigation as a partnership with the firms involved. Therefore, formulating specific needs for expanding knowledge and more generally for sharing the resulting data should remain very open with respect to the firms.

Note: For France there are surveys on innovation and the adoption of technological knowledge (1994 / 96; 1990/92) that furnish rather exact answers through individual company data about the vigour of innovation and partnership policies (several establishments of firms that we will visit appear in these surveys).

3 /Outline of in-company surveys

Information should be gathered at two levels:

- at the level of a firm as a whole. Given both the subject of research and the high-tech nature of the firms studied, the surveys should be centred, in practise, on the R&D functions of firms, taking particular care to analyse the interrelationships with other functions in firms (marketing, technical sales, production, etc.),
- at the level of particularly significant examples of co-operative initiatives with the RES. These examples might be production facilities or laboratories with specific links to the RES (a joint production facility with the RES).

Furthermore, it is planned after conducting the in-company surveys to hold a few interviews with the key personnel of the RES institutions with which the firms maintain regular relationships (see the Work Package 54 in which a comparative evaluations by the key personnel and institutions interviewed are planned.).

3.1 / General supporting information

- Constructing relevant data should rely on two main procedures: collecting objective data and in-depth interviews.
- The purpose of gathering this information is to enable Sesi researchers to understand the economic and industrial position of the firms as well as the operations of their innovation systems.
- In the beginning, the general data should aid in setting up socio-economic framework for the firms and to understand the context of co-operative initiatives with the RES. This data should also be discussed with our interlocutors during the interviews.
- This data should be gathered and organised before the interviews, if possible. Practical considerations, however, may lead to beginning, if necessary, with interviews about specific R&D projects (for example the RP Rorer - Hoechst-Marion-Roussel merger).
- The individuals interviewed should be chosen according to their position in a firm's organisation and, of course, in co-operation with the main interlocutors in the firms.

These interviews should be conducted with:

- key R&D personnel,
- the technical department,
- the human resources department,
- the key product line personnel,
- head marketing personnel.

3.2 /Information about firm - RES relationships

In the next step, information directly related to relationships between firms and the RES should be collected. This step is the core of the study and should be conducted with semi-directed interviews.

Generally speaking, it is important that data gathering should not disturb interlocutors in the firms. Thus, some information could be put together by Sesi staff beforehand. Other information might be taken from regular publications of the firms (reports to stockholders, various brochures, documents given to the group working committee, etc.). We expect the firms to update and fill out previously gathered information (with social reports, for example).

4/ Giving data

It is important that in producing the monograph, solid interactions with the firms result. At the very least, a preliminary version should be submitted to key interlocutors in the firms. Later, in meeting with researchers/key company personnel and possibly policy makers, the principle dimensions of the SESI project should be discussed (see the Work Package 54 in which comparative evaluations by the key personnel and institutions interviewed are planned).

| |
|--|
| <p style="text-align: center;">Data-gathering interview guide (general information and RES/firm relationships)</p> |
|--|

The guide is intended for the general management as well as human resources, R&D, marketing, product line and project departments.

1 - General data

1.1 - General organisation of the firms (interlocutor: general management department)

- Brief history of a firm (the most important events and decisions):
 - in R&D
 - in organisation
 - product policy

- Organisation charts, subsidiaries, accounts of companies, etc.
- International organisation of a firm,
 - its position on international markets,
 - its holdings or buy-outs of other firms/sales of assets,
 - the position of the national subsidiary in the multinational's organisation in terms of products and research and development
- The relationships between strategic development policies and R&D policies.

Useful documents: reports to stockholders, various brochures, documents given to the working group committee.

Also, certain meetings within the firm (for example, orientation meetings for new employees) could be a tool to inform SESI staff quickly about policies and strategies.

Appendix 4

The position of industries in their national innovation systems

From the point of view of the SESI project, it is essential to develop an approach that avoids the risks of a term by term comparison between a particular industry in country A and its counterpart in country B. In order to avoid these risks, each industry studied - pharmaceutical, IT and telecommunications - has to be positioned within each national economy. It was on this basis that we ordered from the "Observatoire des sciences et techniques" (OST) unpublished data consistent with the industries and countries selected for this project. This report contains an initial attempt to interpret these OST data, although it has to be noted that they do not wholly fulfil our expectations. This applies particularly to the "small" EU member states included in our project: as will be seen, there are gaps in the statistics for Austria and, particularly, for Portugal.

Our present investigation will be conducted in three stages:

- We will focus initially on patent applications as a synthetic indicator of technological performance in the three sectors in question: telecommunications, IT
- In the second stage, we will examine the resources used, i.e. expenditure on industrial R&D, and the potential resources available, i.e. advances in knowledge (performance in terms of scientific publications).
- Finally, an examination of competitiveness and export performance will attempt to translate into economic terms the investments made in R&D and technological development.

Technological performance: patent applications by industrial sector (European and US patents)

Table II-1
World share (%) in European patents by industrial sub-sector
(1996)

| | European Union | France | Germany | UK | Austria | USA | Japan | World |
|--|----------------|--------|---------|-----|---------|------|-------|-------|
| Aeronautics | 43.6 | 16.0 | 12.4 | 9.8 | 0.2 | 42.5 | 2.2 | 100.0 |
| Radio and T.V. sets, telecoms. Equipment | 34.6 | 6.1 | 11.3 | 5.6 | 0.4 | 37.1 | 22.6 | 100.0 |
| Office machines and calculators | 21.6 | 4.6 | 6.9 | 4.1 | 0.3 | 44.5 | 29.0 | 100.0 |
| Pharmaceutical products | 36.3 | 6.6 | 12.9 | 7.5 | 0.6 | 43.0 | 12.7 | 100.0 |
| Transport other than cars | 60.3 | 9.7 | 30.5 | 5.9 | 2.0 | 21.6 | 10.0 | 100.0 |
| Chemical products | 41.1 | 5.0 | 19.5 | 6.3 | 0.6 | 36.5 | 15.5 | 100.0 |
| All sectors | 43.1 | 7.0 | 17.3 | 6.3 | 1.0 | 33.9 | 14.7 | 100.0 |

INPI and OEB data, data processing by OST

Table II-2
Index of specialisation by industrial sub-sectors in European patents
(1996)

| | European Union | France | Germany | UK | Austria | USA | Japan | World |
|--|----------------|--------|---------|------|---------|------|-------|-------|
| Aerospace | 1.20 | 2.22 | 0.97 | 1.98 | 0.30 | 1.38 | 0.15 | 1.00 |
| Radio and T.V. sets, telecoms. equipment | 0.82 | 1.00 | 0.74 | 0.99 | 0.26 | 1.10 | 1.54 | 1.00 |
| Office machines and calculators | 0.48 | 0.56 | 0.41 | 0.57 | 0.13 | 1.35 | 2.11 | 1.00 |
| Pharmaceutical products | 0.88 | 0.82 | 0.87 | 1.06 | 0.52 | 1.26 | 0.97 | 1.00 |
| Transport other than cars | 1.45 | 1.98 | 1.42 | 0.85 | 1.82 | 0.42 | 0.63 | 1.00 |
| Chemical products | 0.89 | 0.62 | 1.05 | 0.88 | 0.71 | 1.20 | 1.10 | 1.00 |
| All sectors | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

INPI and OEB data, data processing by OST

These tables show the position of the sectors under investigation here - telecommunications¹¹¹, pharmaceuticals and IT¹¹² (here "office machines and calculators") - within the national innovation system (NIS). To confine ourselves to the French and German cases, none of the three sectors in question is in a position of strength in terms of patents, unlike the aerospace industry¹¹³ in France and transport other than cars in Germany. On the other hand, the choice of industries for the SESI project includes one of the best placed sectors in the British productive system, in both relative and absolute terms.

Having said this, the positions on either side of the Rhine are less bad in the pharmaceuticals industry than in the IT sector where, following the example of the rest of Europe, the technological weaknesses of Germany and France are even more marked. An approach based on technological spheres, i.e. one that cuts across individual industries, will bring the French and German positions in the life sciences into sharper focus. In biotechnologies, France accounts for only 5% of European patents, following a slight relative decline between 1990 and 1996¹¹⁴; the German position, at less than 7%, has deteriorated more markedly.

¹¹¹ For reasons of statistical reliability, the telecommunications industry is included in the manufacture of other means of transmission/broadcasting, in particular television sets.

¹¹² One of the major limitations of the present analysis lies in the fact that it is limited to the manufacturing component of activity in the IT sector and excludes software and computer services companies.

¹¹³ In what follows, the aerospace industry will be used as a model of excellence for France (which it is in the UK as well; the transport sector plays the same role in Germany).

¹¹⁴ In terms of technological sphere, it is possible to isolate "telecommunications", on the one hand, and "IT", on the other: the French positions here are a little less unfavourable than in sectoral terms, with world shares in European patents of 6.7% and 5.8%.

Conversely, in the "pharmaceuticals/cosmetics" sphere, the positions on both sides of the Rhine are relatively more favourable, with a world share in European patents in 1996 of 8% for France and 10.3% for Germany; performance in France has improved since the beginning of the decade (107 compared with a 1990 index of 100) and deteriorated markedly in Germany (77 compared with the 1990 index).

In terms of American patents, the French positions, like those of the two other major European countries, are considerably weaker than in Europe. Nevertheless, it is clear that the weakness is less marked in the pharmaceutical sphere than in the other sectors, and that this applies even more clearly in biotechnologies (the loss of position in terms of world share in US patents was only 5% between 1990 and 1996). This situation reflects the move of European firms into Northern America, through the establishment of subsidiaries and, in particular, the takeover of American firms.

The French and German positions in 1996 in all the sectors represented in the OST statistics show a continuation of their downward trajectory (-18%). In France and Germany, the decline is particularly marked in the "audio-visual and telecommunications" sphere, whereas Austria has considerably improved its relative position. It is less marked in the French IT industry - where positions had already declined considerably - and the French pharmaceutical industry, although the German position in this latter sector constituted a very serious decline. It should be noted that the UK remains to some extent immune from the decline in Continental Europe, at least in the IT and pharmaceutical sectors.

Table II-3
World share in American patents by industrial sub-sector (1996 compared with 1990 base of 100)

| | European Union | France | Germany | UK | Austria | USA | Japan | Rest of the world | World |
|--------------------------------------|----------------|--------|---------|-----|---------|-----|-------|-------------------|-------|
| Aerospace | 75 | 84 | 61 | 71 | 63 | 120 | 79 | 330 | 100 |
| Radio/T.V. sets, Telecomm. equipment | 88 | 72 | 73 | 82 | 126 | 131 | 78 | 170 | 100 |
| Office machines and calculators | 93 | 96 | 79 | 106 | 218 | 128 | 73 | 205 | 100 |
| Pharmaceutical products | 86 | 95 | 70 | 103 | 95 | 132 | 70 | 117 | 100 |
| Transport other than cars | 86 | 57 | 102 | 101 | 94 | 199 | 84 | 118 | 100 |
| Chemical products | 95 | 94 | 88 | 103 | 73 | 119 | 75 | 124 | 100 |
| All sectors | 89 | 82 | 82 | 91 | 85 | 132 | 78 | 119 | 100 |

INPI and OEB data, data processing by OST

Generally speaking, the scale of the French decline in terms of US patents is similar to that in the European Union as a whole. However, the picture in the various sectors is more contrasted: a very marked decline in IT and telecommunications, but an improvement in the situation in the pharmaceutical industry, which again reflects the decision of French firms to establish themselves in North America. Their results contrast strongly with those of their British and German counterparts. As a result, the index of specialisation for the French pharmaceutical industry is advancing much more quickly in terms of American patents than those of their French and German counterparts.

Actual and potential resources: scientific output and funding

Attempts to build up leading positions in technologies, as expressed in terms of European and American patents, will be based on two types of resources in particular: scientific output, which may not of course be harnessed solely for the benefit of firms in the country where the basic research was carried out, and expenditure on R&D.

European positions in scientific output

In general terms, scientific positions in Europe are less favourable than the technological positions (32.6%, compared with 43.1%, Tables 1 and 9). France follows this general pattern (5.1% of world scientific output, 7% of European patents), which is even more marked in Germany but the opposite of the British situation. It is difficult to draw the same parallel at sectoral level, since there is no strict correlation between economic activities and scientific disciplines. Nevertheless, it can reasonably be assumed that "basic biology", "medical research" and "applied biology" are closely connected to the pharmaceutical industry and the biotechnology sphere. Less directly, advances in physics, engineering sciences and maybe in mathematics are likely to contribute to technological progress in the IT and telecommunications sectors.

As is well known, the UK is characterised by the relative excellence of its academic system. It produces particularly enviable results in the life sciences, and even more so in medical research. This scientific position is a crucial resource for science-based industries or technological spheres such as pharmaceuticals and biotechnologies. French scientific communities, on the other hand, occupy average or mediocre positions in the life sciences. However, French performance in this area has improved considerably since the beginning of the 1990s, particularly in applied biology, where the situation used to be particularly unfavourable. While the French position in mathematics is particularly enviable, it is only average in physics and only mediocre in engineering sciences. Overall, this does not constitute a scientific environment likely to favour the manufacture of IT and telecommunications equipment, if this type of link can be said to have any significance at all (the situation did improve slightly between 1990 and 1995).

Table I-4
World share of scientific output (%) by scientific discipline
(1995)

| Disciplines | European Union | France | Germany | UK | Austria | USA | Japan | Rest of world | World |
|--------------------------|----------------|------------|------------|------------|------------|-------------|------------|---------------|--------------|
| Basic biology | 33.2 | 5.5 | 6.2 | 8.2 | 0.5 | 39.2 | 9.1 | 18.5 | 100.0 |
| Medical research | 37.8 | 4.8 | 5.7 | 12.0 | 0.9 | 36.8 | 7.4 | 18.0 | 100.0 |
| Applied biology-Ecology | 28.8 | 4.0 | 5.1 | 7.8 | 0.4 | 33.5 | 7.6 | 30.1 | 100.0 |
| Chemistry | 31.3 | 5.3 | 8.3 | 6.2 | 0.5 | 23.0 | 12.0 | 33.8 | 100.0 |
| Physics | 29.6 | 5.2 | 8.1 | 5.5 | 0.5 | 27.3 | 9.9 | 33.2 | 100.0 |
| Space sciences | 30.1 | 4.9 | 5.1 | 8.4 | 0.4 | 38.0 | 3.6 | 28.2 | 100.0 |
| Sciences for engineering | 26.0 | 3.8 | 5.4 | 7.2 | 0.4 | 35.5 | 8.4 | 30.1 | 100.0 |
| Mathematics | 31.3 | 7.1 | 7.1 | 5.4 | 0.7 | 33.0 | 4.2 | 31.5 | 100.0 |
| Total | 32.6 | 5.1 | 6.3 | 8.5 | 0.6 | 33.9 | 8.3 | 25.2 | 100.0 |

ISI data (SCI, COMPUMATH), data processing by OST

Industrial R&D expenditure by sector

Table I-5
Industrial R&D expenditure : OECD share (%) in industrial R&D
by industrial sub-sector
(1994)

| | European Union | France | Germany | UK | USA | Japan | OECD |
|-----------------------------------|----------------|------------|-------------|------------|-------------|-------------|--------------|
| Aerospace | 28.7 | 10.4 | 7.9 | 5.8 | 67.2 | 1.6 | 100.0 |
| Radio/TV sets, telecomm equipment | 36.3 | 10.2 | 13.5 | 4.3 | 35.7 | 23.5 | 100.0 |
| Office machines and calculators | 21.3 | 4.4 | 6.4 | 5.3 | 39.9 | 36.1 | 100.0 |
| Pharmaceutical products | 35.5 | 6.3 | 6.5 | 12.8 | 45.2 | 16.9 | 100.0 |
| Other transport | 30.6 | 8.7 | 3.4 | 3.5 | 53.8 | 12.4 | 100.0 |
| Chemical products | 33.6 | 6.8 | 15.0 | 6.0 | 42.1 | 23.1 | 100.0 |
| Total | 31.2 | 7.2 | 11.4 | 5.5 | 43.1 | 23.2 | 100.0 |

OECD data (STAN), data processing by OST

This examination of industrial R&D expenditure in 1994¹¹⁵ produces a somewhat different picture from that based on (European) patent shares, although any comparisons have to be treated with caution (OECD base for industrial R&D expenditure, world base in the case of European patents). The aerospace industry is still the privileged sector of the French high technology sphere, pharmaceuticals and IT are in average or mediocre positions in terms of R&D, while telecommunications (including the production of radio and TV sets) occupies the leading position in terms of **R&D expenditure, accounting for 23% of total French R&D expenditure**, ahead of aeronautics (16.5%), the motor industry (13.5%) and pharmaceuticals (8.8%). IT is a poor relation, accounting for only 3.6% of expenditure. The ranking is very different in Great Britain, where the pharmaceutical industry leads the field by a considerable distance (23.4% of total expenditure), ahead of telecommunications (12.8%) and aerospace (12.2%), with IT accounting for 5.8% of the total R&D effort..

The sums committed perhaps give a more concrete idea of the R&D effort at national and industry level (see Table 11). In general terms, French R&D expenditure is 31% greater than expenditure in Great Britain and 37% lower than in Germany. Nevertheless, in the pharmaceuticals industry, expenditure in Germany and France is about the same, with their combined total barely reaching the level of expenditure in Great Britain (and 28% of US expenditure). In all three countries, R&D expenditure in the IT sector is particularly weak (their combined effort represents only 40% of American expenditure and 44% of that in Japan), especially in France, which is considerably outdistanced by Germany and the UK. The telecommunications and audio-visual sector is one of the few (at least the only one of the three studied here) in which the European R&D effort exceeds that in the USA, with French expenditure alone representing 28.6% of US expenditure (37.7% for Germany and 12% for Great Britain).

Assessing the effectiveness of industrial R&D expenditure

It would be possible to take the analysis further by adopting the approach based on "comparative advantage in sectoral specialisation"¹¹⁶ developed by the OST in its 1998 report. The aim of this approach is to compare advantages in terms of R&D, technologies (European patents) and exports. The first disadvantage with this method is that it does not provide results at a sufficiently disaggregated level to be compatible with our choice of sectors. Nevertheless, the OST report does contain results for pharmaceuticals and some other sectors. They confirm the mediocrity of the French performance in electronics (which covers both telecommunications and IT), which is even worse in technology and, particularly, exports than it is in R&D. The French pharmaceuticals industry achieves average results in R&D and technology, good ones in exports (but less good than Europe as a whole).

¹¹⁵ R&D expenditure in France is said to have declined considerably since that date: more information is required on how this translates into industrial R&D, and more specifically how each industry is affected.

¹¹⁶ Sectoral share/share of economy as a whole.

**Table I-8 :
Comparative advantages in sectoral specialisation 1994**

| Sectors | exports ----- | | | | technology----- | | | | R-D ----- | | | |
|----------------------------|----------------|--------|---------|------|-----------------|--------|---------|------|----------------|--------|---------|------|
| | European Union | France | Germany | UK | European Union | France | Germany | UK | European Union | France | Germany | UK |
| Aerospace | 1.64 | 2.69 | 0.52 | 2.05 | 0.92 | 1.44 | 0.70 | 1.07 | 1.01 | 2.28 | 0.72 | 1.07 |
| Electronics | 0.61 | 0.52 | 0.47 | 1.19 | 1.04 | 1.20 | 1.01 | 0.84 | 0.69 | 0.80 | 0.56 | 0.80 |
| Pharmaceuticals | 1.88 | 1.53 | 1.31 | 2.09 | 1.14 | 0.88 | 0.57 | 2.34 | 0.84 | 0.95 | 0.75 | 1.19 |
| Capital goods | 1.33 | 0.89 | 1.35 | 1.03 | 0.92 | 0.60 | 1.10 | 0.87 | 1.03 | 1.02 | 1.06 | 0.96 |
| Land transport | 0.87 | 1.13 | 1.56 | 0.76 | 1.13 | 1.02 | 1.49 | 0.68 | 1.40 | 1.63 | 1.73 | 1.07 |
| Chemicals | 1.03 | 1.21 | 1.10 | 1.18 | 1.00 | 0.98 | 1.12 | 0.95 | 0.95 | 0.74 | 1.10 | 1.04 |
| Natural resource intensive | 0.92 | 1.19 | 0.81 | 0.88 | 0.75 | 0.91 | 0.49 | 0.65 | 1.10 | 1.03 | 0.97 | 1.07 |
| Labour intensive | 0.90 | 0.72 | 0.79 | 0.73 | 1.02 | 0.90 | 1.21 | 0.72 | 1.24 | 1.18 | 1.23 | 1.08 |
| Total | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

Source Chelem-CEPII, data processing by OST

Economic competitiveness in the high technology sphere: some information on the context

Structural positions vary markedly from sector to sector. In terms of patents, the positions of Germany and France are very close to each other but contrast sharply with that of Great Britain. Both of them have deficits in the balance of trade in IT, while Great Britain has a surplus. In the case of telecommunications, the balance of trade is positive in Germany and France, but negative in Great Britain. On the other hand, the balance of trade in pharmaceuticals is positive in all three countries, although the surplus is smaller in France.

Table I-9
Balance of trade in high technology sectors
(in Mecu) (1994)

| | France | Germany | UK | Portugal | Austria | USA | Japan |
|-------------------------------------|--------|---------|-------|----------|---------|---------|--------|
| Aeronautics | 6 972 | -814 | 2 180 | -388 | -131 | 24 186 | -4 045 |
| Measuring apparatus and instruments | -265 | 6 230 | 1 425 | -260 | -446 | 8 052 | 5 232 |
| Pharmaceutical products | 1 667 | 3 790 | 3 161 | -410 | -283 | 1 407 | -2 307 |
| IT hardware | -4 314 | -6 485 | 476 | -532 | -1 249 | -18 432 | 21 192 |
| Electronic components | 625 | -786 | 754 | -199 | -59 | -6 272 | 25 438 |
| Telecommunications equipment | 685 | 735 | -112 | -316 | -448 | -4 057 | 16 858 |
| All high-tech sectors | 5 372 | 2 669 | 7 883 | -2 105 | -2 616 | 4 884 | 62 368 |

Source Chelem-CEPII, data processing by OST

Since 1991, the situation has deteriorated markedly in the French IT industry (the deficit rose by 57%, compared with only 15% in Germany); in pharmaceutical products, the improvement in the balance of trade is somewhat less marked (+38%) in France than in Germany (+41.6%), but considerably greater than in the UK (+18.6%). The 1994 figures for telecommunications also reveal a positive trend, with the trade account more than doubling. Was this the first effect of the renewed R&D drive?

This said, however, the improvement observed must not be allowed to conceal the fact that, overall, French losses of market shares in high-tech exports are greater than those experienced in Great Britain and, particularly, Germany. The decline is slight in pharmaceutical products, more marked in telecommunications and considerable in IT.