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STUDYING RESEARCH COLLABORATION USING CO-AUTHORSHIPS

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Scientific collaboration has become a major issue in science policy. The tremendous growth of collaboration among nations and research institutions witnessed during the last twenty years is a function of the internal dynamics of science as well as science policy initiatives. The need to survey and follow up the collaboration issue calls for statistical indicators sensitive enough to reveal the structure and change of collaborative networks. In this context, bibliometric analysis of co-authored scientific articles is one promising approach. This paper discusses the relationship between collaboration and co-authorship, the nature of bibliometric data, and exemplifies how they can be refined and used to analyse various aspects of collaboration.

Introduction

Interaction among scientists has for long been the essence of scientific practice. Most phases of the research process are associated with a fairly large amount of communication activities: scientists talking to each other, writing and reading papers and letters. But scientists do not only communicate research results and information to each other, they also co-produce and co-report research results - in short they both communicate and collaborate. Collaboration is an intense form of interaction, that allows for effective communication as well as the sharing of competence and other resources. Looking at the dramatic increase of co-authored articles between individual scientists as well as among research institutions, one is inclined to assume that collaboration has become a prerequisite for modern science. If more than half of the papers produced by the scientists at a given university are co-authored with scientists at other universities or research institutions it is no longer meaningful to talk about the university as a sole producer of knowledge. It is rather the network of interacting scientists that is the critical production unit (*Melin and Persson*[1]).

Scientific collaboration appears to a large extent to be organized by the scientists themselves. However, there are a number of science policy initatives that foster research collaboration. From a science policy perspective research collaboration has

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become a central issue. This is a reflection of the general tendencies towards internationalization of the various sectors of modern society, but also a consequence of the need for coordination and joint funding of costly experiments. Another issue deals with the interaction of different segments of national research systems, for example the interactions among universities, research institutes and industry. At a more general level the collaboration issue can be looked upon as a consequence of science reaching a "steady state" at which the synergetic effects will play an increasingly important role for the production of scientific knowledge (*Ziman*[2]). Collaboration can thus be seen as one of a set of science policy tools that is needed in a situation when scientific growth can no longer be based on an ever increasing expansion of its manpower.

Recently, *Katz and Martin*[3] discussed several aspects of collaboration, its causes and effects as well as validity and reliability problems associated with using co-authorships as an indicator of collaboration (See also *Harsanyi*[4] for an extensive review). In this paper we will take a somewhat more practical approach, concentrating on the actual use of co-authored papers as a way of analysing scientific collaboration. We will discuss the relationship between collaboration and co-authorship, the nature of bibliometric data, how they can be refined and used to analyse various aspects of collaboration.

The co-authorship as a measure of collaboration

A scientific document is *co-authored* if it has more than one author. It is *institutionally co-authored* if it has more than one author address suggesting that the authors come from various institutions, departments or other kinds of units.

When using co-authorships as an indicator of scientific collaboration there are a number of validity issues one needs to consider. The causal diagram in Fig. 1 outlines some of these problems. For example, we have to realize that collaboration does not necessarily lead to co-authored papers, collaboration might lead to other outputs, such as patents, deepend personal contact, or nothing at all. There may be other causes of co-authorships besides research collaboration, for example when research leaders demand to have their names on the articles without actually contributing to the specific work reported. In most articles the number of authors are equal to or greater than the number of addresses. But, some authors may for various reasons decide to list more than one address, which may or may not mean that several institutions have contributed to the reported work. *Katz and Martin*[5] estimate that some 5-10 percent of the articles, depending on what country is studied, have more addresses than authors. Finally, one has to realize that there are various forms of research collaboration as well as reasons for collaboration that a bibliometric study is not able to reveal. In fact, all dotted lines and squares in Fig. 1 need other sources of information to be analyzed.

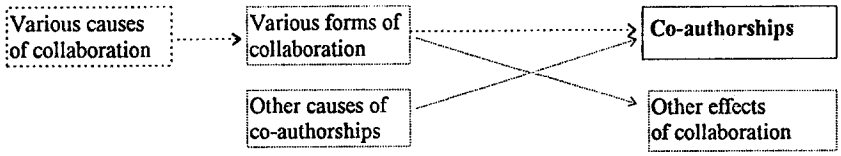

Fig. 1. Co-authorships and its causes

Thus, when we infer from co-authorships to collaboration we are running the risk of neglecting some collaboration as well as being insecure about the actual reasons behind co-authorships. Consequently, we should use co-authorship data as a rough indicator of collaboration and also try to collect other kinds of data to reduce the various kinds of uncertainties involved. However, in practice it is hard to estimate the influence of such unknown factors since we usually deal with a fairly great number of co-authored articles and co-authorship links. We will simply have to accept a certain level of uncertainty. What we could hope for, is that significant scientific collaboration leads to co-authored papers in most cases, the main reason being the priority claims of the scientists involved.

The possibility that collaborative work does not result in jointly published articles were analysed in a small scale study at Umeå university. Only five percent of the authors had experienced situations in which collaboration did not result in co-authored papers (*Melin and Persson*[6]). The usual reason for exclusion of authors is that they have made only minor contributions to the study. To conclude, there is hardly a tendency for collaboration to be underrepresented when studying co-authorships. While waiting for more validation studies of this kind, we could at least use co-authorships as a first step to identify collaboration events and the various parties involved. However, to learn more about the substance of collaboration we have to rely on complementary information.

Retrieving and constructing co-authorship data

Data on co-authored articles can be retrieved from almost any bibliographic database. However, when it comes to institutionally co-authored papers the *Science Citation Index*™ (SCI) and the *Social Sciences Citation Index*™ (SSCI) are the most reliable sources. Subject bibliographies, such as *Engineering Index* and *Chemical Abstracts*, only register the first listed address. An example of a record with several addresses is given in Fig. 2. Here, the AU-field contains the author list; in this

example there are six authors. The address field, with the CS-tag, has five addresses, which suggests that there are two authors from the same institution. However, we cannot decide to which address each author belongs. As a consequence most co-author studies concentrate on the addresses.

The addresses contain in most cases four parts: the main organization, a department of that organization, the city and the country. In some instances there are only three levels, mostly excluding the departmental level. In the databases, the addresses have several spelling variants, so there is a great need for standardizing the data. The standardization is a quite complicated and time-consuming task, especially if all addresses of a database have to be dealt with. The country part is generally well standardized, and the city information can be rather easily standardized by eliminating the postal codes. However, the main organization may have a large number of variants, as well as the departments in that organization. Some bibliometric institutes, for example the CWTS in Leiden, are continously trying to standardize the addresses to enable large scale analysis of institutional article production, citation analyses and co-authorships. In some instances the main organizations are coded into broader sectors, such as universities, research institutes, industry etc, thus allowing for studies of inter-sector collaboration.

FN- Science Citation Index (Jan 93 - Dec 93)
GA- LY720|
TI- LONG-RANGE TRANSPORTED POLLUTANTS AND CONDUCTIVITY OF ATMOSPHERIC ICE ON INSULATORS|
LA- ENGLISH|
AU- FIKKE SM; HANSSEN JE; ROLFSENG L; GORUR R; SCHNEIDER HM; LAMPE WD|
JN- IEEE TRANSACTIONS ON POWER DELIVERY, 1993, V8, N3, P827-840
DT- ARTICLE|
NR- 6|
CS- NORWEGIAN GRID CO/STATNETT//NORWAY; NORWEGIAN INST AIR RES/EUROPEAN MONITORING & EVALUAT PROGRAMME/LILLESTROM//NORWAY; NORWEGIAN ELECT POWER RES INST/HIGH VOLTAGE INSTALLAT GRP/TRONDHEIM//NORWAY; ARIZONA STATE UNIV/TEMPE//AZ/85287;GE CO, DEPT POWER SYST ENGN, EPRI, HIGH VOLTAGE TRANSMISS RES CTR, LENOX, MA; SWEDISH TRANSMISS RES INST/LUDVIKA//SWEDEN||

Fig. 2. A bibliographic record from SCI describing an institutionally co-authored article

The structure of the addresses makes it possible to study co-authorships using countries, cities and main organizations as the unit of investigation. The information provided by other fields of the bibliographic record enables one to limit the study to a certain time period by using the publication year of the article, or to a given field by

using the journal name of the article. The journals can be arranged into journal subject categories, sub-fields or major fields. There are some ready-made classifications available, such as those listed in the *Journal Lists* of SCI. A classification of co-authored articles based on journal subject categories can be used for defining the fields in which the collaboration takes place.

However, in order to analyse the actual collaboration between institutions from various disciplines we have to rely on the address information. In many instances, the departmental addresses indicate the discipline of the particular institution, for example, DEP PHYS, DEP PHYSIOL or DEP CHEM. Although the departmental information is often incomplete and far from fully standardized, this is the only way to analyse interactions between disciplines in terms of co-authorships.

When analysing co-authorship data there are some options that one has to consider, which may vary depending on the type of problem one has:

1. *Choice of aggregation level*

   The study may focus on countries, cities (regions), main organizations, individual scientists or groups of scientists.

2. *Article analysis*

   A co-authored article can be studied as such: is it a nationally or internationally co-authored paper, does it contain interaction between universities and industry, is it internally co-authored?

3. *Networks analysis*

   A co-authored article can be split up into co-authorship pairs indicating collaborative links. These links can be studied one by one or be used to form networks consisting of several links. Note that a large number of pairs may be generated by a single article, depending on the number of addresses listed.

When the study has developed to the point of specific research questions and definitions of the data structure needed, there are still choices to be made regarding the type of measures involved. Besides straight counts of articles or links, there are several normalized measures of interaction that reduces the effects of varying sizes of collaborating units. *Salton and McGill*[7] list several measures of vector similarity which can be used. There are also a number of mapping techniques used to make graphical representations of co-authorship data such as Multi Dimensional Scaling (MDS) or

Correspondence Analysis. A comparison of measures and mapping methods have been presented by *Luukkonen et. al.*[8].

In order to illustrate some of the types of analysis one might apply to co-authorship data, we will take some examples related to Umeå University, other Swedish universities and a selection of the major research countries.

A study of a single university

In Sweden, as in many other countries, there is an ongoing debate of whether one should allocate research money to the whole spectrum of colleges and universities, or instead strengthen the larger universities. Is it possible to conduct advanced research at small universities, or is there, besides research funding, also a need for a certain size regarding facilities and the number of departments, employees and students, in order to make "good" science? Studies of articles production and co-authorships may come up with some answers. If small research units have just about the same relative amount of article production as large ones have, and if small units collaborate internationally just as much as big universities, there is no economics of scale in these matters.

From the point of view of a given university institutional collaboration can take various forms (Table 1). About one fourth of the articles from Umeå University were authored by a single institution and another fifteen percent of the articles were internally co-authored. The majority of the papers were externally co-authored, one fourth with one or more national institution and one fourth with international institutions. A mixture of national and international institutions appeared in the remaining seven percent of the articles. In a large scale study of more than 30 universities *Melin and Persson*[9] found a striking similarity among the universities in terms of the amount of external collaboration. It seems that universities of various size have just about the same proportion of external co-authorships and within a given country the amount of international co-authorships is just about the same for most universities. The most obvious implication of these findings is that small as well as large universities are equally dependent on close interaction with the rest of the national and international R&D-systems.

In Sweden, as in many other countries, there is a general feeling that the interactions between universities and industry should be strengthened at the national level. The expected outcome is sometimes expressed in terms of a better match of research and development, which may be beneficial for both industries and universities. Of course, such interactions do not necessarily have the aim of increased collaboration resulting in co-published papers between industry and academia. There

are many other forms of "weak" interactions that might be productive. Still, it could be interesting to study the amount of co-authorships between academia and other sectors within the research system. A time series analysis is needed to see if there are any trends towards an increased inter-sector collaboration. Here, for mere demonstration, we shall have a closer look at the amount of collaboration between Umeå University and institutions in other sectors, nationally and abroad (See also *Melin*[10], *Kaloudis*[11]).

Table 1
Umeå University: percent of articles with internal, national and international co-authorships at Umeå University in 1993
Data source: SCI on CD-ROM

Forms of institutional co-authorships:	Articles
Authored by a single department at Umeå University	26.45
Internally co-authored at Umeå University	14.86
Nationally co-authored	26.75
Nationally and internationally co-authored	6.69
Internationally co-authored	25.26
Number of articles	673

Table 2 shows the number of co-authorship pairs as well as co-authored papers that Umeå University has within the university sector compared to other sectors. Naturally, most of the collaboration takes place in the university sector, but a great deal of interaction also involves governmental instututes and hospitals. The private sector, mostly industries, is of some importance, comprising about ten percent of the co-authorship pairs. A longitudinal approach would enable us to speak about trends in these matters. We would then be able to see if there is an ongoing integration of the various sectors of the national R&D-system. A methodological remark: the effect of using articles as units of analysis instead of pairs appears to have a limited effect when measuring co-authorships.

When it comes to foreign collaboration, the hospital sector comprises a much smaller part, which can be attributed to the role that the national hospital sector has in clinical testing of drugs and therapies. Foreign industries and institutes are frequent collaboration partners of this university (Table 3). This is an interesting finding, since it suggests that interactions between academia and industry is not only a matter of national concern - it might even mean that the national industrial base is not broad enough to satisfy the collaborative needs of the universities.

Table 2
Umeå University: percent of co-authorships with main types of institutions in 1993
Data source: SCI on CD-ROM

External institutions	Articles (n=508)	Pairs (n=799)
Universities	54.92	59.32
Governmental institutes	19.29	17.65
Hospitals	15.94	16.15
Industries	8.27	5.51
Private institutes	1.57	1.38
Total	100.00	100.00

Table 3
Umeå University: number of co-authorship pairs by type of institution; international *vs* national, 1993.
Data source: SCI on CD-ROM

External institutions	Foreign institutions	National institutions	Total
Universities	210	264	474
Governmental institutes	99	42	141
Hospitals	19	110	129
Industries	20	24	44
Private institutes	11	0	11
Total	359	440	799

A cross-tabulation of sector and field shows that much of the interactions take place in clinical medicine and biomedicine. If we take a closer look at the industrial co-authorships we find that they include the big pharmaceutical companies Astra and Pharmacia. Symbicon, a biotech firm closely affiliated with the university, also appears as co-author in a number of articles (Table 4).

Finally, in Table 5, the collaboration on the country level is distributed by field. As expected from what is already known from studies of country collaboration, USA is the most frequent partner, and Germany has reached a second place. This is indicative of a change towards relatively more interaction with continental Europe, which also is evident when we look at the co-authorships for Sweden as a whole (Table 6).

Table 4
Umeå University: number of co-authorships by type of institution and major field, 1993
Data source: SCI on CD-ROM

Major field	Univer-sities	Govern-mental institutes	Hospitals	Industries	Private institutes	Total
Clinical medicine	274	25	114	24	4	441
Biomedicine	79	26	6	9	5	125
Geosciences	28	30	-	2	2	62
Chemistry	29	27	3	2	-	61
Biology	33	13	-	-	-	46
Engineering	14	7	4	2	-	27
Physics	10	10	-	2	-	22
Interdisciplinary	5	1	2	-	-	8
Agriculture	2	2	-	2	-	6
Mathematics	-	-	-	1	-	1
Total	474	141	129	44	11	799

A study of a single country - Sweden

Most of the tables mentioned above can be repeated for a whole country, although it takes much more effort to standardize the insitutional names. However, a study of country collaboration hardly needs any refinement of the data. In Table 6 the number of co-authorship pairs that Sweden has with some major regions are given. During the last few years there has been rather dramatic relative growth of co-authorships with the countries in the European Union.

In Table 7 the co-authorships found by studying articles produced by Swedish universities are distributed by science region and major field. It is quite obvious that the Nordic arena is of great importance in clinical medicine. In biomedicine the USA and Canada are almost as important as the Nordic- and EU-countries. On the other hand EU-countries are much more frequent collaborators in physics. So, this shows that the dependence on various countries or country-regions is field specific.

Table 5
Umeå University: number of co-authorships by major field and country in 1993
Data source: SCI on CD-ROM

Country:	Field: Cm	Bm	Gs	Chem	Bio	Phy	Eng	Inter	Ag	Total
USA	29	29	12	6	4	-	12	-	-	92
Germany	-	9	8	16	-	8	-	-	-	41
Japan	10	2	8	-	1	-	2	-	-	23
Finland	13	-	-	-	4	1	1	2	-	21
UK	10	2	2	3	2	-	-	2	-	21
Canada	11	2	4	1	2	-	-	-	-	20
Denmark	9	3	4	3	1	-	-	-	-	20
Norway	16	-	-	-	-	-	-	1	2	19
France	6	4	2	3	-	-	-	-	-	15
Russia	1	2	3	2	-	7	-	-	-	15
Netherlands	8	4	-	2	-	-	-	-	-	14
Ethiopia	10	-	-		-	-	-	-	-	10
Italy	-	2	2	4	-	2	-	-	-	10
Belgium	6	-	-	3	-	-	-	-	-	9
China	4		-	-	-	-	-	-	-	4
Portugal	-	4	-	-	-	-	-	-	-	4
Switzerland	2	-	-	-	1	-	-	-	-	3
Australia	-	-	-	-	-	-	2	-	-	2
Austria	-	-	-	-	-	2	-	-	-	2
Chile	-	2	-	-	-	-	-	-	-	2
Estonia	-	2	-	-	-	-	-	-	-	2
India	-	-	2	-	-	-	-	-	-	2
Spain	-	-	-	-	-	2	-	-	-	2
Czechoslovakia	1	-	-	-	-	-	-	-	1	
Hungary	1	-	-	-	-	-	-	-	-	1
Kenya	1	-	-	-	-	-	-	-	-	1
Poland	-	-	-	-	1	-	-	-	-	1
Tanzania	1	-	-	-	-	-	-	-	-	1
Uruguay	-	1	-	-	-	-	-	-	-	1
Total	139	68	47	43	20	18	17	5	2	359

Note:Ag=Agriculture, Bio=Biology, Bm=Biomedicine, Chem=Chemistry, Cm=Clinical Medicine, Eng=Engineering, Gs=Geosciences, Inter=Interdisciplinary, Mat=Mathematics, Phy=Physics

Table 6
Sweden: Co-authorship pairs with major science regions in 1993
Data source: SCI, online via Dialog

	1990	1991	1992	1993	1994	1995
EU-countries	1422	1525	2214	2263	2659	2449
North-America	1245	1354	1477	1548	1744	1630
Nordic countries	691	716	982	984	1158	1106

Table 7
Swedish universities: number of co-authorships; science region and major field in 1993
Data source: SCI on CD-ROM

	North-America	Nordic countries	EU-countries
Clinical medicine	1441	4009	2261
Physics	423	383	2435
Biomedicine	450	460	431
Geosciences	170	277	402
Chemistry	94	238	218
Biology	111	200	127
Engineering	99	128	86
Interdisciplinary	102	32	55
Agriculture	22	89	11
Mathematics	42	19	20

Collaboration among countries

Most studies on co-authorships reported so far focus on the country-interactions in science as a whole or within major science fields. The number of internationally co-authored papers has doubled in about fifteen years. The dependence on the international scene is proportionately higher for small countries, which is a more or less logical consequence of the fact that the smaller a country is the greater the share of scientists available outside it, and the greater the chance to collaborate with someone from another country. But there are also other factors explaning the pattern of country-collaboration. Besides the size of the countries, the interactions within the network depend on the geographical distance separating the nodes, cultural, linguistic and political barriers (*Andersson and Persson*[12], *Luukkonen et al*[13], *Okubo et al*[14], *Leclerc and Gagne*[15]). The effect of geographical distance within national research has been demonstrated by *Katz*.[16]

Data on country-to-country co-authorships can be generated quite easily from the online versions of SCI and SSCI. We selected 25 of the most productive countries in terms of articles according to the SCI. Then we counted the number of co-authorships for each pair of countries. Table 8 shows the upper left corner of the 25×25 country co-authorship matrix. The diagonal elements carry the number of papers for each country. As can be easily seen, USA dominates the network quite dramatically, mainly because of the size of its research system. If one drew a map based on these numbers one would find USA in the middle surrounded by a number of small and medium-sized satellites. This is in some way the true picture. Then one may control for the effects of

Table 8

The 25 most frequent country co-authorship pairs in 1994

	USA	UK	Japan	France	Canada	Italy	
USA	292191	5471	4426	3757	5583	2888	....
UK	5471	70640	752	1663	1003	1200	....
Japan	4426	752	62785	477	530	277	....
France	3757	1663	477	44582	925	1184	....
Canada	5583	1003	530	925	36084	319	....
Italy	2888	1200	277	1184	319	26968	....
India	810	284	150	119	150	92	....
....	.....	.....	.....	.....	.....	....	....

Note: Diagonal values indicate the number of artciles produced by a given country

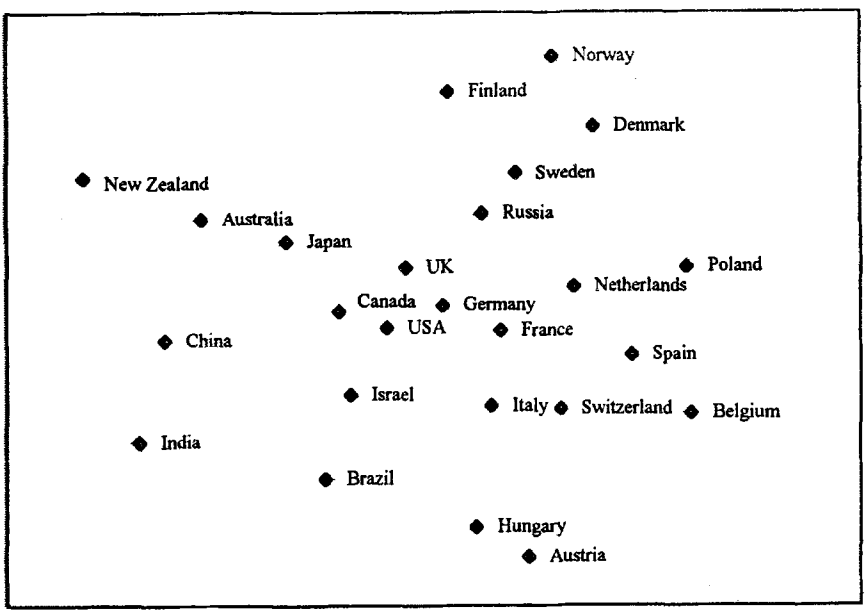

Fig. 3. An MDS-based country co-authorship map for 1994

size using a normalized measure such as taking the correlation coefficient between the column vectors of the matrix. Figure 3 presents a map based on the correlation coefficients. The coordinates of the map were found by using a Muldi-Dimensional-Scaling(MDS) program. In this case the MDS-program took the correlation matrix as input values and then tried to find the best fitting two-dimensional representation in the form of coordinates, which then were used for drawing the map. The axes of the diagram have no substantial meaning in themselves - the interpretration of the map is up to the reader. On our map, countries with similar co-auhorship profiles will be close to each other and countries with low correlations will be located far apart. Looking at the map we can assume that geographical distance is the major force at work, since there is apparently a west-east and a north-south dimension that separates the countries. We can easily identify a the Nordic and the Asian region. The English speaking countries, US, Canada and UK, are located close to each other in the center of the map and the countries of Europe are grouped in the lower right part. On this map Russia is between the Scandinavian countries and continental Europe, which suggests that Russia collaborates on a broad European basis.

Other forms of interaction

Besides co-authorships studies citation analysis can be used to study the interaction between individual scientists, their research organizations and countries. One citation based technique would be to trace citations to articles produced by a given unit. The *citing* articles can then be studied in terms of their institutional and geographical location, the field of the citing paper etc.

Tracing citations to articles is an example of direct interaction through the literature. Indirect interaction through the literature can be identified by counting the number of shared cited references among a set of articles. This type of citation based bibliographical coupling could for example be used to identify areas of common interest between organisations or sectors.

If one were to analyse interactions based on citations between universities and industry one would need a specialized bibliometric database and software. Even small scale studies of a few hundred articles require considerable manual effort without an automated system. Nevertheless, a combination of co-authorships and citation analysis could be an interesting approach. It is reasonable to assume that scientific networks are based on several forms of interactions that reinforce each other - scientists that read and cite the same literature tend to meet, which may lead to collaboration and co-authored papers and/or citations to each others documents.

Summary

The results of co-authorship studies can be used in a research policy perspective. They give an overview of the main features of the scientific communication system; the collaboration can be seen from the perspective of one single research institution, a specific country and its research units or the global collaboration pattern. Especially, if the co-authorship patterns are studied over time there is a possibility to test or evaluate various assumptions and science policies, in sofar as they relate to scientific collaboration.

Co-authorships can be retrieved and analysed in a number of ways depending on the specific question at hand. Rather than starting with such questions, we have tried to explain how co-authorship data can be retrieved, standardized and analysed. We have also discussed some of the validity questions associated with co-authorship studies. The main issue at hand is to what extent co-authorship data reflects actual collaboration. Some forms of collaboration will not generate co-authored articles and some co-authored articles do not reflect actual collaboration. Thus, there is a growing need for validation studies that clarifies the relation between bibliometric analyses of co-authorships and actual research collaboration. Until we know more exactly what co-authorships represent and what kind of collaboration they do not capture, and what proportions the different kinds of collaboration may reach, the reservations that we have pointed out must be considered. There is no doubt that proper skills and scrutiny limit the potential errors when using co-authorships as an indicator of research collaboration.

Notes and references

1. G. MELIN, O. PERSSON, Hotel Cosmopolitan - A bibliometric study of collaboration at European universities *Paper presented at the Fourth International Conference on Science and Technological Indicators: Performance at the National, Regional and Institutional Level"* in Antwerpen, Oct 5-7, 1995.
2. J. ZIMAN, *Prometheus Bound: Science in a Dynamic Steady State*. Cambride University Press, Cambridge 1994.
3. J. S. KATZ, B. R. MARTIN, What is Researh Collaboration?, *Research Policy*, (1996) (forthcoming).
4. M. A. HARSANYI, Multipel Authors, Multiple Problems - Bibliometrics and the Study of Scholarly Collaboration: A Literature Review", *LISR*, 15(1993) 325-354
5. *op. cit.*
6. *op. cit.*
7. G. SALTON, M. J. MCGILL, *Introduction to Modern Information Retrieval*, McGraw-Hill, London 1983.
8. T. LUUKKONEN, R. J. W. TIJSSEN, O. PERSSON, G. SIVERTSEN, The Measurement of International Scientific Collaboration, *Scientometrics*, 28 (1993) 15-36.
9. *op. cit.*
10. G. MELIN, The Networking University, *Scientometrics*, (1996) (forthcoming).

11. A. KALOUDIS, Communication Patterns and Productivity in a Norwegian R&D-sector, *Paper presented at the Fourth International Conference on Science and Technological Indicators: Performance at the National, Regional and Institutional Level*" in Antwerpen, Oct 5–7, 1995.
12. Å. E. ANDERSSON, O. PERSSON, Networking Scientists, *Annals of Regional Science*, 27 (1993) 11–21.
13. T. LUUKKONEN, O. PERSSON, G. SIVERTSEN, Understanding patterns of international scientific collaboration, *Science, Technology and Human Values*, 17 (1992) 101–126.
14. Y. OKUBO, J. F. MIGUEL, L. FRIGOLETTO, J. C. DORE, Structure of International Collaboration in Science: Typology of Countries Through Multivariate Techniques Using a Link Indicator, *Scientometrics*, 25 (1992) 321–351.
15. M. LECLERC, J. GAGNÉ, International Scientific Cooperation: The Continentalization of Science, *Scientometrics*, 31 (1994) 261–262.
16. J. S. KATZ, Geographical Proximity and Scientific Collaboration, Scientometrics, 31 (1993) 31–34.