Chapter 11

ANALYZING SCIENTIFIC NETWORKS THROUGH CO-AUTHORSHIP

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Abstract: Co-authorship is one of the most tangible and well documented forms of scientific collaboration. Almost every aspect of scientific collaboration networks can be reliably tracked by analyzing co-authorship networks by bibliometric methods. In the present study, scientific collaboration is considered both at individual and national levels, with special focus given to multinational collaborations. Both literature data and original results witnessed a dramatic quantitative and structural change in the last decades of the 20th century. The changes, to great extent, can be attributed to the universal tendencies of globalisation and the political restructuring of Europe. The standards and, particularly, the visibility of scientific research, as a rule, benefit from the ever increasing level of collaboration, but the profits do not come automatically. This fact underlines the necessity of a regular quantitative monitoring of inputs and outcomes, i.e., bibliometric surveys.

1. INTRODUCTION

Scientific collaboration is a complex social phenomenon in research that has been systematically studied since the 1960s. Increasing collaboration was reported by *Smith* (1958), *Clarke* (1964, 1967), *Price* & *Beaver* (1966), *Patel* (1973) and *Heffner* (1979) in the context of growing funding, that is, directly or indirectly by economic factors. According to *deSolla Price* (1963) massive funding is one of the characteristics of 'big science'; team work is another. Team work requires large personnel, which, in turn, is strongly dependent of the financial support available for the research.

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Besides the economic factors, intra-scientific factors (see, for example, studies by *deB. Beaver* & *Rosen* 1978, 1979, *Luukkonen* et al., 1992, 1993), especially changing communication patterns and increasing mobility of scientists, are also influencing collaboration. These factors motivate co-operation in 'less expensive' areas such as pure mathematics and theoretical research in social sciences, too. *deB. Beaver* (2001) has expanded the above-mentioned notion of funding-caused collaboration by giving a list of 18 purposes for which people collaborate. This list includes, beyond the access to funding and equipment, among others, also access to expertise, speeding up progress, enhancing productivity, and reducing isolation.

According to *Patel* (1973), involvement in (collaborative) research is manifested by authorship and by what he calls sub-authorship. Sub-authors are persons the contribution of whom is acknowledged by the authors of the publication as substantial assistance. In a recent study, *Laudel* (2001) has shown on the basis of a sample of interviewed scientists that a major part of collaboration is not acknowledged either through a proper acknowledgement or through co-authorship. A large share of persons involved in the preparation of a scientific paper does thus not appear either as co-author or as a sub-author of the publication. Consequently the question arises of how far co-authorship and sub-authorship are an adequate measure of collaboration. The relationship between *contributors*, *co-authors* (and *sub-authors*) and *co-writers* can thus be interpreted as a chain of subsets where co-authors form just a subset of contributors and those scientists who are actually writing the publications are, in turn, a subset of contributors acknowledged as *co-authors* and *sub-authors*.

Also *Katz* & *Martin* (1997) have found many cases of collaboration that are not 'consummated' in co-authored papers. They argue that co-authorship is no more than a partial indicator of collaboration. Intensifying collaboration, however, goes with growing co- and sub-authorship, as has been shown in several studies (for instance, *Patel*, 1973). We can thus conclude that there is at least a positive correlation between collaboration and co-authorship and sub-authorship at the level of individual actors.

The phenomenon described by *Laudel* and *Katz* & *Martin* rather applies to so-called *intramural* collaboration, that is, to collaboration within one department, research group or institute. Extramural collaboration, above all international collaboration, on the other hand, is usually well acknowledged. Moreover, does the relationship between collaboration and authorship change if not individual authors, but supra-individual co-operative research, such as that of teams, institutes, or even countries, is considered? The answer is yes, although, the relationship at the intra-institutional level at the same time does not necessarily change.

Kretschmer (e.g., 1994) has analysed aspects of social stratification in scientific collaboration at the micro level. The main findings are that extramural collaboration is characterised by similarity of the social status, whereas intramural collaboration shows significant differences of the social status of the co-authors. Interpreting these findings in the context of Laudel's results, we can conclude that the contribution of a quite large number of co-workers with lower status is 'only' acknowledged through sub-authorship or might remain even unacknowledged.

Newman (2001, 2003, 2004) has analysed the structure of collaboration networks on the basis of individuals' co-authorship patterns. Among other things, he has shown that co-authorship networks form 'small worlds' in which pairs of scientists are separated by only a short path of intermediate acquaintances. A similar model was developed and analyzed by *Barabási* et al. (2002).

Katz and *Martin* (1997) have found a conceptual problem with the single-authored but multi-institutional, or even international, papers. The paper by *Glänzel* (2001) on national characteristics of international collaboration itself might serve as an example for such a form of 'collaboration' which is often caused by multiple assignment and/or mobility of the author. In any case, it manifests an official relationship and involvement of the two or more institutions or countries. According to *Katz* & *Martin* at least 5–15 percent of collaborative papers at a national level seem to involve this form of 'collaboration' caused by multi-institutional authors. Despite this phenomenon, co-authorship seems to reflect research collaboration between institutions, regions, and countries in an adequate manner. Results of collaborative research at this level published in co-authored papers can thus be analysed with the help of bibliometric methods.

The findings by *Laudel* and *Katz* & *Martin* result in the conclusion that collaboration of individual scientists and that of institutions or of even higher levels of aggregation, have to be clearly distinguished. Nevertheless, the analysis of individual co-authorship gives insight into structural changes of collaboration at this level, too.

Institutional collaboration can, in turn, be studied in two important aspects: the first one concerns collaboration between different research institutions disregarding their organisational type. We consequently speak about inter-institutional collaboration — and in terms of published research results — about inter-institutional co-authorship whenever at least two different research institutions have contributed and thus the address of at least two different institutions appear in the byline of the paper. The effect of possible association between the institutions on collaborative patterns, as well as the role of strong federal structures in several countries with autonomous regions, makes, however, universal and comparative large-scale

studies difficult. Most studies of inter-institutional collaboration are, therefore, restricted to national or regional analyses (e.g., *Gómez* et al., 1995, *Hicks* & *Katz*, 1997). A study of domestic inter-institutional collaboration in Canada, Australia, and the UK has uncovered an interesting phenomenon, namely, that research cooperation decreases exponentially with the distance separating the collaborative partners (*Katz*, 1994).

Co-operation between different sectors such as university, industry, and government is studied as a second important type of 'extra-mural' collaboration. Within the framework of the Triple Helix model introduced by *Etzkowitz* and *Leydesdorff* (for instance, *Leydesdorff* & *Etzkowitz*, 1996) this type of collaboration has gained a new dimension.

As indicated above, institutional collaboration is shaped by institutional sectors (cf., scientific co-operation between universities and between firms, respectively) and collaboration across sectors is characterised by regional or national peculiarities. Similarly to the inter-institutional collaboration, studies of collaboration across sectors are preferably studied in their national context (e.g., *Hicks* & *Katz*, 1997).

A third phenomenon has been studied by *Cronin* (2001). He characterises the extraordinarily large number of authors of single papers in several subfields of biomedical research and in high energy physics as 'hyper-authorship'. Indeed, publications with hundreds of co-authors affiliated with dozens of institutes in ten and more countries are no longer the exception to the rule. *Cronin* questions the possibility of fixing the degree of the individual co-authors' contribution to the paper since "to be an author is not necessarily to be a writer". Besides this phenomenon, an increasing number of multi-institutional or multi-national publications can be observed in other fields, too (e.g., *de Lange* & *Glänzel*, 1997, *Glänzel* & *de Lange*, 1997). Nevertheless, most of these publications cannot be considered in the context of hyper-authorship.

The present paper — as a consequence of the phenomena described above — will be focussed on the following three levels:

1. The *individual level*, that is, the level of individual scientists not aggregated to any unit like department, institution, region, or country;
2. the *cross-national level*, that is, collaboration between scientists with affiliation in different countries regarded as collaborating pairs: and
3. *multi-national collaboration*, that is, collaboration between more than two countries taken into account explicitly.

The paper gives an overview of the development and application of indicators based on co-authorship, of their methodological background, and their use in research evaluation. In addition, the paper provides a review of

co-authorship analysis focussing on relevant issues at the abovementioned levels of aggregation.

The bibliometric data used for this study are based on bibliographic data extracted from the 1980–2000 annual cumulations of the *Science Citation Index*® (SCI) of the *Institute for Scientific Information* (ISI — Thomson Scientific, Philadelphia, PA, USA). All papers recorded in the annual volumes as *article, letter, note,* or *review* were taken into consideration. At the level of authorship of individuals the number of all co-authors has been counted for *articles* and *notes* only.

The papers were assigned to countries based on the corporate address given in the byline of the publication. All countries indicated in the address field have thus been taken into account.

2. METHODS AND RESULTS

Research studies and reports on national and European science and technology indicators have recently presented figures reflecting intensifying scientific collaboration and increasing citation impact in practically all science areas and at all levels of aggregation (see, e.g., *Narin* & *Whitlow*, 1990; *Narin* et al., 1991; *Moed* et al., 1991; *Glänzel*, 1995; REIST-2, 1997; *Glänzel* et al., 1999). In the following three subsections this phenomenon will be studied at three important levels of aggregations.

2.1 The individual level

In a recent paper *Persson* et al. (2004) studied the effect of inflationary bibliometric values. In this context they have found, besides a growing number of publications, a strong increase of the number of active authors. In particular, the number of papers has grown by slightly more than one third (36%) between 1980 and 1998, and the number of authors have grown by almost two thirds (64%) in the same time span. Thus the authors concluded that the only possible interpretation of this tendency lies in a change in the patterns of documented scientific communication, and collaboration has changed in the last two decades, and that this tendency has inflationary features. The question arises of whether the density of co-authorship networks at this level has increased by forming stable teams of co-authors or if collaboration is, rather, characterised by the temporary creation of occasional links.

In a first step all research articles (document type: *article* or *note*) indexed in the 1980, 1990, and 2000 volumes of the SCI were analysed. The results are summarised in Table 11.1.

Table 11.1 Statistics on the co-authorship distribution in all fields combined in selected years

SCI Volume	*Share of single-authors papers*	*Co-author mean*	*Reciprocal of harmonic mean*
1980	24.8%	2.64	0.52
1990	15.7%	3.34	0.43
2000	10.7%	4.16	0.37

The share of single-authored papers in all fields combined continuously decreased. While in 1980 still about one quarter of all papers had only one single author, this share decreased to roughly 15% ten years later to reach the level of 10% in 2000. The average number of co-authors shows that this development reflects increasing multi-authorship. The average paper already has nowadays more that 4 co-authors. The change of the reciprocal of the harmonic mean reveals further interesting details: The average 'contribution' of a co-author reduced from about a half (0.52) in 1980 to slightly more than one third (0.37) in 2000. The increasing deviation of the harmonic means from the arithmetic mean indicates *increasing inequality* in the co-authorship distribution.

The breakdown by subject fields (cf., *Glänzel*, 2002) shows that all areas of science are characterised by intensifying collaboration associated with the increase of the share of multi-authored papers. In the medical fields the share of single-authored papers decreased from about 22% in the clinical and experimental specialties and about 15% in biosciences and biomedical research in 1980 to somewhat less than 9% and 6%, respectively, in the year 1998. The mean co-authorship grew from roughly 3 to 4.5 in clinical medicine and to 5 in biosciences and biomedical research. The corresponding share in chemistry halved from 15% to 7.5% — the average number of co-authors changed from 2.7 to 3.6 in this field. In mathematics, finally, a field that has always been a domain of individual scientists rather than that of teams, the share of single-authored papers dropped from roughly two thirds in 1980 to 40% in 1998. A mathematical publication in 1998 had two co-authors on an average compared with 1.4 co-authors in 1980. Similar patterns and developments have been observed in the social sciences, too. *Cronin* et al. (2003) reported an essential increase of collaboration and co-authorship in *psychology*, while philosophy is less affected by this tendency.

At the same time productivity of authors seem to increase. The question arises, of how co-authorship and publication activity interact. In a recent paper by *Braun* et al. (2001) on publication and collaboration patterns in *neuroscience*, as well as in the above-mentioned study by *Glänzel* (2002), the interaction of co-operativeness and publication activity has been analysed. When average productivity is plotted against mean co-operativeness, field specific patterns can usually be observed: Productivity

increases first with co-operativeness until a field specific threshold is reached; beyond this level, correlation turns negative. This threshold value ranges depending on subject peculiarities from 1–2 in mathematics, over 3–4 in chemistry, to 5–6 co-authors in neurosciences and biomedical research. These values beyond which collaboration does not exhibit higher productivity seem to be closely related to the co-authorship means of the corresponding fields (see the discussion above).

(Co-)authors can be classified into four types according to their anterior and posterior records. The relation between co-authorship and publication activity of the author types reveals information about the potential role of co-authors in forming stable teams or in creating occasional links. *Price* & *Gürsey* (1976) provided an elaborated scheme of what they called the "actuarial statistics of the scientific community". They introduced the categories *continuants*, *transients*, *newcomers*, and *terminators* which proved to be useful in the analysis of cooperation patterns (cf., *Braun* et al., 2001). According to the definition of *Price* & *Gürsey*, transients are authors publishing in the given year but neither before nor after, newcomers are authors publishing in and after the given year but never before, terminators were publishing before and in the given year but never after and continuants were publishing before, in and after the given year. For the continuants and, to a certain extent, also for the newcomers and terminators, a clear 'critical value' in the co-operativity–productivity plot as described above has been found in *neuroscience*. Productivity of transients is 'more uniformly' distributed over co-operativity without any distinguishable 'critical value'. The preference structure of authors of the four categories for cooperating with each other revealed another interesting aspect of co-authorship. The overwhelming part of papers co-authored by continuants and that co-authorship relations among these three categories, i.e., *transients*, *newcomers*, and *terminators*, are usually also mediated by continuants makes the notion of 'collaboration in stable teams' as the engine of intensification of co-authorship more than likely. This observation is in line with recent results by *Newman* (2004) on the structure of scientific collaboration networks.

The interaction of co-authorship with productivity is only *one* aspect of interaction with performance. A further important aspect can be analysed in the light of citation processes, namely, in the context of giving and receiving citations. Several recent papers have shown that collaboration has a measurable influence on citation behaviour. We just refer to the above-mentioned study by *Persson* et al. (2003) here. The authors have found that co-authored papers have longer reference lists than single-authored papers. Moreover, the number of references grow with the number of co-authors. Each co-author adds on average roughly half a reference to the list. The

number of citations a paper receives is — on average — also strongly dependent of the number of co-authors. The effect is especially dramatic if authors from different countries have collaborated. However, this effect is subject to the following analysis, which will be deepened in the second section.

Summarising we can conclude that — even if co-authorship were indeed no more than a partial indicator of scientific collaboration at the level of individuals —, studying this phenomenon allows a deep insight into measurable interaction between collaboration and indicators of scientific communication and performance at this level, too.

2.2 Cross-national collaboration

International co-authorship links have undergone dramatic structural changes in the last 25 years. Besides stable links and coherent clusters, new nodes and links in the international co-publication network have crystallised. In recent years fundamental mechanisms in international cooperation have been the subject of a number of different studies. In contrast to intra-national collaboration, where co-operation decreases with the distance of collaborating partners (see *Katz*, 1994), intensity of international collaboration is determined, besides by geographical proximity, by other factors, too. Among important factors influencing research collaboration are, e.g., the country size and political and economic reasons, as well as certain aspects of mobility and migration at the individual level. And unlike in the individual case where, indeed, those eighteen reasons listed by *deB. Beaver* (2001) are the main motivation why people collaborate in scientific research, there are also strong influences of historical, cultural and linguistic proximities on co-operation patterns at the national level. When one considers international collaboration the economic and/or political dependence of a country or geopolitical region (such as the different forms and degrees of neo-colonial ties) or large or special equipment (such as CERN in Switzerland and the observatories in Spain or Chile), which are often shared in large multinational projects, also condition co-operation, apart from any individual motivation. However, by far not all collaboration links between individual countries reflect symmetric relationship. Some links between several countries are thus characterised by specific unidirectional (or better asymmetric) co-authorship affinity (cf., *Glänzel* & *Schubert*, 2001). Some of these asymmetric patterns with strong historical background must be interpreted in the context of so-called *strong neo-colonial ties in science* (see *Nagtegaal* & *de Bruin*, 1994).

Some of the main lessons concerning international co-operation/co-authorship were concisely summarised in the comprehensive study of *Narin*

and his co-workers (*Narin* & *Whitlow*, 1990; *Narin* et al., 1991). According to their key findings:

1. Internationally co-authored papers, whether co-authored by two countries within the EC or between an EC and a non-EC country, were twice as heavily cited as papers from a single EC country;
2. There was a steady rise in international co-authorship within and outside of the EC, and within and outside the EC targeted fields;
3. Tendencies for international cooperation were independent of country size and determined mainly by linguistic and historical factors;
4. The analysis of publications from the Less Favoured Regions of the EC revealed that the co-operating capabilities of these regions were very field dependent, corresponding in general to their national profiles.

International co-authorship, which is, in contrast to the level of individuals, assumed to reflect collaboration in a rather adequate manner, is accepted as a basically *positive phenomenon*. Nevertheless, *Braun*, *Glänzel* and *Schubert* have also pointed to problematic aspects of international collaboration. Thus extensive collaboration might be used as means for compensation for the negative financial effects which have hit the basic research system of several East European countries before and after the political and economical changes of the nineties (see *Braun* & *Glänzel*, 1996). The strong neo-colonial ties binding small scientific systems to those of large economies abroad might serve as another example. Strong (asymmetric) affinity thus may express a high degree of dependence of a scientific system from others. The continuously growing share of French co-publications with Algeria and Morocco in this context is striking.

Comprehensive macro-studies of international collaboration in the sciences by *Schubert* & *Braun* (1990) and *Glänzel* (2001) have shown that the share of internationally co-authored papers in most countries dramatically increased during the last two decades. In their study *Schubert* & *Braun* observed that foreign co-authorship can be approximated by national publication productivity through a power law in which the exponent is less than one. Big countries have thus, in general, lower shares of international co-publications than medium-sized or small countries have. Nevertheless, the growth of the share of international co-publications can be observed independently of the country's size. The increase is thus a global law. We will give some examples to illustrate this effect. According to *Schubert* & *Braun* the share of internationally co-authored papers in the USA, USSR and Japan in the begin of the 1980s of the last century lay significantly below 10%; by the end of the last century these shares reached and partly exceeded the value of 20%. For big and medium-sized developed countries, there was

an increase from about 10%–20% in the early 80s to about 30%–50% at the end of the 90s (cf., *Glänzel*, 2001).

However, not only number and strength of several bilateral links has increased during the last decades; the whole network of international co-publications has undergone dramatic structural changes. In order to visualise this structural change we will map the co-authorship links of the most active countries in the world broken down by country pairs for the years 1980, 1990 and 2000. We have used Salton's (cosine) measure as an indicator of international collaboration strength. This measure is defined as the number of joint publications divided by the square root of the product of the number (i.e., the geometric mean) of total publication outputs of the corresponding pair of countries (cf. *Glänzel*, 2001). In order to guarantee that the results can be considered statistically reliable, we have chosen countries with at least 2000 publications in all fields combined in 1990 or 2000, and have plotted links for country pairs with at least 50 joined publications at three different levels of strength. The dramatic intensification of international co-publication as well as the structural changes in the collaboration network is presented in Figures 11.1 through 11.3.

The map presented in Figure 11.1 resembles those in Figure 11.3 in *Schubert* & *Braun* (1990) and in Figure 5 in *Glänzel* (2001). Schubert and Braun have analysed the international collaboration of 36 countries in the sciences in the period 1981–1985 and *Glänzel* has compared collaboration patterns of the most active 50 countries in 1985/1986 (Figure 5 in his paper) with those in 1995/1996. Little can be added to their findings: The authors detected several clusters of unequal size, namely, a big one including Western Europe, USA, and Canada, and two smaller ones with the Scandinavian and the Eastern European countries, respectively. Three tiny clusters, finally, included Australia and New Zealand, Egypt and Saudi Arabia, and Brazil and Argentina, respectively.

Germany and the USA can be considered the most important partners for the East European countries in the period around 1990. Interesting is the great share of Romanian–French co-authorship and the almost outstanding role of German co-operation in Bulgaria and Czechoslovakia. This confirms earlier results according to which Germany is usually the first important co-operation partner for East European scientific communities (see *Glänzel* & *Winterhager*, 1992); Germany can thus be considered the "gateway to the west" for Economies in Transition in Eastern Europe.

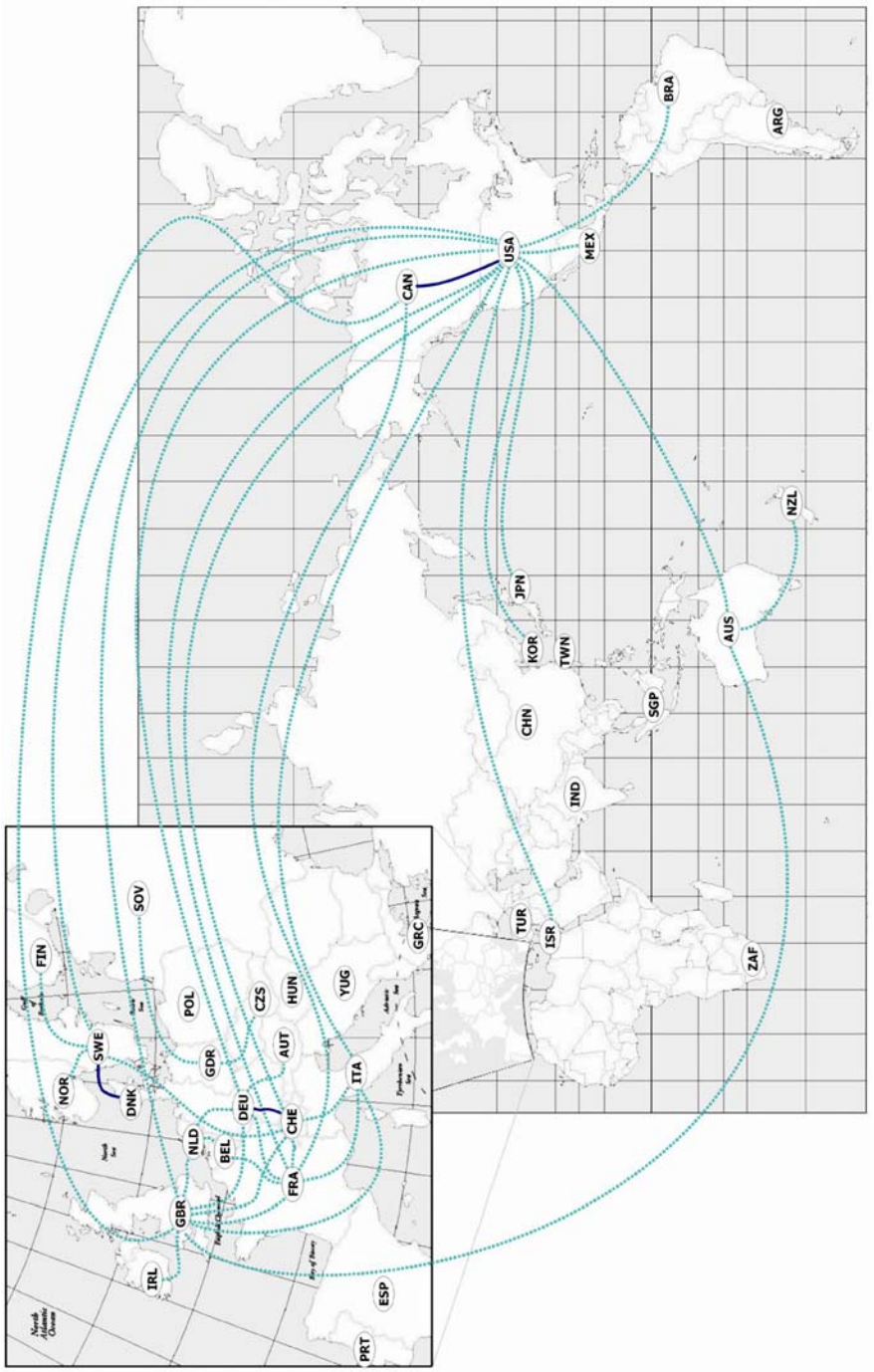

Figure 11.1. Co-authorship map for most active countries in all fields combined in 1980 based on Salton's measure (dotted line ≥ 1.0%, solid line ≥ 2.5%, thick line ≥ 5.0%)

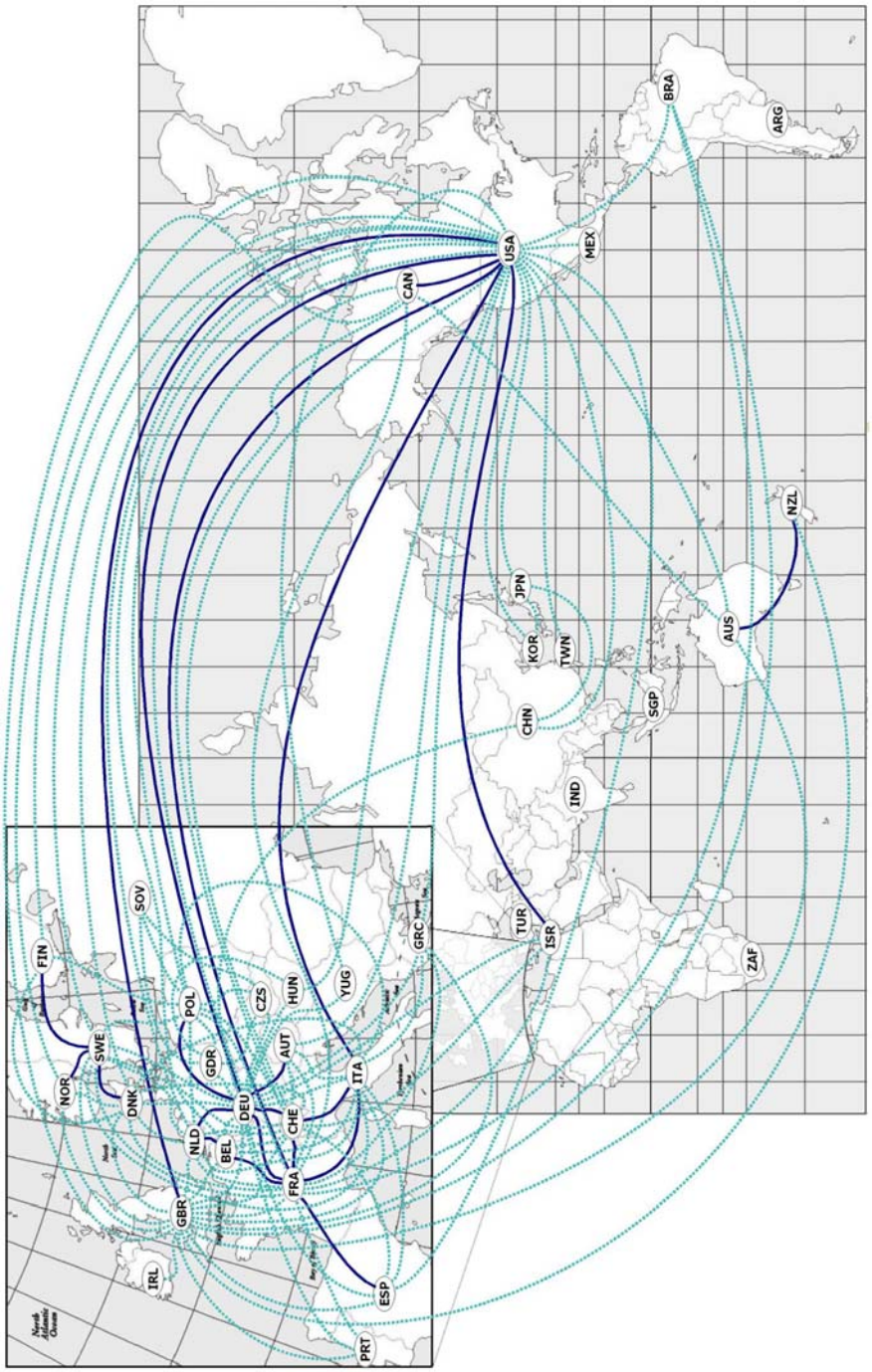

Figure11.2. Co-authorship map for most active countries in all fields combined in 1990 based on Salton's measure (dotted line ≥ 1.0%, solid line ≥ 2.5%, thick line ≥ 5.0%)

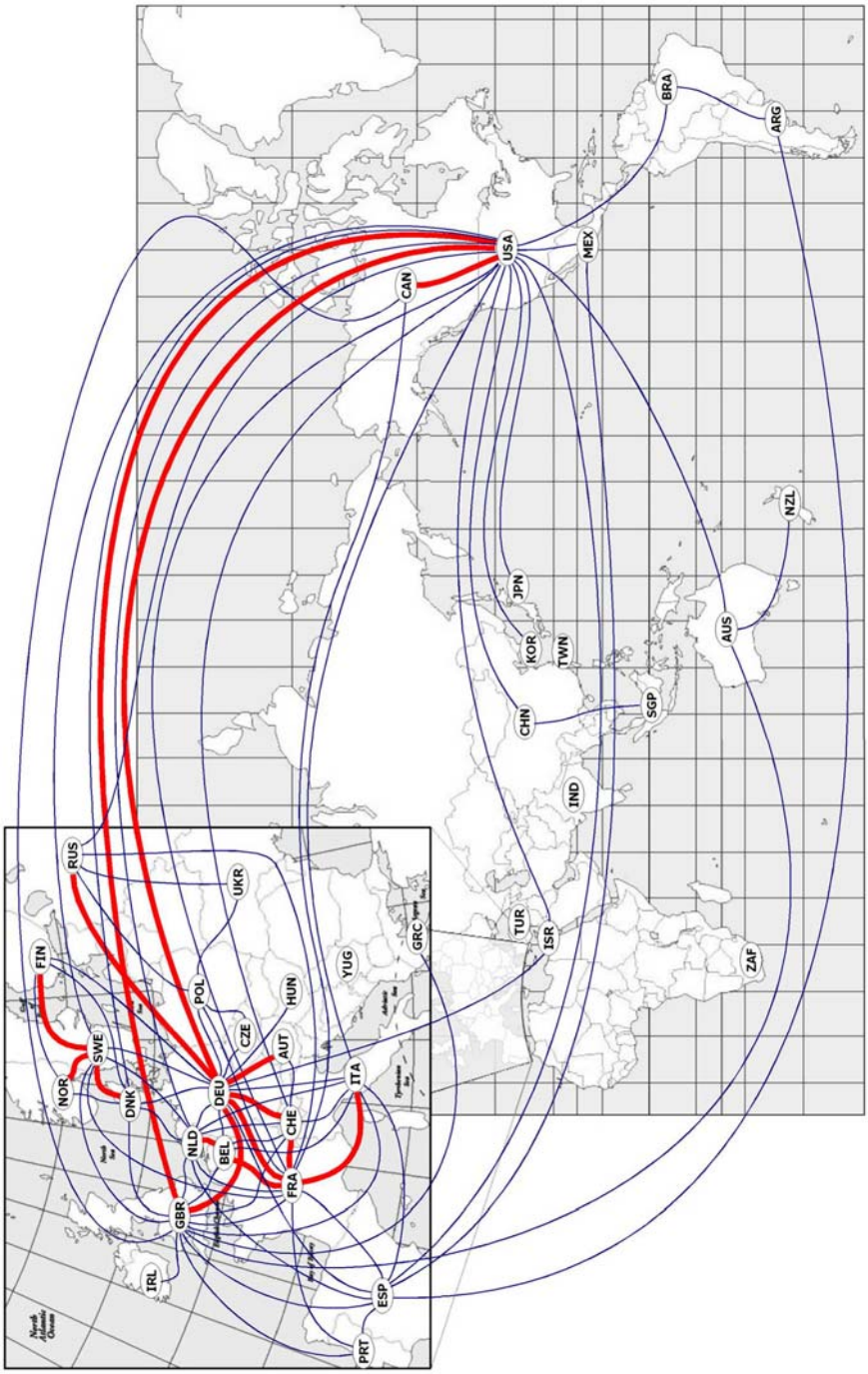

Figure 11.3. Co-authorship map for most active countries in all fields combined in 2000 based on Salton's measure (dotted line ≥ 1.0%, solid line ≥ 2.5%, thick line ≥ 5.0%)

From the global perspective Germany is besides the USA, France, and UK, also one of the world's most important nodes in the network of international collaboration (cf., Figures 11.2 and 11.3).

In addition to the above maps we would like to report interesting observations we have made concerning smaller countries not plotted in Figures 11.1–11.3. There are strong stable links both between Algeria and France, and Morocco and France which can be interpreted in the context of the abovemention neo-colonial ties. Other local links arose and/or died out in the period of the last twenty years; among those we find the strong links between Cyprus and Bulgaria as well as Cyprus and Romania with strength of almost 8% according to Salton's measure in 2000. However, these links are based on small publication and co-publication set. A similarly strong link was established between Cuba and Mexico (6% in 2000). The strong link between the Czech Republic and Slovakia substantiate how closely the scientific systems of the two countries still are. The most interesting phenomenon is the co-publication link between China and Hong Kong: While there was practically no collaboration between these countries in 1980, their collaboration affinity evolved from 1.7% in 1990 to one of the strongest in the world map a couple of years before the crown colony returned to China (5.9% in 1995/1996) in order to vanish by 2000.

The development of country links mapped in Figures 11.1–11.3 clearly shows a trend towards a global network of scientific collaboration. The third section will be devoted to this phenomenon, namely, from the perspective of multi-nationality of collaborative research. Before we deal with this aspect of collaboration we still look at national profiles, visibility and citation impact of international co-publications.

If one compares national publication profiles of domestic and internationally co-authored publications, both theoretically, 4 possible types of changes in the profiles can be observed. Using the *Activity Index* suggested by *Frame* (1977), *Glänzel* (2001) has shown in his study about national characteristics in international collaboration that all of these four types occur in practice. In several countries collaboration has no significant effect on their publication profiles (e.g., Germany or Romania in 1995/1996), in other countries, such as Slovenia and Switzerland in the same period, collaboration seems to strengthen their national peculiarities. In a third group, for instance Japan and China, the opposite effect could be observed. In the last group the effect of collaboration on the national publication profile is less pronounced. Besides the well-balanced co-publication patterns of the first group, collaboration in the second and third group allows interesting speculations: Countries may conduct collaborative research mainly in their favourite subject field, or may, conversely, use collaboration as a means of compensating lacking domestic efforts in fields

of relatively lower activity, which is, in turn, to the detriment of fields with higher activity.

The question arises of how far international collaboration has a measurable effect beyond national research profile also on *visibility* and *receptions*, i.e., on citation impact. The often observed relative high visibility and high citation attractivity of internationally co-authored publications resulted in what we can already consider the following commonplace: international co-publications appear in high impact journals and receive more citations than 'domestic' papers. On average this statement indeed seems to hold. The studies by *Glänzel* & *Schubert* (2001) and *Glänzel* (2001) have confirmed these assumptions. Nevertheless, the authors of these studies have shown that the above rule by far does not apply to all international papers.

In those fields where *targeting* is a more important aspect than 'global visibility', international collaboration often has a positive effect. In order to reach their audience, authors in clinical medicine often publish their results in their national language in their national journals. Their behaviour can, however, completely change if co-authors from abroad are involved. According to *Glänzel* (2001) the deviation of most countries' *mean expected citation rate* of international publications from that of domestic papers based on 3-year citation windows gauged against the world standard is in the fields clinical medicine, biomedical research, physics and engineering strictly positive. The opposite case, when a country is publishing its internationally co-authored papers on average in journals with lower impact can be observed, above all, in mathematics but, in part, also in chemistry and earth and space sciences. Not only are less advanced countries concerned, but also highly developed countries like the USA, in chemistry, and Australia, in mathematics, (cf., *Glänzel*, 2001). This observation may be at variance with the widespread notions concerning greater visibility of international co-publications. Similar contradictory observations could be made concerning the factually received citation rates of internationally co-authored papers. While the national totals of the citation impact of co-publications in all analysed fields often lie distinctly above the domestic 'standards', the situation changed if the citation impact is analysed by country pairs. Co-publications of several country pairs may attract fewer citations than expected on the basis of the corresponding domestic reference standards. *Glänzel* & *Schubert* (2001) called this type of co-publication links *cool links.* Unlike in biomedical research, where the observed citation impact of most analysed country pairs in the abovementioned study by *Glänzel* (2001) was higher than the domestic impact of at least one of the involved partners, and often higher than the world standard, too, the patterns in chemistry and mathematics reflect a somewhat different situation. Besides the

outstandingly high citation impact of co-publications of several country pairs, the attractivity of joint papers of some pairs was unambiguously low in these fields. Here developing countries and Eastern Europe are the most concerned. International co-authorship seems, therefore, not always to pay for all partners. Glänzel has also analysed the citation distributions over domestic and international papers in his study, and found that citation patterns are normally characterised by significantly different frequency distributions and not merely, as one might expect, by statistical outliers such as a few highly cited or many uncited papers.

2.3 Multi-national collaboration

The increase of multi-national co-authorship (besides the traditionally large multi-national research projects conditioned by special research facilities) reflects aspects of *globalisation* in scientific research.

Among the motivation for multi-national collaboration, the use of large equipment and instrumentation as a form of *big science*, economic reasons as well as political factors play an important part. Scientific collaboration is clearly stimulated (or hindered) by national, regional and global political interests. The auspices of the EC may serve as an example for a stimulation of the process of regional international scientific collaboration. Many multinational research projects are only possible in the framework of the large European programmes (*Narin* & *Whitlow*, 1990; *Narin* et al., 1991, REIST-2, 1997). Multiple institutional affiliations in the context with growing mobility have apparently become a further measurable factor. Nevertheless, multinational research — as all collaborative research — certainly not conditioned by these factors alone.

Figure 11.4 visualises the change of the share of bilateral, trilateral, and multinational international papers in time. 17% of all internationally co-authored papers in 2000 has authors with corporate addresses in more than two countries while this share amounted to 10% in 1990, and was still below 7% in 1980.

In order to measure the change of multi-national collaboration in time in the mirror of international co-publication links, *de Lange* & *Glänzel* (1997) and *Glänzel* & *de Lange* (1997) introduced the *Multilateral Collaboration Index*. This indicator is a national measure which can be interpreted as the mean number of partners involved in a country's international publications. According to *de Lange* & *Glänzel* (1997) and *Glänzel* & *de Lange* (1997), both the share of international papers and the degree of multilateral collaboration — mainly in the life sciences and in physics, but to a lesser extent also in chemistry and engineering — have grown considerably during the last decades. The values of the multilateral collaboration index have in

practice increased for the most active 38 countries studied in the years 1983 and 1993.

In a recent study *Glänzel* & *de Lange* (2002) have analysed citation patterns of multi-national papers. They concluded that countries, in general, benefit from participation in multinational projects. This holds, again above all, for the life sciences. Nevertheless, in some cases in the natural sciences 'visibility' of multinational publications measured by 3-year journals impact did not significantly deviate from that of bilateral or even domestic papers.

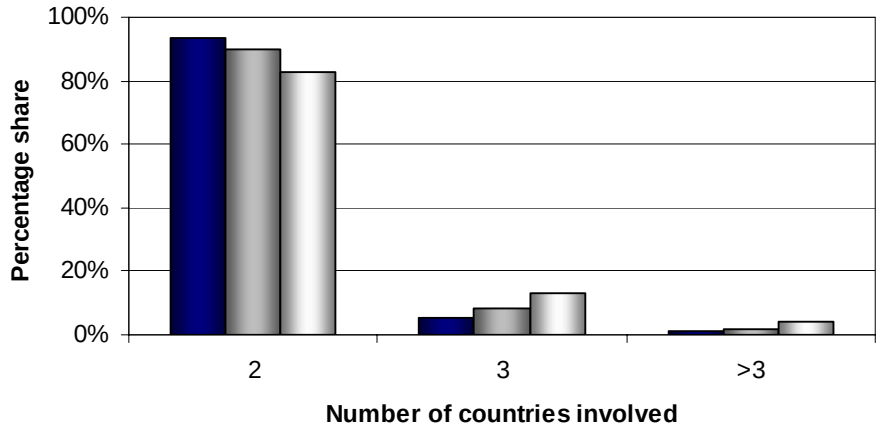

Figure11.4. Share of countries involved in international publications (1980 — dark, 1990 — grey, 2000 — light)

It is perhaps worth mentioning that most of these multi-national co-authorships studied in the above papers by *Glänzel* & *de Lange* are based on collaboration of three or four countries, and thus cannot be considered as what *Cronin* (2001) has characterised as 'hyper-authorship'.

3. CONCLUDING REMARKS

Research collaboration and co-authorship in science is an interesting multi-faceted phenomenon. In order to understand and to interpret collaboration and co-authorship in a correct manner, co-operation must be studied at each level of aggregation in its specific way. Collaboration among individuals is at least in part subject to other motivations than collaboration between institutions and countries. Growing international collaboration is not only an expression of 'big science' but also part of the globalisation process in scientific research.

Nevertheless, whatever level we consider, research cooperation, in general, and co-authorship, in particular, appears to be 'cost effective', on the long run. It is true not only in economic sense, but also if more general value concepts, e.g., those measurable with bibliometric tools are concerned. Collaboration is able to promote research activity, productivity, and impact, and therefore is to be encouraged and supported by the means of research management and science policy. The benefits, however, do not come automatically. This fact underlines the necessity of a regular quantitative monitoring of inputs and outcomes, i.e., bibliometric surveys.

The results of the above research issues thus have beyond their significance for monitoring and mapping structural aspects of scientific research, also strong implications for the application of bibliometric indicators in research evaluation. Interaction of co-authorship with other important processes of scientific communication such as publication activity and citation behaviour may also result in reconsidering the construction of bibliometric standard tools to guarantee the validity of conclusions drawn from bibliometric results.

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