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The French research system: which evolution and which borders?

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Introduction :

It is now widely accepted that investment in technology, innovation and research is a crucial factor in economic growth. But curiously, the relevant level of governance of these investments and their positive externalities remains at the national level, in spite of the internationalization of technologies and companies. Consequently, the concept of a National Innovation System (Sharif, 2006) remains operative to a certain extent, especially in France where the Colbertist system was dominant. H. Etzkowitz and al. (1998) confirms that “*a complex web of relationship has grown up between academics, university originated start-ups and larger firms*”. In the French case, the analysis suggests two major hypotheses: first, the military public market explained the existence of national triple helix (Serfati, 2007) and secondly, the academic institutions specialized in research and education had some preferences on local or national firms. Nowadays, P. Papon (1998) explains that the French research system is deeply involved in the crisis of the nation state, that cannot longer pilot technological and scientific development as it was the case in the decades following the Second World War.

In our communication, we would like to complete this analysis with the data base on industrial contracts signed by the CNRS (French National Center for Scientific Research). We test this assumption of “national” border that can be viewed as an intense concentration of contracts for some national “champions”. Our working

material is the data base of the contracts of the units of the CNRS with economic partners, that has been collecting information since 1986¹. The fact of having a base (40 000 contracts) going from 1983 to 2006 offers the possibility to consider different periods for the analysis of the evolution of these contracts during 20 years, and specifically the evolution² of labs' and firms' distribution. In this way, statistics and graphic software for social networks will be used for the quantitative approach.

Two objectives will guide the statistical study: first, highlighting the principal characteristics (evolution of the number of contracts, representation of different subjects, distribution of the sectors, geographical localization of the partners, concentration of the partnerships, etc) according to a relevant "periodization" and, second, to use the techniques of representation of the networks (Ucinet and Pajek) to illustrate the durability of the contracts and fidelity of the partnerships. As for the second case, the objective is to test the contribution of the sociometric approaches in the understanding of the resilient phenomena, like relationships between academic firms and institutions. These results will be explained and commented with the expertise on relationship between science and industry accumulated by M.P. Bès in previous studies, focused on engineering sciences³.

In the first part, we underline the intense concentration of the CNRS contracts considering the level of actors' behaviour. In this section, we present our data with some descriptive statistics highlighted by other studies focused on research partnerships. Secondly, we present the application of Social Network method to our data, in order to complete the precedent analysis by observation and analysis of network forms. It allows explaining the question of concentration and fidelity in partnership. In the end of the communication and with the former results, we discuss again the old notion of scientific community (Crane, 1972) revisited with the social networks approach.

¹ This work would not be possible without the help from the CNRS service in charge in industrial relations, thanks to the different managers.

² Of course, any longitudinal method contains problems in selection, follow-up and choice of coherent data. We choose to explain, at each step of this research, our criteria in selection.

³ - M-P. Bès & M. Grossetti, "Creative knowledge environments between individual and organisation levels", 4th Triple Helix Conference, Copenhagen, Denmark – Lund, Sweden, November 6th-9th 2002.
- M-P. Bès & M. Grossetti, "Collaboration trajectories between CNRS research laboratories in Engineering Sciences and firms : genesis and evolution, Paper presented to the European Association for Evolutionary Political Economy Conference, November 2-5, Berlin, 2000.

I. Research Partnerships for CNRS labs

I.1. Research Method and Data

Our working material is the data base of contracts of CNRS (French National Center for Scientific Research) signed by the different units (labs in the text) and implemented by the legal service in each CNRS regional delegation. For every contract, we have got some quantitative information (numerous of lab in CNRS classification, date, duration, numerous of French department for the labs' and firms' location) and qualitative data (lab name, contract title, firm name). In previous studies, the liability of this database was soon demonstrated (Grossetti & Bès, Grossetti & Nguyen). This tool cannot be used to establish a technological survey or to follow a scientific trajectory by firm, domain or activity because of our involvements to respect confidential informations. Of course, it will be possible to follow the successive contracts signed by a firm with CNRS units and so to understand the major strategic technological areas. Here, all investigations are conducted in a global analysis of the French research system and without name of organizations.

Let us underline the difference with studies based on publications or patents: they have only a view on the results of cooperation and scientific alliance and underestimate the whole aspects of research partnerships: exchange in human resources, dissemination in ideas, methods and materials, experimental aspect in science, and so on. These are all the aspects of cooperation between several actors invested in research, which do not lead to direct results as publications or patents. A data base of research contracts is a better tool to understand the research networks and especially, to observe the network evolution and the behaviour of incoming and outgoing actors.

I.2. Available data about contracts of CNRS labs

After a long task⁴ focused on cleaning, normalizing and collecting useful⁵ data, we obtained a data base, involving 26028 contracts between CNRS units and firms, for the period (1986-2000) informed about the following characteristics: the name of research unit, its location (12 areas), the leader's name, the scientific domain (classified into 8 departments), the firm's identity, its location, the starting date of the contract, the duration done by number of months. Moreover, we coded the economic activity of the firms, with the INSEE nomenclature in 31 different sectors. Table 1 summarizes the descriptive statistics of this set of contracts:

Table 1. descriptive statistics of the CNRS contracts 1986-2000

Number of contracts	26024
Number of firms	3642
Number of scientific labs	1680
Average number of contracts per firm	7
Average number of contracts per lab	15
Average duration of a contract	20 months

Even if the number of firms is twice than the number of labs, it is the inverse phenomena in terms of average per kind of partner: there are twice more contracts by lab than by firm. It seems that for a scientific team, it's a normal activity to have some partnership with firms: it allows increasing the global financial amounts for the laboratory, to finance some investments in high equipment, to finance PhD thesis but also to work on real and applicative subjects and to compare several applications. For a firm, the activities related to innovation, knowledge propriety, intellectual rights, and R&D alliances are more strategic and depend on several factors as the complementarities between internal and outsourcing research.

By the study of duration, let us remark that the majority of the contracts (96%) last for less than 3 years, and that 73% covers a period of 3 years, which is the duration for a PhD thesis. The involvement of PhD students is an important characteristics of

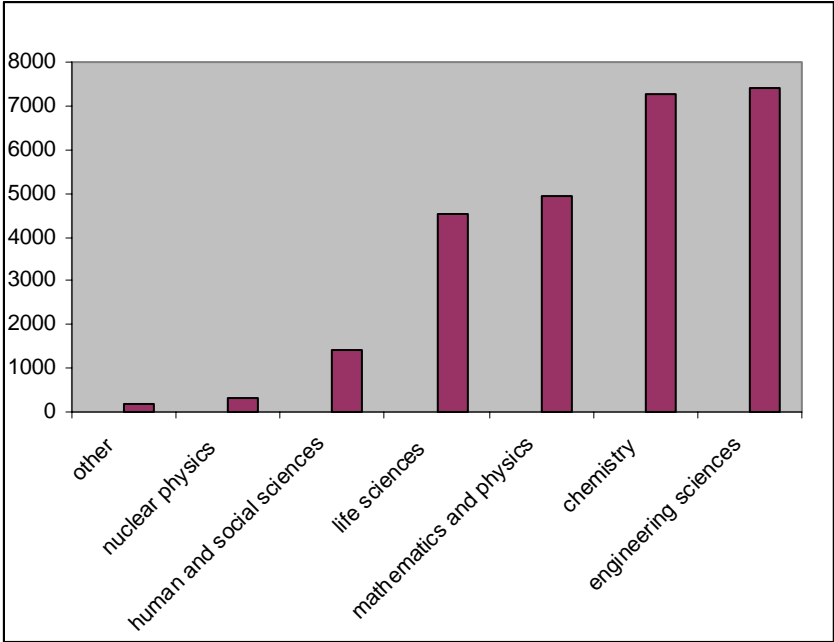
⁴ We have benefit from the help of Adrien Defossez, a Master Student in economy, which conducts this part with serious and method. Thanks for his help.

⁵ The major difficulty was to manage the evolution of organizations : creation and disappearance of labs and firms, fusions and acquisitions, new classification in scientific domain, etc.

research contracts, because of the mobility of the student and of his capability to maintain ties between the two partners (Bès, 2004).

We have also to underline that the CNRS (French Center of Scientific Research) does not cover all the scientific fields while two others National Centers are focused on medical research (INSERM) and agricultural and agronomics field (INRA). That explains the weak representation of biotechnology or chemistry firms in our data base and of course, the importance of Engineering sciences. Indeed, in the following graphic, it's possible to read the distribution of contracts per scientific domains, defined by the CNRS as scientific department.

Graph 1. Number of contracts per CNRS scientific department

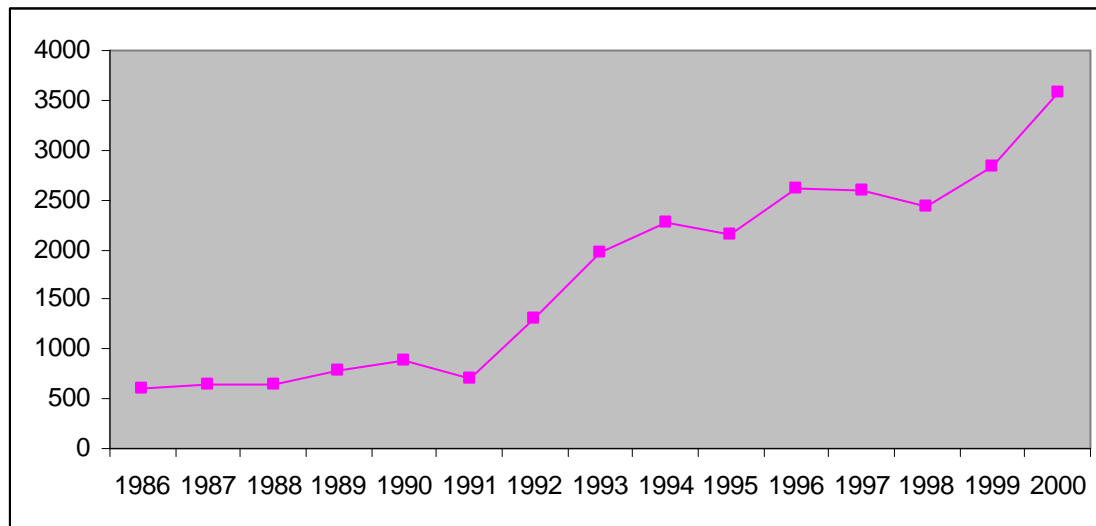


In many contracts, the main scientific domains are engineering sciences and chemistry, which are the most representative areas to the trend of “commercialization of science” (Malissard, P., Gingras, Y. & Gemme, B., 2003 ; Powell & Owen-Smith, 2004). In these disciplines, patents, start-up and co-publications have increased very fast since the 1980’s years, after the Bay Dohle Act’s effect in the United States and then, in other developed countries. In our case, 4 scientific domains (life sciences, mathematics and physics, engineering sciences, chemistry) cover more precisely the main CNRS contracts (93%) in which the last two share 56% of contracts. In addition,

this distribution remains constant over time. The life sciences represent only 17% of the contracts due to the presence of INSERM specialized in this scientific field.

Considering the evolution of number of contracts, we obtain the following graphic.

Graph. 2. Evolution in number of contracts during the period 1986-2000



As we can see in this graphic, the number of contracts increased strongly during this period, from 600/year to more than 3500/year in 2000. It is possible to identify three successive periods: during the first period (1986-1991) the number of contracts is stable around 710/year, during the second period (1992-1997) the number of contracts grows from 31.2% per year, then a third period (1998-2000) in which the growth rate is even higher (47%/year).

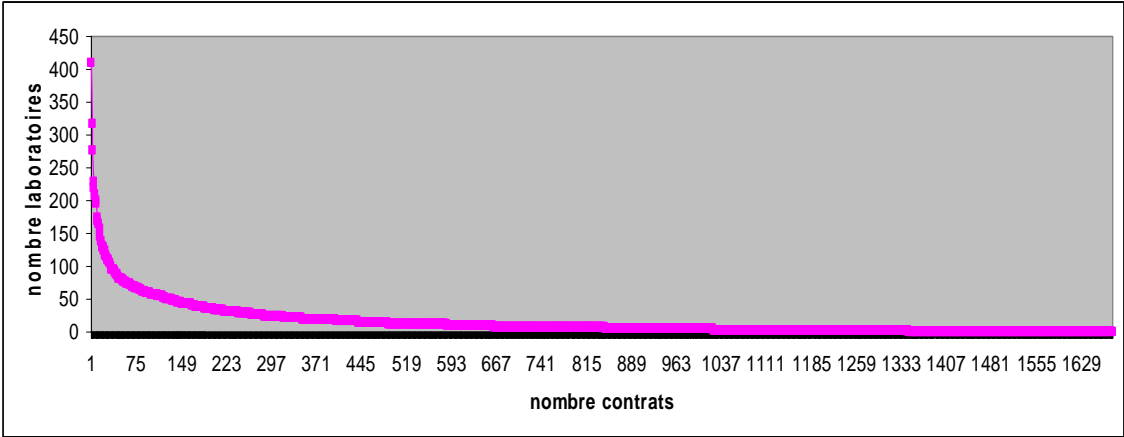
However this graphic does not integrate the duration of each contract and represents only the number of contracts without distinction between long and very short relationship.

In our purpose, an interesting question is to question if this increase is due to the reinforcement of the contractual activities of any partners (firms or labs) or due to the appearance of new comers in this science market. It will be interesting to observe the contractual activity of the major firms.

I.3. Concentration

In the following graphic, we report the number of labs per number of contracts. It underlines the extreme “concentration”: few labs sign the majority of contracts. The old “Merton” effect, which designs the star system in science, appears also in our study, focused on research contracts with economic partners.

Graphic 3 : Distribution of CNRS units per number of contracts during (1986-2000)



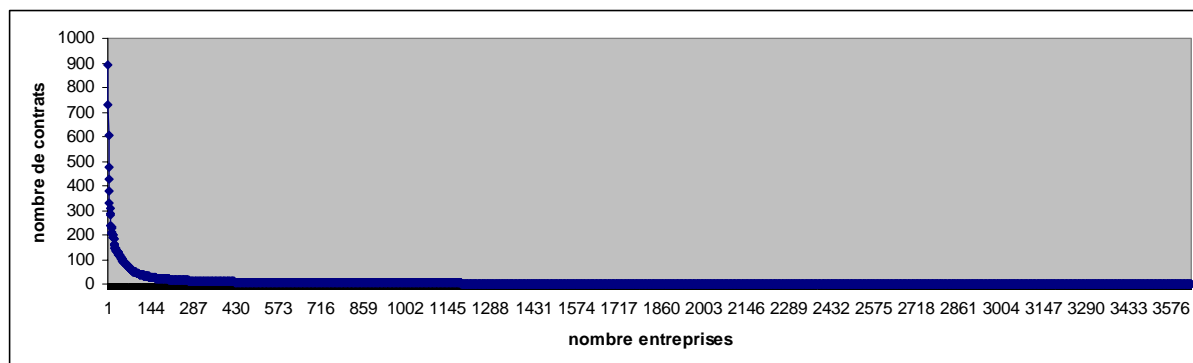
This fact is confirmed by a more precise table, in which we precise the number of labs associated to the percentage of contracts.

Table 2 : Distribution of labs per number of contracts

Number of contracts	Number of labs	Share of contracts
between 173 and 409 contracts	11	10%
more than 169 contracts	32	20%
more than 44 contracts	153	50%
more than 14 contracts	468	80%

The most important lab in terms of contract has signed 409 contracts with economic partners. 10% of the contracts is concentrated between just 11 labs, 50% of the contracts is concentrated between 153 labs each holding more than 44 contracts. Among the 20 first units, 10 are working in Chemistry and 10 in Engineering Sciences. Only 3 out of 20 are located in the region “Ile de France” and two regions gather 10 of these labs.

Graphic 4: Distribution of economic partners per number of contracts during (1986-2000)



The concentration among the economic partners is more intense whereas the “first” has signed 891 contracts with the CNRS. The 10 first firms gather 18% of the contracts with research units. Among the 20 first, that is to say 26.2% of the activity, we find initially the European Commission, then the Public Corporations (2030 contracts) and finally, two enterprises present in chemical and oil sectors.

Table 3: Distribution of contracts per activity sector

Activity sector	number of contracts	Share
Industry	11004	42%
Public	8367	32%
Service	6410	25%
Other	216	1%
Agriculture	27	0%
Total	26024	1

The industrial sector gathers 42% of the CNRS contractual activity but the public Administration (public authorities, Ministries, Public corporations, European Commission) has also many contracts with the CNRS (32%).

There is an intense concentration in this data base, characterized by the presence of some labs specialized in Engineering Sciences, located in Province, engaged in some contracts with a public industrial firm.

This concentration does not provide information on neither the centrality of the actors nor their positioning in the partnership chain: the largest could be on the edge of the partnership network. In the second part we will observe more closely the evolution of the general structure of research networks selected according to various criteria. The point is to link the theme of concentration to that centrality.

II. Social Networks in Research Partnerships

We found in the literature focused on R&D cooperation some stylized facts, in relation with our questions about concentration, centrality and existence of some leaders or intermediate actors. The major characteristics are the following:

- Proximity effects: we know that there are more contracts between two partners located in the same area than between the other. See Saxenian for the Silicon Valley or Grossetti & Bès, for the Engineering Sciences.
- Social embeddedness: Through the analysis of around one hundred joint research contracts established between CNRS laboratories and firms during the period from 1960 to 2000, we (Grossetti & Bès, 2001) have shown the important role of social relations (44 %) in making contacts between partners.
- Trust and path dependency: the importance of the phenomena of loyalty and mutual confidence between partners in the coordination of contracts is mentioned in several studies (Joly & Mangematin, 1996)
- The informal transfer of ideas and technology through the professional mobility and the human contacts is one of interesting results of STS (Science and Technology Studies) for the social network approach: the information circulate between the relationships.
- R&D accords, technology agreements take organizational forms different from integration or from market exchanges: temporary, flexible, with trust and social aspects: Powell (1990) spoke about network.
- Research partnerships provoke different kinds of apprenticeship based on the externalities as, knowledge about a specific technology, a mastery of technical instruments, a scientific methodology or about one specific industrial market (Bès, 2007).

All these results underline the embeddedness of economic and social features in the dynamic of market science: every contract is the result of a series of personal relations and of strategic involvements (Grossetti & Bès, 2001).

In this second part, we test the capacity of social network methods to explain the partnership's evolution between research public teams and firms in the French case over the period 1986-2005. By building different networks (networks of firms, networks of scientific teams) and calculating some structural parameters (density, network centralization, connectivity, path length, etc.) we are able to observe the major changes in collaborations in different periods. In the first section, we built several research networks of some major French firms and comment the results. In the second section, we built successive networks of one scientific domain and test the "small world" hypothesis.

II.1. The "research network" of major firms

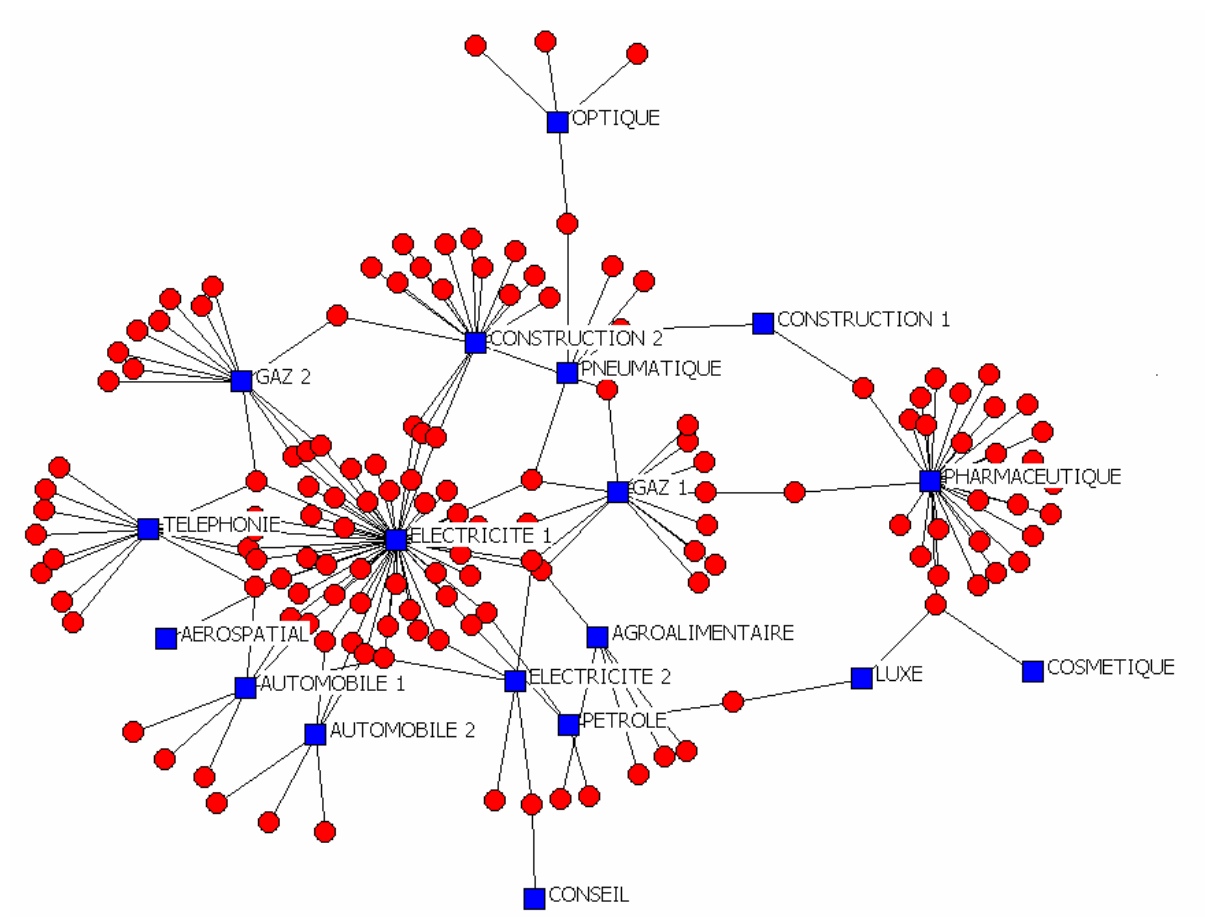
We have selected the 40 major French firms with a criterium of French stock market index, done in July 2007⁶ and we have searched systematically their name in the database. This method allows following the same sample during several periods. In the other hand, it eliminates all firms, which have undergone important change in their shareholding and which have been disappearing from the financial top classification.

These "CAC 40" major French firms, represent 20% of the contracts in the data base. 20% is underestimated by the method of data processing, it doesn't depend on the strength of ties (duration of contract for example). If it includes an indicator of strength (number of months) the former number will probably double. The pertinence comes from the criteria in financial investments realized by the major firms.

⁶ The CAC 40, which takes its name from Paris Bourse's early automation system (Continuous Assisted Quotation), is a French stock market index, which integrates the financial value of the 40 first firms. The index represents a capitalization-weighted measure of the 40 most significant values among the 100 highest market caps on the Paris Bourse.

We transformed the data done in a table by a matrix in which the lines represent the labs and the columns represent the firms. The software Ucinet has got a visual representation of the relationship between the major firms and the labs.

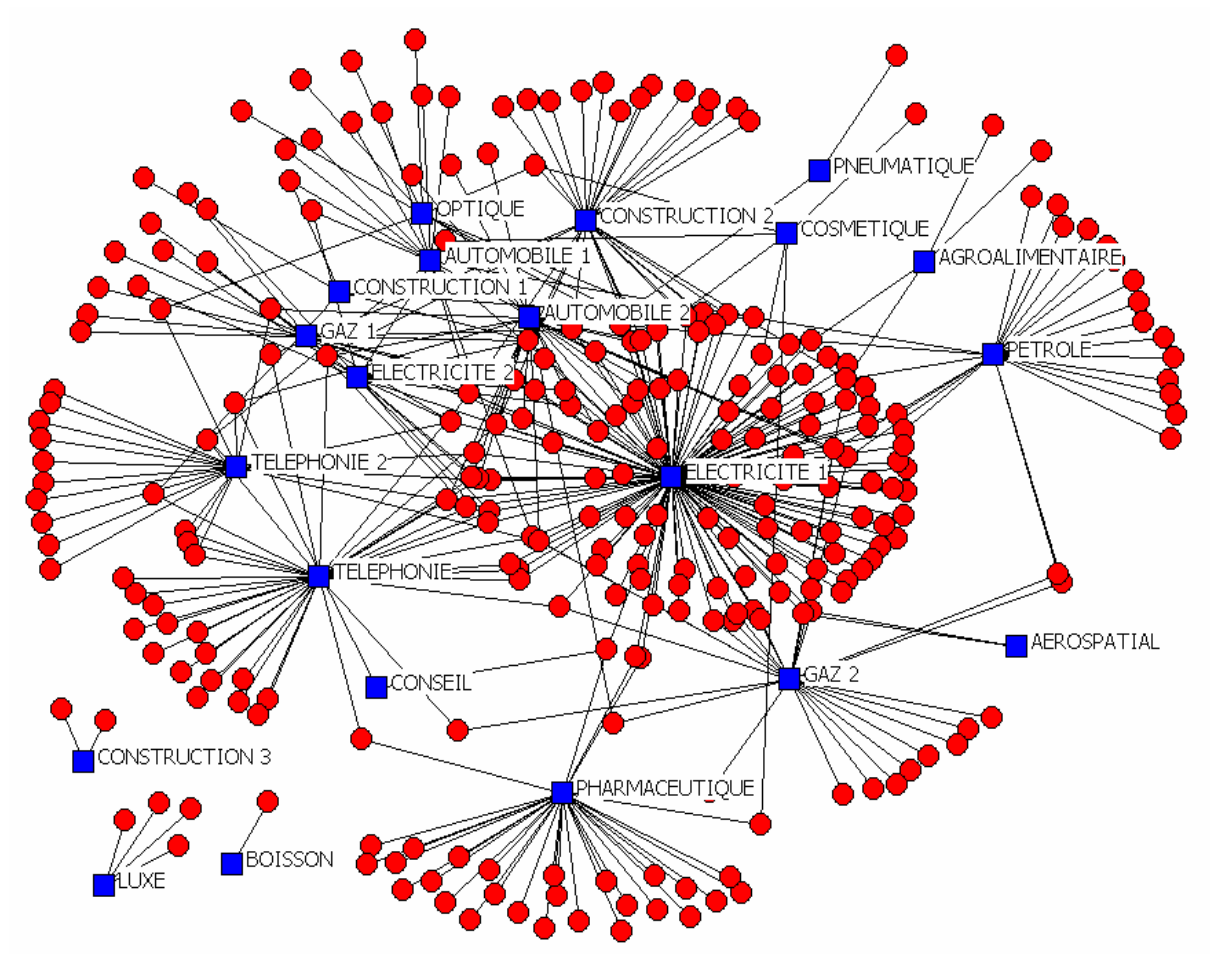
Graph 5 : First Network labs-CAC40 firms⁷, 1988-1990



This network presents a center which is a firm specialized in electricity and eight “cliques” in considering the number of labs in relation between several firms and the leader. Every clique is structured by 2 or 3 firms. 4 sectors are distant from the center and few related to the other organizations. The pharmacy sector has a particular position: away from the center but with as intense research activity. No lab is related to more than 3 major firms and 75% of them are related to only one firm.

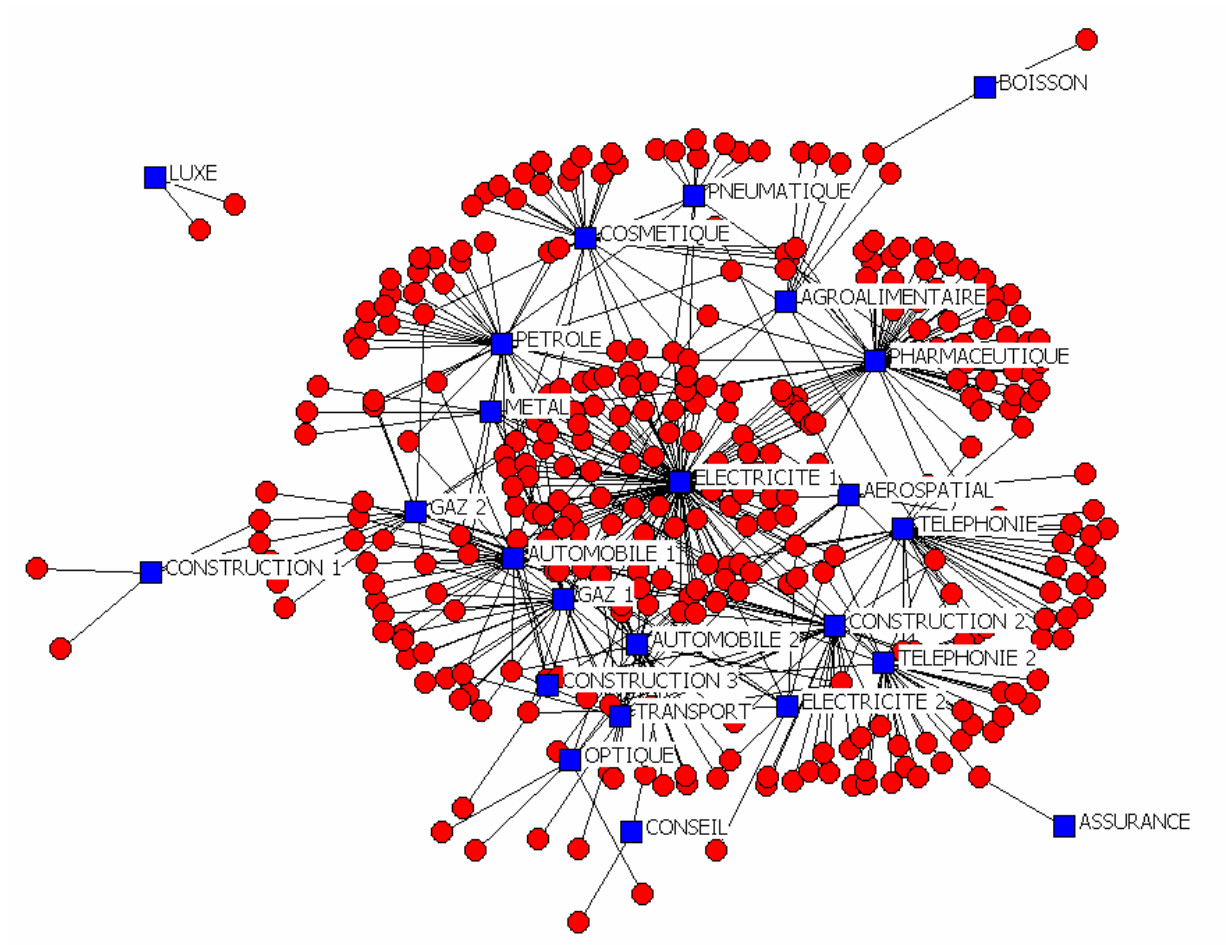
⁷ To respect the confidential information, we chosen to present the enterprises by their activity sector.

Graph 6: Second Network public labs-CAC40 firms, 1993-1995



There is an increase of the density with always Electricite 1 as the network center, which concentrates, like in this first period, 30% of this network ties. The “second knives” are now often directly connected to the network center and there are 3 firms out of the main network. The number of labs increases from 141 to 269 and any of them work from now on with 4 or 5 major firms. In the same period, the number of labs increases from 18 to 21.

Graph 7: Network public labs-CAC40 firms, 1998-2000



It is easy to observe the increase of the network density and at the same time, the increase in the number of ties. The share of labs with only one tie with the major firms has decreased during the successive periods: it begins with 75% at the first period and drops to 69% at the second period to 67% for the last one. The center and the “second knives” reinforce also their position. The average distance between two firms has decreased as if the dissemination of information is getting better in time.

With this type of graphic, the first economic comment concerns the increase of research activity due to the major French firms, in terms of number of contracts and number of partners, in a context of competition and innovation. Although it’s well known that the French financial investment in research is lower than that from other foreign companies, the trend between 1988 and 2000 is the reinforcement of relationship with CNRS units. The second comment concerns the increasement if ties between all the actors (that is the density) which can be interpreted as a

standardization in the strategy of scientific research: all firms are related to the same labs and none is very specific in terms of technological exploration.

Let us consider now the dissemination of ideas, materials and personal through firms and labs, as some economists underline the transfer of know-how between rivals (Von Hippel, 1987 ; Bozeman & Mangematin, 2004). On the lab's side, it well-know that, in spite of property rights, externalities of knowledge exist in the industrial relationship (Bès, 2007).

II.2. Scientific networks

Here, we test the hypothesis of “small world” presented in the literature focused on innovation as the specific general structure of social networks. The “small worlds” networks are inbetween regular networks - where each member is connected with his neighbour - and random graphs in which the distances between two unspecified members are very short. In fact, in a “small world” network, the actors are able to take a smaller route (a short cut) to create a relation with another actor. Some networks of innovators are “scale-free” (Barabasi & alii, 2002) as in biotechnology (Gay & Doucet, 2005) but many of these networks look like “small worlds” (Watts, 1998) as in scientific collaboration (Newman, 2001). For R. Cowan, (2004), the “small world” is the best structure for innovation while the random graphs are significant in the process of diffusion.

In this literature, we find several criteria used to prove the existence of a “small world”: the criteria of high clustering coefficient, a law average geodesic length, that increases slowly with the diameter. However these criteria (high degree of clustering and weak path length) are not always sufficient to prove the existence of these types of networks and we prefer to choose three criteria: a decreasing line in log-log degree distribution, an average short path length, a high connectivity degree. In this case, the question is, specifically, not to obtain exactly these criteria but to observe a trend towards the “small world” structure.

II.2.1. Process of building firms networks in a scientific domain

Now, the questions were how to observe the evolution of forms in the network of firms and labs and to explain the diffusion of information, ideas, scientific results and methods through the actors involved in a research activity. In following the literature focused on scientific diffusion, it's easy to underline the existence of communities structured by the scientific disciplines (Mullins, 1972 ; Amin & Cohendet, 2006), in which the institutions are stable and the diffusion of information is free. Even if the frontiers of an epistemic community are not stable and last for ever, we use the CNRS classification separating into several departments (8) to distinguish the different scientific disciplines. We choose then to select the Chemistry department, to draw the networks for two periods and to calculate the "small worlds" indicators.

The drawing process of the Ucinet Network begins with the building of appropriate matrix labs-labs: it's the product between the matrix labs-firms done by the table in the CNRS data base and its directly transposed to a matrix. This labs-labs network doesn't represent the firms, which are necessary in the background. Every tie between two labs represents the existence of k contracts signed by these two labs with these same k firms.

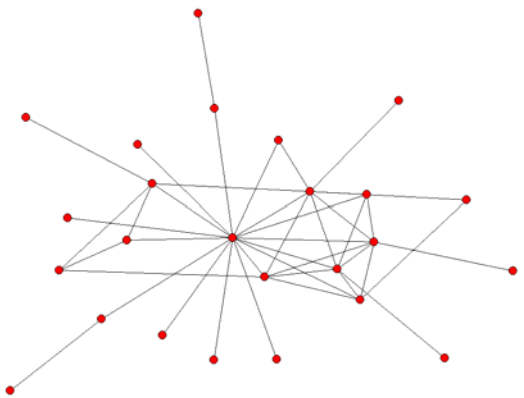
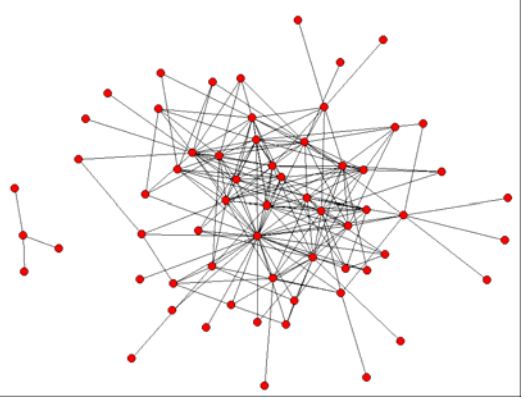
As this network involves two different actors (economic partners and research units called labs), it contains two dimensions, related to two sorts of social ties: direct ties between two partners (contracts) and indirect ties (through the same partner). It isn't a network in terms of a homogeneous social tie between the actors but, it can be viewed as a "meta-network", a community of experts in which some information are disseminated.

II.2.2. Example of successive networks

In the same method used early, we selected two periods (1988-1990) and (1998-2000) and built the matrix and the network associated, in using Ucinet software. For a correct visualization, the two graphs 8 and 9 involve only the levels superior to 28.

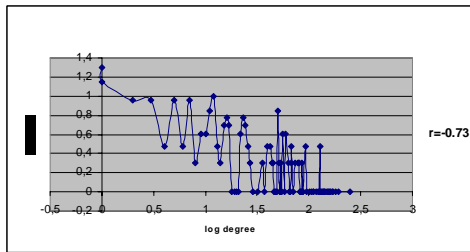
⁸ For the first graph, The whole graph involves 3164 ties and 142 labs whereas this one presents only 84 relations for which the number of ties is superior to 2, i.e. 25 labs (17%).

The hypothesis of “small world” or “scale free” has to be tested with the smoothing of degree distribution, as mentioned in the graph 10.

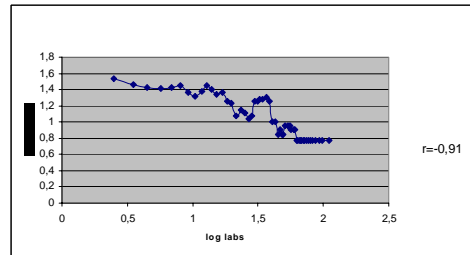
Graph 8: Simplified Chemistry/1st Network, 1988-1990		Graph 9: Simplified Chemistry/2nd Network, 1998-2000	
			
Table 4: indicators about Chemistry 1st network “1988-1990”		Table 5: indicators about Chemistry 1st network “1998-2000”	
Number of actors	142	Number of actors	247
Number of components	1	Number of components	2
Size of the major component	128	Size of the major component	225
Number of isolated components	14	Number of isolated components	20
Number of ties	3164	Number of ties	7568
Clustering coefficient	1.178	Clustering coefficient	1.162
Average path length	1.978	Average path length	2.153
Connection degree	> 2	Connection degree	> 2
density	0.158	Density	0.125

Graph 10 : log-log Plot of degree distribution

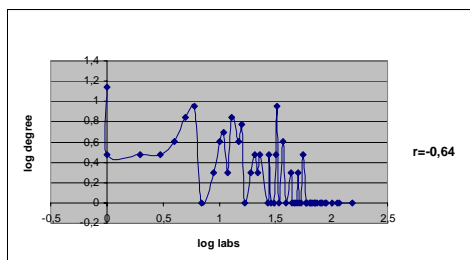
1988-1990



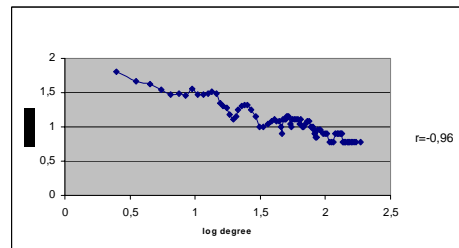
Smoothing 1988-1990



1998-2000



Smoothing 1998-2000



Here, we obtain two decreasing curves that reinforce the existence of criteria obtained in “scale free networks”. There are a lot of labs with a weak connection degree and few individuals with a high connection degree, called hubs. Let us notice that the two incline coefficients are smaller (-0.58 for the first and -0.54 for the second) than in the literature (-3). This fact comes perhaps from the “small world” effects, which involve a high clustering coefficient: there are also some “hubs” around a lot of individuals slightly connected but also, any individuals intermediate, with a number of relations. In fact, the previous results, presented in the tables 4 and 5, get the profile of “small world” network: two weak densities, two clustering coefficients, and two short average path lengths. Moreover, in the time, the linear smoothing is better as if we have got a trend to “worldation”.

In the other scientific areas - except in the Nuclear and Physics department -, the same indicators give us some comparable results, that is a weak density around 0.2, a clustering coefficient superior than 1 and an average path length near to 2.

Results and Conclusion:

This first application of Network methods and tools to the CNRS contracts allows us to obtain some results: at first, the major firms's scientific network is not "scale-free" as if competition and strategy between the most large firms dominate the behaviour in R&D investments and management of contracts with public research units. However, in second part, we demonstrate that every discipline network is a "small world", *i.e.*, that it exists several scientific communities in which the diffusion of information is free and easy, even if its forwards through any actors (some labs or some firms). Probably, there are several "small worlds" in this database as in the scientific collaboration networks. It seems that the industrial research does not disturb too much the properties of scientific network, as it's well known in the literature of Sciences Studies (Merton, Mullins, Crane, for example).

As perspective in this work, we will continue the analysis of the Network evolution (observation of individual positions) in two directions: the first theoretical perspective is to highlight the differences between physical networks (data processing or electronic network) and social networks (contract networks, social exchange networks, etc.). What does represent a "meta" network with two dimensions and two types of ties? While the second perspective of this work is to reinforce this preliminary study in the question of concentration: Do the "hub" actors reinforce their positions in the network? How to introduce the "small" firms? -, and the question of fidelity : how many contracts repeat in time? is there a structural or individual fidelity?

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