National System of Innovation in France: the case of information technology industry

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Introduction

The aim of this paper is to describe the functioning of French innovation system through a case study of information technology industry. For this purpose, I intend to use the conceptual framework of "national system of innovation", more and more legitimized in the field of Economics of Innovation. Indeed, the economic literature became, from the mid-80's, clearly interested in such a concept (Freeman 1987, Nelson 1992, Lundvall 1992, Edquist 1997), to explain new trends of economic activity based on the knowledge incorporated in science and technology. It is out of the scope of this paper to discuss about all characteristics of this literature. Although composed by different schools, this economic literature shows certain convergence in its approaches. It seems profitable, for my own analysis, to highlight some common aspects that could serve as guideline.

Firstly, the innovation process which constitutes the engine of modern economy is seen as a socially bounded one, rather than as a mechanical and linear process. In other words, the creation of new technology or new idea occurs in "socially embedded process". Such a conception of innovation leads to understand this phenomenon within the national, socio-cultural and idiosyncratic contexts.

Secondly, all approaches give to national institutional infrastructure a key role, in order to comprehend the innovation capacity of a nation, its structural changes and its economic performance. Therefore, the crucial issue is to put into evidence the internal coherence which may be logically established between the innovative behaviours of firms and the incentive mechanisms supported by a set of national institutions.

Thirdly, once given, this coherence in a national system of innovation represents both the resources and the constraints for firms, because it tends to favour a certain way of innovation and at the same time to prohibit any deviation from a dominant pattern[1]. This creates an institutional inertia, phenomenon termed "path dependency", which defines powerfully a national innovative trajectory over time. Thus, even if a dominant pattern of innovation specific to a nation evolves over time, the speed and the scope of this change remain often limited by the institutional inertia effect.

Fourthly, the national institutional infrastructure is considered as a environment which interacts with firms. This environment includes many kinds of institutions: laws, regulatory rules (patents legislation, technical standardisation etc.), trade customs; market competition, user/producer relationships, subcontracting system, alliance or cooperation behaviours; banking system, financial regulation; public institute of research, university, training system etc. Although each of these elements plays its specific role in the construction of national competitiveness, many authors put a strong stress on the importance of combinatory institutions between public and private interests. In this sense, research infrastructure and higher education system must be seen as the most important institutions which produce the public goods for innovative firms.

The main thesis in this paper consists in

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[1] This notion seems to me very closer of what Aoki termed "strategic complementarity".

arguing (1) that the France has historically constructed a particular form of innovation capability through the multiple interaction between firms and institutions, in particular its higher education system and a huge public research institution, (2) that this strong interdependency creates a institutional inertia which continues to influence and to constraint the innovative behaviours of French firms, (3) that the divergent trajectory between hardware and software sectors in French IT industry could be understood, only if one grasped the very nature of institutional arrangements in this country.

After a brief presentation of historical trajectory of French IT industry in the first part, I will deal with its structural dynamics in the second part, by distinguishing the computer sector and the software sector. This sectoral analysis allows to show both a certain weakness of hardware sector and a competitive edge of software sector. In the third part, I will point out the creation mechanisms of cognitive and human resources, in insisting on the role of higher education and research system. Then I will further enlarge the analysis to consider the way in which IT French firms absorb and use such resources.

I-Short History of the French IT Industry

Given the domination of American computer makers, notably IBM in the 1960s, all European countries have at some time perceived the necessity to exercise some form of state-interventionism in the IT industry. French policy in this area has been the most systematic. These policies, which commenced in the middle of the 1960s, were essentially a reaction to the relationship of dependency with the Americans multinationals, and were constructed upon clearly interventionist concepts, resulting in an explicit industrial policy, known as "Plan-Calcul". A lot of political measures under the Plan-Calcul were implemented but didn't succeed in achieving the objectives set out for it.

The formation of a socialist government in 1981 further reinforced the influence of the state on the IT sector, particularly through the nationalisation of the main firms. Under the "Electronic filière" Action Plan, finalised in 1982, the state undertook a vast restructuring programme of the electronic sector around central "poles" within the public sector: Matra and Thomson in components, CGE in office applications and telecommunications, Bull in computer industry, Thomson in electronic consumer goods—including microcomputer—, and Matra and CGE in industrial automation.

After the absorption by Bull of the IT subsidiaries of Thomson and CGE within the framework of the Plan, the French IT sector became organised around three main actors: IBM-France, Hewlett Packard and the Bull, which became the sole "national champion". The latter was able to consolidate its technological position through alliances around the Unix norm, and its commercial position through its captive market in the French Administration. But Bull was hit by the global IT recession at the beginning of the 1990s. Bull suffered disproportionately because it remained a general manufacturer centred on mainframe systems, and had neglected the rise of personal computers (PCs). The 1990 take-over of an American specialist in PCs, Zenith Data Systems, came too late to save Bull from a "historical" demise. Bull now aims at being an integrator of technologies, abandoning progressively its own production of computers in favour of external supplies from its foreign partners: Intel for microprocessors, NEC for mainframes and IBM for servers.

While hardware constructors have been weakened, French software providers (SSII) still show a degree of competitiveness and assure certain success. Software services firms have from the outset assumed the role of consultants/strategists in IT integration within the firm as much as that of software application technicians in the narrow sense of the term, and thus occupy a strategic position in the installation of IT systems. This positioning of the French software firms in the IT sector is inseparable from the historical context. At the moment that the "Plan-Calcul" was put into place, all IT producers were

American. Yet it was politically unthinkable to entrust American multinationals with the realisation of important works of IT engineering in the areas of defence, aerospace or finance. It was therefore necessary to create a national intermediary between the French administration and American producers: the first SSII seized this opportunity, and many such French IT service companies, at least in the beginning, worked with a public client which both accounted for the majority of their turnover and contributed to improving the quality of their technical expertise.

In the 1980s and 1990s, the considerable extension of fields of application and the growing complexity of user needs generated a demand for IT solutions and software packages. A great number of new operators appeared in the software and applications sectors. On the one hand, large firms rapidly began to create subsidiary companies out of their own IT divisions. In particular, all the large banks hived off their IT divisions, thus creating large IT service companies. At the same time, the large electronics companies created networks of IT service subsidiaries. On the other hand, a breeding ground was created for new independent service companies, particularly during the 1980s, with the rapid diffusion of PCs. In spite of a high failure rate, these small firms displayed dynamism and a capacity for adaptation: a good number of such firms developed a more professional orientation, acquiring the know-how to offer "IT service packages". Also, new "cutting edge" software firms, created by the public research centres, were established in high technology areas such as artificial intelligence, software tools, etc. As we will see it later, for example INRIA (National Institute of Computer and Automotive Science) has created 37 research-based start-up from the mid-1980s. With this extremely diverse collection of IT service firms, France was able to build a level of IT competencies which maintained its capacity for adaptation to an information society at a high level.

II-French IT industry Structure: weakness and competitive edge

The French IT industry, as those of most other European countries, has come under intense technological competition from the USA. The structure of supply in the industry is dominated by the presence within France of American firms both in the production of computers and in the editing of software packages. French firms have progressively abandoned computer production; the last remaining producer, Bull, has now repositioned itself as an integrator, with the production of computers left to foreign partners. French strengths can be found in IT services based around system integration and the development of applications. However, French firms in these areas are currently having to adapt to the standardisation of tools and the "industrialization" of the software service market.

In examining the structure of supply in the IT industry, we make a distinction between two separate sectors, namely the manufacture of computer hardware and the software services sector. Such a distinction between hardware and software has become gradually less significant, both with regard to the technology used and in terms of company strategies. For example, 30% of IBM's sales (or 138 billion francs in 1998) are now in services, as the company attempts to compensate for the collapse in prices and thus revenues in its original computer market. Additionally, IBM, which directly employs 10,000 people in France—including 3,000 in service activities—as well as indirectly employing 5,000 computer engineers in 8 subsidiaries, finds itself covered by two separate collective agreements (metallurgy and IT services). As a consequence, its IT workers operate under different regulatory conditions, even if they are working on the same projects or for the same clients. This type of division, which IBM is trying to correct, is a good illustration of the increasing inadequacy of the standard definitions of companies' activities. However, the nature of

Table I-Main actors in software and IT services, 1997

IT service specialists in Europe	Turnover in millions of francs	World-wide software editors	Turnover in millions of francs
IBM (USA)	35.6	IBM (USA)	69.3
EDS (USA)	21.3	Microsoft (USA)	51.5
Cap Gemini (Fr)	16.7	Fujitsu (J)	24.4
Andersen Consulting (USA)	13.3	Computer Associates (USA)	15.8
Siemens-NI (G)	12.9	Oracle (USA)	12.5
Debis S. H. (G)	10.4	NEC (J)	11.9
Computer Sciences (USA)	9.4	SAP (G)	9.2
Sema Group (Fr/GB)	9.3	Hitachi (J)	6.9
Bull (F)	9.2	Novell (USA)	6.3
Atos (F)	8.6	Digital (USA)	6.3

Source: Pierre Audoin Conseil

national statistics, which remain based on a strict division between manufacturing and services, force us to consider the two areas separately.

A) The IT hardware industry

This industry (computer and office machine manufacturers) covers 88 firms (of more than 20 employees) with a total of 41,668 employees (1995 figures). Their combined turnover is 83.4 billion francs, and their total value added some 24.8 billion francs. This sector therefore represents 0.4% of French manufacturing firms, 1.5% of the employed population and 2.7% of total production. There was a clear decline in this sector in the period of global crisis in the IT sector between 1990 and 1995: the number of firms declined from 103 to 88, while the number of employees went from 55,059 to 41,668, a reduction of 24%. The weakness of this sector is revealed through a permanent deficit in the balance of trade: while the industry exports 44.7 billion francs, or 54% of its production, French imports in IT hardware total 66.1 billion francs, giving a deficit of 21.4 billion francs: this deficit has consistently been around 20 billion francs per year since the beginning of the 1990s.

The sector is characterised by an extremely concentrated structure of production: the top four firms—IBM France, Hewlett Packard France, Bull SA and Lexmark International—represent 77.7% of total turnover and 71.5% of employees (Cessi 1995).

IBM France has two production sites; mainframe computers are produced at Montpellier (900 employees), while the site at Corbeil-Essonne (2,800 employees) manufactures semiconductors. Hewlett Packard France has been based in the Grenoble region since the beginning of the 1970s, where it has two sites; the 2,530 employees include both R&D workers for PCs and the manufacturing function: personal computers, servers, portables, etc. The only French producer, Bull, has four research centres - two in France, one in the USA and one in Italy - and two subsidiaries which carry out production: Bull Electronics Angers makes Unix series professional systems, while Nipson International produces printers at Belfort, employing 370 people. Bull sold Zenith to Packard Bell/NEC in 1996; this company continues to produce portables and servers at Angers, with 750 employees. In the domain of office machines, Rank Xerox has a production facility and research centre at Grenoble. Canon France (600 employees) carries out R&D and manufactures photocopiers in Brittany. Elsewhere, Digital Equipment, which was recently bought by Compaq, has 2,900 employees, 500 of which work in a telecommunications development centre at Sophia Antipolis Science Park, where Texas Instruments (570 employees) also has a research centre in digital technologies.

The French computer industry is thus mainly made up of generalist firms which, with the exception of Hewlett Packard France, compete in markets of weak growth or even decline. Producers have proprietary operating systems for mainframe systems, and thus a captive market which represents a large proportion of their activity. None of the firms operates in sectors characterised by high margins, such as workstations, or high growth, such as PCs. The main firms with a presence in France are American PC producers; only one Japanese manufacturer has a production site in France. Bull has been totally absent from the PC market since it was separated from its subsidiaries, notably Zenith Data Systems.

The poor position of France in the PCs area cannot be explained purely in quantitative terms. We must bear in mind that the entire IT industry has been qualitatively reorganised around the PC technology.

The twin trends towards standardisation and "cloning" (IBM compatibles) in the PC production have displaced innovation and commercial dynamism in computer industry. Essentially, the standardisation of the product itself has drastically altered competitive practices within the industry. The successes of client/server systems and of "downsizing" bear witness to the central role now held by the microcomputer in data processing systems. This PC market is not one for high technology products, but rather one of mass production. The criteria for competitiveness are the cost and quality of components, along with productive flexibility. As was illustrated by the problems Bull experienced because its small market share, it is not possible to be competitive without benefiting from economies of scale.

Previously, the computer industry was based on proprietary system architecture. This required a strongly vertically integrated firm —as Bull was until 1990—, engaged in all aspects of the production and marketing process, from microprocessor design to product sales. The advent of microcomputers ended this form of integration. IT systems were progressively rebuilt around the PC networks, with elements of the system being supplied by different firms. Supply became segmented, reducing the power of mainframe manufacturers.

One fundamental aspect of this evolution has been the split between manufacturers and software houses. This is an important development, as the control of computer network architecture has been transferred to the software houses and the producers of microprocessors. This shift has caused a crisis in the former mode of competition, based on proprietary, closed systems. Manufacturer-supplier relations have been fundamentally transformed, with the larger share of value added being created away from the processes of integration and assembly. The value added in hardware is tending to dwindle as the machine itself becomes commonplace and standard. Rather, the production of value added has been transferred to software, or to system architecture (operating systems, network management, programming tools, etc.). This shift in the hierarchy from machines to applications is reflected in the dynamics of prices for software applications and IT services.

Yet the dimensions of competition are changing further. The dual trend towards digitalisation and information networks is rapidly making multimedia applications the next crucial area of competition. Located at the frontiers between audio-visual, IT and telecommunications technologies, multimedia is giving rise to the emergence of new communication tools which are of considerable significance for the future of society. The desire for control of this coveted market has already given rise to intense competition between industrial actors. The stakes for industry are considerable: this new market, which has emerged at the crossroads between different technologies and industries, seems likely to grow rapidly, and has hence attracted a large number of new entrants-IT manufacturers, manufacturers of household electronic goods, cable operators, telecommunications systems operators.

The position of France in multimedia technology is not so bad, although American firms remain dominant in all areas of the market. This situation is due to the combination of two elements: the dynamism of specialist small and medium-sized enterprises based on the continual arrival of new "start-ups"; the proximity between IT services and telecommunication network, a sector protected by the state until recently in France which may create important opportunities to promote local development synergy.

B) The software industry

The French IT industry displays a high capacity of supply in the area of IT services and consultancy (table I). Although marginalized in the production of computers and involved only in certain areas of packaged software, the France is among the European, and even world, leader in IT services. In effect, French companies have generally retained the leading places in extremely dispersed domestic or European markets. The ten largest IT service companies with over 1,000 employees only hold 18–19% of the French market. The remainder is shared among a large number of much smaller, often locally-based firms, which cater for the local economic infrastructure.

According to INSEE figures, tertiary IT activities (consultancy, software services, data processing, maintenance) cover 21,900 firms with a combined turnover of 125.8 billion francs, which created 65.9 million francs of value-added and occupied 191,400 members of the active population in 1995. Such firms therefore represent close to 4% of the number of service firms, 10% of tertiary production and 6% of employment. The sectoral structure (of the software and computer services sector) is strongly dispersed: of 15,550 firms, 6,660 are one-person operations with no employees; only 2,200 have more than 10 employees, and only 128 employ more than 1,000 people.

With regard to the large software and computer services companies, the French software market is characterised by the importance of computer services (table II). Indeed, it is interesting to note that the position of IT services relative to software packages differs according to the area or country in question. IT services account for 80% of the overall market in Japan, as compared to 64% in the USA and 61% in the EU. Within the EU, however, there is a contrast between France, where services are dominant, and Germany, which clearly favours software packages. This diversity in market structures seems to rest not only on cultural practices, but also on the strategic behaviour of client firms and the institutional environment of each country.

However, French software sector is now facing some profound organisational changes implemented by the globalisation of service economy:

Firstly, the nature of work is evolving towards what might be termed the "industrialization of services supply". Many generalist software and computer services companies had long tended to offer tailor-made solutions to the individual demands of their customers, but competition has forced a rationalisation of service production systems. In response to this need, many such companies have attempted to introduce catalogues of services. Here we are not referring to the supply of soft-

Table II-Distribution of software/IT services in 1997 (Ecu millions)

	Software packages	IT Services	Software+Services
Germany	11225 (47%)	12495 (53%)	23720 (100%)
France	4847 (30%)	11446 (70%)	16293 (100%)
United Kingdom	5672 (40%)	8528 (60%)	14200 (100%)
Europe; sub-total	34894 (39%)	55525 (61%)	90419 (100%)
United States	48527 (36%)	86671 (64%)	135198 (100%)
Japan	7898 (20%)	32603 (80%)	40501 (100%)

Source: EITO

ware packages, but rather to a service focused on clearly identified needs, with well-defined tariffs and modes of work. In other words, catalogues of services are being presented, priced in accordance with the level of service supplied and with guaranteed outcomes. This type of industrialisation allows companies to capitalise on their know-how through the supply of a precise service, to recuperate expenditure on development, and thus to significantly reduce the cost of each individual service.

Secondly, French companies have a lower profile than ever in the development of software packages, even for niche markets. Through the globalisation process, even highly specific software packages can immediately be adapted to international demand, and thus have access to enormous markets. To be competitive in this area, however, requires huge investment. At the same time, all service providers have understood the desirability of integration around software packages. Through this, service providers have found a means of employing resources which were previously devoted to simple technical assistance. Thus, many software and computer services companies have been converted into specialists in the integration of software packages. This rise of software package engineering requires greater resources than the provision of services, and thus requires solid financial foundations.

Finally, firms which were previously limited to one-off service provision, are now seeking to develop more regular and stable relationships with their customers, and to this end are developing a wide range of services. For example firms are developing services such as facilities management contracts which commit clients for long periods (a minimum of three, but sometimes seven or even ten years), Further, in linking under the banner of facilities management areas such as operations, maintenance, applications management, etc., firms can develop a whole series of services which aim at creating customer loyalty. Another method of going further in this direction is for service providers to become more involved in the definition of services required, through investing in "turnkey" services which aim to take responsibility for the entire IT functions of companies. Such service relationships thus foreshadow the development of a new type of partnership within the economy.

III-Institutional Creation of Resources for French IT Industry

After a brief presentation which sketched the sectoral configuration of French IT industry, I will now examine how the French system of innovation produces, for IT industry, together the professional actors and the cognitive resources through its higher education system and public research programmes. My hypothesis is that the way in which these actors are formed is not likely to be indifferent with the French IT industry's structure or its strategic behaviour. In other words, I presume a strong interdependency between the resource formation and industrial capability.

III-1 The Higher Education System as a Producer of Human Resources

Since the middle of the 1980s, the French higher education system has succeeded in increasing the supply of IT professionals, without the quality of such education being reduced. Although failing to satisfy all demands, particularly with regard to continuing training, it has proved capable, in cooperation with firms, of diversifying the training offered. The entire French economy has thus benefited from the production of increasingly well-trained IT professionals. Software and IT services companies continue to attract a significant share of newly qualified engineers from the "grandes écoles", who constitute the most socially legitimated supply of human resources. This is an important factor in explaining the strength of French software and IT services companies.

In this section, I start to deal with an evaluation of the stock of computer engineers in the French economy, and its evolution over time, using national statistical sources. I will then consider the means by which computer scientists/engineers are "produced", through an examination of the IT education system and flows of students. Finally, I will briefly consider the structure of the labour market in the IT sector.

A) IT professions in the French economy

Through the national employment survey (INSEE 1989, 1997), we can analyse both the structure and development of the number of jobs linked to IT (computer scientists, programmers, operatives).

Between 1983 and 1989, the total of IT jobs grew by an annual average of 4%, from 247,000 to 316,000. This growth has slowed in the 1990s, with the total reaching 338,000 in 1997. In spite of this recent slowdown, the longer-term growth in IT employment (37% in fourteen years) remains spectacular; in the same period of time, employment growth in the wider French economy was only around 4%.

It is interesting to note that this growth in IT employment has been accompanied by a considerable change in the structure of employment, suggesting that IT occupations have been profoundly affected by technological change. It is possible to distinguish three categories of jobs, which have seen contrasting developments: firstly, the number of specialist IT engineers and managers has grown significantly, from 79,000 jobs in 1983, to 126,000 in 1989 and 181,000 in 1997-a rate of growth close to 8% per year. This category of jobs, at the top of occupational hierarchies, represented 54% of IT employment in 1997, as against only 31% in 1983, and thus plays the central role, both quantitatively and qualitatively, among IT occupations. The number of employees in the second category-programmers and technicians- grew rapidly until the middle of the 1980s, before stabilizing at around 100,000. The third category, composed primarily of keyboard and computer operators, has declined in number, particularly in the 1990s. In the medium term, further strong declines in the numbers of such workers because of the automation of basic IT operations.

I will attempt to characterise two groups of IT workers in which we have specific interest, namely IT engineers/managers and technicians/programmers[2], in terms of qualifications, age and occupational seniority. Table III illustrates some of changes in the characteristics of these populations between 1989 and 1997.

—Of the engineers/managers, the vast majority (85%) are male, with a high level of qualification: 29% attended "grandes écoles", and a further 26% followed university courses above master's level. Thus, 55% have four years of post-baccalauréat education. Only a fifth of this occupational group had the baccalauréat or a lower-level qualification. The percentage of IT managers/engineers who are "self-taught" in this way fell from 34% in 1983 to 20% in 1989, while the proportion with intermediate-level qualifications (two-years post-baccalauréat education) has increased rapidly (from 10% in 1983, to 17% in 1989 and 25% in 1997). This increase in the proportion of "higher-level", or "Bac+2" technicians, is a general phenomenon across the French economy, but is particularly marked in the IT profession, reflecting a French orientation in the training of computer scientists/engineers that places the emphasis on those leaving university education at this level. This population of computer scientists/engineers is also characterised by its youth; 40% are under 35 years old (compared with 30% of workers at this level in organisations across the economy), and only 27% are over 45 years old (as against 37% in the wider economy). However, the relative ageing of computer engineers considerably accelerated between 1989 and 1997.

[2] IT job hierarchies in France are divided into three broad categories: "cadres and ingenieurs", who are those employees responsible for the conception of work, are separated from those responsible for its execution, with technicians and supervisors forming an intermediate level. All further references to "engineers" and "managers" thus refer to high-level employees with responsibility either for management or the design of work, rather than the more traditional English interpretation of what constitutes an engineer.

Table III-Evolution of characteristics of computer/software engineers

	1989		1997	
	Engineers/Cadres	Technicians/ Programmers	Engineers/Cadres	Technicians/ Programmers
Academic Qualification				
− Bac	11%	33%	10%	35%
Bac	16%	25%	10%	18%
BAC+2	17%	31%	25%	35%
BAC+4 and more	56%	12%	55%	12%
Total	100%	100%	100%	100%
Age				
−35 years	47%	59%	40%	47%
35–44 years	38%	28%	33%	35%
45 years and +	15%	13%	27%	18%
Total	100%	100%	100%	100%
Seniority in the firm				
−5 years	45%	43%	40%	42%
5–9 years	22%	20%	25%	22%
10 years and +	33%	34%	35%	36%
Total	100%	100%	100%	100%

Source: INSEE Enquête Emploi

This signifies an increasing degree of stability of such employees within their occupations, where they had previously tended to leave such jobs to move into more general managerial functions.

—The second population, that of programmers and technicians is less male-dominated, with one quarter being women. The group is also extremely young, with half being aged less than 35 years. 47% possess BAC+2 level qualifications (or higher). Although there still exists a significant proportion of "self-taught" programmers (35% do not even have the baccalauréat), the share of "higher-level" technicians with higher education qualifications appears to be very high in the IT sector. In general, these young, higher-level technicians start their careers as programmers before moving towards jobs as analysts/designers in the course of their career. This career path takes some such workers into the manager/ engineer category.

B) The supply structure of computer engineers

The training of computer professional workers in France was long considered inadequate, but clearly improved from the middle of the 1980s onwards, and particularly in the course of the 1990s. Considerable efforts have been made by the education system, in concert with the state, both in initial and continuing training. The state has put in place training programmes for many new careers in the area of IT, such as the training of engineers through apprenticeships. Thus the annual flow of newly qualified computer scientists from the higher education system increased from 4,200 in 1982 to 10,200 in 1991, and reached 20,100 in 1997; in other words, the annual capacity of the higher education system to produce computer engineers increased fivefold over 15 years. There has also been a dramatic increase in the number of students achieving qualifications at the BAC+4 standard or higher, a group which the different areas of the IT sector require as a priority. The comparison with UK and Germany shows the very importance of such efforts: in 1996, the UK trained only 6,000 computer scientists and 4600 electronics engineers, 70% of which had three years' university education. In the same year, Germany produced 6,600 IT graduates, half in universities (6 years or more) and 11,700 electronics engineers, 40% of which were trained in universities. But Germany recently sees the number of university graduates in electronics diminishing.

Independently of the early 1990s IT crisis, which led to a temporary contraction in demand for computer engineers, this quantitative improvement in the labour supply has helped to reduce the mismatch between supply and demand of specialists on the labour market. Moreover, the supply of training for computer scientists appears to be increasingly better matched to demand, as the higher education system has displayed a capacity for producing increasingly specialised qualifications. Dialogue between IT firms and higher education institutions, promoted by the state, has resulted in the establishment of courses and syllabuses which are capable of integrating technological progress, following the example of the MIAGE qualification. Although the renewal of growth in the IT sector from 1997 could bring with it a risk of a new shortage of computer scientists, the French higher education system does appear to be much better equipped than previously.

With regard to initial training, few courses are solely dedicated to careers in software.

Table IV-Formations of Information technology in France (persons)

	1991	1997		
Level of educational attainment	Annual inflow	Annual inflow	Continuation rate of study	Solde (Entry into the labour market)
IUT administrative software course (BAC+2)	} 3800	2800	60 à 65% (1750)	1050
IUT industrial software course (BAC+2)		2500	45 à 50% (1200)	1300
BTS administrative software course (BAC+2)	2000	2300	40 à 50% (1000)	1300
Licences degree (BAC+3)	1500	1700	70 à 80% (1300)	400
Master's degree (BAC+4)	1250	1400	45 à 50% (650)	750
IUP/Miage (BAC+4/5)	800	1200	40 à 50% (550)	650
DEA (BAC+5)	1050	1300	25 à 30% (350)	950
DESS (BAC+5)	1300	1600	5% (100)	1500
PhD (BAC+8)	400	400	—	400
Engineering schools with specialisation in the computer science (Bac+5)	2100	2400	5% (100)	2300
Engineering schools without specialisation in the computer science (Bac+5)		2200	2% (50)	2150
Other courses (AFPA, écoles consulaires)		2500	—	2500
Total				15250

Source: Syntec-Informatique

Note: the number of schooling years after the BAC (Baccalaureate) corresponds to the level of exit from the higher educational system.

Those seeking careers in this area, and entering scientific education, will most likely follow general IT courses (hardware+software) in which programming and software are the dominant elements. These various initial training courses are provided within various tracks that make up the traditional higher education system (Table IV).

1) The first track consists of short courses at the BAC+2 level (DUT-diplome universitaire de technologie, or BTS-brevet de technicien supérieur). Such qualifications are considered vocational and directly focused on the labour market, and attract numerous students who are either seeking a rapid entry to the labour market, or to gain a qualification that will give them access to longer academic courses.

The BAC+2 diploma qualifies students as programmers or IT technicians, but limits them to a certain range of jobs; although it does not prevent them from reaching higher status jobs in the course of their careers, it does tend to restrict them to the technical tasks of programming or maintenance, and makes progress beyond the lowest ranks of management difficult. This is one of the reasons why almost half those obtaining such diplomas continue their studies afterwards, either in universities or grandes ecoles.

2) The second track consists of the longer courses required to qualify for professions at all levels of the IT industry. This stream, which accounts for one third of total annual flows of computer specialists, include several pathways that have different aims.

—The first of these pathways is the most traditional and ranges from degrees in IT to doctorates, via masters' degrees and the DEA (post-graduate diploma). This route, culminating in around 400 doctoral theses per year, has the function of creating a reserve of IT researchers, both for higher education and public-funded research. France has a significant intellectual force of more than 3,000 IT researchers in different public organisations such as the CNRS (National Centre of Scientific Research), INRIA and CEA (Centre of Nuclear Research).

—After a masters' degree, it is also possible to follow a more vocational programme of study, the DESS (one-year postgraduate diploma in an applied subject), which affords direct access to managerial status. This Bac+5 diploma is a relatively recent development, often jointly organised by universities and firms. The fact that these programmes are designed in association with practitioners gives them a reputation for meeting the needs of firms. For example, the Compiègne Technological Institute has often co-operated with major users such as computer services companies, in order to train computer scientists in specific languages.

There is also a specialist master's degree in IT for management, MIAGE. This training course (1,600 hours over 2 years, plus 4 months' in-firm training) has become very popular among the most reputed employers such as IBM and Cap Gemini, and is seen as representing excellence in the area of IT for management. Students are principally recruited among holders of the DEUG (a qualification taken after two years' university study) in sciences or economic science. The selection process is rigorous - on average, only 12% of candidates are admitted. This route is thus very elitist, allowing comparison with the engineering "Grandes Ecoles", and is an exemplary case of success in the attempt to match university training to the requirements of business and industry.

3) The third track is the engineering schools "Grandes Ecoles" themselves; these constitute the French model par excellence. France has 200 such institutions, producing a total of 24,000 graduate engineers per year. While all the écoles offer IT training, only around thirty are generally considered to be "IT schools"; these produce 2,400 IT specialists per year. Additionally, around twenty general engineering schools have significant options in IT, accounting for a further 2,200 engineers. The ability to recruit highly qualified engineers is one of the strengths of the French IT industry, particularly in the service sector. The large software and computer services companies alone attract between a quarter and

a third of newly qualified engineers, depending on the state of competition. Such firms tend to recruit engineering graduates regardless of specialisation, and tend to offer a further 3 to 6 months' training depending on the type of programming used by the company. For this reason, these firms are sometimes regarded as a private extension of the university system for graduates in general sciences.

More generally, it is more important de put stress on the social and professional role of graduate engineers in France. Compared with the Anglo-Saxon countries and Japan where the engineer status is not controlled at all, the French state organises the training of engineers, evaluates the engineering schools and controls access to qualified engineer status: the engineering degree awarded by these engineering schools confers on these graduate engineers a social and professional legitimacy that immediately gives them access to the position of "cadre", which is regarded as an integral part of company management. Protected by a law and recognised by the collective agreement, the emblematic figure of the graduate engineer in France proves to be highly legitimated (Lanciano and Nohara 1999). The French education system deliberately sets out to create a very high level of educational and professional stratification linked to the qualificational pyramid. This multi-layer system is based not only on the varying lengths of time required to obtain the various qualifications but also on institutional duality, such as that created by the distinction between the universities and the "grandes écoles". Students are selected on the basis of academic criteria, despite the existence of technical or vocational streams. In particular, access to higher technical and scientific education is obtained on the basis of tests of general academic attainment, notably in mathematics and physics. Thus the major engineering schools, "elitist" institutions at the top of the academic hierarchy, provide training based on academic disciplines and mathematics-based formation and produce engineers technically "generalists", even though the schools themselves specialise to a greater or lesser extent in certain technological fields (telecommunications, aeronautics, civil engineering, etc.). The most academically able graduates of the "grandes écoles" gravitate towards the State bureaucracy "Corps d'Etat" (i.e. the various branches of the civil service), which is engaged not only in industrial policy but also in large-scale scientific programmes, which gives rise to a certain degree of complicity with industrial firms that are often managed by graduate engineers. This technocracy composed of "state engineers" coordinates and supports a "national big project" (Ziegler 1997)[3].

The role of continuing training within firms is necessarily important in the career management of computer engineers, because of the pace of change of the technology itself, particularly with regard to programming languages. The large software and IT services companies spend, on average, more than 6% of total labour costs on training. Similarly, the average annual volume of training is close to 13 days among computer producers, and around 10 among major users. Beyond the quantitative aspect, the major firms frequently update their training methods and establish their own autonomous training systems: Thomson, an electronics firm, has put in place an internal "Thomson University Campus", where software engineers, for example, can periodically update their knowledge, often with the aid of experts from universities; Bull organises courses in cooperation with the Association for Adult Vocational Training.

C) Careers, Mobility and the Construction of Competencies

According to the INSEE employment survey (1997) the total number of IT workers (engineers/managers and technicians/program-

[3] This author analyses deeply the way that differences in the forms of socialization of engineers between France and Germany create the divergences on the public industrial policy in the two countries. The existence of "state engineers" in France and its absence in Germany seem to lead to the "mission-orientated" policy in the former case and to the "diffusion-oriented" policy in the later case.

Table V-Characteristics of computer/software engineers by sector

	Computer Industry 10800 persons	Software House 94800 persons	User 185000 persons
Academic qualification			
– BAC	23%	12%	23%
BAC	6%	10%	16%
BAC+2	25%	26%	30%
BAC+4 and more	46%	52%	31%
Total	100%	100%	100%
Age			
– de 25 years	3%	4%	3%
25–39 years	39%	68%	57%
40–49 years	25%	23%	28%
50 years and +	33%	5%	12%
Total	100%	100%	100%
Size of enterprise			
–50 employees	41%	53%	40%
50 to 499	5%	28%	23%
500 and +	54%	19%	37%
Total	100%	100%	100%
Seniority within the firm			
–1 year	12%	13%	12%
1 to 5 years	7%	38%	19%
5 to 10 years	19%	30%	23%
10 years and +	62%	19%	46%
Total	100%	100%	100%

Source: INSEE Enquête Emploi

mers) is around 281,000. This can be divided into 94,800 in software and IT services companies, 10,800 in computer manufacturers, 61,500 in users in the manufacturing sector, and 113,900 in users in the service sector. In fact, 40% of all IT workers are employed by service-sector users, including 10.3% in commerce, 6.4% in financial institutions and 6.8% in telecommunications. Naturally, however, software and IT services companies are the biggest employers, accounting for around a third of this population. Of the IT professionals employed by such firms, the vast majority (72,000) are engaged in some aspect of software development. While the number of employees in commercial functions is increasing rapidly, the proportion has still not reached 10%. By speciality, 58% of IT practitioners work in IT for management, 15% in industrial IT, 12% in scientific IT and 15% in systems and networks.

Computer manufacturers employ relatively few of these workers (only 3.9% in 1997): while such companies remain the largest employers of IT professionals within the manufacturing sector, their relative share has diminished in the 1990s, while increasing numbers of such workers can be found in industries such as aeronautics or automobiles.

The same statistical source makes it possible to break down the IT professional population by industry (Table V). This will provide some insight into the employment policies adopted by the different sectors which use IT workers.

As far as computer manufacturers are concerned, IT professionals represent around 60% of the engineer population. Although there are a significant number of researchers and sales engineers in this industry, these can be assimilated into the IT professional category, to the extent that they share the same IT "culture". Among the ranks of technicians, however, programmers are outnumbered by maintenance workers. The IT workers in this sector tend to be considerably older and to have longer job tenure than similar workers in different sectors; 54% are over 40 years old and have more than ten years' seniority. This demographic structure reflects both the relatively well-established nature of the industry and also the fact that the specific nature of the competencies held by many such workers (system engineering, system architecture or operating systems) acts as a brake to mobility. As was demonstrated during the crisis of the IT industry, the IT workers employed by computer manufacturers are not always capable of retraining in the area of applications. Finally, such workers tend to be somewhat polarised between those that work in very large establishments, and those in small firms, often subcontractors for the manufacturers.

Users employ a more heterogeneous population of IT professionals, who tend to work more in the area of programming. Although relatively young, these workers tend to be less well qualified and less mobile. A substantial proportion arrives in the IT function following internal promotion.

The software and IT service companies attract the youngest, most mobile and most highly qualified IT professionals, who often work for small businesses. These characteristics result from two phenomena which structure the labour market for IT professionals:

Firstly, software and IT service companies remain major employers of newly qualified graduates. Most new recruits are qualified to at least Bac+4 level, and many are graduates of the "grandes écoles". This mutual attraction between young graduates and the software and IT service companies is based on an "implicit contract" through which the strategic interests of both parties are temporarily aligned. For the young workers, the software and IT service companies provide a first experience of employment, the opportunity to learn different technologies, a variety of tasks and the possibility of work in different areas; for the companies, these workers have considerable attributes, including a readiness to take on work for which it is sometimes difficult to find employees (frequent travel and secondments, variable hours of work, heavy workloads etc.), adaptability to sectoral or technological change, and lower pay expectations. After this initial period of a few years, the mobility of IT professionals accelerates fairly rapidly. Indeed, many software and IT service companies organise their personnel management around this mobility, and focus on the need to renew their human resources: for young IT workers with professional experience, there is a strong temptation to seek to gain greater rewards for their competencies elsewhere. Three options are open to them: to attempt to bid up their wages by moving between companies, to work for themselves or to work for software users, often large enterprises or public sector organisations, which are more capable of offering career prospects. This last option, which is in fact the most popular, creates flows of IT professionals out of the IT service sector. The IT service companies themselves appear to be able to accommodate this high level of job mobility, which has the advantages of reducing pressure on wage costs and above all of overcoming the difficulties which arise in career management within the firms.

However, this pattern within the software industry has become somewhat destabilized since the start of the 1990s. The economic difficulties faced by the IT sector have considerably reduced the mobility of IT professionals: the rate of turnover, estimated at 20% during the 1980s, fell to less than 5% in the first half of the 1990 s, before returning to around 10%. In spite of a recovery in the rate of turnover in recent years, it appears that IT professionals now tend to defer moving to the external labour market, or even to remain in software and IT service companies. Although this development is partly a result of economic circumstances, the process of stabilisation also reflects change within the companies themselves, which have moved from being service providers, depending mainly on being able to "loan" IT personnel, to another stage of development, where services and software packages have become more industrialized, thus creating a need to accumulate knowledge over time. In this new environment, companies are forced to create a new form of contractual relationship with their workers of high intellectual capacity, and hence to change their human resource policies, in order to offer attractive career prospects to IT professionals. In particular, there is the problem of how to treat high-level consultants and experts, given that the number of jobs available at the top of the hierarchy is likely to remain insufficient in relation to the number of engineers/managers.

III-2 Higher education and R&D institutions as cognitive resources for innovation

IT Industry is based on a range of so-called "generic" technologies: namely materials technologies, signal processing, telecommunication and transmission technologies. The design and development of all IT products is based around these technologies and applied mathematics. Thus the entire industry is dependent on a shared reservoir of technological knowledge.

Yet this technological basis does not form a homogenous discipline. Rather, it is constituted through the linking together of a multiplicity of different forms of knowledge produced in a number of different disciplines. Thus R&D activities depend on bringing together competencies and knowledge that have developed relatively independently of each other. New products are often created by bringing together pre-existing technologies (Nelson and Winter 1982). Here, innovation mainly consists of combining already known elements in an original way, thus creating new applications in new areas.

Historically, France has tended to develop large-scale scientific programmes managed by the state in various technological spheres. As we mentioned it above, this state-led scientific programmes is profoundly rooted in the way of which the state technocracy is build up by state engineers "Corps d'Etat". The development of what we might term "technological districts" also bears the mark of this history, to the extent that they have often been constructed through the establishment of public research institutes, engineering schools and public-sector companies in specific locations. As far as IT is concerned, the Plan-Calcul, and the development programme for the electronics industry have played an important role in the emergence of technological districts which continue to act as a catalyst for cooperation between industry and research: at certain sites, close collaboration takes place between higher education, public research institutions and companies. However, the logic of a large-scale, state-led scientific programme has been shown to have financial, political and strategic limits. While remaining located in local high-tech areas, IT firms have been forced to strengthen and, above all, reconfigure their collaborative networks beyond national frontiers.

A) Statistical information on R&D in the IT Sector

According to the Ministry of Technology and Research (MTR 1997), the IT manufacturing industry (comprising 70 computer and office equipment manufacturers) spends 3,353 million francs on R&D, or 4.7% of the turnover of the sector, and employs 3,258 researchers, which represents 9.7% of its workforce. The 526 firms in the software and IT service industry spend 2,916 million francs per year, or

Table VI-Characteristics of R/D activities in IT industry (1995)

	Computer industry	Software house	All sectors (private sector)
Number of firms concerned by R/D	70	526	4684
Total number of employees	33662	37208	2533286
Turnover (in millions of French francs)	71896	29488	2762531
Number of R/D researchers/engineers	3258	3801	66618
Total expenditure of R/D (in millions of French francs)	3353	2916	136443
Of which public financing	595 (18%)	124 (4%)	15396 (11%)
Domains of R/D	(100%)	(100%)	(100%)
Fundamental Research	0.4%	0.5%	4.2%
Applied Research	8.0%	15.8%	25.5%
Development	91.6%	83.7%	70.3%

Source: Ministère de l'Education Nationale, Recherche et Développement dans les entreprises, résultats 1995.

9.9% of turnover, on R&D; 10% of the workforce, some 3,801 employees, are researchers. The IT manufacturing industry and the software and IT service industry account for 2.5% and 2.1%, respectively, of total national R&D expenditure, and 4.9% and 5.7% respectively of the total number of researchers employed (Table VI).

In fact, research expenditure in the IT manufacturing sector is not particularly high in relation to national averages. The 4.7% of turnover spent on R&D is slightly below the national manufacturing industry average of 4.9%, and is well behind that in the aerospace, pharmaceutical or automobile industries. This is in spite of significant contributions from the state, which contributes 595 million francs out of a total of 3,353 million francs of such expenditure, or 17.7%. Part of R&D expenditure tends to be externalised or sub-contracted, with 13% of expenditure taking place outside the firms themselves, probably in the form of contracts with the higher education sector or public sector research organisations. Also, the level of R&D expenditure has stagnated in the last decade, signalling a downward trend in R&D investment: the proportion of turnover spent on research fell from 5.7% in 1986 to 4.7% in 1995. This lack of dynamism reflects both the decline of French producers, particularly Bull, and the fact that R&D activity has been displaced both upstream, to components (i.e. semi-conductors), and downstream, to software.

Meanwhile, the IT service sector has increasingly become a major consumer of R&D activities. After being largely absent from the domain of R&D in the 1970s and 1980s, this sector has made a considerable breakthrough in this area since the end of the 1980s. The increased importance of R&D activities is due to several factors. Firstly, European projects such as Eureka and Esprit, in which several French software and IT service companies have been active participants (e.g. the "Software Factory"), have revealed the importance of R&D in this sector. Secondly, computer manufacturers have gradually become service companies and have devoted more of their R&D capacity to software. Thirdly and finally, software and IT service companies have tended, as we have already seen, to concentrate on producing software packages and to industrialise their products, which has led to an increase in development activities.

B) The development of local co-operative relationships between industry and research

Given the importance of the French state's role in the promotion of electronic and information technologies, the development of cooperation between industry and research cannot be examined without taking into account public policies, which have been characterised by the pursuit of "technological excellence", often in the name of national sovereignty. As the case of the Plan-Calcul illustrates, major scientific and industrial programmes have been implemented by public establishments with a large degree of financial autonomy. Centralisation of technological innovation has gone hand in hand with a preoccupation with national and regional development, which has led the state to intervene by making financial contributions to regional economic development and installing scientific and technical infrastructures. As far as the IT industry in particular is concerned, the Plan-Calcul and the various programmes designed to boost the electronics industry have contributed to the development of certain regional technological centres, firstly through the choices made in the location of public-sector research establishments (CNRS, INRIA, CEA, CNET, etc.), secondly through the expansion of engineering grandes écoles and finally through the establishment of research facilities by public and private companies with high scientific potential. Through such means, an infrastructure has been developed on which local co-operative networks can be based - although the precise form of development has differed from one centre to another. The system of cooperation between industry and research in the French IT industry thus remains largely modelled on a past policy of large-scale programmes. It is noticeable 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 actors in the European IT industry closer together. From the French perspective, however, the constitution of European networks has taken place within local and co-operative arrangements already in place, notably those focused around regional centres. Being established in a locality does not, therefore, seem to conflict with the extension to the European scale of cooperation between the industry, universities and public research.

Apart from the Paris region (Ile de France), which retains half the national R&D capacity, there are four other dynamic regional centres for electronic technologies with a high IT component.

—By far the most important centre outside Paris is the Grenoble region. Often dubbed the French "Silicon Valley", this area occupies first place in the European league table for microelectronic research. In particular, the semiconductor industry benefits from synergies based on a close link between research and production. This region, which accounts for 10% of national expenditure on R&D in electronics, employs 600 researchers, 1,900 engineers and technicians, 500 designers of integrated circuits and 200 computer scientists in service activities. The region has a strong university tradition, which acts as a catalyst for cooperation between public-sector research establishments and engineering schools and companies, both small firms and large groups such as Bull, Hewlett-Packard and Thomson.

—The second centre is constituted around Motorola and IT firms linked to the aerospace/space industry in the Toulouse region. This was explicitly created through national policies in aerospace, space sciences and electronics, namely the decentralisation of the CNES (National Centre of Space Science), the location of Airbus-Industrie and the arrival of Motorola within the framework of the Plan-Calcul. This is the location of one of Motorola's semiconductor production plants, as well as a research centre in power integrated circuits which it runs in conjunction with the CNRS. Additionally, the aeronautic and space industries are both major consumers of electronic technologies, and attract industrial electronics companies such as Thomson and Matra Datasystems, as well as sustaining numerous software companies. This productive infrastructure is fed by flows of engineers trained by engineering schools such as the Ecole nationale supérieure de l'aéronautique as well as scientific universities.

—The third centre, in the Bretagne region, is organised around digital telecommunications technology (IT, telecommunications and networks). This region has several engineering schools and universities which specialise in telecommunications (Ecole Nationale Supérieure de Télécommunication etc.), from which 600 engineers, 950 higher-level technicians and 250 Bac+5 level university students graduate annually. This area attracts numerous high-technology small and medium-sized enterprises, and large corporations such as Alcatel, ATT, Matra and Canon, as well as 4,000 researchers in public-sector institutions such as CNET (National Centre of Telecommunications Research), INRIA. In total, 40% of French research in telecommunications is concentrated in the Bretagne region.

—The fourth centre, Sophia-Antipolis, in the Nice region, was one of the first prototypes of the now-familiar science park. Built in a region with no industrial tradition, its aim, from the outset, was to bring together R&D activities. It is currently home to 700 firms, mostly small and medium-sized technological or research firms, employing more than 2,000 engineers and researchers. Although this centre is not exclusively devoted to electronic activities, the sector is well represented by public establishments such as the Ecole de Mines and an INRIA laboratory, as well as research centres belonging to groups such as Texas Instruments and Digital Equipment.

C) R&D cooperation in the Grenoble region

If all the various aspects of its intellectual activities are taken into account–the number of researchers employed, the concentration of higher education institutions and research laboratories, the tradition of productive exchanges, the presence of technologically advanced sectors and the number of innovator firms–Grenoble can very properly be described as a "technological district", as qualified generally (Salais and Storper 1997).

Unusually for France, this region has a long tradition of cooperation 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 has in the past seen cooperation between local productive actors which would justify the title of "technological district", or local innovation system. It was against this background that IT emerged from the 1970s onwards, and the infrastructure was renewed around a few dominant establishments such as CNET, LETI (Laboratory of Microelectronics) and Thomson in the area of semi-conductors, and INRIA, Bull, Hewlett-Packard and XEROX in the IT sphere. At the same time, a large number of small high-tech companies were created, principally as a result of the decentralisation of research centres.

The Grenoble region therefore constitutes an interesting case of an IT industrial district. Here, however, we will try to describe, by way of illustration, the institutional landscape in Grenoble, and its multiple networks of cooperation between industry and higher education.

With regard to higher education, the region has a scientific university and the INPG (National Polytechnic Institute of Grenoble), which is a public federation of nine engineering schools, over thirty research institutes and a doctoral school. This federal structure has a total of 3,000 engineering science students, producing some 300 doctoral theses per year. In particular, ENSIMAG (Higher National School of IT and Applied Mathematics), a pioneer in IT education, plays a central role in the specialised education of computer scientists (500 students), with symbiotic links between education and research involving the IMAG (Grenoble Institute of IT and Applied Maths) institution. With regard to IT research, there are seven research institute situated on the university campus under the IMAG label and jointly administered by the CNRS, INPG and the Scientific University of Grenoble IMAG combines the functions of scientific research, teaching in the engineering school and university and the supervision of doctoral students. Its 7 institutes vary in size, containing between 30 and 100 people; each brings together several teams working on concrete topics such as multimedia systems, real-time programming, parallel calculation, computer-assisted translation etc. The federal structure allows teams to share resources (IT resources, media library, management etc.), to participate in decision-making and to deal more effectively with external partners. Most of these institutes work at the interface between theoretical and applied fields, and have contacts not only with other public research establishments (CNET, INRIA) and foreign universities, but also with firms. With these different partners, they are capable of developing co-operative networks over time. The type of collaboration with enterprises ranges from sub-contracting to the joint development of software packages and supervision of doctoral theses (through jointly funded scholarships), etc.

With regard to public sector research, INRIA has a research institute in Grenoble with some 230 people. INRIA, founded in 1967 as one of the main elements in the Plan-Calcul, is charged with the tasks of developing a centre of scientific excellence in the area of IT, identifying future IT needs and rapidly bringing products to market in partnership with companies. To these ends, it has five research establishments across France, and a budget (in 1997) of 495 billion francs, of which 81 billion, or around a sixth, consist of 360 contracts with external partners. These are predominantly industrial contracts with companies (40%) and European contracts in the Esprit framework (one-third). It occupies 2,100 people, of which 1,700 are scientists (715 permanent posts, 550 doctoral students/researchers, 650 foreign visitors, and 400 external collaborators from industry or higher education). It also supports 20 technological companies, created since 1984, mostly run by its former researchers; these generated a combined turnover of 480 billion francs and had 860 employees in 1997, either by directly exploiting INRIA licences or prototypes, or by industrialising products in association with INRIA's own researchers. Additionally, the institution has just created a subsidiary, "INRIA-Transfer", a consultancy which aims to support the foundation of new IT companies.

The Grenoble institute has 230 researchers, of which around 100 are doctoral students working on the joint projects with the IMAG Institute mentioned above. In 1997, the Institute was working on nine projects, mostly with external partners, in the following areas:

—Communications IT (networks, internet, systems and applications). Projects in this area involve a significant degree of partnership with firms such as Bull, Rank Xerox, SGS-Thomson, Aerospatiale, Hewlett-Packard, etc.

—Intelligent machines (digital imaging, intelligent vehicles). These involve strong collaborative relationships with EDF (Electricité de France), Renault, CNET, etc.

—Parallel calculation (basic software and intensive calculation). These involve partnerships with software and IT service companies such as Simulog and Matra Cap Systèmes.

Despite all these projects, the Institute has only 70 of its own researchers, who work with around 100 doctoral researchers and around 60 outside partners. It is thus heavily dependent on external resources supplied by the local infrastructure. It co-operates strongly with Bull (which has a research centre in Grenoble) in a "grouping of economic interest" which jointly manages four programmes. Through this relationship, the Institute is permanent host to around ten Bull engineers. This partnership is, in great part, the inheritance of long-established collaboration between Bull's scientific department and the local scientific community (particularly IMAG). INRIA has increasingly become the main catalyst in the process of turning scientific findings into concrete applications.

This brief outline of the situation in Grenoble should only be seen as an illustration, and has no pretensions to representativeness at the national level. However, it provides us with deep insights into the innovative dynamism in France.

Conclusion

The competitiveness of firms does not depend solely on their strategies and actions. It is fundamentally related to the quality of the societal space in which they are integrated, which involves industrial policies, academic-industrial research links and the quality of higher education. From this point of view, the strength of the American IT industry does not seem to rest simply on the innovation capacity of its large firms such as IBM, Microsoft or Intel etc. Indeed, its power seems to rely more on the dynamic engendered by new entrants than the single strength of IBM, which itself appears mismanaged in the "new computer revolution". New firms are constantly being created on innovative projects, (new fields of IT application, new products), based on the mobility of engineers (spin-offs) and often taking advantage of the opportunities offered by risk capital funds. This creation dynamic, founded on capacities for innovation and collective learning, seems to be an essential engine for the transformation of IT in the USA.

Given the renewed offensive of American IT, including in terms of software packages and IT services, Europe certainly seems to suffer from structural deficiencies inherited from past "national champion" policies (weakness of industrial fabrics, concentration of large firms, weakness of upstream/components sectors). Despite these weaknesses, some European countries seem to be showing their capacity to resist the American offensive, drawing on knowledge, competencies 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 innovation rely on existing institutions to revitalise their innovation activities.

The French IT industry, as those of most other European countries, has come under intense technological competition from the USA. The industry's supply structure is dominated by the presence within France of American multinationals, both in the production of computers and the editing of software packages. French strengths can be found in IT services based around system integration and the development of applications. Indeed, French software houses are managing to resist the American pressure not only with their captive market (an important public sector), but also with their quality of service based on cognitive and local proximity to their clients. They are thus able to accumulate specific competencies linked to their particular environments: for example, certain French software houses excel in scientific calculation or production of the state-of-art software, because of their proximity to the aerospace and nuclear industries, etc. Moreover, as in the majority of knowledge-intensive services, the user-producer relationship is of fundamental importance in the IT sector, since the development of software requires a sort of co-production between computer engineers and clients. This is a prime example of a sector where the clients intervene directly in the production of services, hence the importance of the quality of interaction between producers and users, emphasised by Lundvall (Lundvall, 1988). In this way, the competencies accumulated in the sector of application services seem to reflect the structure of the national economy, or more precisely, the international specialisation of a country. From this point of view, the proximity between IT services and telecommunication network, a sector protected by the state until recently in all European countries, may create important opportunities to promote local development synergy.

French IT industry is supported by two institutional arrangements which contribute to produce its most important intangible resources, even if its contribution to industrial success of IT sector is difficult to be estimated in quantitative terms.

One of the resources of these IT firms would seem to be the quality of training of engineers. The sector is highly dependent upon the quality of its human resources, as is the case with the majority of services based on high-level technical knowledge. Indeed, the French higher education system has been able to increase its supply of computer engineers without compromising the quality of its training. Although it is far from satisfying all demands, particularly with regard to continuing training, it has proved capable, in co-operation with firms, of diversifying the training offered. The entire French economy has thus benefited from the production of increasingly well-trained IT professionals. In this way, American firms such as Hewlett Packard or IBM benefit from these highly skilled French engineers, to make its PCs or semiconductors competitive on the international scene.

But what is most evident is that French computer engineering services firms cream off a significant share of newly qualified engineers from the "grandes écoles", who constitute the most socially legitimated supply of human resources. The mutual attraction established between these firms and the "best engineers" is certainly one of the strengths of the French IT services sector.

In addition to the supply of high-level human resources, a not insignificant part of the IT sector benefits from the diffuse effects, integrated into an innovative "milieu" (Gaffard 1990), of the major scientific programmes that France has historically developed. The development of "technological districts" also bears the mark of this history, to the extent that they have often been constructed through the establishment of public research institutes, engineering schools and public-sector companies in specific locations. As far as IT is concerned, several local technological districts constitute a high level of electronics and IT, and continue to act as a catalyst for co-operation between industry and research. In certain sites, close collaboration takes place between higher education, public research institutions and companies, in order to create new potential resources and knowledge.

Bibliography

Aoki M., (1993), Comparative Advantage of Organizational Conventions and the Gain From Diversity: evolutionary game approach, mimeographed, Stanford University.

Bernardy de Sigoyer, M., et Boisgontier, P., (1988), Grains de Technopole, Micro-entreprises Grenobloises et nouveaux espaces productifs, Presse Universitaire de Grenoble.

Brulé J-P., (1993), L'informatique malade de l'Etat, Les Belles Lettres, Paris.

Delapierre M., Zimmermann JB (1991), La globalisation de l'industrie des ordinateurs, Program FAST vol. 11.

Dosi G., Freeman C., Nelson R, Silverberg G., et Soete L., (eds.) (1988), Technical Change and Economic Theory, Pinter, London and New York.

Edquist C., (ed.) (1997), Systems of Innovation, Technologies, Institutions and Organizations, Pinter, London and Washington.

European Commission (1997), Second European Report on S/T Indicators, Luxembourg.

Gaffard J. L., (1990), Economie industrielle et de l'innovation, Dalloz.

INSEE (1994, 1995, 1996), Les entreprises des Services, Système Productif, Paris.

INSEE (1989,1997), Enquête Emploi, Paris.

Lanciano C., Maurice M., Nohara H., Silvestre J-J., (1998), Les Acteurs de l'innovation: comparaison France-Europe-Japon, L'Harmattan, Paris.

Lanciano C., and Nohara H., (1998), The Societal Analysis of Engineers: Comparison between France and Japan, Communication at 10th conference of socio-economics, July, 20 pages.

Lundvall B-A., (1988), Innovation as an Interactive Process: from User-Producer Interaction to the National System of Innovation, in Dosi G., Freeman C., Nelson R., Silverberg G. and Soete L., (eds.) Technical Change and Economic Theory, Pinter, 349-369, London and New York.

Mowery D. C., ed. (1996), The International Computer Software Industry, Oxford University Press, Oxford.

Nelson R., and Winter S., (1982), An evolutionary theory of economic change, Belknap Press of Harvard UP.

Pavitt K. (1984), Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory, in Research Policy, 13, 343–373.

Salais R and Storper M., (1997), Worlds of production: the action frameworks of the economy, Cambridge, Harvard University Press.

Syntec-Informatique (1988, 1991, 1998), Chiffres clés de SSII, Paris.

Ziegler N. J., (1997), Governing Ideas, Cornell University Press.