WHAT IS RESEARCH COLLABORATION?

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Although there have been many previous studies of research collaboration, comparatively little attention has been given to the concept of 'collaboration' nor to the adequacy of attempting to measure it through co-authorship. In this paper, we distinguish between collaboration at different levels and show that inter-institutional and international collaboration need not necessarily involve inter-individual collaboration. We also show that co-authorship is no more than a partial indicator of collaboration. Lastly, we argue for a more symmetrical approach in comparing the costs of collaboration with the undoubted benefits when considering policies towards research collaboration.

1. Introduction

Over recent years, there has been increasing interest among researchers and within science policy circles in the notion of research collaboration.[1] It is widely assumed that collaboration in research is 'a good thing' and that it should be encouraged. Numerous initiatives have been launched with the aim of developing collaboration among individual researchers - bringing them together, for instance, in new or larger centres of excellence, or alternatively in interdisciplinary research groups. There have also been policies aimed at improving the links between science and technology through fostering research collaboration across sectors - in particular, between university and industry. Furthermore, most governments have been keen

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1. In what follows, we are concerned primarily with collaboration in science, although some of the arguments may also apply to collaboration in the social sciences. They are probably less relevant to the humanities where collaboration is apparently less common [see ref 41].

to increase the level of international collaboration engaged in by the researchers whom they support in the belief that this will bring about cost-savings or other benefits.

Implicit in this enthusiasm for research collaboration and in policies aimed at fostering it are a number of assumptions:

(1) that the concept of 'research collaboration' is well understood;

(2) that we are dealing with essentially the same phenomenon, whether we are concerned with collaboration between individuals, groups, institutions, sectors or nations;

(3) that we can in some way measure the level of collaboration and hence determine whether or not it is changing as a result of a particular policy;

(4) that more collaboration is actually better, whether for the advancement of knowledge or for exploiting the results of our scientific endeavours more effectively.

Yet how valid are these rather fundamental assumptions? The objective of this paper is to explore the validity of these assumptions, showing that the idea of a collaboration is far from simple and that it can take many forms. We will examine five questions:

(1) What is research collaboration?

(2) What motivates collaboration?

(3) Who are the collaborators?

(4) How can one measure collaborative activity?

(5) What are the benefits and costs of collaborating, and the implications for research policy?

However, before we turn our attention to these questions in subsequent sections, let us first review the previous literature on research collaboration.

2. Previous Research

The issues examined in the literature on research collaboration fall into a number of categories. First, there is the question of how one can measure research collaboration, and in particular whether one can do so through the analysis of multiple-author (or multiple-address) papers. A second category concerns the factors encouraging the formation of research collaborations. Thirdly, various authors have attempted to identify the sources of collaboration, looking especially at the role of communication and the effects of physical and

social proximity on propensity to collaborate. Lastly, there is the literature analysing the effects of collaboration on productivity and on the impact of joint research. In what follows, we consider each of these categories in turn.

2.1 Multiple Authorship and Collaboration

For decades the multiple-author publication, frequently referred to as a co-authored publication, has been used as a basic counting unit to measure collaborative activity. Smith was one of the first researchers to observe an increase in the incidence of multiple-author papers [57] [2] and to suggest that such papers could be used as a proxy measure for collaboration among groups of researchers. However, he warned that

> Nothing short of a complete description of the kinds of relationships and activities of all persons concerned in the final product would give an approximation of the amount of group effort going into the papers presented. [57, p.598]

Subramanyam has taken this argument further. In his view, one needs to adopt a holistic perspective when evaluating collaboration for the following reason:

> The precise nature and magnitude of collaboration cannot be easily determined by the usual methods of observation, interviews or questionnaire because of the complex nature of human interaction that takes place between or among collaborators over a period of time. Both the nature and magnitude of contribution of each collaborator are likely to change during the course of a research project. [63, p.35]

Furthermore, only some of the more tangible aspects of a collaborative piece of work can be quantified while others most certainly cannot. Even a qualitative assessment of collaboration is extremely difficult because of the indeterminate relationship between quantifiable activities and intangible contributions. For example, Subramanyam notes that

> a brilliant suggestion made by a scientist during casual conversation may be more valuable in shaping the course and outcome of a research project than weeks of labour-intensive activity of a collaborating scientist in the laboratory. [63, p.35]

Despite the limitations of co-authorship measures, many studies have used this technique to investigate collaboration. For example, de Solla Price was an early advocate of the use of multiple-author papers as a measure of changes in collaboration. He produced evidence to

[2]. Smith [57] examined 4,189 papers from *American Psychologist* published between 1946 and 1957. He found that the mean number of authors per paper increased from 1.3 to 1.7 over this period.

support Smith's observation that multiple-authorship has been increasing [58],[3] a trend since confirmed by several other investigators [1, 2, 3, 4, 40, 42].[4] However, such studies have also shown that the rate of increase in multiple-authorship has varied considerably with subject area [40, 61], and in a few cases (e.g. biomedicine [7]) there seems to have been no significant growth.

There is general consensus that the observed growth in multiple-authorship is evidence of an increase in collaboration [2, 3, 4, 7, 16, 40]. However, the assumption that multiple-authorship and collaboration are synonymous must be qualified with the recognition that in some instances not all those named on a paper are responsible for the work and should not share the credit accorded to it. For example, in an early case-study to investigate collaboration, Hagstrom found evidence that some publications listed authors for purely social reasons [19]. More recently, the investigation of several instances of scientific fraud has revealed how common the practice of making colleagues 'honorary co-authors' has become [14].

Although the assessment of collaboration using co-authorship is by no means perfect, it nevertheless has certain advantages [63]. First, it is invariant and verifiable; given access to the same data-set, other investigators should be able to reproduce the results. Secondly, it is a relatively inexpensive and practical method for quantifying collaboration. Furthermore, the size of sample that it is possible to analyse using this technique can be very large and the results should therefore be statistically more significant than those from case-studies. Finally, some would argue [63] that bibliometric studies are unintrusive and indeed non-reactive - that

3. Price [58] presented data from *Chemical Abstracts* for the period 1910-1960 which showed that the number of multiple-author papers increased from under 20 percent in 1910 to over 60 percent in 1960. He found that the number of three-author papers was accelerating faster than two-author papers, four-author papers more quickly than three-author papers, and so on. This observation led Price to the following oft quoted speculation: "Since that time the proportion of multi-author papers has accelerated steadily and powerfully, and it is now so large that if it continues at the present rate, by 1980 the single-author paper will be extinct." (ibid., pp. 86-91)

4. Beaver and Rosen [2, 3, 4] examined the *Royal Society Catalogue of Scientific Papers* over the years between 1800 and 1960. They concluded that during the nineteenth century team-work exhibited a very slow and steady growth from about 2 percent of all research in 1800 to about 7 percent in 1900. However, at the beginning of the century, a significant upward change in the rate of growth occurred. By the beginning of World War I the growth rate had slowed down, but jointly authored research was still increasing at a rapid rate. Since then, the proportion of multi-authored publications has continued to expand.

is, the measurement does not affect the collaboration process. This may be true in terms of an **immediate** effect but others have suggested that the results from a bibliometric investigation may influence collaboration practices over the longer term [39].

As we shall see in more detail below, the complex nature of collaboration is perhaps not as readily amenable to assessment as previous authors have assumed. Bibliometric analysis of multiple-author papers can only be used as a partial indicator of collaborative activity. More specifically, it can only be used to count collaborations where the collaborating participants have put their names on a joint paper.[5]

2.2 Factors Contributing to Collaboration

Numerous authors have studied the phenomenon of collaboration. However, while a wide range of factors apparently contributing to collaborative activity have been identified, few specific reasons have been clearly established to explain how and why it occurs. Collaboration can take various forms ranging from offering general advice and insights to active participation in a specific piece of research. These collaborative contributions can also vary in level from the very substantial to the almost negligible. Sometimes a researcher may be seen as a 'collaborator' and listed as a co-author simply by virtue of providing material or performing a routine assay [62]. In other cases, researchers from different organisations may collaborate by sharing data or ideas through correspondence or discussions at conferences, by visiting each other, or by performing parts of a project separately and then integrating the results.

Previous authors have proposed a great many factors to account for the increase in multiple-author papers. These include the following:

(1) changing patterns or levels of funding [8, 21, 57];

(2) the desire of researchers to increase their scientific popularity [49], visibility and recognition [2, 3, 4, 10];

(3) escalating demands for the rationalisation of scientific manpower [2, 3, 4, 58];

5. Normally, the preparation of a paper with two or more authors would imply that they had come to some formal agreement as to who should be listed as a co-author [for example, see 20]. However, in cases where scientists have subsequently been discovered to have fabricated their results, their co-authors have often claimed that they were not involved in the research. In some instances, they may even have been unaware until later that their names had been included among the list of co-authors; for example, in one case, the fraudulent scientist apparently forged co-authors' signatures on copyright transfer permission forms [14].

(4) the requirements of ever more complex (and often large-scale) instrumentation [40, 41];

(5) increasing specialisation in science [6, 25, 57];

(6) the advancement of scientific disciplines which means that a researcher requires more and more knowledge in order to make significant advances, a demand which often can only be met by pooling one's knowledge with others [17, 35];

(7) the growing professionalisation of science, a factor which was probably more important in earlier years than now [2, 3, 4];

(8) the need to gain experience or to train apprentice researchers in the most effective way possible [2, 3, 4];

(9) the increasing desire to obtain cross-fertilisation across disciplines [2, 3, 4];

(10) the need to work in close physical proximity with others in order to benefit from their skills and tacit knowledge [2, 3, 4].

Indeed, the list of possible contributing factors is almost endless.[6] Even though some of these factors may occur more frequently than others, collaboration is an intrinsically social process and, as with any form of human interaction, there may be at least as many contributing factors as there are individuals involved.

Does collaboration vary with the nature of the research? Smith was one of the first to observe that theoretical work generally produces papers with fewer co-authors than experimental work [57, pp.598-99]. Later evidence has supported this finding and now it is generally accepted that experimentalists tend to collaborate more than theoreticians [18, 40, 58]. Collaboration is particularly common in experimental research involving the use of large or complex instrumentation such as telescopes, particle accelerators or CT scanners [45, 58] Besides the obvious economic benefits, one reason postulated for this high degree of collaboration is the need for a formal division of labour, a point to which we return later. Collaboration may also depend on how basic or applied is the research. For example, Hagstrom [19] has argued that applied research, like experimental research, tends to be more

6. In recent years, political factors have become more pronounced with certain funding agencies, in particular the European Commission, requiring researchers to seek collaborative partners before they apply for financial support. Transportation and electronic communication are two other contributing factors which, up till now, do not appear to have received much attention. They are examined later.

interdisciplinary, and research on a particular problem may therefore require a wider range of skills than any single individual, or even a single institution, is likely to possess. However, this is somewhat at odds with the findings of Frame and Carpenter who conclude that "the more basic the field, the greater the proportion of international co-authorships" [15].[7]

2.3 Sources of Collaboration - the Role of Communication and the Effects of Physical and Social Proximity

Views on the role of social or intellectual forces stimulating collaboration vary widely. On the one hand, Price claimed that collaborative authorship

> arises more from economic than from intellectual dependence and ... the effect is often that of squeezing full papers out of people who only have fractional papers in them at that particular time. [59, p.160]

Conversely, Edge [13] and Stokes and Hartley [62] have argued that co-authorship reflects mutual intellectual and social influence. However, even they agree that most collaborations begin informally and are often the result of informal conversation [13, 19, 60]. Informal communication may then lead to increasing commitment to co-operate, much the same as with communication in the courtship process. Indeed, Hagstrom used precisely this analogy:

> When collaboration is initiated this way [i.e. informally], possible partners may approach it very gingerly, even as boys and girls do not, at the first meeting, suggest the possibility of romantic collaboration, although this may be very much on their minds. [19, p.114]

In addition, spatial proximity seems to encourage collaboration since it tends to generate more informal communication [19, 28]. The closer two potential collaborators are, the more likely they are to engage in informal communication. This is consistent with the results of a recent study which shows that co-authorship decreases exponentially with the distance separating pairs of institutional partners [26].[8] However, this does not rule out the possibility that, in cases where the potential collaboration involves a clear division of labour, scientists may be more concerned with seeking the most appropriate expert partners, even if they have to travel some distance to find them.

7. This finding has since been confirmed by others, [for example, see 33].

8. This study [26] focused on intra-national university-university collaboration - that is, collaboration between universities within the same country.

Collaboration frequently occurs between teachers and students [10]. Even where there is no formal collaboration, the teacher who supervises the training of a student may retain a close relationship with that student over later years. Sometimes this is part of the process associated with the development of an 'invisible college' [60].[9] Invisible colleges are a form of network and represent a good source of potential collaborators.

Social distance between individuals is also apparently a factor influencing whether collaborations develop [19]. In general, collaboration between peers (i.e. scientists of similar standing) is more likely than collaboration between individuals of unequal rank but this is by no means always the case. In this connection, Hagstrom made a curious observation about the relationship between teachers and students - namely, that in some teachers' minds students do not count as collaborators. During his interviews, he asked scientists of co-authored papers if the work was carried out in 'collaboration' with others. A number of scientists replied "no" although most or all of their papers had been jointly written with students [19]. This may have been a reflection of the social distance between teacher and student combined with an implicit belief that 'true' collaboration must involve a partnership of equals.

2.4 The Effects of Collaboration on Productivity and Impact

A pioneering insight into the productivity of scientists was provided by Lotka in 1926 - an insight since confirmed by numerous others. He showed that the number of authors producing n papers is proportional to $1/n^2$ [32]. Thus, the number of researchers producing just one paper in a given period of time is two orders of magnitude greater than the number of researchers producing ten papers in the same time and four orders of magnitude greater that the number producing a hundred papers. Lotka's findings have led some investigators to ask if prolific authors tend to collaborate more than less prolific authors.

Research into this question seems to indicate that high productivity (in terms of published output) is indeed correlated with high levels of collaboration [1, 2, 3, 4, 24, 30, 51, 52, 58, 60]. For example, Pravdic and Oluic-Vukovic analysed collaborative patterns in chemistry at

9. The term 'invisible college' is derived historically from the group of people who were later to organise themselves formally into the Royal Society of London. Before that, they met informally and communicated by letter to keep each other informed of their work [60].

both the individual and the group level [54].[10] They found that scientific output as measured by publications is closely dependent on the frequency of collaboration among authors. The nature of the effect on productivity depends on the type of links; while collaboration with high-productivity scientists tends to increase personal productivity, collaboration with low-productivity scientists generally decreases it. Furthermore, the most prolific authors seem to collaborate most frequently and authors at all levels of productivity tend to collaborate more with highly productive authors than lower-productivity authors.

Besides enhancing personal productivity, collaboration appears to offer authors another advantage when it comes to a paper being submitted for publication. Gordon found a significant relationship between levels of multiple authorship for papers submitted to a leading astronomy journal, and their frequency of acceptance for publication [18].[11] According to Gordon, one reason for this is that

> the degree of technical competence displayed in the multi-authored paper can be enhanced by overlaps existing in areas of specialized competence, and the opportunity for cross-checking and presubmission 'internal refereeing' which this provides for. [18]

Other research has shown that there are further advantages to multiple-authorship. A study by Nudelman and Landers suggested that the total credit given by the scientific community to all the authors of a jointly authored paper is greater on average than the credit allocated to the author of a single-author paper [48].[12] The number of co-authors also appears to be strongly correlated with the impact of a paper. In his study of cancer research, Lawani demonstrated that, as the number of authors per paper increases, the proportion of high-impact papers (i.e. papers earning a high number of citations) also increases [30].[13] Similarly, Crane [10] and

[10]. Pravdic and Oluic-Vukovic [54] examined Croatian chemists who between 1971 and 1978 published 1506 papers listed in the Croatian national bibliography. A total of 853 native and 340 foreign authors contributed to these papers.

[11]. Gordon [18] examined 1859 papers (1090 one-author, 752 two- to five-authors and 17 six- or more authors) submitted to a leading astronomy journal between 1968 and 1974. He found that 63 percent of single-author papers were accepted compared with 78 percent of two- to five-author papers and all of the six or more author papers.

[12]. Using a combination of questionnaires and interviews, Nudelman and Landers [48] found that for the case of a three-author article the first author received 75 percent of the intellectual credit of a single-author paper, the second author 62 percent and the third author 58 percent. Thus, a three-author paper would be given a total of nearly twice the credit of a single-author paper.

[13]. Lawani [30] used inclusion in the *Year Book of Cancer* as a measure of the quality of papers, looking at those published in 1974 and abstracted in 1975 or 1976. He analysed 279 first-order publications (i.e.

Goffman and Warren [18] have shown that research by larger groups tends to be more influential, while Narin and Whitlow [46] have found evidence that internationally co-authored papers are cited up to twice as frequently as single-country papers. Diamond has even gone so far as to suggest, from his study of Berkeley mathematicians, that citations to multiple-author papers are worth more to authors in terms of the effect on their earning ability or salary than citations to single-author papers [11].[14]

In this section, we have seen how there is a considerable literature on the phenomenon of research collaboration stretching back over 30 years or more. In much of this work, collaboration has been simply equated with co-authored papers. In particular, the increase in the incidence of multiple authorship has been seen as evidence of growth in collaboration. One aspect of collaboration on which there has been extensive research concerns the factors encouraging collaboration and accounting for the increase in multi-authored papers. There have also been analyses of the sources of collaboration and the role of communication. Lastly, previous authors have looked at whether collaboration is associated with greater productivity and impact. However, our survey of the literature suggests that there has been very little work on other important aspects of collaboration. The first is the concept of collaboration - how to define it and what it means. Secondly, few authors have examined the adequacy of measuring it through co-authorship. Thirdly, little attempt has been made to distinguish and categorise different levels of collaboration (ranging from inter-individual through inter-departmental and inter-institutional to international collaboration). Finally, while there have been qualitative

publications that were abstracted) and 276 second-order (publications mentioned but not abstracted for reasons of lack of space) and 315 average-order papers (randomly selected from the *Biological Abstracts* and *Science Citation Index* (*SCI*) and published between July 1974 and June 1975). All citations were derived from *SCI* data for 1974-78.

[14]. Diamond [11] examined citations in the 1965-1979 *SCI* to Berkeley mathematicians who published in the 1960s and 1970s. Using regression analysis on two different cohorts, he claimed to find a relationship between citations, number of authors and the marginal dollar value to each author's salary:

	Regression	
Marginal dollar value of	Type I	Type II
1. Citation to single-author paper	$ 92	$272
2. Citation to an article where author is the first of two or more authors	$408	$520
3. Citation to an article where the author is the second and subsequent authors	$112	$394

assessments of the benefits of collaboration, there is little on the additional costs of collaboration.[15] These are some of the 'gaps' in the literature that the rest of this paper will attempt to fill.

3. What is a Collaboration? Where is the 'Boundary'?

As we have seen, there have apparently been few attempts to examine the question of what constitutes a research 'collaboration'.[16] Instead, the concept has been largely taken for granted as though we all know exactly what is meant by the term. Yet is the concept of collaboration so obvious and unproblematic? The dictionary definition of collaboration suggests the working together of individuals to achieve a common goal. Thus, a 'research collaboration' could be defined as the working together of researchers to achieve the common goal of producing new scientific knowledge. However, this begs the question of exactly **how closely** researchers have to work together in order to constitute a 'collaboration'. At one extreme,[17] it could be argued that the international research community is one big collaboration [63] - that basic research is a truly global activity where, in a sense, all researchers work together to advance scientific knowledge. They exchange ideas on what experiments to do next, what hypotheses to test, what new instrumentation to build, how to relate their latest experimental results to theoretical models, and so on. In these and other tasks, members of a research group will not only talk among themselves but will also seek advice and help from others (and will often offer information in return).

In our search for a definition for research collaboration, one possibility would be to include as a 'collaborator' anyone providing an input to a particular piece of research. However, this **weak** definition of collaboration would bring in such large numbers of collaborators that it would be too unwieldy for all practical purposes. At the other extreme, one could formulate a **strong** definition according to which only those scientists who contributed directly to all the main research tasks over the duration of the project would be counted as collaborators. This

15. An exception here is Turney [64].

16. One exception is Edge [13].

17. At the other extreme, one could argue that no two researchers ever have **precisely** the same goals and cannot therefore be said to be truly 'collaborating'.

immediately runs into a problem because, as we describe below, no single individual could possess all the knowledge required to contribute to all aspects of a particularly complex piece of research, an interdisciplinary project or a 'big science' experiment. Thus, the application of the strong definition to, say, the 150 scientists appearing on an experimental high-energy physics paper would suggest that none were truly collaborators because most had worked on a single task (e.g. the construction of the detector), or at least only a few of the principal tasks, and had contributed little to the many other constituent elements of the project.

We are therefore left with the rather unsatisfactory conclusion that a research collaboration lies somewhere between these two extremes. All that we can do is suggest some putative criteria for distinguishing 'collaborators' from other researchers. The collaborators will normally include the following:

(a) those who work together on the research project throughout its duration or for a large part of it, or who make frequent or substantial contributions;

(b) those whose names or posts appear in the original research proposal;[18]

(c) those responsible for one or more of the main elements of the research (e.g. the experimental design, construction of research equipment, execution of the experiment, analysis and interpretation of the data,[19] writing up the results in a paper).

In some cases, the list of collaborators may also include

(d) those responsible for a key step (e.g. the original idea or hypothesis, the theoretical interpretation);

(e) the original project proposer and/or fund raiser, even if his or her main contribution subsequently is to the management of the research (e.g. as team leader) rather than research *per se*.

The group of collaborators will generally exclude the following:

(i) those who make only an occasional or relatively minor contribution to a piece of research;

(ii) those not seen as, or treated as, 'proper' researchers (e.g. technicians, research assistants).

[18]. One obvious criterion for defining 'collaborators' would be those who are listed as co-authors on papers. However, as explained elsewhere, we prefer to maintain a conceptual distinction between collaboration and co-authorship.

[19]. These examples relate primarily to experimental research because this is where collaboration is most common. However, other examples could be listed for theoretical research.

Nevertheless, while the above criteria for distinguishing between 'collaborators' and other researchers may apply in many research circumstances, it is all too easy to identify exceptions to virtually all the above criteria in particular fields, institutions or countries. A research collaboration therefore has a very 'fuzzy' or ill-defined border. Exactly where that border is drawn is a matter of social convention and is open to negotiation. Perceptions regarding the precise location of the 'boundary' of the collaboration may vary considerably across institutions, fields, sectors and countries as well as over time.

4. What Motivates Collaboration?

There are several reasons why the level of research collaboration has been growing over the last 20 to 30 years. One is the escalating costs of conducting fundamental science at the research frontier. In many fields, scientific instrumentation costs have jumped appreciably with the introduction of successive generations of technology. As a consequence, it has often become impossible for funding agencies to provide the necessary research facilities to all the research groups working in the area. Resources have had to be pooled, either at a regional, national or (in the most expensive cases) at an international level. Consequently, the researchers involved have been forced to collaborate more closely.

A second factor encouraging greater collaboration has been the substantial fall - in real terms - in the cost of travel and of communication, accompanied by growing availability and easy access. Air travel is many times cheaper in relative terms than in the 1950s (when a journey by sea and/or or rail was often the only option) or even the '60s, and flights are now readily available between most major cities. Likewise, the falling cost and growing ease of communication, especially following the introduction of fax machines and electronic mail, has made collaboration between scientists, even when separated by great distances, far easier. Furthermore, the above developments have often greatly reduced the time needed to travel or to communicate (or at least to receive a response).[20]

[20]. We noted earlier the comparative lack of research into the effect of transportation and electronic communication on collaboration. This is conceivably a reflection of how difficult it may be to disentangle the effects of such factors as more rapid transportation, decreasing long-distance telephone rates and new communication technologies (fax and electronic mail) from other contributing factors. Research in this

Thirdly, as sociologists of science and others have shown, science is a social institution where advances depend crucially on interactions with other scientists [29]. For some fields, this may entail the creation of formal collaborations, of organised and sometimes quite large teams of researchers. For others, informal links may be all that are required, perhaps in the form of 'invisible colleges' or the 'networks' which have become so popular with certain funding agencies during recent years [53, 62].

A fourth and very closely related factor has been the increasing need for specialisation within certain scientific fields, especially those where the instrumentation required is very complex [12, 18, 58]. This can be seen in its most extreme form in 'big science'. In the case of high-energy physics, in order to carry out an experiment, one needs to bring together experts in such tasks as (a) building accelerators or detectors, (b) writing the software for controlling the equipment and taking data, (c) setting up and running the accelerator during the experiment, (d) analysing the huge quantities of data produced, (e) relating the results to theory, (f) writing up and presenting the results; and (g) fund-raising, liaising with the laboratory management, managing the collaboration, and other administrative responsibilities. No single individual can perform all these specialist tasks in high-energy physics (or at least do all of them well), and a team approach is essential with a fairly formal division of labour.

Fifthly, there is the growing importance of interdisciplinary fields. It is becoming clear that some of the most significant scientific advances come about as a result of the integration or 'fusion' of previously separate fields [27]. New or emerging fields like biosensors, opto-electronics or chematronics (the fusion of chemistry, life sciences and electronics) promise results likely to form the basis of major new technologies [36]. Since few individuals possess the necessary range of skills, the only option is to bring together scientists from relevant disciplines and to forge a collaboration between them. Linked to this is the recognition that advances in certain areas of basic research are crucial for the development of new generic technologies such as biotechnology and new materials. Such research often involves

area might reap interesting findings but would probably require the development of innovative evaluation procedures.

collaboration not only across disciplinary boundaries, but also between sectors - for example, between universities and industry.

Finally, there are various political factors encouraging greater levels of collaboration among researchers. Prominent among these has been the growing integration of Western Europe in the years up to 1992 and the increasing role played by the European Commission in supporting research [43, 47]. Furthermore, just as collaboration between European scientists after the Second World War in organisations like CERN, the European Southern Observatory (ESO) and the European Molecular Biology Organisation (EMBO) was seen as one way of building stronger links between nations, so the recent political changes in Eastern Europe have resulted in calls for Western scientists to collaborate with their colleagues in the East to help bring about stronger political and cultural ties.

5. Who are the Research Collaborators?

At the most basic level, it is **people** who collaborate, not institutions. Direct co-operation between two or more researchers is the fundamental unit of collaboration. However, we often talk about collaboration at other levels - between research groups within a department, between departments within the same institution, between institutions, between sectors, and between geographical regions and countries. Indeed most policies are aimed at fostering collaboration at these higher levels rather then inter-individual collaboration.

Let us consider these other forms of collaboration. For example, two team leaders might agree to their groups focusing on a common research goal - each team bringing their collective knowledge to the problem at hand. This is an example of inter-group collaboration. Yet certain members of the two groups may not work directly with each other. Furthermore, some team members may leave during the course of the collaborative project while new ones may join. Thus, it is not always immediately obvious who is collaborating with whom.

Similarly, two or more heads of departments, institute directors or even heads of state might sign a formal memorandum-of-understanding that commits their respective departments, institutions or countries to closer co-operation on scientific matters. Again, uncertainty surrounds the concept of 'collaboration'. How closely do two departments, institutions or

countries have to work together before the activity is considered to be a collaboration? How formal does the agreement to work together have to be to constitute a 'collaboration'? For example, to qualify as an inter-institutional collaboration, does the collaboration have to be formally sanctioned by the institutions' management or is informal co-operation between individual researchers in the different institutions a satisfactory criterion? Must it involve two or more researchers working at two (or more) institutions? Or could it consist of just one researcher working part of the time at one institution and part at another?

It would seem that the more formal and intensive forms of working together of institutions are generally perceived by the scientists involved as representing a 'collaboration', while the less formal and lower-level interactions going on between institutions all the time are usually judged not to constitute a collaboration.[21] However, as with collaboration between individual scientists, we must recognise the near-impossibility of specifying where a collaboration between two or more institutions ends and the less formal interactions begin.

In addition, besides distinguishing several different levels of collaboration, we also need to recognise that collaboration can occur either **between** or **within** different levels. For simplicity, the prefixes *inter* and *intra*, respectively, have been adopted here to distinguish between these. Thus, *inter*national collaboration means collaboration between nations while *intra*-national collaboration means collaboration within a single nation.

Sometimes, however, a collaboration cannot be clearly classified since it may appear to belong to both an *intra*- and an *inter*- category. For example, consider a collaboration that involves two domestic institutions and one foreign institution. This is clearly an *inter*-institutional collaboration. However, from one perspective this collaboration constitutes an *inter*national collaboration (domestic and foreign), while from another perspective it can be considered a mixture of *inter*- and *intra*-national collaboration. Thus, we see that a collaboration can be either **homogeneous** (i.e. unambiguously either the *inter* or the *intra* form of collaboration) or **heterogeneous** (that is, a mixture of the *inter* and *intra* forms of collaboration). The need to distinguish between the two types will vary depending on the

[21]. Some empirical evidence on scientists' perceptions of collaboration comes from a survey of the authors of university-industry collaborative papers in Japan - [see 22].

problem under investigation. The various different levels of collaboration, of both the *inter* and the *intra* forms, are summarised in **Table 1** below.

{TABLE 1 about here}

6. How Can One Measure Collaboration? The Distinction Between Collaboration and Co-Authorship

The notion that a unit of collaboration can be adequately defined in terms of a multi-authored paper, and that the latter can be used to measure collaborative activity has, as we saw earlier, pervaded the literature on the subject for thirty years. Consequently, when interest emerged in the phenomenon of international collaboration [5, 15, 31, 33, 34, 43, 44, 46, 47, 50, 55], it was sometimes assumed that it could simply be equated with papers listing addresses in two (or more) countries . Similarly, studies of inter-institutional collaboration generally take as their starting point the belief that this can be measured by examining papers listing two (or more) institutional addresses. Surprisingly, there seems to have been relatively little systematic effort to assess the validity of such a bibliometric approach to the measurement of different forms of collaboration.[22] In order to pursue this analysis, it is first necessary to distinguish between collaboration and co-authorship since the two need not be synonymous. Consider the following scenarios:

(a) Two researchers work closely together but then decide to publish their results separately. One possible reason for this might be that they come from different fields, and each decides to produce a (single-author) paper for his or her disciplinary audience. Alternatively, they might just disagree over the interpretation of the findings and decide to write them up in separate papers.

(b) A second example where patterns of co-authorship and collaboration may diverge is where researchers who have not worked together in their research nevertheless decide to

[22]. Bibliometric analysis can be likened to exploring a mineral deposit for precious metals. Bibliometricians use frequency counts and other statistical tools to explore publication databases in search of relationships which can be inferred and which, they assume, may illuminate the activities of the scientific community. However, just as a gold miner must be wary of fool's gold, so a bibliometrician must be certain that the fundamental counting units are appropriate, well defined and clearly understood. This has not always been the case in relation to the measurement of collaboration.

pool their findings and write them up jointly. Examples here might include observations of an astronomical, atmospheric or oceanographic phenomenon.

Thus, in case (a), two researchers might have collaborated very intensively in all aspects of research apart from writing up the results, while for (b) there may have been no collaboration between the scientists in any of the research activities (e.g. experimental design, data-taking and so on) apart from the act of producing a joint paper. Yet a bibliometric assessment would count (b) as a collaboration but not (a). Clearly, one could argue that (a) and (b) represent atypical or rather extreme examples. However, there are countless other examples where a relatively high level of formal collaboration is not reflected in a jointly authored paper or where a fairly low level of joint work nevertheless yields a co-authored publication.

These two scenarios are by no means exhaustive. Consider a group of three collaborators - A, B and C. A and B may choose to write up one paper, while A and C may co-author another (perhaps for a different audience). In terms of co-authorship, there would then be no indication that B and C had in fact collaborated, simply because (for one reason or another) they had never appeared as joint authors on a publication. Obviously, there may be many other examples where a collaboration is not 'consummated' in the form of a joint article.[23]

For co-authorship to be a truly accurate reflection of collaboration, it would require that, in all cases where the 'level' or intensity of joint work by collaborating researchers was above a certain minimum threshold, a jointly authored paper **always** resulted (in which all the collaborators appeared as co-authors). Conversely, if the level of working together of a number of scientists was below this minimum threshold, they would **never** appear as co-authors of a publication [63]. Having expressed it in this way, one can immediately appreciate how unrealistic such a criterion would be. Therefore, co-authorship can never be more than a rather imperfect or partial indicator of research collaboration between individuals.

Besides inter-individual collaboration, international collaboration is probably the next most familiar form. Here, a similar problem arises when a bibliometric assessment is attempted. The scenarios (a) and (b) described above in relation to inter-individual collaboration might

[23]. It is as if one were attempting to measure the incidence of marriage by using as an indicator the birth certificates of children listing the couples who are the parents! Clearly, numerous marriages would not be detected with this indicator, while many other 'non-marriages' would be counted.

occur but in this case the scientists are from different countries. However, there are other possibilities specific to international collaboration. Take the following scenarios:

(c) Researchers from several countries may collaborate quite intensively, working together at a single institution. However, because all their papers list only that institution, only one country ever appears in the address given on those publications.

(d) An individual researcher has two institutional affiliations - for example, a university department and a hospital - and these institutions are located in different countries.

Here, case (c) fails to yield any papers containing addresses from more than one country, while case (d) may produce several. A bibliometric analysis would conclude that there was international collaboration involved in (d) but not (c) even though (d) centres on one individual while (c) involves several people from different countries working closely together.

Next, let us consider the bibliometric assessment of inter-institutional collaboration. The obvious starting point would again appear to be the institutional addresses given on the resulting papers. If two or more institutions in the same country are listed on a paper, can we then assume that some form of inter-institutional collaboration has taken place? Immediately, it is apparent that we are faced here with similar problems to those discussed in relation to international collaboration but this time at the institutional level. The four scenarios (a) - (d) cited above can all be reformulated in terms of different institutions rather than different nations: for instance, scenario (d) might take the following form:

(d) An individual researcher may give two addresses for example, because he/she has a joint appointment at two institutions, is on sabbatical, has a visiting fellowship or is on secondment and lists both his/her permanent address and the institution visited.

Having identified instances where co-authorship and collaboration are not necessarily equivalent, we next need to address the question of how frequently such examples of non-equivalence occur in reality. To take the last of the four examples listed above, one of the authors [26] has recently examined papers with one author but two institutional addresses. In an analysis of inter-university collaboration in the UK, Canada and Australia using data for 1981-1990 from the *Science Citation Index,* a visual inspection of randomly selected publications revealed the extent of this phenomenon. The following three examples are

derived from the 1990 Canadian data-set.[24] Each publication has only **one** author, but each publication lists **two or more** corporate addresses.

Example 1:

TI: EVALUATING PREFERENCE IN LABORATORY STUDIES OF DIET SELECTION
AU: RODGERS_AR
NA: UNIV BRITISH COLUMBIA,DEPT ZOOL,ECOL GRP/VANCOUVER V6T 2A9/BC/CANADA/
YORK UNIV,DEPT BIOL/N YORK M3J 1P3/ONTARIO/CANADA/
JN: CANADIAN JOURNAL OF ZOOLOGY-JOURNAL CANADIEN DE ZOOLOGIE 1990 VOL.68 NO.1 PP.188-190

Example 2:

TI: CLEAR-CELL CARCINOMA OF THE ANAL-CANAL - A VARIANT OF ANAL TRANSITIONAL ZONE CARCINOMA
AU: WATSON_PH
NA: UNIV MANITOBA,FAC MED,DEPT PHYSIOL/WINNIPEG R3E 0W3/MANITOBA/CANADA/
UNIV MANITOBA,DEPT PATHOL/WINNIPEG R3E 0W3/MANITOBA/CANADA/
JN: HUMAN PATHOLOGY 1990 VOL.21 NO.3 PP.350-352

Example 3:

TI: EFFECTS OF 6 DIFFERENT CYTOKINES ON LYMPHOCYTE ADHERENCE TO MICROVASCULAR ENDOTHELIUM AND INVIVO LYMPHOCYTE MIGRATION IN THE RAT
AU: ISSEKUTZ_TB
NA: ISAAK WALTON KILLAM HOSP CHILDREN,INFECT & IMMUNOL RES LAB,5850 UNIV AVE/HALIFAX B3J 3G9/NS/CANADA/
DALHOUSIE UNIV,DEPT PEDIAT/HALIFAX B3H 4H2/NS/CANADA/
DALHOUSIE UNIV,DEPT MICROBIOL/HALIFAX B3H 4H2/NS/CANADA/
JN: JOURNAL OF IMMUNOLOGY 1990 VOL.144 NO.6 PP.2140-2146

In the first example, the author listed addresses for two institutions, in the second, two departments in the same institution, and in the third, two corporate addresses in the same institution and a third in a different institution. Can these be considered as legitimate cases of inter-institutional collaboration? On the one hand, because only a single author is involved, one could argue that there is no collaboration at all. On the other, such publications may be perfectly valid institutional collaborations since they will often reflect an agreement between departments or institutions to share a researcher; the collaboration is then manifested as a publication from the 'shared' researcher listing the various institutional addresses.

In order to understand this apparent paradox, it is necessary to make a conceptual distinction between different **types** of collaboration - inter-individual, inter-institutional, international and so on - and to recognise that, say, an inter-institutional or an international collaboration need not necessarily entail an inter-individual collaboration.

[24]. The same effect is apparent in the UK and Australian data. Nor is it confined to medical research, as we shall see below.

In the same study of university collaborations in the UK, Canada and Australia, a count was made of the occurrences of (i) one-author publications listing two (or more) institutions and (ii) all publications listing more institutions than authors (which includes one-author publications listing two or more institutions). Before looking at the results, we should note that the approach inherently underestimates the number of instances of this type of inter-institutional collaboration based on a 'shared' researcher. For example, a publication may list three authors and two corporate addresses, where one author may have a joint appointment at both institutions while the remaining authors reside at only one of the institutions. In this case, the only element of inter-institutional collaboration is again the 'shared' researcher. Yet because this paper has more authors than institutions, it has not been counted in our analysis. And because the *Science Citation Index* provides no means for determining individual author-institution affiliations,[25] it is impossible to detect such cases of inter-institutional collaboration based on a shared researcher where there are other single-institution co-authors involved.

Figure 1 below shows that the number of UK, Canadian and Australian publications listing more institutions than authors represents a significant percentage of all university collaborations. For Australia and the UK, some 5-6 percent of multi-institution papers fall into this category, while for Canada the figure is 10-14 percent. The next question is whether this pattern varies across fields. To investigate this, we first categorised papers using a journal classification scheme produced by CHI Research in 1986 [37]. We found that in general the highest proportion of publications with more institutions than authors occurs in clinical medicine (40-50 percent of all papers with more institutions than authors) where many researchers apparently hold joint posts in university departments (or research laboratories) and hospitals. However, the phenomenon also occurs in other fields such as biomedical research and physics (each with 10-15 percent of the papers with more institutions than authors),

[25]. The *Science Citation Index* does not link individual authors with their institutions. If one is given a paper by three authors listing two institutions, it is impossible to know from the *SCI* data which author is affiliated with which institution. However, even if one were to analyse the original journal articles and establish which authors are linked to which institutions, this would still not get round the conceptual problem of deciding whether an inter-institutional collaboration based solely on a shared researcher represents a 'true' collaboration or not.

biology and earth and space science (5-10 percent) and chemistry, mathematics and engineering (each with less than 5 percent).

{FIGURE 1 about here}

Various other forms of research collaboration can be distinguished besides those already discussed. One type of increasing prominence is that involving collaboration between two or more institutional sectors [22] - for example, between universities and companies or government laboratories. The analyst attempting to measure this form of collaboration through the use of multi-institutional papers immediately faces similar problems to those discussed above. For example, the holder of a joint-appointment in a university and a hospital, or an academic on secondment to industry, may give both addresses. Alternatively, a postdoctoral fellow may move from a university to a government laboratory or a company and again list both institutions on his/her papers. In some cases, the appearance on a publication of two addresses in different sectors may reflect genuine inter-sectoral collaboration with the research reported in the publication being carried out at both locations. In other instances, however, this may not be the case. For example, the postdoctoral fellow mentioned above may have conducted all the research at the university and merely listed the new address for the purpose of subsequent correspondence; or the holder of the joint university-hospital appointment may do all his/her research at the university and only treat patients at the hospital. Consequently, there must again be some doubt about the reliability of using multi-address papers as an indicator of inter-sectoral collaboration.[26]

The final type of collaboration to be mentioned here is that between departments or sections within the same institution [53]. With the current enthusiasm for initiatives aimed at improving the links between scientific disciplines (for example, through the establishment of interdisciplinary research centres cross-cutting existing discipline-based departments), these collaborations are also of topical policy interest. In order to obtain empirical evidence on the

[26]. Since the problem arises from the same source as in inter-institutional papers - namely, the researcher shared between two (or more) institutions - one would expect the effect to be approximately similar in size (i.e. roughly 5-15% of multi-sector papers). However, in some cases the 'shared' researcher may be based in two institutions within the same sector (e.g. two hospitals). Consequently, the size of the effect is probably a little smaller for inter-sectoral collaboration than for inter-institutional collaboration.

extent to which such inter-departmental collaboration is taking place, the obvious starting point is the departmental addresses given on papers.

Yet what are we to make of the single author who lists two departments - is this a true example of inter-departmental collaboration? In some instances, it may be the result of a formal decision by two departments to offer a joint position to an individual - in other words, an explicit attempt to forge links between the two departments. This will not always be the case, however; the degree of inter-departmental research collaboration may be quite small, with the individual concerned conducting all of his or her research in one department and merely teaching in the other. Hence, the analysis of departmental addresses listed on papers may not always give an accurate picture of inter-departmental collaboration.

7. What are the Benefits and Costs of Collaboration?

We have seen how various professional, economic, social and political factors encourage collaboration. But what are the benefits to individual collaborators? And what are the costs?

Modern research is increasingly complex and demands an ever widening range of skills. Often, no single individual will possess all the knowledge, skills and techniques required. In principle, he/she might be able to learn or acquire, say, all the techniques needed to solve a particular problem, but this can be very time-consuming. If two or more researchers collaborate, there is a greater probability that between them they will possess the necessary range of techniques. The first type of benefit from collaboration is therefore the **sharing** of knowledge, skills and techniques. In collaborations, there may be a fairly formal division of labour. For example, one person may be good at constructing, operating and maintaining scientific instrumentation and another at analysing the data produced. Collaboration thus ensures a more effective use of their talents.

A second and closely related type of benefit is the **transfer** of knowledge or skills. As noted earlier, it can be time-consuming for an individual to update their knowledge or to retrain. Furthermore, not all the details concerning new advances are necessarily documented. Much of the knowledge may be tacit [9, 56] and remains so until researchers have had the time to deliberate and set out their findings in a publication. Frequently, considerable time elapses

before the knowledge appears in written form. Collaboration is one way of transferring new knowledge, especially tacit knowledge. Furthermore, research requires not only scientific and technical expertise, but also the social and management skills needed to work as part of a team. These cannot be readily taught in the classroom - they are best learned 'on the job' by engaging graduate students or young postdoctoral researchers in collaborative activities.

Thirdly, collaboration may bring about a clash of views, a cross-fertilisation of ideas which may in turn generate new insights or perspectives that individuals, working on their own, would not have grasped (or grasped as quickly) [23, 45]. The act of collaborating may thus be a source of stimulation and creativity. Hence, collaboration is greater than the sum of its parts. Such benefits are likely to be largest when the collaboration involves partners from more divergent scientific backgrounds. However, the difficulties in working productively together may then be greater. This is one of the 'costs' of collaboration discussed below.

A fourth type of benefit is that collaboration provides intellectual companionship. Research can be a lonely occupation, probing the frontiers of knowledge where few, if any, investigators have been before. An individual can partly overcome that intellectual isolation through collaborating with others, forming working and perhaps also personal relationships with them.

Moreover, the benefits of working with others are not confined to the links with one's immediate collaborators. Collaboration also has the effect of 'plugging' the researcher into a wider network of contacts in the scientific community. An individual researcher may have good contacts with 50 or 100 other researchers in his or her field around the world whom he/she can contact for information or advice. By collaborating with others in another institution or country, the individual can greatly extend that network.

In addition, collaboration can enhance the potential visibility of the work. Using their network of contacts, one's collaborators can diffuse the findings, either formally (e.g. through pre-prints, seminars or conference presentations) or through informal discussions. Together, collaborators are likely to arrive at a more informed decision as to the best journal in which to publish the results (or the one most likely to accept the paper). Once published, the paper may be picked up in library searches by scanning for work produced by any of the collaborating

authors, multiplying the chance that it will be located and used by others. On average, it is therefore likely to be cited more frequently and to have greater impact.

The result of all these benefits from collaboration is that research can, in principle, be carried out more effectively. However, collaboration also entails certain costs. These can take a variety of forms. Firstly, in financial terms, although collaboration may result in savings for research funding agencies, it nevertheless entails some additional costs. For inter-institutional, inter-sectoral and international collaborations, travel and subsistence costs are incurred as researchers move from one location to another. Equipment and material may also have to be transported. Once moved, the instrumentation may need to be carefully set up again, perhaps requiring the assistance of technicians from the original institution, incurring further costs.

Secondly, collaboration brings certain costs in terms of time. Indeed, for many researchers, these may be more important since time is now in certain respects a more valuable resource than funding.[27] Time may have to be spent in preparing a joint proposal or securing joint funds from two or more sponsors, and in jointly defining the research problems and planning the approach. Different parts of the research may be carried out at different locations, again introducing time costs. Time must be spent keeping all the collaborators fully informed of progress as well as deciding who is to do what next. Differences of opinion are almost inevitable and time will be needed to resolve these amicably. Writing up results jointly may also take more time where there are disagreements over the findings and their significance, or over who should be included among the co-authors and in what order they should be listed. Moreover, besides these direct time costs, there are also such indirect time costs as recovering from the effects of travel (e.g. 'jet lag'), working in an unfamiliar environment, and developing new working and personal relationships with one's collaborators.

Thirdly, collaboration brings certain costs in terms of increased administration. With more people and perhaps several institutions involved, greater effort is required to manage the research. If the collaboration is large or spans a considerable distance, it might need more

27. In interviews with 120 scientists and engineers working in British university departments, the availability of time to conduct research was ranked as the second most important factor determining the research performance of departments, after the calibre of the staff but some way ahead of funding [see 38].

formal management procedures which may create problems of bureaucracy. Even when this is not the case, when difficulties arise, they may nevertheless be blamed on 'bureaucracy' and foster a sense of grievance against other collaborators which needs to be sorted out by the project management. A more formal management structure may also stifle the creativity of the researchers, offsetting the benefits of cross-fertilisation outlined above.

Furthermore, where two or more institutions are collaborating, there is often the problem of reconciling different management cultures, financial systems, rules on intellectual property rights and so on. There may also be differences over reward systems, promotion criteria and time-scales, and even a more general clash of values over what is the most important research to pursue, how to carry it out, or over commercial or ethical implications. All these potential differences need to be reconciled if serious problems are not to disrupt the collaboration.

In short, collaboration in research brings significant costs as well as undoubted benefits.

8. Conclusions

Although there have been many studies of collaboration, little has been published on what exactly is meant by the concept of 'collaboration' nor on the adequacy of attempting to measure it through co-authorship. Likewise, little consideration has been given to distinguishing different forms of collaboration nor to analysing the additional costs it entails.

Our analysis shows that collaboration is very difficult to define. Partly, this is because the notion of a research 'collaboration' is largely a matter of social convention among scientists. There is little consensus on where other, less formal links between scientists 'end' and collaboration 'begins'. What some might deem a 'collaboration', others may merely regard as a loose grouping or a set of informal links. What constitutes a collaboration therefore varies across institutions, fields, sectors and countries, and very probably changes over time as well.

Among the factors which motivate collaboration are funding agencies' need to save money, the growing availability and falling (real) cost of transport and communication, the desire for intellectual interactions with other scientists, the need for a division of labour in more specialised or capital-intensive areas of science, the requirements of interdisciplinary research, and government encouragement of international and cross-sectoral collaboration.

As we have seen, collaboration can occur at several levels and one needs to distinguish carefully between these. The various forms include collaboration between individuals, groups, departments, institutions, sectors and countries. Definitions of these higher levels of collaboration are no easier to arrive at than for inter-individual collaboration. Yet it is important to make this distinction between the different levels because an inter-institutional or international collaboration may not necessarily entail an inter-individual collaboration.

Collaboration is conventionally measured through multi-author or multi-address papers. Such an indicator must be treated with caution. There are many cases of collaboration that are not 'consummated' in a co-authored paper and which are consequently undetectable with this approach. Conversely, there are other cases of, at best, only very peripheral or indirect forms of interaction between scientists which nonetheless yield co-authored publications. Co-authorship is only a rather approximate partial indicator of collaboration.

In addition, there is a conceptual problem with the one-author, two-institution paper. No inter-individual collaboration is involved, but is this still an inter-institutional collaboration? Our empirical investigation of the multi-institutional author shows that the phenomenon is not uncommon. At a national level, at least 5-15 percent of collaborative papers seem to involve this form of 'collaboration'. In the light of this 'shared researcher' phenomenon, the only solution would appear to be to distinguish inter-institutional collaboration from inter-individual collaboration and to recognise that the former need not always involve the latter.

Finally, we identified the main types of benefit from collaboration and the associated costs. Some costs are financial, others more to do with the time requirements, the management of the collaboration, and with reconciling different cultures and value systems of researchers. When considering collaboration, researchers, funding agencies and policy-makers have often previously tended to see only the benefits and consequently to view collaboration as 'a good thing' that should be universally encouraged. In future, we would argue, a more symmetrical approach should be adopted to assessing the potential costs and benefits. We must recognise that, in some circumstances, the costs may very well outweigh the benefits. Unfortunately, at present there is no means of systematically appraising all the costs and benefits of collaboration, and therefore no way of establishing whether the benefits do actually outweigh

the costs. Nevertheless, policies for science which assume, explicitly or implicitly, that more collaboration should be encouraged need to be re-examined.

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FIGURE 1

Percentage of university publications in *SCI* listing more institutions than authors

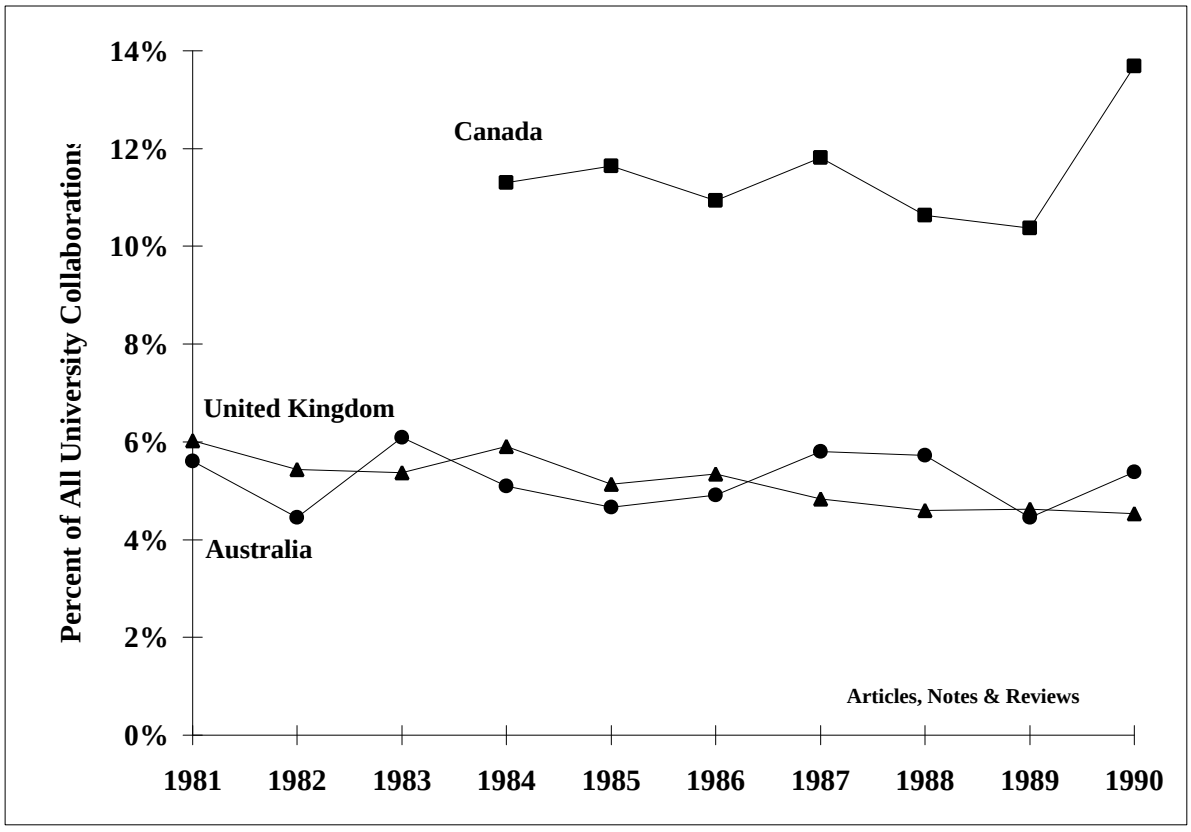

TABLE 1

Different Levels of Collaboration and Distinction between *Inter* and *Intra* Forms

	Intra	Inter
Individual	-	Between individuals
Group	Between individuals in the same research group	Between groups (e.g. in the same department)
Department	Between individuals or groups in the same department	Between departments (in the same institution)
Institution	Between individuals or departments in the same institution	Between institutions
Sector	Between institutions in the same sector	Between institutions in different sectors
Nation	Between institutions in the same country	Between institutions in different countries