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# A method for measuring network effects in scientific cooperation

## Article (Accepted version)
## (Refereed)

**Original citation:**
Lahlou, Saadi (1993) *A method for measuring network effects in scientific cooperation.* *Bulletin de méthodologie sociologique* (40). pp. 64-89. ISSN 0759-1063
DOI: 10.1177/075910639304000104

(1993) - LAHLOU, Saadi. A Method for Measuring Network Effects in Scientific Cooperation. *Bulletin de Méthodologie Sociologique*, 1993, 40, 64-89.

# A method for measuring network effects in scientific cooperation

Saadi Lahlou[1]

Summary :

A method for quantitative assessment of the evolution of scientific networks with a light-and-fast mailed questionnaire is presented, through its use in the evaluation of the SCIENCE/STIMULATION programmes of the European Community Framework programme.

The methodology is based on the behavioral description of relationships between labs sharing an EC contract, before and after the programme. Networks are described by a "mean value" of relationships between pairs within the network. Quantitative indicators, obtained through monovariate and multivariate statistical methods, allow comparing the situation before and after the programme, and therefore yield clues for programme impact assessment. An attempt to visualize network evolution with multivariate analysis is presented.

## 1. Nature of the problem

Cooperation between research laboratories is an important part of scientific activity. It is supposed to be an added value of large research programmes, since the incited links might yield further cooperation after those programmes end. Also, it enhances the cohesion of the scientific community and eases the flow of knowledge and research personnel.

EC Science and Stimulation programmes were set up within the EC Framework programme to stimulate cooperation and collaboration between European research laboratories in the fields of exact sciences. Support from the SCIENCE Plan can be given for up to three years to the research teams for travel, staff, computing equipment and meetings plus an extra 20 % for overheads. Individual fellowships for travel and living expenditures in another country have also been awarded in considerable number.

One of the hopes is that these programmes help building EC research networks, and this criterion was submitted to an assessment for the evaluation of the programmes. But no method was available for it, and the very concept of scientific cooperative network remained fuzzy. This paper describes by which methods this assessment was made

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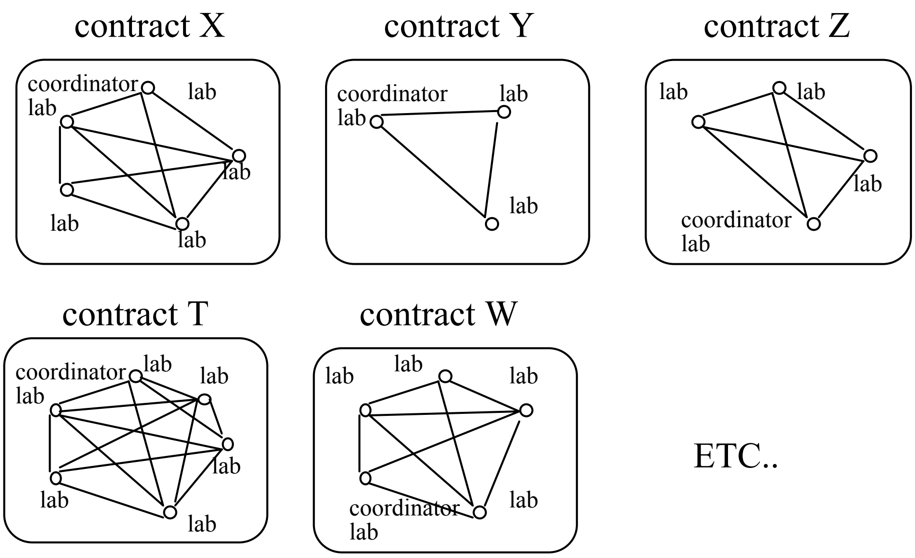
This paper is made after a survey realized for the Evaluation Panel (CEC, DG XII) of Science and Stimulation Programmes, by SHS Consultants and the Crédoc. For further questions and detailed description of the methodology, full report ("EEC Science & Stimulation programmes. Evaluation survey : methodology, operations & data analysis. Crédoc, SHS Consultants, Feb. 1990") can be consulted through EC DG XII.

The situation

183 contracts, involving 629 labs in 12 EC countries, were to be analyzed. Each contract involved from 2 to 29 labs working together on the same project (funded by the programme), including one "coordinator", more specifically in charge of contract coordination and communication with DG XII.




The Commission wanted to describe, along parameters relevant to the objectives to the programmes, the effects on the participating labs. As in particular one such parameter, the network effect, was still only vaguely defined our objective became to answer the questions :

- What changes were brought about in the relationships between the labs in relation to the objectives of the programme ?
- What content does the notion of networks among research labs really have ?

We are therefore facing a more general problem of the birth of networks through external incentive, not only from a pure scientific interest, but also from the pragmatic point of view of a structure (the commission) wanting to enhance the networking effects. This brought constraints on the quantitative evaluation : time (roughly 3 months altogether), and lightness of the questionnaire (2 pages maximum), since labs often complain about the burden of filling administrative forms.

## 1.1. Method

### 1.1.1. Defining networks

Although much work has been done with networks involving only one type of relation (mainly in physical networks with fluid-like transfers between knots, e.g., water supply, electrical or telephonic networks), few theoretical or practical methodologies concerning the quantitative analysis of networks with differentiated qualitative fluxes were known to us at the time. Considering theoretical investment in graph theory was hazardous in the schedule given, since we could not guarantee finding an efficient algorithm appropriate for non-connex graphs such as the ones involved, we chose a statistic approach, including multivariate analysis techniques, appropriate for all-range data exploration. This explains why this paper is pragmatically oriented, and has no bibliography.

We chose to consider the set of labs involved in each contract as a potential local network, independent of the rest of the labs in the world. This is, naturally, a strong hypothesis, but the amount of data that could be collected in reasonable time allows no more[2]. The idea is to assess the effect of SSP on these local networks, by comparing the level of their collaboration *before* the contract and *after*. The first step is then to build up two matrixes of relationships between labs, one before contract, and one after, and then to assess the impact of the contract on the first matrix (relations previous the contract) by comparing it to the second.

Considering the difficulty of obtaining summed-up information on relationships within local networks, the first option was to focus on bilateral relationships between the labs involved in each contract, and to sum up this information in some way to get global information on each contract. To make this option more clear, let us consider one contract, X, involving labs A, B, C, and D ; A being the coordinator. This contract involves 6 couples of labs : {A, B}, {A, C} {A, D}, {B, C} , {B, D}, and {C, D}.

In the ideal case, suppose we have a mean of describing the nature of the relationships in a couple, that we call, for the moment, "value", without more precision. To get first-hand information on all these couples, we must contact at least 3 labs among the 4 involved. Considering that all labs may not answer, it is more secure to contact all 4 labs. We will then get, supposing all labs answer, information on each of the 12 pairs (that is : ordered couples, where (A, B) is distinct from (B, A)). E.g. : for pair (A, B) the answer of A about its relationship with B, (A, B) ; and the answer of B about the same relationship : (B, A). This is valuable in the sense that we can compare those (subjective) data, and, if they differ, compute a "mean" value on relationship {A, B}. It is then possible to compute a synthetic value of contract X, for example the mean value of all the pair values on which we have information.

We would then have a data file consisting of a list of contracts, each with a measure of the mean level of relationship between the labs involved. Each contract is then assimilated to a local network. Assessment of the effect of the programme can then be based on the comparison between the level of relationship before the contract and after.

### 1.1.2. Measuring relationships

Let us now come to the "value" of relationships. It is difficult to measure its intensity, since relationships can take many forms, and that we cannot bluntly assume that there is a linear gradation of relationships, from "no contact at all" to "permanent and all-range collaboration". It may be that different types of networks exist, each with a specific combination of relationships, and that those ideal types would work as "attractors" in the mathematical sense of the term. Common observation of

[2]Proper network evaluation would need to get information, from *each* lab in the world, with *all the other* labs in the world. Our method is therefore applicable only when the network boundaries are defined.

lab networks shows that there are some with weak but regular relationships, like durable interpersonal contacts, with casual co-publication, some with intense and permanent links, including sharing research funds on most projects, some with episodic but intense collaboration, etc. We disposed of no "models" of such networks, and the first thing was to assess them empirically. So, we decided to characterize the state of relationships between pairs of labs by checking the existence of various types of relationship. We started with a dozen interviews of researchers to make a list of the existing modalities that the relationships could take, and we came up with the following list of 9, "no contact" and 8 types of relationships :

"0" = no contact, or just reading each others' publications
"1" = some casual contacts (mail, telephone, meetings in congresses or open seminars only)
"2" = personal contacts between some of your scientists and theirs, including short visits
"3" = exchange, buying or communication of research material (raw data, samples, measurement apparatus...)
"4" = exchange of scientists, or stays of a scientist in the other lab for longer than a week, for the purpose of training, specialization, or technology transfer.
"5" = co-authored publications (in reviews or conferences, symposia, etc.)
"6" = regular meetings or closed seminars between labs
"7" = close relations : permanent exchange or collaboration on several projects (joint experiments, etc.)
"8" = sharing funds on research contracts

Those modalities are just a fast choice of what seemed to be the most frequent types of contacts. Ex-post analysis of more than 400 "open" answers of the labs let us think that this choice was, if not perfect, at least acceptable. Still, it seems that item 3 was not always correctly understood : control showed that some labs only included in this item the exchange of ponderous material, forgetting raw data.

### 1.1.3. Assessment criteria

One important difficulty is : what is success ? Measuring the effects of a programme only implies technical difficulties, but assessing success cannot be done unless success criteria have been defined independently of effect measurement. This should be, in our point of view, one of the bases of evaluation methodology. Still, practice shows how difficult it is for new projects : one can define pertinent success criteria only when one has a precise idea of the precise effects of a programme, and experience of what effects are indeed positive. For one thing, unforecasted boomerang effects can only be assessed afterwards. SSP was such a new programme, and, therefore, we were not given success criteria by the commission, except that "enhanced network activity" was desired.

The criterion that we have taken is the "volume" of relations. We assume that, the more relations there are, the more network effect there is. Should this hypothesis be wrong, one can still use the results as we mainly observed the changes in relationships pattern before and after contract. Only in our conclusions do we use this interpretation rule : "more relationships is better".

To sum up our methodological options, our theoretical choices were the following :
- to analyze each set of laboratories involved in a contract as a small, independent, network ;
- to analyze the nature of relationships within these local networks through relationships between *pairs* of labs ;
- to build an appropriate checklist to characterize the nature of relationships within pairs ;
- to compare the state "before contract" and "after", in order to assess programme impact ;
- to explain this impact through the nature of local networks, and the attitude of labs towards the programme.

Technically, we chose :
- to use a statistical analysis, sustained and validated by qualitative approach ;
- to use "light-and-fast" methods in data collecting, in order to avoid labs the "paper-filling syndrome";
- to use the Commission flexible data base to personalize all questionnaires. This relational data base contains information on all the contracts, obtained through the application forms, and permitted not to ask again too much information during the survey.

## 2. Survey and basic results

The survey was made on all labs involved in ongoing contracts (pr. October 1989) of the SCIENCE/STIMULATION Programme.

The questionnaire was tested by telephone on a couple of labs, and sent to the whole sample. The questionnaire is written in English, and has a standard shape. The second page (Q2, Q3, Q4) is the same for all the labs, but the beginning of the questionnaire, concerning contract specifications, and Q1 (relationships between labs), is personalized for each respondent. Questionnaires were generated from the flexible data base of the Evaluation Division

ICI INSERER UN FAC SIMILE DU QUESTIONNAIRE, SUR UNE DEMI-PAGE.

Personalization of the questionnaires certainly was a main reason for the good return rate and the quality of the data obtained. Also, several variables[3] from the data base were by this mean introduced in the questionnaire before it was sent to the respondents :

contract number (including type : stimulation or science),
number of labs in the contract,
identification of respondent,
nature of respondent (coordinator or simple partner),
Discipline (physics, maths, etc.),
nature of contract (operation or twinning),
identification of each lab by its EC data base code, country of each lab.

This enables respondents to answer the questionnaire in a few minutes without having to look in their own contract files, and helps them remember who are their partners, if necessary.

The questionnaire seemed short to the eye, through some "easy tricks". The numbering of questions goes from 1 to 4. In fact, there are 16 closed questions, 1 open question, and from 2 to 58 questions[4] concerning the relationships between labs, before and after contract. These relationships are non-exclusive, which means that two labs can, for instance, exchange research material (item 3) and/or scientists (item 4). This yields 257 possible types of relationships between pairs[5]. The labs gave more precise information than what a quick look at the questions reveals, since we asked this information for the state of relationships before and after contract. In fact, we can, in theory, position the lab pairs in a matrix of 257x257 possibilities for contract impact, that is 66 049 modalities.

Also, automatic generation of the questionnaire fortunately left a large empty space in the first page for most of the questionnaires, since space had to be planned for the few contracts involving many labs. This makes the questionnaire look even shorter.

[3]The amount of the contract was not included in the questionnaire, but it was also extracted from the data base, and used in data processing.

[4] depending on the number of labs involved in the contract.

[5] That is ($2^8$ + 1) combinations, considering that item 0 ("no contact") is not compatible with any of the other 8 items.

## 2.3. Mailing and return rates

The questionnaire was mailed to the 629 labs. It was fully personalized, and mailed with a personal letter. The respondents were told to send back the questionnaire in a delay of 15 days. After 21 days, all the coordinators who had not answered were phoned, and a personalized questionnaire was faxed to them, when the original had been lost.
Spontaneous return rate was good, and rather fast : 35% three weeks after the first mailing.

Final "usable"[6] return rates are :

| | respondents | labs involved | return rate |
|---|---|---|---|
| coordinators | 155 | 181 | 86% |
| partners | 270 | 418 | 65% |
| Total | 425 | 599 | 71% |

If we now consider response rate by contract, as we could compute 179 contracts out of the 181 that were finally kept , response rate is 99%. This good return rate is due to several factors.

- labs had received money from the EC, and thus were "interested" clients ;
- most of the contracts were still running ;
- excellent appreciation of the programme by the participants, as can be seen through enthusiastic appreciation in the open question, and often in the accompanying letter sent back by the labs with their questionnaires ;
- personalization of the letter and questionnaire ;
- "light-and-fastness" of the questionnaire, which average length was 1,5 page ;

These factors should be taken into account in further applications of the method : users might expect lower response rate if they do not have such positive incentives.
Country of origin significantly affects on response rate, but not the discipline of labs. Response rate was better in contracts involving few labs, although it is difficult to link this effect with the intensity of relationship within the networks.

## 2.4. Data analysis

After the questionnaires were received, they were checked, numbered, transferred onto magnetic support and analyzed.

[6] In fine, about 20 questionnaires were received and not processed, wether they arrived too late or were not filled up correctly. Those figures are computed on the 181 contracts that were finally kept in the sample, after elimination of 2 atypical contracts. Coordinators are counted here as such only in the one contract were they are so, even if they are involved in several contracts in SSP.

## 2.4.1. Pairs of labs

Three main files have been computed. The first is the basic file, containing raw data. The second is the "pairs" file, in which statistical observations are pairs of labs. The third is the "networks" file, in which the statistical observations are the contracts, which, we call, by abuse, "networks". A contract involves several labs working in collaboration on the same project.

All those files are of rectangular type, which means that they look like matrixes, in which the rows are observations, and the columns are variables. Each cell constituted by the intersection of a row X and a column Y contains the value of the variable Y for the observation X, that is to say, Y(X).

The basic file contains the exact translation of the questionnaires, names excepted. Each line is a questionnaire, and the columns are the answers to the various questions. This means 425 lines.
This basic file was used to check and "debug" the data. Once the file cleaned, it was transformed in the so-called "pairs file", and computed with the SAS statistical package.

In the pairs file, observations are pairs of labs. Remember that, unlike couples, pairs are ordered : the pair of labs (A, B) and the pair (B, A) are two distinct observations.
The variables are all the variables in the questionnaire, including contract information and the answers to closed questions. This means that, for a pair (A, B), the answers of A to the questions Q2 and Q3 have been attributed to (A, B). Also have been attributed to this pair the variables concerning the contract in which it answered about its relations with B[7].

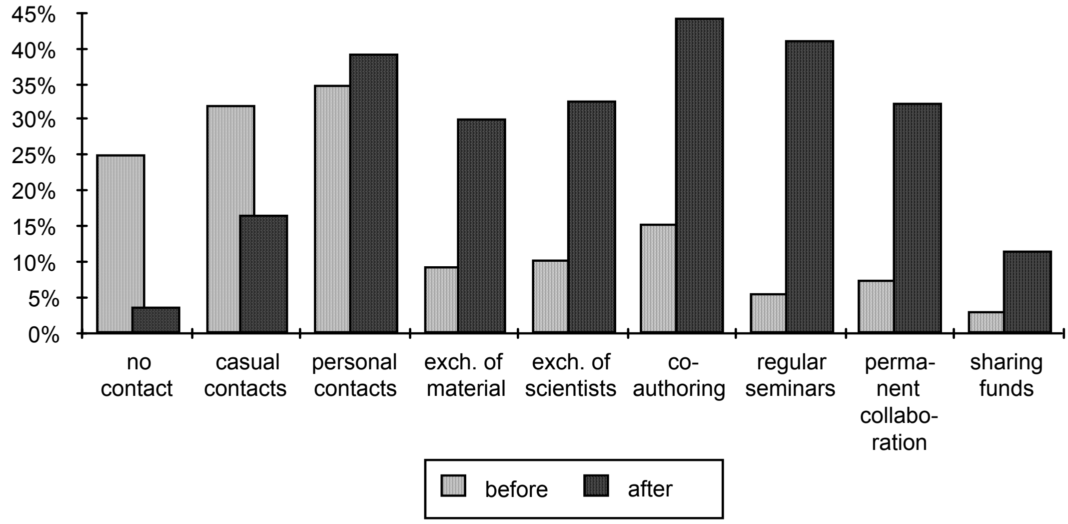
Statistical analysis of the pairs file showed a massive effect of the programme on the declared relationships. The following table shows the frequency of each type of relationship between pairs, "before contract" and "after". This can be considered as a raw quantitative indicator of network activity.

[7] In some hypothetical case, suppose A and B are both involved in contract X and also in contract Y. A has received two questionnaires, one concerning contract X, and one concerning contract Y. B has also received two questionnaires, one for evaluation of contract X, and one for Y. If A and B have both sent back their questionnaires to us, we have 4 questionnaires, that contain the following pairs : (A,B,X), (A,B,Y), (B,A,X), (B,A,Y). The pair file will contain 4 different pairs.

| | before contract | after[8] |
|---|---|---|
| *no contact* | *24,4%* | *3,9%* |
| *casual contacts* | *32,2%* | *16,9%* |
| | | |
| personal contacts | 35,1% | 39,4% |
| exchange of research material | 9,5% | 30,2% |
| interchange of scientists | 10,4% | 32,9% |
| co-authoring | 15,6% | 44,5% |
| regular seminars | 5,9% | 41,3% |
| permanent collaboration | 7,8% | 32,4% |
| sharing funds | 3,4% | 11,7% |

"Positive items" (co-authoring etc.) increased, while "negative items" (no contact, casual contacts) decreased. Existence of personal contacts between scientists of different labs apparently remains unchanged. But the number of scientists involved in each lab has probably increased.

Profile of relationships between partners, before and after contract.
(pairs file)




## 2.4.2. Networks

Analysis of the pairs file, through bilateral relationships, showed a sharp increase of the number, type and level of these relationships. Indeed, the programme affected the labs. But the whole is more than the bare sum of parts, and what we want to investigate here is precisely this "more than the bare sum". Has some structure (network ?) appeared during the programme ? We then come to the necessity of comparing the group of labs involved in a contract before and after the programme, to see how this group as a whole has changed. We thus created a file where the individuals are the

[8] Total is higher than 100% since items are non-exclusive. Results are computed on "pairs" file.

networks.

In this file, observations are contracts. We assimilate a contract (convention between different labs and the EC, where the EC funds those labs as a group to work in common on a specific project) to the group of tender labs. We did so with the idea that a group of labs working together on a single project might become a small network. So the underlying idea is : let us take a group of labs involved in a contract with the EC. We are going to measure whether they are "more of a network" after the contract, when they have worked together on the same project in this EC Programme frame, than before. If yes, we shall conclude that this programme indeed creates or enhances networks. As one can see, the idea is very simple, except for the fact that we have little knowledge of how to measure this "networkness".

How can we sum up information concerning labs connected in a contract, so as to consider a network as one single object ?

The information concerning the contract itself (number of labs in the contract, discipline, nature of contract), is not a problem.

For the closed questions (e.g. : what is the frequency of contacts with other labs ?), it is not so difficult : we can get a mean value of the answers of pairs in contract, for each modality, or for the frequencies of contact, synthesize a continuous variable (once a week = 52, once a month =12 etc.), and compute the mean value for all respondents in one contract.

The main problem lies, of course, in the computation of a mean "value" for relationships between labs. The gross solution would be to consider each type of relation as an independent variable, and compute the mean.

For example, if the structure of answers for a contract involving A, B, and C, is :

| | "before" | "after" |
|---|---|---|
| | 0 1 2 3 4 5 6 7 8 | 0 1 2 3 4 5 6 7 8 |
| (A,B) | 1 0 0 0 0 0 0 0 0 | 0 0 0 1 0 1 0 0 0 |
| (A,C) | 0 0 0 0 0 1 0 0 0 | 0 0 0 1 0 1 1 0 0 |
| (B,C) | 1 0 0 0 0 0 0 0 0 | 1 0 0 0 0 0 0 0 0 |
| (B,A) | 1 0 0 0 0 0 0 0 0 | 0 0 0 1 0 1 1 0 0 |
| (C,A) | 0 0 0 0 0 10 0 0 | 0 0 0 1 0 1 1 0 0 |
| (C,B) | 01 0 0 0 0 0 0 0 | 1 0 0 0 0 0 0 0 0 |

we can create for the contract the same 18 variables (9 before and 9 after), and compute for each variable the column mean on all respondents. For example, the first variable will have the score (1+1+1)/6 = 0.5, the second will have the value 1/6, etc. The problem is that this way of doing implies a considerable loss of information, because we loose the information on combinations. For instance, the value 1/6 for the second variable would be the same if the "1" came from pair (C, A) and not from pair (C, B). And, if it came from pair (C, A), the relationship-before between (C, A) would then be 010001000 and not 000001000. So, computing in this way is not fully satisfying on theoretical grounds.

Therefore, our first option, before we started dealing with the *real* data, was the following. We computed all the 257 combinations of relationships between pairs (in fact, 257 before, and 257 after). Each pair was assigned a "1" on the combination it declared, and "0" in all others. Until here, no loss of information. We then applied the computation of means described in the former paragraph on those combined variables.

This solution has many theoretical advantages that shall not be described here, for the simple reason that, unfortunately, on real data, the result showed less satisfying than with the grosser method. We had expected precision increase with this method, since it had proved much more efficient in a former study [9]. The underlying problem is that the file is too full of "holes" (zeroes) to get good enough distribution curves on each variable, so that the artifacts of the method overcome significant results, even if those results do not shock common-sense. Such a heavy method (in computing terms) is to be applied, if ever, only on large or very dense networks, but this could hardly be known before testing.

So we used the gross method, the "contracts" file is mainly a computation, by contract, of the means of the "pairs" file.

## 3. Results on networks

The same methodology was applied to "pairs file" and "contracts file". Both analyses yield similar results : there is a sharp increase of all forms of relationships between labs compared to the situation before contract, building relationships seems to be a progressive but probably non-linear process, relationships are cumulative. Only the results on the contracts file will be presented here after, since they prove more interesting in respect of network assessment methodology.

### 3.1. Network analysis

First, we can look at what is the declared use of contracts. On the following graph, each item is represented with the mean value in contracts (remember the items were rated from 0 -"this is not how we use it"- to 4 -"we use it mainly for that"-), Therefore, the higher the value, the higher the item was rated by respondents. The graph shows that the contracts were mainly used for building a permanent

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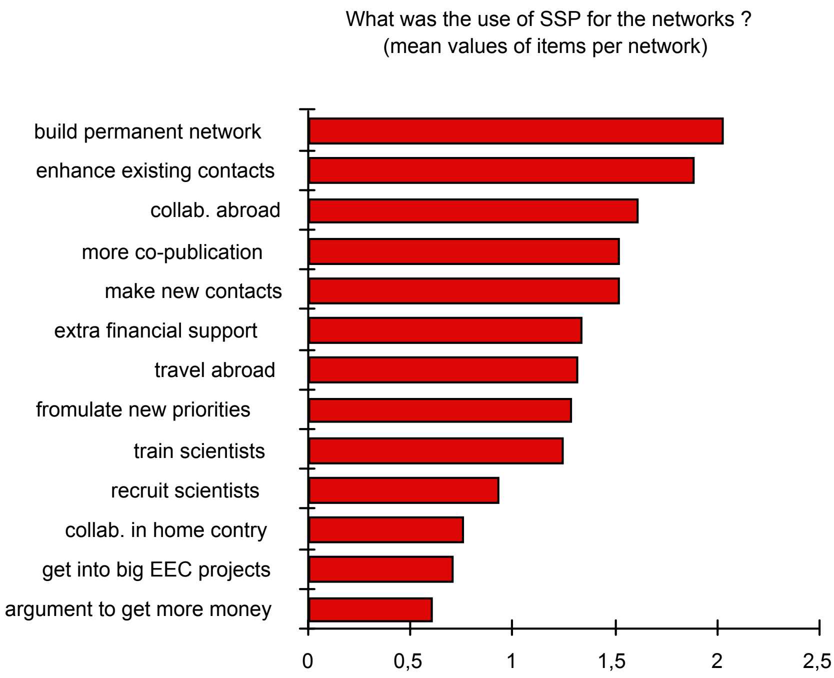
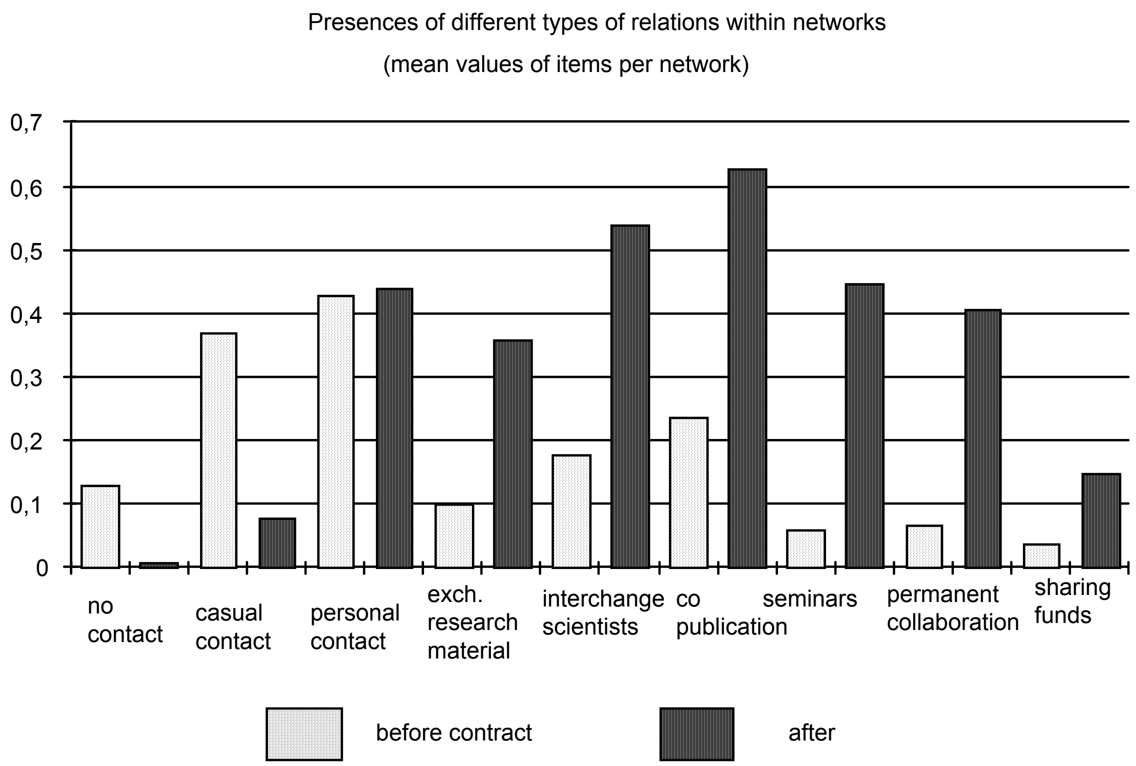
[9] An attempt to determine empirical proximities between foodstuffs by classification under contiguity constraint in two successive factorial spaces. The subject is a bit far from network assessment, but, formally, the problems are very close (Lahlou, 1988).

network, and enhancing existing contacts[10].




If we now look at the general evolution of relationships within contracts, we find that all "positive" forms of relations have significantly increased. The most important development was the rise in interchange of scientists and co-publication in most contracts. But the most spectacular increase comes in the items "seminars", and "permanent collaboration".




[10] The same result was observed on the pairs file.

The main difference between this analysis on contracts and the analysis of pairs is that, here, our observations are local networks. For all items, we consider the mean value in local networks (contracts)[11]. This analysis shows slightly better effects of the programme than when observed on pairs, because it includes what we could call "network effect", that is, some relations can be present in a network only through one or two pairs.

The network effect is probably one of the reasons why increase in relationships can be so fast. For example, suppose A, B and C are in a contract ; A  and B have close relations, but C is a newcomer that only has casual relations with A. We can suppose that, as C gets closer to A during the contract, he will also get closer to B, through some positive scale effect. The newcomer benefits of the already existing level of relationship, as if he adapted to a "baseline" level that is already high. This is sociologically understandable : if the general atmosphere of a meeting is already very informal and friendly, newcomers will sooner reach this communication style ; existing procedures between partners can simply be copied by newcomers, instead of having to be invented…

## 3.2. Factors structuring networks

We tried to synthesize the state of relationships within networks, using multivariate data analysis techniques. The idea is to consider networks as objects characterized by their profile of relationships, and to build such a space that would be organized by the main "dimensions" of relationship pattern. In such a space, dimensions will be the organizing factors of the relationship pattern. Such dimensions will oppose types of relations that are negatively correlated (e.g. : "no contact" & "permanent collaboration"), and bring together types of relations that are positively correlated (that is, that are observed to go together in contracts, e. g. "exchange of research material" & "co-publication").

As multivariate analysis has the property of giving somewhat symmetrical role to variables (relations) and observations (contracts), in such a space, contracts that have the same pattern of relationship will flock together, and be distant from contracts that have other types of relationship.

Several methods have been tested[12], on several types of files, and they give comparable results. We shall present here only one of these, a  principle component analysis where the active variables are the 9 variables "after". Roughly, this space is organized by the correlation between the relational variables "after". We hereby built a relational space in which contracts are placed.

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[11] E. g. a value of 0.5 for an item means that there is a mean of 50% pairs in each contract that have that kind of relationship. For example, let us consider a "typical contract" that would have the mean characteristics of our sample. Before SSP,  10% of the pairs in in this contract exchanged research material, and now they are 35% to do so.

[12] Multiple Component Analysis (using contingency  tables on modal variables) on relations "before" only, on relations "now" only, on relations "before" and "now" simultaneously, and the same analyses using Principal Component Analysis, which deals with continuous variables and hence can be used with the "contracts" file, but is sensitive to mass effects.

The analysis yields three main factors.

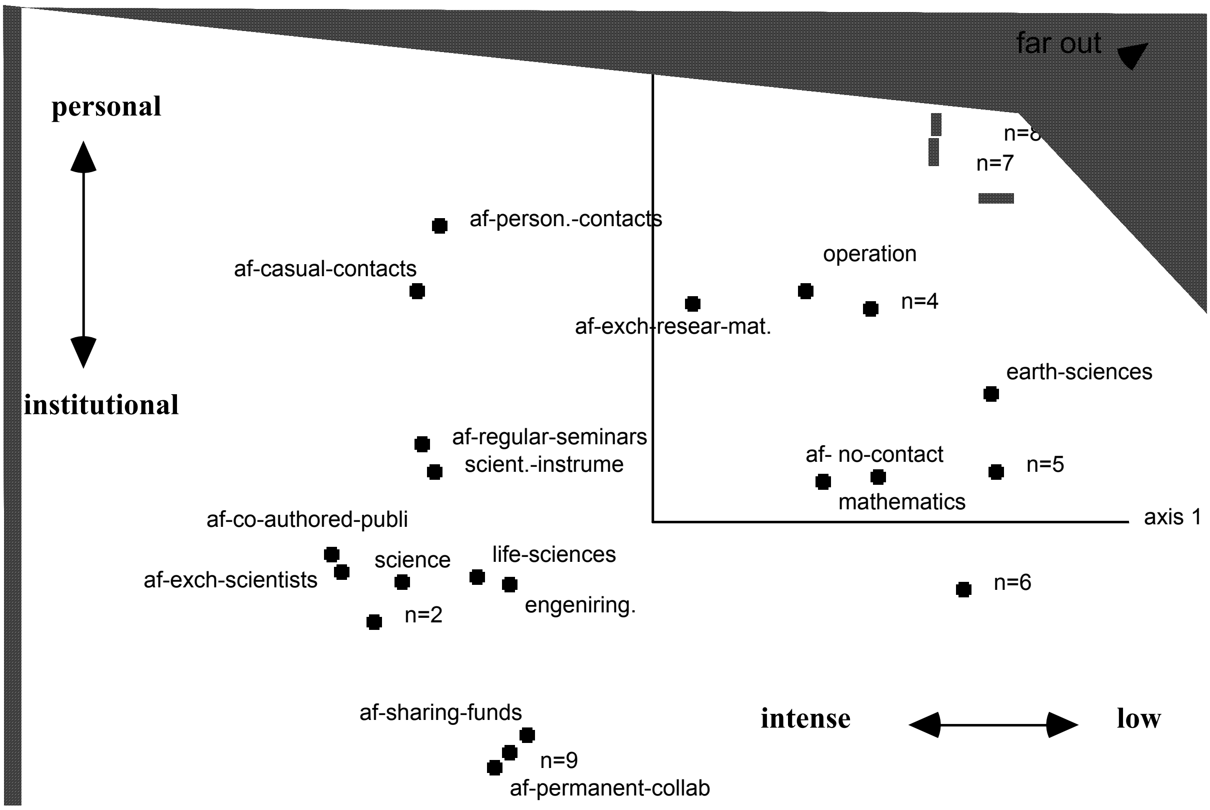
Factor 1 is a factor of density of relationships. On one side, it is correlated with co-authoring, interchange of scientists and research material, seminars and personal contacts. On the other side, it is correlated with no contacts and casual contacts. One could say this factor opposes dense relationships and scarce relationships. This is easy to understand : relations are roughly correlated, labs that have a close work together will use most types of relations, when loose collaboration implies *few of all the types* of relations.

Factor 2 deals with the range of relationships. On one side, it is correlated with personal contacts, exchange of research material, and casual contacts. On the other side, it is correlated with sharing research funds and permanent collaboration. We infer that this factor opposes personal relations (scientist-centered) and institutional relations (between labs). This effect reminds us that institutions are objects consisting of people. The objects we observed are the institutions, but in fact there are two types of relevant objects in networking : people (building social networks) and structures (building business networks). One can predict boldly that this effect will be observed in all measurements of networks between organizations.

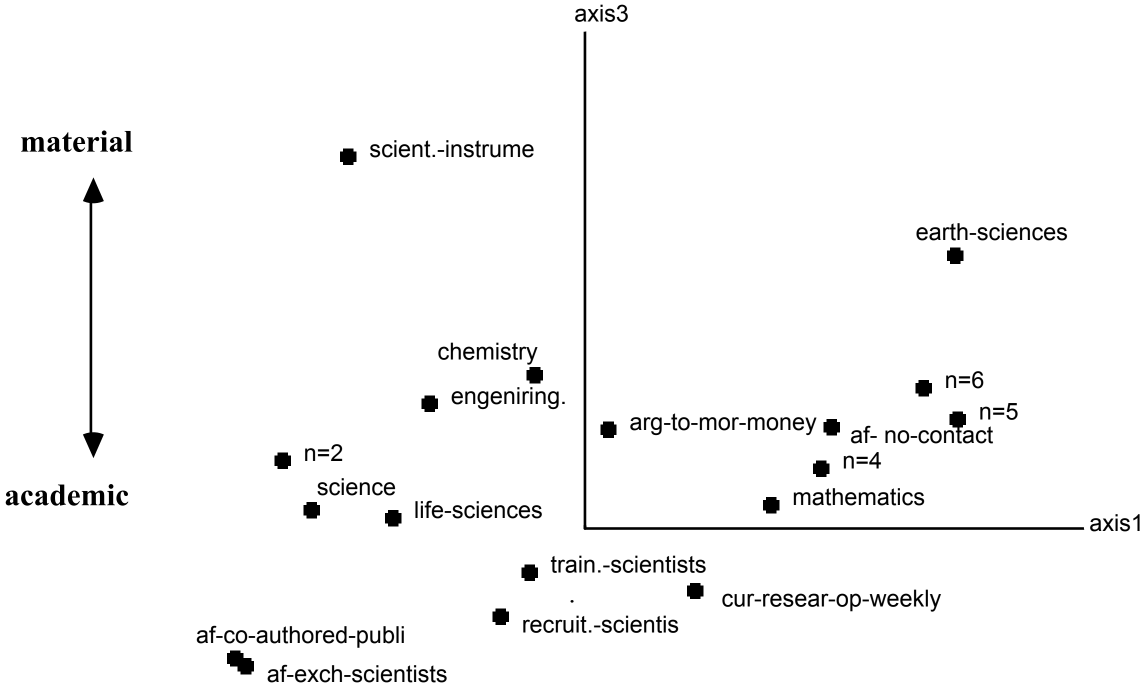
Factor 3 opposes the tone of relationships. On one side, it is correlated with interchange of scientists and co-authoring ; on the other side it is correlated with sharing funds and exchange of research material. It seems to oppose academic relationships and material-oriented relationships. This is a pragmatic distinction that enlightens the nature of networks : several strategic objectives of the actors might underlie the visible effects of networks. It seems here that scientists produce two types of outcomes : academic publications, and experimental results, and that a network might develop a local culture oriented more towards one than towards the other. This result is consistent with academic commonsense, and shall not be further discussed here.

In conclusion, beyond the obvious and expected results of the first factor (quantitative intensity of relationships is a main dimension), other dimensions of scientific network appear, that measure qualitative factors : relations between labs can be between institutions or between scientists, and can be rather classically (academic) or more project oriented. These empirical results enrich our original view of "dense networking is more relationships".

If we project on the first plane the most significant items, we can see some interesting results. For example contracts involving only 2 labs yield more intense relationships, and then labs as institutions are involved, while contracts involving many labs seem to have connected scientists rather than institutions. "Operations" contracts (result oriented) induced more personal relations than "twinning" contracts (intended to bring together labs). Contracts oriented towards "training scientists" have a rather institutional tone…




Projection on second plane (axes 1 & 3) mainly shows the material orientation of contracts in scientific instrumentation and earth sciences, chemistry, and engineering sciences, while contracts oriented towards recruiting scientists have a more academic tone[13]



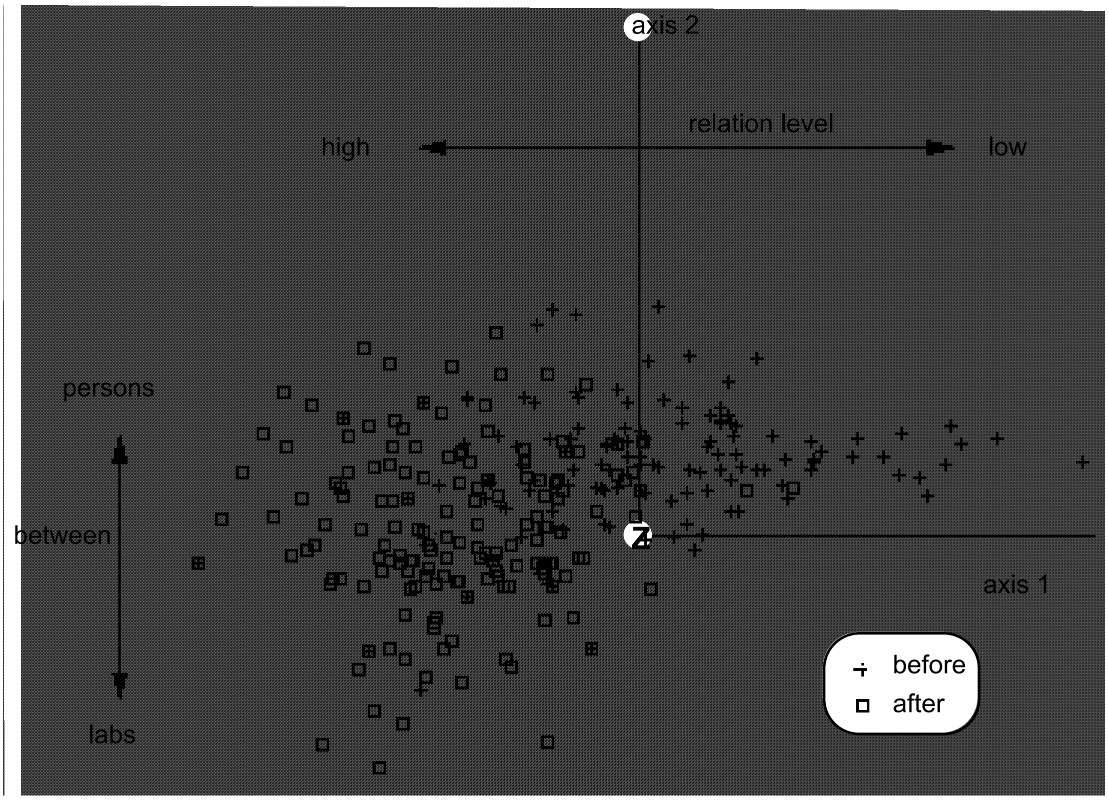

We shall not insist on those results. First, because multivariate analysis is never a proof, but only a

[13] Here must be said that qualitative analysis showed that "exchange of research material, although DATA were namely included in the question) seems to have been too often understood as exchanging ponderous material (matter, and not information). This probably induces some bias in our results. Still, the results obtained seem to convey significant information.

clue. Second, because they are linked with this specific programme, and we are here interested in methodology, not in specific results.

What must be retained of this analysis is that networks can be considered as objects characterized by some specific dimensions. These dimensions, in this case, are measurable by their coordinates on factors. It is, therefore, possible to measure those structures with quantitative indicators. In this case, the scales would be global intensity of contact between partners, personal/institutional tonality of relationships, and material /academic orientation of research production.
Given those scales, it is then possible to measure what is the influence of various variables (amount of contract, subject, discipline, countries of origin, number of labs…) on the evolution of networks, by crossing those scales with the variables.

Let us now look at the position of contracts before and after in this space of relations.




On this graph, contracts are projected in their before ("+") and after ("□") positions on the first factorial plane (axis 1 = factor 1 and axis 2 =factor 2). The zone where most "before" contracts are is circled with a dotted line, when the zoner of "after" contracts is circled in dark zebra line. Obviously, we see here the general effect of the Programme : networks moved from the up-right zone (few contacts, between-scientists) to the down-left zone (intense, inter-labs contacts). We can then infer that the programme allowed the potential networks, initiated by individual in several labs, to become intense relationships involving their institutions.

As intense relationships seem to involve labs (instead of individuals) more than scarce relationships, one can wonder whether the success of SCIENCE /STIMULATION Programme is linked with the fact that it was, finally, centered on providing help on logistic aspects of research work, and not directly on research itself. Unlike other big programmes, oriented towards the production of a given kind of results, SCIENCE provided non-specific logistic supports. To take a crude metaphor, suppose research is a trip in your car, where sectoral EC research programmes provide the gasoline, SCIENCE provided oil to the motor.

As one can see, this analysis allows to feed the evaluation commission with questions concerning the very mechanisms of programme impact on networks.

## 3.3. Classification of networks

Another way to assess the effect of the programme is to make a classification of the pairs of labs, before contract and after, according to the type of relationships they have. Instead of rating the level of relationships with quantitative indicators, we try here to see how many labs switched from a position in a class with low relationship to a high relationship class. The rate of labs that have not "progressed" would then be a quantitative indicator of the programme's degree of failure.

### 3.3.1. Networks before

We made a classification of contracts "before" and "after". The classification was done with automatic hierarchic classification procedures. This procedure sets in the same class contracts that have the same relational profile, by clustering[14].

Before contract, "contracts" can be classed in 4 different "before" classes.

<u>BF-Silent pair (44 contracts, 25%) :</u>

Contracts in this class are characterized by a high rate of "no contact" between their pairs. These contracts involve pairs of labs that do not know each other. This does not mean that all the labs do not have contact with each other, but rather that we have "chains" (A is in contact with B, B with C, but A and C have no contact). This is why we called them "silent pair".

This class is more typical of labs who used SCIENCE to make new contacts (of course !), and often increase collaboration with labs in their own country. Frequency of contact in these contracts was slightly lower than in other classes.

It is more typical of contracts involving more than 2 labs.

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[14] In fact, the classification was made on the basis of the coordinates of contracts in factor spaces of "relations before" for the "before classification", and in the space of "relations now" for the "now classification", but, as all factors were used, the result is theoretically the same as if we had used the basic sets of 9 binary corresponding variables used for factor analysis.

BF-Casual contact (68 contracts, 38%):

This class contains contracts were relationships between pairs were mostly casual.

SCIENCE contracts were often used here to recruit new scientists, make new contacts, and travel.

BF-Linked (52 contracts, 29%):

Networks in these contracts can be considered already existing with a low relational profile. Co-authoring, personal contacts, and interchange of scientists existed before award was obtained.

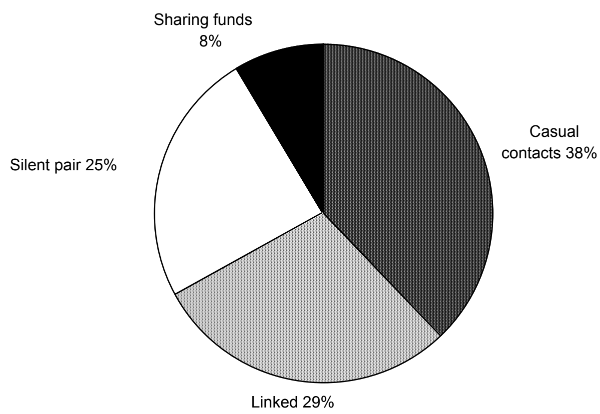
The use of SCIENCE for the concerned labs was mainly : more co-authoring, recruiting scientists, enhance existing contacts.

It is more typical of contracts involving 2 labs (46 % of the 2-lab contracts are in this class, and they account for 73% of the class).

BF-Sharing funds (15 labs, 8%):

This class contains contracts that have tight relations, and often shared research funds prior to the contract. They declare "permanent collaboration", and most types of relations.

The following graph shows the respective importance of the "before" classes of contracts.




### 3.3.2. networks after the programme

After contract, "contracts" can be classed in 6 different "after" classes.

NCL-Silent pair (5 labs, 3%) :

This class is similar to the "silent pair" class before. These contracts often include pairs who had "no contacts" before. Note that this type of network fell from 25% to 3% after the programme.

NCL-Casual contact (20 contracts, 11%):

This class contains contracts were relationships between pairs are mostly casual, and personal. These contracts often include pairs who had "no contacts" before contract.

<u>NCL-Weak links (50 contracts, 28%):</u>

In this class, relations of various types between labs exist, but are much lower than the average.

<u>NCL-High/personal (40 labs, 22%):</u>

This class contains contracts that have personal relations, exchange research material, co-publish, but share no funds and do not declare permanent collaboration. Relations seem to lie mainly on a personal basis.

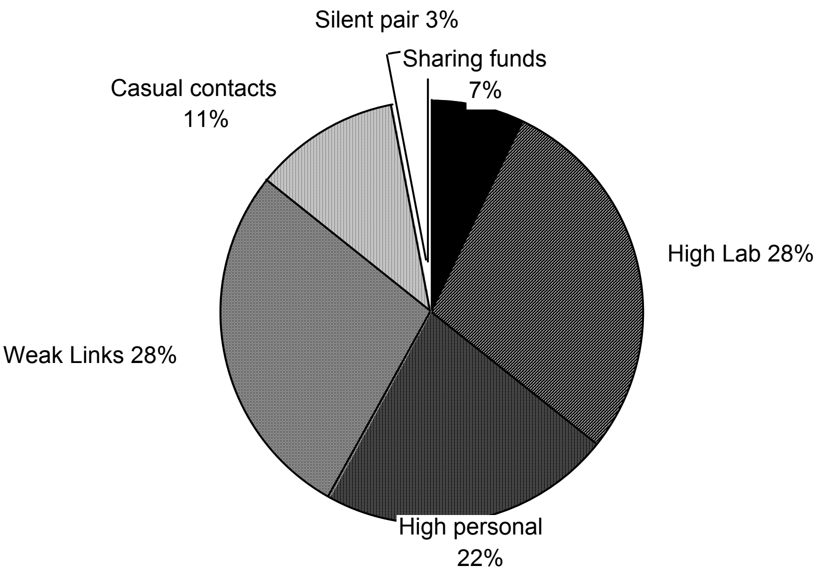
<u>NCL-High/labs (51 labs, 28%):</u>

This class contains contracts that interchange scientists, co-publish, and declare "permanent collaboration". Relations here seem to be relations between labs as entities, more than personal relations. It is more typical of contracts involving 2 labs.

<u>NCL-Sharing funds (13 labs, 7%):</u>

This class contains contracts that have tight relations, and share funds. They declare "permanent collaboration, and most types of relations, including exchanging research material. The level of relationships of this NCL-sharing funds is higher than the BCL-sharing funds.

The following graph shows the respective importance of the "after" classes of contracts.

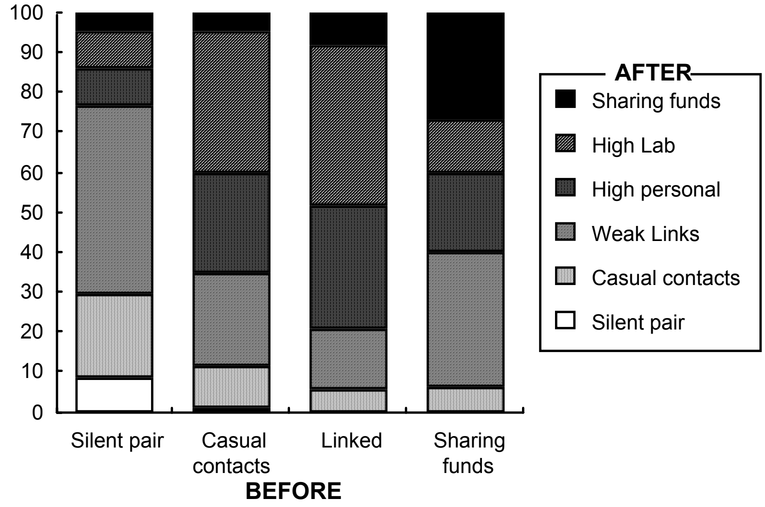



We could say that, before being award a contract, 29% of the cases could be considered as potential networks, and 8% as actual networks.

After the support, only 14% of contracts have scarce or casual relations, and cannot be considered as operating networks. 28% can be considered as potential networks, 50% as actual networks, and 7% as good networks, with a high relational level.

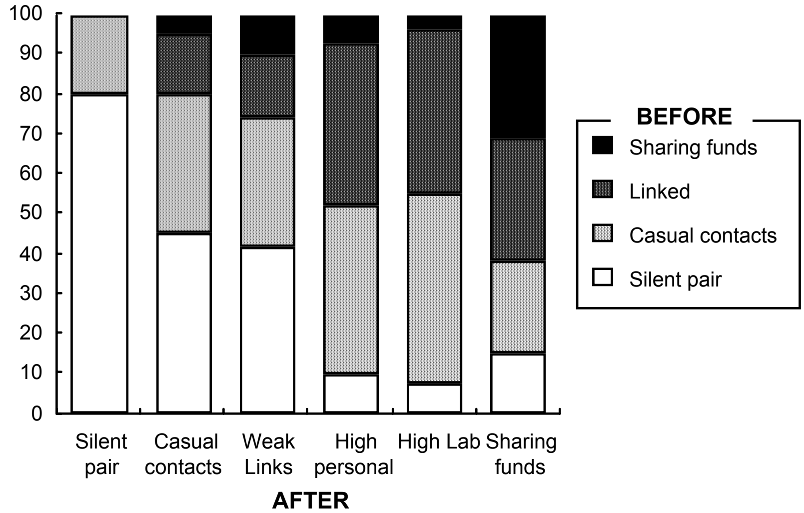
## 3.4. Changes

The following graphs show the evolution of the various classes, before and after contract.
The first shows what happened to the "before" classes.




For example, we can see (first column) that one half of the contracts that were in the BCL-silent pair class before are after in the NCL-weak links class.
As expected, the relation after is all the more intense as it was strong before. But we can see (and this might be a result of the "network effect") that an important percentage of contracts with rather low relational level could improve its status quite well.

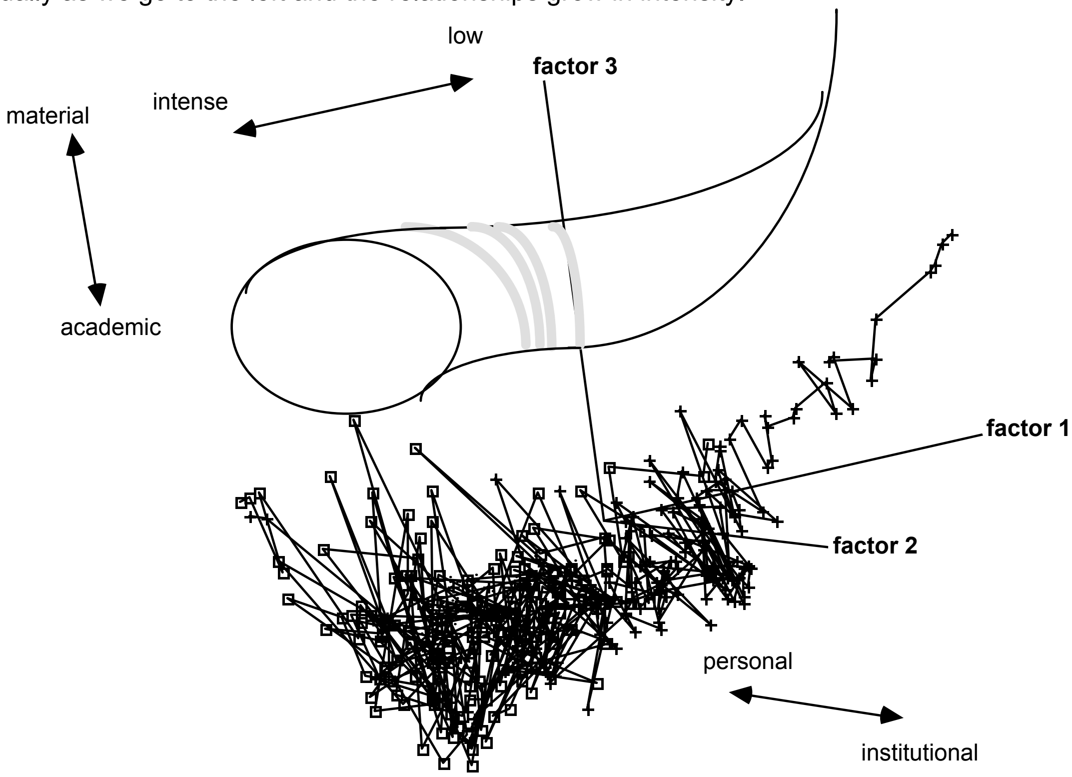
The second graph shows where the "after" classes come from.



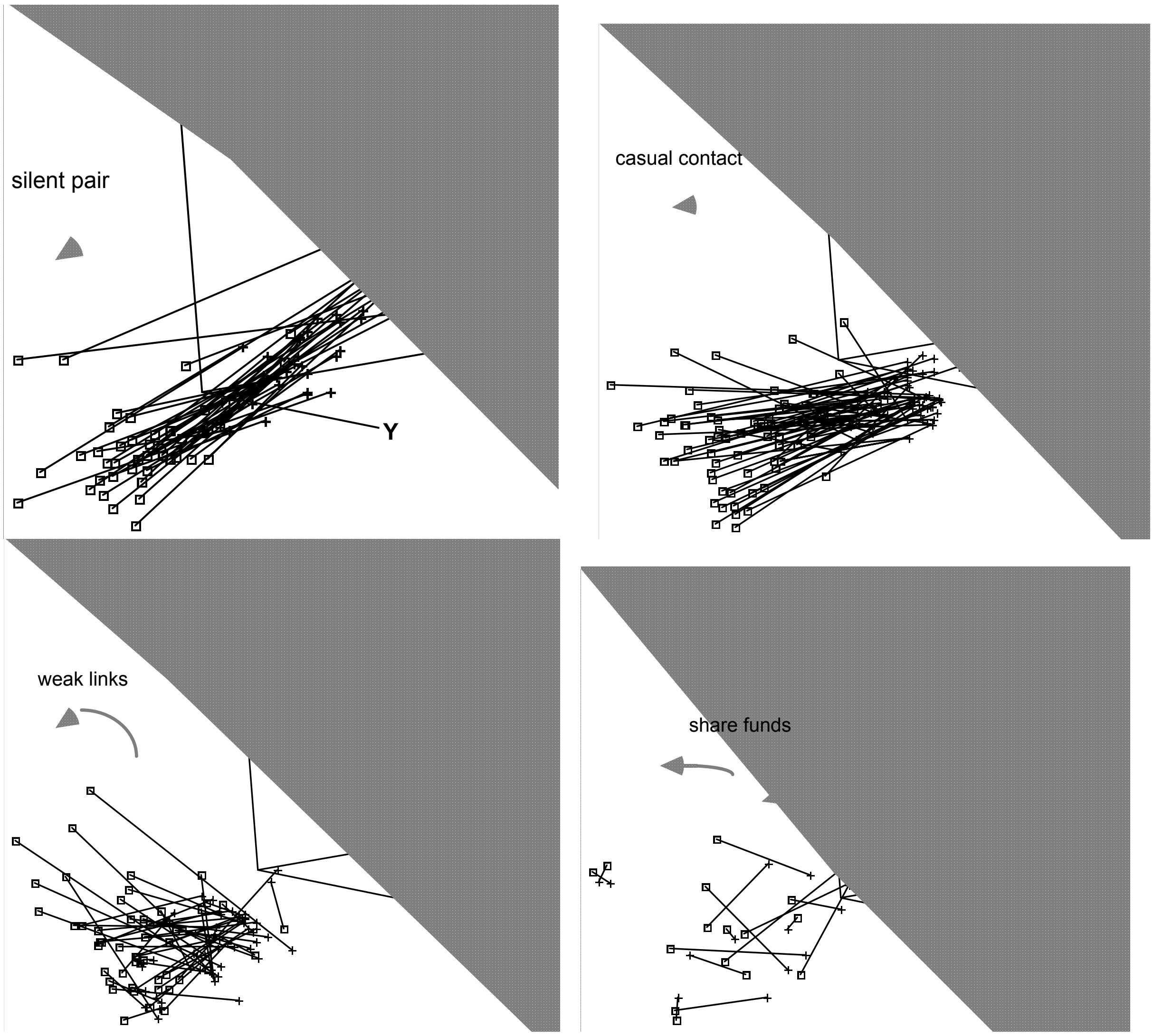

It shows the same conclusions.
For example, we can see that columns on the right (high personal, high labs, share funds) are darker than the ones on the left, because those classes are made of contracts that already were in high-relational classes before the programme.

One must remember that classes are unequal in size. This way of presenting histograms is therefore slightly dishonest, but it allows to see the effect better. However, this method allows to measure the effect of the programme, and, in some ways, to lighten the mechanism of network building within contracts.

Another way of approaching the network evolution mechanism is to look at the evolution of networks in the space of relationships. If we examine figure A in three dimensions (the 3 first axes), we can see that it has grossly the shape of a horn, the point of which is on the right size (no contacts), and widens gradually as we go to the left and the relationships grow in intensity.




This shape is logical : there is only one way of having no relationships with others, but, there are many different ways of having a lot of relationship. We tried to check the existence of attractors, by joining together the position of networks "before" and after". On the following graphs, one can see, for each class before, the position of the networks "before" and "after"



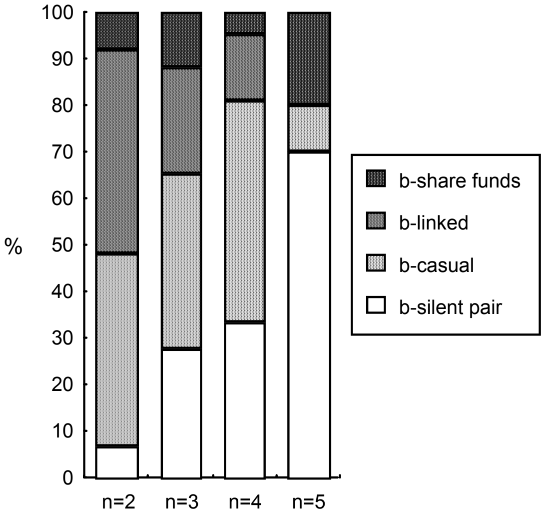

As one can see, the networks from each class evolve in a rather similar way in low relationship classes, and divergence starts when relationships become intense. The general trajectory goes from the small end of the "horn" to the large end. Those results confirm the previous, but data are too scarce to allow precise investigation of the existence of attractors. Nevertheless, the method seems interesting and should be applied on further data.

Before we conclude, let us examine some results that show how these quantitative indicators could be used for evaluation.

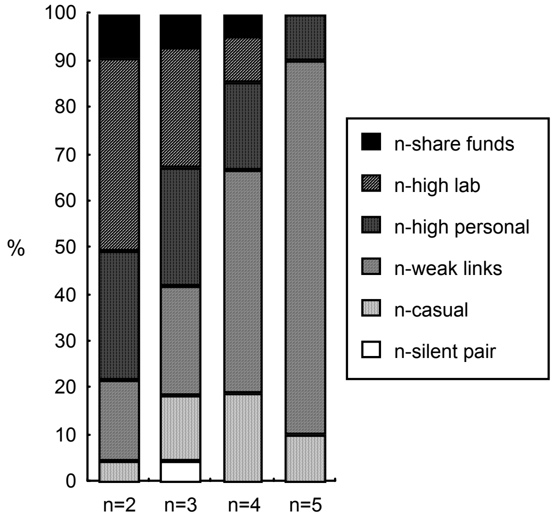
Here is the repartition of the contracts by number of labs in network and class of relationships, before and after[15]. The obvious effect is that the relationships are all the more intense that the networks are small, before contract or after. The programme enhanced relationship level in all types of networks, but did not change this ranking.

15 Only on networks involving 2 to 5 contracts, since bigger networks were not enough numerous to be statistically significant.

relation class /network size : before




relation class /network size : after




In the same way, results concerning the effect of discipline, of funding amount, of declared use of funds by the labs, of nationality, could be obtained, with their degree of statistical significance.

## 4. Conclusion : main results

The study allowed to draw the following conclusions :

The impact of the programmes, as measured by the quantitative survey, is strongly positive on the density of relations within networks. All forms of collaboration studied increased sharply within pairs of labs, often with a factor 3. Before the contract, half of the pairs had little or no contact, and less than 30 % can be considered having a significant level of relations between labs. After contract, only 18% of pairs have little or no contact, and one can consider that at least 37% of them are then involved in what seems to be strong relationships including sharing research material, funds and personnel.
The frequency of contacts between labs varies between phases of collaboration. Frequency of contacts between labs remains relatively low by social standards : generally from 1 to 3 contacts per month.
Roughly, the stronger the relations before, the stronger they are after. Still, many pairs went directly from low-level relationships to high-level ones. But growing relationships between labs do not follow a linear development. There is a gap between no contacts and casual contacts, and two steps seem to make a big difference : exchange of research material, first, and then sharing funds on research projects.

If we now consider local networks, the results are about the same, but we can measure them in a different way : before awards, 29% of contracts could be considered as potential networks, and 8% as actual networks. Afterwards, only 14% of contracts have scarce or casual relations, and cannot be considered as operating networks. 28% can be considered as potential networks, 50% as actual

networks, and 7% as good networks, with a high relational level.
The existence of a "network effect" that would allow labs to increase their relationships with other labs by transitivity should be investigated."

These conclusions helped the evaluation panel in their assessment of the programmes, which was the first objective of the survey. They were consistent with the other approaches used in this evaluation (peers review, qualitative survey).

Apart from the local use for this specific evaluation, and beyond all its technical limitations, this survey allows us to make some general methodological conclusions. A light-and-fast quantitative survey can yield pragmatic results on evaluating the impact of an external incentive on existing networks. As these surveys cannot, by construction, yield a very large amount of information, they must be connected with qualitative analysis in order :

a) before survey, to define precisely the evaluation criteria and their measurement scale,

b) after survey and during data processing, to valid hypotheses and enlighten the specific problems that appear during data analysis.

Network assessment can be roughly done with the crude statistical methods used in this survey. Behavioral approach for relationship description can lead to network scaling, and comparison before/after allows research on the mechanism of network pattern evolution. This method is applicable wherever the boundaries of the networks to be studies are known, which is a very restrictive case. Still, as methods for identifying network boundaries in a general population of individuals are available, the method could be applied to study the evolution of the network local structure in time, even if their boundaries change, provided that networks are individually identified.