

Further elaboration of a graph-theoretical analysis of R&D collaboration

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1. Background

The objective of this paper is to propose a number of analytical applications that can result from a graph-based mapping of public-supported and private R&D collaboration.

The graph-theoretical mapping of R&D collaboration in the Framework Programmes (FWP) of the EU, in the more near-market Eureka initiative and in private technology alliances has been carried out for Belgium (Meeusen and Dumont, 1997 ; Dumont and Meeusen, 1999) and was extended with Spain and Switzerland within the former Focus Group on organisational mapping (OECD, 1999).

The analysis so far has provided some interesting preliminary results which were however for the greater part of a descriptive nature.

We will show how the graph-theoretical mapping can be further elaborated for more analytical purposes and econometric estimations which may provide useful insights on the research topics of the Focus group on Innovative Firms and Networks.

2. Methodology and present results of the graph-theoretical mapping of R&D collaboration

The graph-theoretical approach that has been proposed for the mapping of the R&D network fits within the paradigm of social network analysis. Data on the relations between different entities can be used to create a graph that enables to detect linkages in different types of networks and the impact these network relations may have on the behaviour of its members (Sprenger and Stokman, 1992). As such it seems an appropriate analytic tool to trace the increasing interactions and (tacit) knowledge flows between firms, universities, research institutions and other actors of the NIS.

The analyses that have been carried out so far used data from participation in 'pre-competitive' FWP projects of the EU (EC, 1997b), more 'near-market' Eureka projects (Eureka, 1999) and participation in international (strategic) technology alliances (MERIT, 1998).

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The network criterion is the question whether two actors collaborate in a R&D project (FWP, Eureka) or have established a co-operative agreement. All actors are defined in a pointfile to which additional data can be added (organisation type, nationality, industrial sector, balance sheet data, ...). All pairs of linked actors appear in a tail-head combination in a linefile in which data on the specific project or agreement can be added (starting date, ending data, number of partners, closeness to market, ...), or data that are specific for the corresponding pair (e.g. financial participation, interlocking directorship,...).

We will summarise the most important results of the analyses that have been carried out for Belgium and within the FG on organisational mapping.

More details can be found in Dumont and Meeusen (1999) and OECD (1999).

* Networking has become an apparent feature of the present innovation process and business strategies. There are however important differences among actors, sectors and countries with regard to the occurrence, magnitude and motives of collaboration in basic and applied research and the development of new products and processes.

* The present results seem to confirm that firms of small countries are significantly more inclined to engage in partnerships with foreign actors than firms of large countries (see also Christensen, Rogaczewska and Vinding, 1999). This suggests that they rely on networking to compensate for insufficient resources and appropriate partners in their home country: networking as a substitute for scale.

* Subsidised R&D collaboration is still highly dominated by a small group of actors (often large multinationals)

* A comparison of specialisation patterns reveals a certain mismatch between technological activities and economic performance. The ascertainment of high scientific achievement and relatively poor technology and economic performance for a number of European countries has been called the 'European paradox' and is explained by a poor link between science and technology and by weak commercialisation efficiency (EC, 1997a).

* In the FWP of the EU, that aim to foster pan-European collaboration, countries on average are still inclined to collaborate with neighbouring or culturally related countries, whereas both small and large countries tend to prefer collaboration with partners from large countries. The preference for other countries is more outspoken the closer the collaboration gets to the development of products or processes. This supports the argument of Christensen, Rogaczewska and Vinding (1999) that collaboration, especially when the exchange of tacit and disembodied knowledge is involved, is still strongly dominated by cultural affinities.

* There is little if any evidence at all to support the pipeline model which suggests the sequence of pre-competitive research, followed by more near-market collaboration and the establishment of strategic private agreements.

As there were only three countries in the FG on organisational mapping for which the analysis was fully completed the participation of more countries would certainly enrich the analysis and substantiate the results.

However in this paper-more than just promoting the graph-theoretical mapping as carried out so far-we intend to show how the approach may be helpful for the analysis of some research topics that have been set out by the FG on Innovative Firms and Networks. More precisely we think the approach can be useful in the analysis of differences between countries, sectors and types of collaboration, in analyzing the dynamics of networks and in detecting potential market, systemic and policy failures (i.e. topics 3 and 5 in Schibany and Polt, 1999) .

3. Analytical elaboration of the graphical mapping of R&D networks

On a descriptive level the graph-based mapping allows to establish the differences between countries and sectors as to the importance of the different types of collaborative R&D patterns.

By using available data on public-supported and private technology partnering, the R&D network of a country, as consisting of collaborating firms, universities and research organisations both within the national borders or within transnational R&D projects and private technology alliances, can be mapped.

The use of 'objective' and uniform data can elucidate some questions, raised by surveys that have been carried out and can raise some new questions. This may help to clear out a theoretical framework and to outline future surveys or case-studies.

For more analytical applications a prerequisite is to supplement the data on the links with detailed data on the actors.

If for (all) firms the sector classification can be established, the number of intra- and intersectoral collaborative links of a country can be computed. If we regard the public-supported collaborative R&D projects or private alliances as a market it is possible to compute sectoral market shares for every country. A Constant Market Share (CMS) analysis would allow for a dynamic decomposition of the evolution of country and sector shares in pure competitiveness effects, composition effects and adaptation effects (See Fagerberg and Sollie, 1987; Laursen and Christensen, 1996).

The market share of a given sector i of country j in period t can be defined as :

$$MS_{ijt} = NL_{ijt} / \sum_i \sum_j NL_{ijt} = (NL_{ijt} / \sum_j NL_{ijt}) \cdot (\sum_j NL_{ijt} / \sum_i \sum_j NL_{ijt}) = CS_{ij} \cdot IS_i \quad (1)$$

MS_{ijt} represents country j 's sector i 's share in the total number of collaborative links.

NL_{jt} is the number of collaborative links of country j 's sector i with other sectors².

CS_{ij} is the share of country j 's sector i in the aggregate of sector i for all countries. IS_i is the share of the aggregate sector i in the aggregate of all sectors and all countries.

If we now look at the change of the market share MS_{ij} we can derive the following decomposition:

$$\Delta MS_{ij} = MS_{ij,t+1} - MS_{ij,t} = \Delta CS_{ij} \cdot IS_i + CS_{ij} \cdot \Delta IS_i + \Delta CS_{ij} \cdot \Delta IS_i \quad (2)$$

The change of the market share can be decomposed in three terms.

The first term reflects a pure competitiveness effect as it measures the part of the overall change which can be explained by the change of shares of country j 's sector i , measured at a constant share composition at the aggregated group level. The second term can be seen as a composition effect. It reflects the part of the overall change due to a change of the composition at the aggregated group level, measured at constant shares in all sectors. Finally the last term, which is a second order interaction effect, could be seen as an adaptation effect. If the effect is positive it reflects that country j is moving out of declining sectors or moving into growing sectors.

So by applying the CMS approach to R&D collaboration the sectoral dynamics of networking can be analysed at the global level of a country group as well as at the level of each individual country.

Furthermore the overall change of each country and of each country's sectors can be decomposed and explained by differences in competitiveness, sectoral composition and changing specialisation.

The effects can be computed for public-supported collaboration as well as for private alliances which would reveal the (dynamic) match/mismatch between both types of collaboration.

The effects could also be compared to real CMS effects which would give insight in the link between technological specialisation and performance and market performance from a dynamic perspective.

It is of course also possible to apply a CMS analysis not just to sectoral links but also to intersectoral links which would enable us to analyse the dynamics of intra- and intersectoral partnering.

It would be useful to compare the results of the latter approach with the results of surveys and I/O based analyses (e.g. Debresson and Hu (1999) , Roelandt and den Hertog, 1999).

Because, as pointed out by Debresson (1999), innovative networks often straddle nations and encompass foreign partners the use of available R&D collaboration data can broaden the framework of inter-firm networking by focusing both on national and international linkages whereas I/O analysis is mostly confined to national or regional networking. The graphical mapping may also supplement or readjust the picture of innovative networking that has resulted from the exclusive use of existing I/O linkages to map innovative inter-firm linkages. Although the importance of supplier-buyer linkages for innovation is well established (e.g. Debresson et al., 1997 ; Christensen, Rogaczewska and Vinding, 1999) innovative networks are also often found to be too complex to be reduced to value-added chains.

² Universities and research organisations could be considered as distinctive know-how sectors.

As innovation can be expected to alter existing value-added links this may be an important consideration when analysing the dynamics of innovative networks that could be cleared out by a comparison of I/O based clusters with clusters revealed through R&D collaboration.

Another consideration with regard to I/O analysis is the generally acknowledged increasing tacitness of R&D flows and spillovers.

Griliches (1992) defines disembodied spillovers, which he views to be more important than embodied spillovers, as “[...] *ideas borrowed by research teams of industry i from the research results of industry j. It is not clear that this kind of borrowing is particularly related to input purchase flows*” (Griliches (1992), p. S36)

With regard to the difference with an I/O approach we think that the model of international market share dynamics used by Laursen and Meliciani (1999) could be extended to analyse the effect of inter-sectoral R&D linkages as computed from the graphical mapping and to compare this effect with the effect from I/O computed technology linkages.

Laursen and Meliciani propose the following autoregressive model specification :

$$MS_{ijt} = \alpha_1 MS_{ijt-1} + \alpha_2 RDS_{ijt} + \alpha_3 ULC_{ijt} + \alpha_4 INV_{ijt} + \alpha_5 UL_{ijt} + \alpha_6 DL_{ijt} + \alpha_{7i} + \alpha_{8j} + e_{ijt} \quad (3)$$

RDS stands for country j 's sector i 's R&D expenditures related to country j 's population to correct for country size. ULC is a measure for cost competitiveness. INV gives investment in fixed prices again divided by population. Investment is seen as a measure for embodied technical change.

UL and DL are the upstream respectively downstream linkage variables which by multiplying intermediate I/O coefficients with sectoral R&D expenditures are seen as proxies for technology based inter-sectoral linkages. α_{7i} and α_{8j} are respectively specific sector and country effects.

A reformulation of equation (3) allows for simultaneous estimation of short-run and long-run effects and reduces the probability of spurious regression.

If we compute (inter)national sectoral and intersectoral technology linkages as revealed through participation in public-supported R&D consortia or in private technology alliances we could include these variables in equation (3). This would allow us to compare the effects of I/O based technology linkages with the effects of R&D collaborative linkages.

As an increase of a given sector i 's market share can be expected to result in an increase of its I/O linkages the model seems less exigent from I/O based linkages than from collaborative linkages, especially since the latter probably relate more to future market shares than to present market shares. The model should therefore be controlled for causality and for obvious reasons also for multicollinearity and could be estimated with different dynamic specifications.

It would also be interesting to find out whether present I/O linkages can be explained by past collaborative links or put differently whether the correlation between the change in I/O linkages and

change in market shares is explained by past collaboration that has enhanced innovation which resulted in a change in the technical I/O coefficients.

The interesting application of the Pavitt taxonomy by Laursen and Meliciani (1999) could also be extended to control for the importance of linkages with universities and research labs in the four types of Pavitt sectors.

Because our data on R&D collaboration is on the microlevel of individual agents equation (3) can obviously also be applied to firm data. Variables of firm performance can be regressed on variables of inter-firm R&D collaboration (a.o.). This would enable us to estimate the effect of a firm's own R&D efforts as well as the effect of R&D spillovers and knowledge flows that occur through R&D partnering, given of course that firm R&D expenditures are known.

If an international group of similar firms is considered we would be able to analyse the difference in R&D collaboration and the dynamic aspects of each individual firm compared to group behaviour and performance and try to analyse the extent to which some measures of firm performance can be explained by the (dynamic) pattern of R&D collaboration.

It should be clear that the proposed approach is rather time consuming and labour intensive (The roadmap that has been used for the activities of the FG on organisational mapping and which contains a detailed description of the steps that were followed for common cleaning and matching of data and graph creation is given in annex. We also included a sample of a point – and linefile, which are used to create the graph and a representation of the graph that results from the sampled linefile). As pointed out before data on the collaborating organisations should be added to allow for in-depth analysis and estimation.

However, we consider that the analytical properties as described above can give very useful insights in a considerable number of research topics that are of interest to the FG on firm networks and innovative firms and that the relatively straightforward and uniform methodology offers the opportunity of a thorough international comparative analysis that justifies the considerable efforts.

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ANNEX

Roadmap for the research on the international comparison of networks of joint R&D projects and agreements (Paris, 11 december 1997)

The following 'roadmap' discusses the successive steps in the proposed research strategy.

1. The CORDIS-data per country are extracted from Edition 1996-IV CD-ROM holding the CORDIS database of RTD activities financed by the EU (ISBN 92-8277090-7).

The Windows software that comes along with the database has, in actual practice, only limited query capabilities. Given that we opt for a strategy where, per country, we only would consider projects and agreements which involve at least one national company (thereby excluding for instance the numerous RTD projects which involve only national universities and institutes of higher education), we should be able to formulate the query accordingly. The query language possibilities supplied with the CD-ROM are such that, in principle, such a query is possible, but the latter unfortunately does not yield the required results (enquiries with the CORDIS administration learned that indeed the query engine does not work properly). We had no other choice than to formulate a simpler query in which we extract the records of those projects which contain at least one national actor, regardless of its type.

This yields the unstructured textfiles *xxcordtxt* ('xx' being the country acronym).

2. The ad hoc programme *pcord.exe* converts the unstructured CORDIS textfiles into a structured (rectangular) format. Together with a file (*xxcord2.txt*) containing for each project as many records as there are partners in the project, a file is created which, along with the record number in the CORDIS-database for identification purposes, also contains the title of the project (*xxcord3.txt*).

The FORTRAN format of the *xxcord2.txt* records is the following

```
write(2,207) cntry, region, town, name, acro, type, prime, prog, progrn, rcn, sda,eda, pjs, k
207format(a2,1x,a6,1x,a10,1x,a40,1h[,a8,1x,a3,1x,al,lx,a15,1x,a15,1x,a5,1x,a10,1x,a10,1x,a1,1x,i5)
```

name is the name of the actor (partner), *acro* is its acronym (preceded by the '[' sign, and left blank at this stage), *type* is IND, ROR, NCL, CON, EDU, OTH, or blank (unknown) and refers to the quality of the actor, *prime* is 1 or 0 depending on whether the actor is prime contractor or not, *prog* is the name of the RTD programme, *progrn* is the record-number of the project within the programme, *rcn* is the record-number within the CORDIS database, *sda* and *eda* are the start-date and the end-date of the project, *pjs* is the project-status ('E' for executing, 'C' for completed), *k* is the internal recordnumber in the file. (note : 'a2' means a left-adjusted alphanumeric field of length 2, 'i5' means an integer field, right-adjusted, of length 5, '1x' means one blank).

The format of the **xxcord3.txt** records are as follows :

```
write(3,301) ij,k,prog,rcn,title
301 format(i5,1x,i5,1x,a15,1x,a5,1x,a150)
```

ij is the internal record-number of this file, k is the corresponding recordnumber of the prime contractor in the cordis2.txt file, and title is the title of the project.

3. The fact that many records in the original CORDIS database-records, and therefore in the derived files **xxcord.txt** and **xxcord2.txt**, do not contain the 'type' information means that **xxcord2.txt** and **xxcord3.txt** still contain many 'redundant' projects since *prcord.exe* plays safe and does not eliminate projects which contain at least one national partner of unidentified type, or, for that matter, of type ROR, NCL, CON and OTH (research institutes. 'non-commercial' organisations, consultancy firms, and others').

This elimination process should be done manually by each national team, concurrently on **xxcord2.txt** and **xxcord3.txt**.

Let us call these 'sifted' files **xxcord2s.txt** and **xxcord3s.txt**.

xxcord2s.txt should, via EXCEL, be sorted on the fields *cntry*, possibly also on *region* and *town* (although the quality of these fields is not 100% trustworthy), and *name*, so that as much as possible the records of the same actors, but with their names written in different ways, are close to each other. This will facilitate the process of allocating acronyms to the actors.

The acronyms, to be inserted immediately after the '[' sign in **xxcord2s.txt**, may not use more than 8 characters and the first character should refer to the country.

The records in the EXCEL file obtained at the end of step 4 should be sorted back such that records of the same projects come back again together : sorting on the fields *rcn* (descending) and *prime* (descending). Let us call this output-file from EXCEL **xxcord21.xls**.

4. Still in EXCEL, **xxcord21.xls** will have to be completed, per country, with equivalent records from the EUREKA database, which can be consulted from the internet (<http://www2.eureka.be/home/index.html>). The site is a powerful one (rapid, and with a powerful query engine), and project-records are downloadable in a structured form. Input of the variables in **xxcord21.xls** has to be done manually however by each country team.

The same has to be done for the MERIT/CATI data of R&D agreements of co-operation between firms.

Let us call the resulting file **xx22.xls**.

5. The ASCII fixed-format version of **xx22.xls**, **xx22.prn** is the basic input into the FORTRAN programme which will create the lines of the graph, *pr2.exe*. Only those lines are considered in which at least one of the nodes is 'national'. Lines between foreign actors are not outputted. The format of

each record written is basically 'tailhead'. Discriminating between the tail and the head of a line is important for so-called directed lines. It is suggested to define the lines between the prime contractor and the other partners in a project as being 'directed' (the prime contractor being at the tail of the arrow). Lines between partners which are not prime contractors are undirected (the sequence of tail and head in this case is of no importance).

The name of the line-file for country xx is called **xxline.txt**.

xxline.txt is the basic line-set input-file for the network-analysis software (GRADAP or UCINET).

The format of the records is according to the following write-statement

```
write(2,200) acro1,acro2,dir, ltyp, source, prog, rcn, sda, eda, pjs, npar, uni, subs
200 format (a8,1x,a8,1x,al,1x,a1,1x,al,1x,a18,1x, a5,1x,a8,1x,a8,1x,al,1x,i3,1x,al,1x,e14.7)
```

dir is 0 or 1 in the case of an undirected, resp. directed line (if dir is 1, then acro1 is the tail of the arrow, i.e. the prime contractor ; ltyp indicates the type of the line ('P' for a line in a (subsidised) R&D project, 'A' for a line in a (non-subsidised) R&D agreement) ; source relates to the database ('C' for CORDIS, 'E' for EUREKA, 'M' for MERIT-CATI) ; npar is the number of partners in the project, uni is 0 or 1 whether one of the nodes of the line is an institute of higher education; subs is the amount of the subsidy of the project (if available (EUREKA)), or the amount involved in the agreement (sometimes available in MERIT-CATI records).

pr.exe in addition creates a file, **xxacro.txt**, which contains, per project which is processed, the acronyms of the partners together with the corresponding programme, the number of partners in the project n_{par} , and the corresponding number of lines created by that partner in the project ($n_{par} - 1$).

xxacros.txt is the version of **xxacro.txt**, alphabetically sorted on the acronyms. This last file is used by the programme *redacro.exe* to create the basic point-set input-file for the network-analysis software (**xxpoint.txt**): one record for each acronym while infos are immediately added that contain information on the number of projects in each programme in which the actor is active, and the number of lines that go with this.

6. EXCEL is then used to edit the 'national' records in **xxpoint.txt**: ideally a number of basic economic variables should be added so as to be able, in the graph-analytical phase, to analyse relevant subgraphs. The obvious minimal set of variables is: NACE sector code, value-added, turnover, employment.

Let us call this augmented version **xxpointa.txt**.

7. A number of procedure-files for the GRADAP network-analysis programme, written for the Belgian analysis, are available for use for the other countries.

Sample of a Belgian pointfile

500	SOLTECH	BSOLTECH	348	3	4.1	1	1.921	0.09	BE	R5123	IND	3001
501	SOLVAY	BSOLVAY	253	4653	9.2	9	345.910	0.14	BE	R5300	IND	1050
502	SONACA	BSONACA	764	1527	1.5	7	2.027	0.23	BE	R5232	IND	6041
503	SONY	BSONY	6153	432	5.1	2	1.853	0.32	BE		IND	1130
504	SOPHIS	BSOPHIS	8392	119	8.2	6	2	0.90	BE		IND	8560
505	SOUDOBEAM	BSOUDOBI	3191	22	4.3	2	1	1.30	BE	R5242	IND	4140
506	SPA MONOPOLE	BSPA	4281	478	7.2	6	702	0.54	BE	R5243	IND	4900

Sample of a Belgian linefile

1	FBERTIN	BSOLVAY	1	P	C	C	ESPRIT	4	33822	15/07/96	14/07/99	E	5	1
2	UEDU	BSOLVAY	0	P	C	C	ESPRIT	4	33822	15/07/96	14/07/99	E	5	1
3	BSOLVAY	SDESTEL	0	P	C	C	ESPRIT	4	33822	15/07/96	14/07/99	E	5	1
4	BSOLVAY	SANTIBIO	0	P	C	C	ESPRIT	4	33822	15/07/96	14/07/99	E	5	1
5	ULASTMUS	BSAM	1	P	C	C	ESPRIT	4	33818	01/05/96	30/04/98	E	4	0
6	ZSYSDEV	BSAM	0	P	C	C	ESPRIT	4	33818	01/05/96	30/04/98	E	4	0
7	BSAM	UEGROUP	0	P	C	C	ESPRIT	4	33818	01/05/96	30/04/98	E	4	0
8	FTRIALOG	BMIETEC	1	P	C	C	ESPRIT	4	33805	15/07/96	14/01/98	E	6	0
9	SIKERLAN	BMIETEC	0	P	C	C	ESPRIT	4	33805	15/07/96	14/01/98	E	6	0
10	UEATEC	BMIETEC	0	P	C	C	ESPRIT	4	33805	15/07/96	14/01/98	E	6	0
11	HELGECO	BMIETEC	0	P	C	C	ESPRIT	4	33805	15/07/96	14/01/98	E	6	0
12	ITHOMSON	BMIETEC	0	P	C	C	ESPRIT	4	33805	15/07/96	14/01/98	E	6	0

Graph resulting from the above sampled linefile

