Bibliometric Assessment of Intranational University-University Collaboration

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Finally, I would like to extend loving thanks to my father who was always available via electronic mail to answer questions concerning mathematical techniques and to entertain philosophical discussions on the nature of science and technology.
I hereby declare that this thesis has not been submitted, either in the same or different form, to this or any other University for a degree.

Signature:
Abstract

The objective of this thesis was to perform a bibliometric assessment of *intranational* (i.e. within a single country) university-university collaboration within the United Kingdom, Canada and Australia. Innovative methodologies combined with conventional bibliometric techniques, previously used in the evaluation of international collaboration, elucidate the collaborative patterns and trends within the university community.

A reasonable amount of bibliometric analysis has been done on scientific collaboration at the international level and within networks of researchers working in a select specialty. However, little, if any, bibliometric research has been performed on *intranational* institutional collaboration, in particular, university-university collaboration. This is indeed curious since most nations likely spend significantly more on scientific research and development in institutions of higher learning than on international scientific activity.

This bibliometric assessment analysed corporate addresses from articles, notes and reviews recorded in the *Science Citation Index* which were published by UK and Australian universities between 1981 and 1990 and Canadian universities between 1984 and 1990. The analytical processes involves three steps. First, the university addresses are unified and a science field is assigned to each publication. Secondly, the unified data is used to produce a publication matrix for each of eight science areas and the combination of all these areas for each year. Finally, the publication matrices are algebraically manipulated to produce co-occurrence collaboration matrices.

The unified data is employed to measure the annual national and university scientific output and the total number of university collaborations. The collaboration matrices are used to derive yearly counts of the university-university collaborations in each science field. Also, the matrices are used as input into a software package which produces geographic maps displaying above average collaboration linkages. These maps can be dynamically cycled which assists viewers to visualise how collaborative activity has been changing with time in each university community.

Some trends found in international collaboration are seen in *intranational* university-university collaboration. Notably, an increase in academic staff produces a proportionately larger increase in scientific output. However, an increase in scientific output produces a proportionately smaller increase in university-university collaborations. In contrast to international collaboration, the frequency of collaboration in basic science areas is similar to that observed in applied science areas. As a matter of fact, evidence is presented that suggests it may be inappropriate to classify generic areas of science as basic or applied.

Certain *intranational* collaboration characteristics are examined that have not been investigated at the international level. For example, this research shows that collaborations occur most frequently between geographically close partners and the frequency of collaboration decreases exponentially with the collaboration distance. Over the decade there has been a tendency for the distance to decrease in the UK and Australia and increase in Canada. Also, a new analytical technique reveals that over the decade collaborative activity in the UK and Canada has tended to concentrate in fewer universities where as the distribution has become more even among Australian universities.
Introduction

A central ritual common to this group [molecular biologists] is called the 'Collaboration Dance'. It may be performed by as few as two members or as many as 15 participants. When large groups perform the dance a well defined hierarchy exists, sometimes distinguishable from division of labour during the dance, but most often revealed at the close of the dance when a paper is written with the order of authors usually reflecting the hierarchy. Sometimes the order is alphabetical; however, experienced dance members often change their names so as to assure first position on such manuscript. Occasionally this ordering process is equal in time to the dance itself. The dance unfolds with a preliminary gathering of participants. There is a ritualistic exchange of refreshments such as tea or coffee. Some groups share cookies or smoke together. During the early process participants pay homage to one another through verbal exchange of compliments regarding past achievement while carefully circling each other gracefully, occasionally making eye contact. The major part of the dance consists of each member performing a task in full view of all participants or privately.

[Excerpt from a letter from Jane Goodall to Louis Leakey about 'a tribe called Molecular Biologists' Source: The Race to Synthesis a Human Gene London, Sidgewick and Jackson (1988) p 224]
The objective of this thesis has been to perform a bibliometric assessment of *intranational* (i.e. within a single country) university-university collaboration within the United Kingdom, Canada and Australia in order to determine if the patterns and trends of collaboration differ from those found at the international level.

The investigation of collaboration has been a research theme in science and technology studies for at least four decades. Underlying many of these explorations is a fundamental belief that collaborative activity is intrinsically 'good' and that this inherent value benefits individual scientists and engineers as well as institutions and nations.

There are two main types of collaboration studies. The first uses predominantly quantitative techniques to measure and map collaborative activity. For example, bibliometric methods are commonly utilised to measure the level of collaboration by counting co-authored scientific publications. De Solla Price (1963) first popularised this method in his seminal publication, *Little Science Big Science*. Mapping also involves bibliometrics but, in addition, it uses other analytical tools to construct 'maps' that display the intensity of collaborative links between co-authors. Measuring and mapping methods have also been employed to explore collaborative activity between research groups, institutions, nations and more recently sectors of the economy. The second type of study uses primarily qualitative methods to investigate factors and mechanisms that motivate collaboration. Research in this area typically involves interview-based studies designed to uncover reasons that stimulate collaborators to work together. In some instances, collaboration maps derived from bibliometric techniques may be used as a focus for investigating social, economic, political and other motivational factors which underlie collaborative activity.
Most bibliometric analyses of scientific research collaboration have centred on activity at the international level and within research specialties. Little, if any, bibliometric research has been done on *intranational* collaboration, in particular, university-university collaboration with in a single country. This is rather curious for two reasons. Firstly, most nations spend significantly more on scientific research and development internally than on international scientific activity. Yet there have been numerous investigations of international collaboration and very few on domestic collaboration. Whether this has occurred merely by chance or has been driven by curiosity about such things as the globalisation of science is unclear. Secondly, many countries have introduced programmes to encourage university-industry and university-university collaboration so as to promote better use of facilities and scientific labour, stimulate interdisciplinary research and facilitate the transfer of knowledge. However, the use of bibliometrics or indeed any empirical information to analyse national collaborative activity and to look for the effects of such programmes has been almost non-existent.

If research on *intranational* collaboration is so limited, what information, if any, was used by policy makers when they formulated their *intranational* collaboration programmes? Did they intuitively feel that the collaborative patterns and trends which occur at the international level also apply at the level of the nation? It was questions like these that motivated this research project.

1.1 **The Research Question**

This thesis explores the following question:

Does *intranational* scientific research collaboration exhibit the same patterns and trends as international scientific research collaboration?
This general question is actually composed of a number of sub-questions, the origin of which will become clearer when we examine the research that has been carried out previously on international collaboration. Even though background information on international collaboration has not yet been presented, it is worth mentioning these questions so they can be kept in mind as the discussion proceeds. Generally stated, the questions are:

a. Can a bibliometric methodology similar to the one used to investigate international collaboration be developed to analyse *intranational* collaboration?

b. Do a greater proportion of *intranational* collaborative papers occur in basic than in applied scientific research?

c. What is the relationship between a university's scientific output and the level of university-university collaboration?

d. Do larger universities collaborate less with other universities than smaller universities?

e. Is *intranational* university-university collaboration influenced by geographical proximity?

f. Have national policies which encourage *intranational* collaboration had any impact on the level of university-university collaboration?

The general bibliometric method that was used involved analysing corporate addresses from articles, notes and reviews recorded in the *Science Citation Index* and published by UK and Australian universities between 1981 and 1990 and by Canadian universities between 1984 and 1990. A university-university collaborative publication was defined as any publication in which two or more domestic university names appeared in the corporate address field.

Three basic steps were involved in the analysis process. First, university addresses were unified to eliminate data-entry errors and to assign

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1In the methodology chapter it will be argued that counting these publication types is a good method to account for the published scientific output.
standardised names to individual universities. Also, a science field was assigned to each publication to facilitate evaluation of collaboration by discipline. Second, the unified data were used to produce a publication matrix (publication x university) for each of the eight science areas (physics, chemistry, mathematics, clinical medicine, biomedical research, biology, earth and space sciences, and engineering and technology) and the combination of all these areas for each year. Finally, the publication matrices were algebraically manipulated to produce co-occurrence collaboration matrices (university x university) tabulating the number of collaborations that occurred between pairs of universities.

The unified database was employed to measure the annual national scientific output, university scientific output and the total number of university collaborations. The collaboration matrices were used to derive yearly counts of the university-university collaborations in each science field. Also, the matrices were used as input into a software package which produced geographic maps displaying stronger than average collaboration links. These maps can be rapidly 'cycled' to assist the viewer in visualising how collaborative activity in each university community has changed over time.

1.2 Thesis Structure

The thesis is organised into two parts: the analytical framework, and bibliometric findings and discussion.

Part one, the analytical framework, which is composed of chapters two to five, presents relevant definitions, discusses previous research findings, provides historical and structural information on the university communities in each country and details the methodology used to perform the bibliometric assessment of intranational university-university collaboration.
Chapter 2, on research collaboration, explores the notion of a research collaboration and discusses some of its more problematic properties which make it difficult to assess. The chapter poses five questions and outlines some general issues that surround these questions. The five questions addressed are: (1) what is a research collaboration? (2) what motivates collaboration? (3) who are the collaborators? (4) how do you measure collaborative activity? and (5) what is the value of collaborating? The function of the chapter is not to answer the questions but rather to show that the idea of a collaboration is not as simple as one might have thought and requires further consideration.

Chapter 3, on previous work, provides an overview of the research work that has been published on collaboration. It is composed of two sections: general findings and international collaboration. The first gives an overview of the nature and dynamics of collaboration while the second concentrates on the findings from, and techniques used in, the bibliometric assessment of international collaboration. It is in this section that the background for each of the previously posed research questions is covered and as well certain other key issues.

Chapter 4, on the university community, provides background and contextual information on each national university community. There are three sections: national context; the university community; and a comparison of national science activity. First, some of the general economic and statistical indicators for each country are compared to illustrate similarities and differences between the three countries. Next, the historical evolution of the university community in each country, the inter-university organisational structure and the mechanisms through which public funds for scientific research are delivered to the universities are described. Finally, a brief comparison is made of each country's national scientific activity using various statistics and bibliometric indicators.
Chapter 5, on methodology, is devoted to a detailed presentation of the bibliometric methodologies used in this research. There are five sections which examine in turn the computing resources and software used in the analysis; the nature of the data-sets and the methods employed to unify\(^2\) them; the manner in which collaborations were counted; the mathematical techniques utilised to construct various matrices and indicators; and the prototype procedure used to produce collaboration maps.

Part two, on bibliometric findings and discussion, which is composed of chapter six to eight, contains the findings and discussion of the bibliometric assessment of intranational university-university collaboration.

Chapter 6, on scientific output, examines the national scientific output of the three countries, their university scientific output and the relationship between university size and university scientific output using the number of published scientific research papers as a measure of scientific activity. The scientific outputs will be used as baseline statistics in subsequent chapters.

Chapter 7, on university collaboration, is composed of five sections each of which investigates collaboration in the university community from a different perspective. The first looks at the overall level of collaboration in the university community without regard for the type of collaborative partner. Also, the nature of an institutional collaboration is examined more closely. The second section analyses institutional collaboration as it relates to the number of authors and the number of institutions that are listed on a publication. The third section focuses on the growth of university-university publications. The fourth examines the

\(^2\)Data-entry errors may occur when publication information is entered into the Science Citation Index database. Furthermore, sometimes the author(s) may inadvertently spell the name of an institution wrong or forget to enter the name of the city or country in which the institution resides. The process of cleaning up these errors and assigning standardised institution names is called unification and will be discussed in the methodology chapter.
level of collaboration in each science area from four different perspectives: an inter-country comparison of collaboration in basic and applied science fields, an intranational comparison of collaboration by science field, an examination of the relationship between university published scientific output and university-university collaborative activity and an analysis of the effect of geographical proximity on collaboration. The fifth section uses a vector analysis technique to show how the distribution of collaborations in each university community has changed with time.

Chapter 8, on the collaboration maps, investigates a prototype mapping technique which is used to visualise how university-university collaborative links within each university community change over time. First, an explanation is given of how to display and interpret the maps. Next, three sets of collaboration maps are investigated in detail to illustrate typical patterns of collaboration that have been identified in the three countries. (A complete description of all the collaborative maps is presented in the appendix.) Finally, a comparison of the collaborative networks in each science field is made to illustrate the similarities and differences across the three countries.

The last chapter summarises the conclusions. Here, the research questions that were posed in the introduction, previous work and the university community chapters are answered. The chapter concludes with a section examining the wider policy implications of the findings from this bibliometric assessment of intranational university-university collaboration in the UK, Canada and Australia.
Part One

Analytical Framework

*Universities*, in its primitive sense, merely signifies "association", "corporation." "In the language of civil law", observes Malden, "all corporations were called *universitates*, as forming one whole out of many individuals.

The universities then, at their origin, were merely academic associations, analogous, as societies of mutual guaranty, to the corporations of workingmen, the commercial leagues, the trade guilds which were playing so great a part at the same epoch; analogous also, by the privileges granted to them, to municipal associations and political communities which date from the same time.

Research Collaboration

Over recent years, there has been increasing interest among the scientific community and within science policy circles about the notion of research collaborations. It is assumed that collaboration is 'a good thing' and that it should be encouraged. Numerous initiatives have been aimed at developing collaboration among individual scientists - bringing them together, for instance, in new or larger centres of excellence. There have also been policies aimed at improving the links between science and technology through fostering research collaboration across sectors - in particular, between universities and companies. Furthermore, most governments have been keen to increase the level of international collaboration engaged in by the scientists they support.

Implicit in all this enthusiasm for research collaboration and in policies aimed at furthering 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, institutions, sectors or nations; (3) that we can in some way measure the level of collaboration and hence determine whether it is actually increasing as a result of a particular policy; and (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 all these rather fundamental assumptions?

The function of this chapter is not to provide an answer to this question but rather to show that the idea of a collaboration is not so simple obvious and requires further thought. We will investigate five questions: (1) what is a research collaboration? (2) what motivates collaboration? (3) who are the collaborators? (4) how do you measure collaborative activity? and (5) what is the value of collaborating? Each question will be examined briefly and without reference to the research literature published in the area. The objective is to stimulate thought and achieve some conceptual clarity. A detailed review of relevant literature will be presented in the next chapter.

2.1 **What is a Research Collaboration?**

The dictionary definition of collaboration suggests the working together of researchers to fulfil a common goal - in this case, the task of producing new scientific knowledge. However, this begs the question of exactly how closely they have to work together in order to constitute a 'collaboration'. At one extreme, it could be argued that the whole scientific community is one big research collaboration - that science is a truly global activity where, in a sense, all scientists work together to further scientific knowledge. They exchange ideas on what experiments to do next, what theoretical ideas 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 offer information in return).

In seeking a definition for research collaboration, one possibility would be to include anyone providing an input to a particular piece of research as a
collaborator. However, this weak definition of collaboration would bring in such large numbers of collaborators that it be too unwieldy for practical purposes. At the other extreme, one could formulate a strong definition according to which only those scientists who contributed to all the various research tasks jointly over the duration of the project would be counted as collaborators. This immediately runs into problems because, for example, no single individual could possess all the knowledge required to contribute to all the facets of a high-energy physics experiment - the building of the detectors, the writing of specialised software to control the instrumentation, analysis of the results, and so on. 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 they had worked on a single task (e.g. detector construction), or at least only a few of the 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. It excludes those who make only an occasional or relatively small contribution to a piece of research. Yet it may include some who are not necessarily involved in all aspects of the research - who may, for example, have built the detector in a particle physics experiment but not participated in any of the other activities.

A research collaboration therefore has a very 'fuzzy' or ill-defined border. Exactly where that border is drawn is a matter of convention [or alternatively, is open to negotiation], and perceptions regarding the precise location of the 'edge' of the collaboration may vary across fields, countries and sectors (e.g. universities, industry), as well as over time.
2.2 **What Motivates Collaboration?**

There are several reasons why there has been a growing interest in the phenomenon of research collaboration over the last decade or so. One of the most obvious is the escalating costs of conducting fundamental science at the research frontier. In many fields, scientific instrumentation costs have jumped appreciably as successive generations of technology have been introduced. As a consequence, it has often become impossible to provide the necessary research facilities to all the individual research groups working in the area. Resources have had to be pooled, either at a regional, national or (in the most expensive cases) international level, and the researchers involved have consequently 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 much cheaper in relative terms than in the 1950s (when a journey by sea 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 more attractive.

Thirdly, as a result of the efforts of sociologists of science and others, it is now widely recognised that modern science is a social process, where advances depend crucially on interactions with other scientists. 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 it required, perhaps in the form of the 'networks' which became so popular during the 1980s.
A fourth and very closely related factor has been the increasing requirement for specialisation within certain scientific fields, especially those where the instrumentation required is very complex. 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 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 do all these tasks (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 significant research advances come as a result of the integration or 'fusion' of previously largely separate fields. 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 new technologies. Since few individuals possess the necessary range of skills, the task becomes one of bringing together scientists from relevant disciplines and forging a collaboration between them.

A sixth and intimately related factor is the recognition that advances in certain areas of basic research are crucial for the development of new generic technologies such as biotechnology, new materials, and information and communication technology. Such research often involves collaboration across disciplinary boundaries, and may also require collaboration between universities and industry.
Finally, there are various political factors encouraging greater levels of collaboration among researchers. Principal among these has been the growing integration of Western Europe as it moves towards 1992 and the more prominent role being played by the European Commission in supporting research. Furthermore, just as collaboration between European scientists after the Second World War in organisations like CERN, ESO and EMBO was seen as one way of building stronger links between nations, so the recent political changes in Eastern Europe are likely to result in calls for Western scientists to collaborate with their colleagues in the East to help bring about stronger political and cultural ties.

2.3 Who are the Research Collaborators?

Cooperative activity between two or more scientists is a fundamental form of collaboration. Yet, it is possible that two team leaders might agree to encourage their teams to focus on a common research goal - each team bringing its collective knowledge to the problem at hand, even though some team members may leave while new ones join. This is an example of team collaboration. Similarly, two or more head of departments, institute directors or even heads of state might develop a formal memorandum-of-understanding that commits their respective departments, institutions or countries to closer cooperation on scientific matters. Thus we see that one must clearly identify the collaborators in order to properly investigate collaborative activity.

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 interaction have to be to constitute a ‘collaboration’? For example, to qualify as a valid institutional collaboration, does the collaboration have to be formally sanctioned
by the institutions' management or is informal cooperation between individual researchers a satisfactory criterion? Must it involve two or more researchers working at two (or more) institutions, or can it consist of just one researcher working at two institutions?

The more formal and intensive interactions between scientists are generally perceived by the scientists involved as representing a research collaboration, and the less formal and lower-level interactions going on between scientists all the time are usually judged not to constitute a collaboration. However, again we must recognise the near-impossibility of specifying where collaboration ends and the less formal interactions begin, but nevertheless this appears to be a useful distinction.

In addition, several different types or levels of collaboration need to be separated. These include collaboration between individual scientists, between departments or groups within the same institution, between institutions, between sectors and between countries. Collaboration can occur between or within different levels, and for simplicity, the prefixes inter and intra, respectively, have been adopted in what follows to specify these. Thus, international collaboration means collaboration between nations while intranational collaboration means a collaboration within a nation. Similarly, interdepartmental collaboration implies a collaboration between departments while intradepartmental collaboration suggests a collaboration within a department.

Sometimes a collaboration cannot be clearly classified and 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 interinstitutional collaboration. However, from one perspective this collaboration is considered to be an international collaboration.
(domestic and foreign), while from another perspective, it can be considered a mixture of inter- and intranational collaboration. In other words, a collaboration can be homogeneous or heterogeneous and the need to distinguish between the two types will vary depending on problem under investigation.

2.4 How Can You Measure Collaboration?

The notion that a unit of collaboration can be adequately defined in terms of a multi-authored paper (to be discussed in chapter 3), and that the latter can be used to bibliometrically measure collaborative activity has pervaded the literature on the subject for thirty years. Furthermore, when interest emerged in the phenomenon of international collaboration, it was simply assumed that it could be equated with papers listing addresses in two (or more) countries. Similarly, studies of inter-institutional collaboration generally took as their starting point the belief that this could be measured by examining papers listing two (or more) 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. 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 accurate, well defined and clearly understood. As we shall see, this has not always been the case in relation to the measurement of collaboration. Hence, it is frequently necessary to distinguish between
collaboration and co-authorship since the two need not be synonymous. Consider the following two examples.

(a) Two scientists work closely together but then decide to publish their results separately. One possible reason for this might be that they came 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 type of situation where patterns of co-authorship and collaboration may diverge is where scientists who have not worked together in the course of their research nevertheless decide to pool their findings and write them up jointly. Possible examples here include observations of a particular oceanographic, atmospheric or astronomical phenomenon.

Thus, in the case of (a), two or more scientists could 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 a joint paper. Yet, a bibliometric assessment would count (b) as a collaboration while (a) would not. Clearly, one could argue that (a) and (b) represent atypical or rather extreme examples. However, there will be 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 interaction nevertheless yields a co-authored publication.

The above two examples are not by any means exhaustive. Another case where patterns of collaboration would not be reflected in co-authorship might involve a group of three collaborating researchers - A, B and C. A and B may choose to write up one paper, while A and C may co-author another article (perhaps for a different audience). In terms of co-authorship, there would 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 'consumated' in the form of a joint article.

For co-authorship to be a truly accurate reflection of collaboration, it would require that in all cases where the 'level' or intensity of interaction between 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 interaction between a number of scientists was below this minimum threshold, they would never appear as co-authors of a publication. Having expressed it in this way, one can immediately appreciate how unrealistic such a criterion would be.

A similar problem arises when a bibliometric assessment of international collaboration is performed. The two situations mentioned above in relation to inter-individual collaboration might occur but in this case the scientists are from different countries. The collaborators may (a) work closely in all stages of their research but decide to write the results up in separate papers in their own country; or (b) carry out their research separately but decide to pool their results in a joint publication. However, there are other possibilities that are specific to international collaboration. Consider the following examples:

(c) Scientists from several countries may collaborate by working together at a single institution, with the result that only one country ever appears in the address given for their publications.

(d) An individual scientist may give two institutional affiliations on his or her papers - for example, a university department and a hospital or a research centre; if these institutions are located in different countries, this will appear (in a bibliometric analysis) to represent an international collaboration.
We are faced with essentially the same problems when performing a bibliometric assessment of inter-institutional collaboration. The obvious starting point is the institutional addresses given on 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, however, it is apparent that we are faced with similar problems to those discussed in the international collaboration but at the institutional level. The four examples cited above can be rephrased as follows: (a) researchers at two institutions may collaborate very closely but elect to write up their results separately; (b) researchers at two institutions may not collaborate at all in the course of their research, but pool their results to produce a joint paper; (c) researchers from several universities may work at a central research facility and give only that single address on their papers; and (d) an individual researcher may give two (or more) addresses for example, because the researcher has a joint appointment at two universities, is on sabbatical, has a visiting fellowship or is on temporary secondment and lists both his/her permanent address and the institution visited.

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 sectors - for example, between universities, companies and perhaps 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 any papers. In some cases, the appearance of two addresses on a publication may reflect genuine
inter-sectoral collaboration with the research reported in the publication being carried out in 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 intersectoral collaboration.

The final type of collaboration to be mentioned here is that between departments or sections within the same institution. With the current vogue 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 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 author who cites 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 their research in one department and merely teaching in the other.
2.5 What is the Value of Collaboration?

Previously we outlined some possible reasons why collaboration occurs and suggested a few professional, economic, social and political factors which encourage its occurrence. These factors provide the impetus for collaboration but are there any advantages to collaborations?

One possible benefit is knowledge transfer. It is costly for an individual to seek to upgrade or retrain within a science field or in an adjacent but related field. Furthermore, all the details concerning new advances are not necessarily documented. Much of the knowledge acquired by researchers is tacit and remains so until researchers have had the time to deliberate about the ramifications of their findings. Frequently, a significant passage of time is required before the knowledge exists in written form. Collaboration is one way to transfer new knowledge, especially tacit knowledge, to an individual, or even an institution, while participating in the advancement of science without incurring a discontinuity in research productivity for retraining.

Just as social isolation can lead to psychological despondency, so professional isolation may lead to intellectual despondency. When a researcher probes the frontiers of knowledge, by definition few, if any, investigators have investigated before. The process of giving an intuitive insight into a cognitive notion can be a lonely journey. This intellectual isolation which may be partly ameliorated through collaborative discussions and research inquiries with other researchers.

As already mentioned, a great deal of today's research involves teamwork which entails a set of social and management skills. These cannot be readily taught in the classroom - they are best learned 'on the job'. Perhaps, one of the most efficient ways of teaching graduate students such skills is to engage them in collaborative activities.
Finally, the old adage that ‘two minds are better than one’ suggests the idea that economies of time can be gained through cooperation. There is little doubt that some people can master all the techniques that are required to solve a particular problem. However, before the learning process can begin, the researcher has first to be familiar with the fact that the necessary techniques exist. Acquiring this knowledge may perhaps be as time-consuming as learning the methodologies. There is a greater probability that the collective knowledge of two or more researchers can reduce the time required both to learn of the existence of a technique and to master it. It is even possible that one of the collaborators may have already mastered the missing tool.

2.6 Summary

A number of conclusions can be drawn from the previous analysis. The first is that the concept of collaboration is problematic. We have seen how it is extremely difficult to define 'collaboration' in practical terms. Part of the problem is that the notion of a research collaboration is largely a matter of social convention among scientists. What some might deem a 'collaboration', others might merely regard as a loose grouping, a set of informal links, or perhaps a 'network'. As a result, what constitutes a collaboration will vary across fields, sectors and countries, and very probably changes over time as well.

Secondly, it is clear that one must distinguish carefully between different types of collaboration. These include collaboration between individuals, between departments (within a single institution), between institutions, between sectors and between countries. One reason for making this distinction is that a collaboration between two institutions or two countries may actually involve only a single researcher. In other words, an inter-institutional collaboration or an
international collaboration may not necessarily involve an inter-individual collaboration.

A third conclusion is that the measurement of collaboration through the analysis of multi-author or multi-address papers must be treated with some caution. Such an approach is likely to bring in some instances of non-collaboration, but also to exclude possibly quite a few collaborations that never yield a jointly-authored paper. Co-authorship is, therefore, only a rather approximate indicator of collaboration.

Fourthly, the incentives that motivates collaboration are varied. Economic pressures, increased mobility, social processes, specialisation and political forces all contribute to encourage collaborative activity.

Finally, among other things, the rate of knowledge transfer, the reduction of intellectual isolation, the acquisition of team-building skills and increased time efficiency may be recognised by the individual, institution or nation as a valuable by-product of collaboration.

The next chapter examines previously published research on collaboration where some of the material presented in this chapter will be investigated in greater detail.
Previous Work

Very little, if any, bibliometric research appears to have been carried out on *intranational* collaboration, in particular university-university collaboration within a single country. However, a great deal has been published on multiple-authorship and its relationship to collaboration, the quality and value of collaboration, the social dimension of collaboration and *international* collaboration activity. These investigations, particularly those focusing on international collaborations, will provide the context within which the research findings from this project will be examined and compared.

This chapter is composed to two sections: general findings and international collaboration. The first section gives a broad picture of the nature and dynamics of collaboration and examines such issues as the validity of using bibliometric techniques to assess collaborations; the factors which promote collaborations; general notions on the relationship between collaboration, on the one hand, and personal productivity and research quality, on the other; the role of communication and geographical distance in collaborative activity; and mapping collaborative networks in groups. The second section concentrates on the findings from, and techniques used in, the bibliometric assessment of international collaboration. Specifically, this section examines how international collaboration differs between basic and applied research, how the scientific size
of a country effects its level of collaborative activity, the role of geographical and
sociopolitical factors on collaboration and the effects of government policy. In
addition, specific questions are posed concerning the nature of *intranational*
university-university collaborative activity which are to be investigated later.

3.1 **General Findings**

3.1.1 **Multiple-Authorship and Collaboration**

For decades the multiple-author publication, frequently referred to as a
coauthored publication, have been used as a basic counting unit to measure
collaboration activity unobtrusively. Smith (1958) was one of the first
researchers to notice an increase in the incidence of multiple-author papers in
his study of psychology\(^1\). He may also have been the first to suggest that
multiple-authored papers could be used as a proxy measure for collaboration,
as well as to point out difficulties with such a measure:

> ... the fact that some abstracts mentioned individuals whose
assistance was worthy of acknowledgement is no assurance that
there was not in fact some *collaboration*. Nothing short of a
complete description of all 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. [Smith (1958) p 598]

In fact, according to Subramanyan (1983), a holistic perspective must be
maintained when evaluating collaboration because

\(^1\)Smith examined 4,187 papers from *American Psychologist* published between 1946
and 1957. He found that the mean number of authors per paper had increased from 1.3 in 1946
to 1.7 in 1957.
The precise nature and magnitude of collaboration cannot be easily determined by the usual methods of observation, interviews or questionnaires because 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. [Subramanyan (1983) p 35]

Furthermore, only some of the more tangible aspects of a collaborative work can be quantified while others cannot. Even a qualitative assessment of collaboration is extremely difficult, if not impossible, because of the indeterminate relationship between quantifiable activities and intangible contributions. For example, Subramanyan (1983) contended 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. [Subramanyan (1983) p 35]

We see that the complex character of collaborative activity is not readily amenable to qualitative and quantitative assessment. Bibliometric evaluation of multiple-author papers can only be used as a partial measure of collaborative activity. It can only be used to count publications where the collaborating participants have formally agreed to put their names on a paper.

De Solla Price advocated the use of multiple-author papers as a measure of changes in collaboration. In his seminal book, *Little Science, Big Science*, (Price, 1963) he stated:

Surprisingly enough, a detailed examination of the incidence of collaborative work [as reflected in multiple-authorship] in science shows that this is a phenomenon which has been increasing steadily and ever more rapidly since the beginning of the century. It is hard to find any recent acceleration of the curves that would correspond to the coming of the big machine and indicate this as a recognisable contributing cause. [Price (1963) pp 86-91]
Price presented data from *Chemical Abstracts* for the period 1910-1960 which showed that the number of multiple-author papers had increased from about 24 percent in 1910 to 35 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 to his often 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. [Price (1963) pp 86-91]

This generalisation was slightly misleading and may have been made for contentious rather than academic reasons. Many natural and social processes follow an 's'-shaped or logistic growth curve. There is no reason why co-authorship activity should not also display a similar growth pattern. Logistic growth starts slowly, proceeds through an exponential growth phase but then passes through a point of inflection into an ever slower growth phase which asymptotically approaches a final level.

Clarke (1964) suggested logistic growth as an alternative after finding that biomedical writers had showed no marked trend to increasing multiple-authorship since the Second World War\(^2\). She argued that biomedical writers had reached the inflection point by the end of the 1940s and came to her own emphatic conclusion that

Perhaps the more mature and seasoned scientists who make up the Federation [Federation of American Societies for Experimental Biology] find less need for multiple research collaboration than do

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\(^2\)Clarke used data from papers presented to the *American Societies for Experimental Biology* from 1934 to 1963. She found that the number of authors per paper increased from 1.95 in 1936 to 2.19 in 1946 and then remained fairly constant at about 2.3 through to 1963.
the chemical writers who are, on the average, less well established as independent investigators [Clarke (1964) p 824]

Was this perhaps a rather naive and hasty conclusion? Would an investigation of post-1963 publications from the same source reveal an exponential growth in co-authorship due to such factors as the interdisciplinary expertise needed to cope with the rapid advances in biomedical instrumentation and analytical methods that started in the late 1960s and continue to this day? Perhaps, the point to be made here is that, while bibliometric assessment of historical data may provide an insight into the collaborative activity of a past era, it has only rather limited value as a predictive tool.

Even though Price’s projection for 1980 was inaccurate, the general trend towards increasing multiple-authorship has been confirmed by other investigators (Balog, 1979; Beaver and Rosen3 Part III 1979; Meadows and O’Connor, 1974; Merton 1964). Furthermore, Meadows (1974) has corroborated Clarke’s (1964) finding that the rate of increase in multiple-authorship varies considerably with subject area. Caution must be exercised when extrapolating bibliometric findings from one discipline to all disciplines because a multiple-authorship trend found in one science area may not have occurred in another science area.

There appears to be widespread consensus that this increase in multiple-authorship is a confirmation of an increase in collaboration (Beaver and Rosen, 1978; Beaver and Rosen, 1979; Clarke, 1964; Gilvarry, 1952; Price, 1963; Meadows and O’Connor, 1971). However, the notion that multiple-

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3Beaver and Rosen examined the Royal Society Catalogue of Scientific Papers for 1800-1960. They concluded that 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, for the first time 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 it was still increasing at an unprecedented rate. Since then collaborative research has continued to expand.
authorship and collaboration are synonymous must be prefaced with the understanding that in some instances not all those named on a paper are responsible for the work and should not share the recognition. By way of example, in the course of a case study to investigate collaboration, Hagstrom (1965) encountered an industrial researcher who argued that the number of authors was not always a reliable indicator of collaboration. He claimed that he had participated in publications that listed authors for purely social reasons who had not been involved in the research activity.

Although bibliometric co-author-based assessment of collaboration is not a perfect technique, it has certain advantages (Subramanyam, 1983). First, it is invariant and verifiable. In other words, given access to the same data-set, other investigators should be able to verify the results. Second, it is a relatively inexpensive and practical method for quantitatively evaluating collaboration. It might be added that the size of the sample that can be analysed using this techniques can be very large and perhaps statistically more significant than studies which rely solely on case studies. Finally, it has been claimed (Subramanyam, 1983) that bibliometric studies are non-reactive; the measurement does not affect the collaboration process. This may be true in terms of a real-time effect but it has been suggested that the results from a bibliometric investigation may effect future collaboration habits (Martin, Skea, and Ling, 1992).

In conclusion, it appears that bibliometric co-authorship analysis is an analytical technique that is suitable for enumerating collaborations among authors who have formally recognised their cooperation through the production of a joint research publication.
3.1.2 **Factors Contributing to Collaboration**

In one sense, the scientific community collaborates on a world-wide scale to probe and understand the mysteries of nature (Subramanyan, 1983). We could extend this notion and adopt the conviction that it is human nature to understand the world around us, and therefore we could say that the totality of human endeavour is collaborative. However, neither this extended view nor Subramanyan's view provides much insight into the pragmatic reasons why individual researchers collaborate. Using more modest models several authors have studied the nature of collaboration but few definitive reasons have been established to describe its occurrence; usually only factors which contribute to collaborative activity have been identified.

Collaboration can range from offering general advice and opinions to active participation in the research and these collaborative contributions can vary in level from the very substantial to the negligible. Sometimes a scientist may be listed as a co-author simply for providing material or performing a routine assay (Stokes 1969). Scientists in different organisations may collaborate by sharing data or ideas through correspondence or discussions at conferences, by visiting each other or by actually performing parts of a project separately and then integrating the results.

A great many factors have been proposed to account for the increase in multiple-authored papers. These include the following: (1) changing patterns of funding (Clarke, 1967; Smith, 1955), (2) scientific popularity (O'Connor, 1970), visibility and recognition (Beaver and Rosen, 1978), (3) rationalisation of scientific manpower (Price, 1963; Beaver and Rosen, 1978), (4) demands of complex large scale instrumentation (Meadows and O'Connor, 1971; Meadows, 1974), (5) increasing specialisation in science (Bush and Hattery, 1956; Jewkes, Sawers and Stillerman; 1959; Smith, 1958), (6) the degree of
advancement of a particular discipline (Goffman, 1980; Maanten, 1970), (7) the professionalisation of science (Beaver and Rosen, 1978), (8) the need to gain experience, train researchers and sponsor proteges (Beaver and Rosen, 1978), (9) the desire to obtain cross-fertilisation (Beaver and Rosen, 1978), (10) and decrease spatial distance (Beaver and Rosen, 1978). The list of factors is almost endless. Even though some of these factors will occur more frequently than others, collaboration is a social process and, as such, there are likely to be as many contributing factors as there are reasons for individuals to communicate.

A phenomenon that appears to contribute to different rates of collaboration in different fields was first observed by Smith (1958). It led him to speculate that, as a general rule, theoretical work produced papers with less co-authorship than experimental work. Later evidence supported this idea and now it is accepted that experimentalists tend to collaborate more than theoreticians (Gordon, 1980; Hagstrom, 1965; Meadows, and O'Connor, 1971; Price, 1963; Smith, 1955). For instance, frequent collaboration has been observed in experimental research that involves the use of complex instrumentation (Edge and Mulkay, 1966; Gordon, 1980; Price, 1963) such as a telescope, linear accelerator or CT scanner. Besides the obvious economic implications, it has been postulated that the reason for this large amount of collaboration is the need for a high degree of division of labour. In other words, research involving a complex piece of instrumentation frequently requires cooperation among a large group of individuals with specialised skills.

Hagstrom⁴ (1965) suggested that applied research, like experimental research, tends to be more interdisciplinary and research on a particular

⁴Hagstrom interviewed seventy-nine professional scientists (33 in mathematics, 27 in physics and physical chemistry, 16 in biology, organic chemistry, physiology and metallurgy) at five US universities.
problem may involve a wider range of skills than any single individual could possess. These observations lend themselves to the generalisation that experimental and applied problems appear to involve more collaboration than theoretical problems.

Transportation and electronic communication are two contributing factors which, up till now, do not appear to have been thoroughly investigated. Surely, it is plausible to assume that since the turn of the century the decrease in relative cost and the increase in speed, availability and reliability of transportation and electronic communication has afforded a greater proportion of the scientific community more mobility and easier access to colleagues than their predecessors. Very likely, this has provided scientists with more opportunities to develop their network of research relationships, thereby facilitating more collaborative interaction. The lack of research into the effect of transportation and electronic communication on collaboration is conceivably a reflection of how difficult it may be to disentangle the effects of such factors as rapid air and ground transportation, decreasing long-distance telephone rates and new communication technologies (fax and electronic mail) from other contributing factors. Research in this area would presumably reap interesting findings but might require the development of novel evaluation procedures.

3.1.3 **Productivity, Quality and Value**

A pioneering insight into the productivity of the scientific community was provided by Lotka in 1926 and has since been confirmed by numerous other investigators. He showed that the number of authors producing \( n \) papers is proportional to \( 1/n^2 \). In general, 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? Alternatively does the increase in co-authorship activity merely echo a decline in personal productivity (Phillips, 1955; Smith, 1955)?

Research into this question seems to indicate that high productivity correlates with high levels of collaboration (Balog, 1980; Beaver and Rosen, 1979; Hodder, 1980; Lawani, 1984; Pao, 1980; Pao, 1981; Price, 1963; Price and Beaver, 1966; Pravdic and Oluic-Vukovic, 1986). For example, Pravdic and Oluic-Vukovic (1986) analysed collaborative patterns\textsuperscript{5} at both the individual and the group level. They found that scientific output as measured by publications is highly dependent on the frequency of collaboration among authors and that productivity is affected by the different types of links; collaboration with high-productivity scientists tends to increase personal productivity while collaboration with low-productivity scientists decrease it. Furthermore, the most productive authors seem to collaborate the most and authors at all levels of productivity tend to collaborate more with highly productive authors than lower-productivity authors. Therefore, it seems that an increase in multiple-author papers is correlated with an increase in productivity.

Besides increasing personal productivity, collaboration appears to have another advantage when it comes to a paper being accepted for publication. Gordon (1980) found a significant relationship between levels of multiple

\textsuperscript{5} They examined Croatian chemists who between 1971-1978 published 1506 papers listed in the Croatian national bibliography. A total of 853 native and 340 foreign authors contributed to these papers.
authorship for papers submitted to a leading astronomy journal\textsuperscript{6}, and their frequency of acceptance for publication. He established that 63 percent of single-author papers were accepted while 77-86 percent of two- to five-author papers and all of the six- to eight- or more author papers were accepted. Gordon proposed the reason for this was

> The degree of technical competence displayed in the multi-author papers can be enhanced by overlaps existing in areas of specialised competence, and the opportunity for cross-checking and presubmission 'internal refereeing' which it provides for. [Gordon (1980) p 198]

One factor he failed to mention was that as the number of co-authors increases the pool of highly qualified external referees may decrease. We could speculate that this might present difficulties for the editor who may be forced to rely on fewer external referees for multi-author papers than for a single author paper.

Other research has shown that there are further advantages to multiple-authorship. Nudelman and Landers (1972) presented evidence that the total credit given to all authors of a jointly authored paper is greater\textsuperscript{7} than the credit given to the author of a single-author paper. Similarly, Diamond (1985) suggested from his study of Berkeley mathematicians that citations to multiple-author papers were worth more to the authors in terms of their salary\textsuperscript{8} than citations to single-author papers.

\textsuperscript{6}Gordon examined 1859 papers (1090 one-author, 754 two- to five-authors and 17 four- or more authors) submitted between 1968 and 1974 to a leading astronomy journal.

\textsuperscript{7}By using questionnaires and performing interviews they found that for the case of a three-author article the first author received 75 percent of credit, the second author 62 percent and the third author 58 percent of a single-author paper. Thus, a three author paper would have approximately twice the value of a single-author paper.

\textsuperscript{8}Diamond examined 1965-1979 SCI citations to Berkeley mathematicians who published in the 1960s and 1970s. Using regression analysis on two different cohorts, he found
High quality and authorship level appear to be strongly correlated (Lawini, 1986). In cancer research\(^9\), as the number of authors per paper increases, the proportion of high quality papers also increases. Similarly, when this phenomenon was examined at the level of the nation, Lawini found that the level of quality and the quantity of a country's productivity were highly associated. In general, it appears that those countries which produced the most, also produce the best science.

Unfortunately, Lawini used ranking techniques to examine the relationship between quality and quantity at the national level. This did not afford him the opportunity to determine if there was a non-linear effect dependent on country size; it could be that, while larger countries do produce more output of higher quality, the increase in quality need not increase linearly with size. Indeed, a closer examination of his rankings shows anomalies like Japan (which ranked third in quantity but seventh in quality) and France (which ranked seventh in quantity but third in quality). This suggest that there could be a non-linear relationship between country size or output and quality.

\[^9\text{Lawani used the Year Book of Cancer as a measure of quality. All papers examined were published in 1974 and abstracted in 1975 or 1976. He used 279 first-order publications (publications that were abstracted) and 276 second-order (publications mentioned but not abstracted) and 315 average-order papers (randomly selected from SCI data and published between July 1974 to June 1975). All citations were derived from 1974-1978 SCI data.}\]

<table>
<thead>
<tr>
<th>Marginal dollar value of</th>
<th>Type I</th>
<th>Type II</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Citation to single-author paper</td>
<td>$ 92.30</td>
<td>$272.05</td>
</tr>
<tr>
<td>2. Citation to an article where author is the first of more than one author</td>
<td>$408.07</td>
<td>$519.81</td>
</tr>
<tr>
<td>3. Citation to an article where the author is the second, third or fourth author</td>
<td>$111.73</td>
<td>$393.50</td>
</tr>
</tbody>
</table>
There is an inherent difficulty with the assessment of quality - a publication that is judged to be high quality in the eyes of one person may be seen as low quality by another. For example, Mazlish (1982) suggested that quality can have at least two meanings: an "inside" or scientific meaning and, on the other hand, an "outside" meaning. The internal aspect is the quality perceived by professional peers. The external aspect is quality as related to society: the effect on quality of life - economic, social, political and strategic - and human interest and value\textsuperscript{10}. Although this is an interesting observation, and external quality may indeed have some relevance to social and political attitudes, it probably has relatively little influence on publication rates which are more likely to be determined solely by the quality of the research as evaluated through consensus internal to the scientific community.

Finally, although a highly charged debate is still in progress, there appears to be a generally held view that citation frequency is positively related to the perceived quality of a publication (Bayer and Folger, 1966; Garfield 1970, Lawani, 1977; Lawani and Bayer, 1983). Even so, there are plenty of examples of highly cited papers that are not judged to be of high scientific quality but they may have high value in terms of fuelling a scientific debate and spawning new research activity; the cold fusion paper is a case in point.

### 3.1.4 Communication and Distance

As we have seen, the reasons and manner in which individuals collaborate are diverse. Similarly, views on the role of social and/or intellectual

---

\textsuperscript{10}Mazlish suggested that scientific research and development on poison gas or bacterial warfare might be of the "highest" quality judged from the "inside" and the "lowest" quality judged from the "outside".
forces vary widely. For example, Price (1963) claimed that collaborative authorship

... arises more from economic than intellectual dependence and that the effect is often that of squeezing full papers out of people who have fractional papers in them at that particular time. [Price (1963) pp 86-91]

Conversely, Edge (1979) and Stokes and Hartley (1989) 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 (Edge 1979, Hagstrom, 1965; Price and Beaver, 1966; Stokes, 1966).

Informal communication often proceeds to successively greater commitments to co-operate, much the same as communication in courtship. Hagstrom (1965) used this precise analogy:

When collaboration is initiated this way [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. [Hagstrom (1965) p 114]

In addition, spatial propinquity (Hagstrom, 1965) seems to lead to more collaboration since it is likely to produce more informal communication. The closer two potential collaborators are, the more likely they are to initiate informal communication. However, if the potential collaboration involves a clear division of labour, scientists are likely to seek expert assistances even if they have to travel some distance. Paradoxically, Griffith and Miller (1970) found that

... individual scientists may be reluctant at one extreme, to travel seventy-five feet to utilise another person’s store of knowledge but, at the other extreme, would willingly travel hundreds or thousands of miles to communicate with other persons in other circumstances. [Griffith and Miller (1970) p 125]
Collaboration frequently occurs between teachers and students (Crane, 1972) and even without formal collaboration, the teacher who trains a student often retains a close relationship with the student in later years. Sometimes this contributes to the development of an 'invisible college'. The term 'invisible college' is derived historically from a group of people who later organised themselves formally into the Royal Society of London (Price and Beaver, 1966). Before that they met informally and communicated by letter to keep each other informed of their work. Invisible colleges are excellent networks which are a good source of potential collaborators.

Social distance between individuals is also apparently a factor (Hagstrom, 1965). In general, collaboration between peers is more likely than collaboration between individuals of unequal rank. However, a curious observation was made by Hagstrom (1965) about the relationship between teachers and students. He found 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 done in 'collaboration' with others. A number of scientists replied "no" although most or all of their papers had been jointly written with students. This may have been an unconscious recognition of the social distance between a teacher and a student.

3.1.5 Networks and Groups

Bibliometric analysis is often used to map the network structure of collaborative linkages between groups of researchers, or even between laboratories, institutions or nations. While this section discusses the results of specialty-based investigation into research groups, it illustrates some of the underlying principles used in the bibliometric assessment of international collaboration.
Collaboration may take place within and between subgroups in a specialty. Price and Beaver (1966) analysed communications in an information exchange network that had been formed to speed the rate of communication of research findings in the investigation of oxidative phosphorylation. They found that, on the basis of co-authored memos and prepublication papers, the network was formed from numerous non-intersecting subgroups of various sizes. The larger groups contained a few very productive researcher and many relatively low-productivity ones. The subgroups were linked to one another through their leaders who communicated with each other.

In addition, they found that, even though the number of authorships per paper did not vary significantly with group size, personal productivity did vary with group size. The larger groups and individuals who worked alone produced a higher than average number of papers per person than medium-sized groups.

Stokes and Hartley (1989) found similar group relationships when they examined co-authorship linkages among biochemists and molecular biologists. They chose co-authorship over citation analysis because they claimed:

The use of citation and co-citation of bibliographic items with multiple authors maps the cognitive, but not necessarily the social, structure of specialties. One can say which are the central and significant scientific papers, but not who are the central and significant scientists. This is because the coauthor order is not a reliable guide to the contributions of individual coauthors. Citations, in a coauthorship environment, acknowledges intellectual, not necessarily personal, debts. However, coauthorship associations between scientists acknowledge both, and so provide an opportunity to identify and measure social activity and influence within scientific specialties. [Stokes and Hartley (1989) p 102]

Stokes and Hartley were slightly presumptuous with their assertion that citations recognise only intellectual and not social debt. After all, it costs very little to acknowledge a colleague whose research findings maybe questionable but
whose political connections are substantial by citing one of their research publications in a non-critical section of a paper.

Their bibliometric analysis revealed that two types of figures played a significant role in inter- and intra-group linkages. The two figures they identified were 'key figures' - scientists with significant social influence who co-authored more than 60 per cent of the papers from a group - and 'bridging figures' - scientists who co-authored papers in more than one group thereby linking groups together. Stokes and Hartley concluded their bibliometric analysis illustrated scientist that worked in the same research area consisted of a number of collaborative groups of varying size - some interconnected by bridging figures, others isolated but possessing key figures.\footnote{They studied scientists involved in DNA Polymerase research. Their data were gathered from the 1978/1980 \textit{ISI Atlas of Science: Biochemistry and Molecular Biology} and consisted of 18 documents, each cited at least 17 times in 1978. The mean number of co-authors per paper was 2.7 - ranging from 1 to 7. Of the 276 authors they examined, fifteen were 'key figures' and thirteen were 'bridging figures'. There were four authorship groups who were not connected at all. Two groups were connected by bridging figures and the remaining five groups formed an interconnected collaborative network linked together by a web of bridging authorships.}

Peters and Van Raan (1989) also used bibliometric co-authorship analysis to investigate the social dimension of collaboration. They found that, as long as research groups\footnote{Peters and Van Raan examined co-authorship/collaboration between departments in the faculty of chemical engineering at Twente University of Technology in Enschede. They analyzed 1342 papers from two areas, materials engineering and process engineering, published between 1980 and 1987.} are not isolated (in terms of the number of joint publications), collaboration maps produced from co-author analysis should adequately reveal the network of groups and projects. However, they observed that co-author maps based on \textit{ISI data only} differed from those based on \textit{ISI} and other data combined; some linkages were completely due to 'non-ISI' journal publications. Furthermore, it was difficult to make a distinction between
primarily 'intellectual' and/or 'social' groups without seeking the opinions of scientists working in the field. They concluded that co-author analysis seems to be able to identify influential figures in research groups within a university faculty but not all of them.

Edge (1976) has warned that quantitative co-authorship analysis can produce a distorted picture of group interaction. He claimed it could underestimate the level of motivational influence because close collaboration sometimes results in separate publications, and it could overestimate it because some co-authoring scientists had little or nothing to do with the work, but not all of them.

In general, there seems to be ample evidence to indicate that co-authorship analysis of scientific publication can provide a picture of some of the network of relationships that exists within and between groups. Also, even though this research primarily investigated groups, it is possible that similar techniques can be used to examine the collaborative networks that exist between institutions.

3.1.6 **Size versus Scientific Output**

The previous discussion examined the use of bibliometric co-author analysis to map the network structure of groups. At the beginning of the discussion it was argued that some findings from Price and Beaver (1966) point to the existence of a relationship between group size and productivity. Even though this topic does not appear to be directly related to the basic understanding of collaboration, it sets the stage for some research findings concerning the relationship between scientific output and *intrana*national collaborative. The following material provides some insight into the relationship
between the size of a group (such as a laboratory, institution and nation) and its scientific output.

Price (1969) showed that economies of scale exist at the national level. He used bibliometric methods to assess international scientific research activity. First, he demonstrated that approximately 0.7 per cent of GNP devoted to basic research is the minimum expenditure in basic research required by a country to maintain a scientific effort which can be sustained over time. In addition, he illustrated that there is a log-linear relationship between the number of scientific authors in a country and its economic size\textsuperscript{13}. He noted that

... the share each country has of the world's scientific literature by this reckoning turns out to be very close - almost always within a factor of 2 - to that country's share of the world's wealth (measured conveniently in terms of GNP). The share is very different from the share of the world's population and is related significantly more closely to the share of wealth than to a nation's expenditure on higher education. [Price (1969) pp 10 -11]

Frame (1979) investigated a similar relationship for developed and underdeveloped countries\textsuperscript{14}. Using 1972 Science Citation Index data, he performed a detailed investigation between the relationship of scientific size (publications) and GNP. In both instances, the relationship was log-linear but the regression lines were slightly different. The regression equations that fitted the developed countries data best was given by

\[ Y = 1.43X^{1.07} \times 10^{-8} \]

\textsuperscript{13}He used 1967 GDP data and the International Directory of Research and Development Scientists, published by the Institute for Scientific Information. He found that 90 percent of the world's science resided in the top 14 nations, and that 40 nations accounted for all but 1 percent of the world's scientific output.

\textsuperscript{14}Frame used publication counts for 107 countries from the 1973 Science Citation Index. A total of 271,435 publications were used. Of these 95.4 percent were attributed to 33 developed countries and 4.6 percent were attributed to 74 underdeveloped countries.
or

\[ \ln(Y) = 1.07 \ln(X) - 18.06 \]

where \( Y \) is the number of publications and \( X \) is GNP. In comparison, the best regression equation for underdeveloped countries was given by

\[ Y = 8.82X^{1.12} \times 10^{-10} \]

or

\[ \ln(Y) = 1.12 \ln(X) - 20.85 \]

These regression lines are nearly parallel. However, the small difference in the slopes has an interesting interpretation if examined in terms of the economic concept of the elasticity, \( \varepsilon \), defined as

\[ \varepsilon = \frac{dY}{dX} \cdot \frac{1}{X/Y} \]

For a log-linear relationship

\[ Y = aX^b \]

or

\[ \ln(Y) = b \ln(X) + \ln(a) \]

the elasticity coefficient, \( \varepsilon \), is the slope \( b \) since

\[ \varepsilon = \frac{d\ln(Y)}{d\ln(X)} = b \]

The elasticity coefficient indicates how a very small change in \( X \) will effect \( Y \). If the elasticity coefficient \( \varepsilon = 1.0 \) then a small increase in \( X \) produces the same small increase in \( Y \); if \( \varepsilon > 1 \) then a small increase in \( X \) produces a proportionately larger increase in \( Y \); and if \( \varepsilon < 1 \) then a small increase in \( X \) produces a proportionately smaller increase in \( X \).
For both developed and underdeveloped countries, \( \varepsilon \) is close to but greater than 1.0, implying that a small increase in GNP would result in a slightly larger increase in scientific output. However, this effect would be somewhat greater in an underdeveloped than a developed country.

Cohen (1978, 1981) examined the per capita publication rate of laboratory-size groups\(^{15}\) and observed that it was independent of laboratory size. He established that there is a linear relationship between the number of authors in the laboratory and the number of publications. Also, he found an inverse linear relationship between laboratory size and the number of single-authored papers - larger laboratories have proportionately more co-authorships. This finding suggests that the belief that bigger research groups are more productive is unsubstantiated.

These three studies indicate that a different relationship may be found between size and output on depending whether the investigations is carried out at the level of the large groups (nation states) or small groups (laboratories). Economies of scale that may be observed at the level of the nation state may disappear at the level of the research laboratory.

### 3.2 Bibliometric Assessment of International Collaboration

Since few, if any, investigations have been carried out on *intranational* collaborative research activity, the following examination of *international* collaboration will be used to formulate hypotheses that may be tested at the *intranational* level.

---

\(^{15}\)Cohen examined 1977-78 data for Rockefeller University, the National Institute for Medical Research and the National Cancer Institute at the level of the laboratory.
Frame and Carpenter (1979) were two of the first researchers to investigate international collaboration in detail using co-authorship measures. Their investigation was restricted to industrialised countries\textsuperscript{16}. They examined international co-authorship patterns in a number of scientific fields using 1973 *Science Citation Index* data. They assumed an international collaboration had occurred between two countries if the authors of a publication reported affiliations with institutions in both countries. In addition to examining the aggregated data, they used the *Computer Horizon* journal classification scheme to disaggregate it into nine fields of science: clinical medicine, biomedical research, biology, chemistry, physics, earth and space science, engineering and technology, mathematics and psychology.

Their research, which will be discussed in more detail later in this section, produced three general findings:

1. The more basic research areas (physics, mathematics, earth and space science, and biomedical research) have a greater amount of international co-authorship than the more applied research areas (chemistry, biology, clinical medicine and engineering and technology);

2. A log-linear relationship exists between national scientific output and collaboration; the larger the national scientific effort, the smaller the proportion of international co-authorship; and

3. International co-authorships occur along discernible geographical lines, suggesting that extra-scientific factors (eg. politics, geography and language) play a strong role in determining who collaborates with whom in the international scientific community.

\textsuperscript{16} Frame and Carpenter's investigation was confined to the US, UK, West Germany, France, Italy, Canada, Australia, New Zealand, South Africa, Israel and Sweden.
Since the publication of this work a number of researchers have pursued this line of investigation. Some researchers have examined a more diverse spectrum of countries (Lomnitz, Rees and Cameo, 1987; Luukkonen, Person and Sivertsen, 1990; Schubert and Braun, 1990) while others have limited their focus to the European community (Lewison and Cunningham, 1989; Moed, Bruin, Nederhof and Tijssen, 1990; Narin, Stevens and Whitlow, 1990; Schott, 1988). Some of their findings will be presented later.

3.2.1 Basic Versus Applied Research Collaborations

Frame and Carpenter (1979) found that international institutional collaboration occurred most frequently in earth and space sciences (4.45 per cent) and physics (4.23 per cent) and less frequently in the field of engineering and technology (1.46 per cent). They concluded that:

... predominantly basic fields (that is, earth and space science, physics, mathematics and biomedical research) have higher levels of international collaboration than predominantly applied or clinical fields (that is, biology [including agricultural research], psychology, clinical medicine and engineering and technology). Chemistry straddles the middle ground. [Frame and Carpenter (1979) p 483]

Luukonen, Person and Sivertsen (1990) came to a similar conclusion after examining international collaboration using Science Citation Index data for 1981-1986. Using a line of reasoning first proposed by Price (1986), they concluded that

If this is true [that there is more collaboration in basic science research], then financial as well as cognitive reasons (the need to coordinate observations made in various geographical sites; international orientation of basic fields) might be important in explaining field-to-field differences in the degrees of international co-authorship. [Luukonen, Person and Sivertsen (1992) p 119]
These findings seem to confirm what sociologists and historians of science have suspected for some time. For example, Storer (1970) felt that basic research is oriented towards an international community since it involves universal truths of global interest. Herzog (1976) hypothesized that the level of international scientific collaboration is a consequence of the reward orientation of scientists. Basic researchers in high-consensus disciplines (physics and geology) have an international orientation because it is the global community that gives them recognition for their achievements. In contrast, Miles (1972) claimed that the high level of international collaboration in earth and space sciences is a consequence of the unique nature of the discipline. He felt that these areas required the coordination of individuals and resources on a broad international scale. On the other hand, applied researchers work in economically or socially relevant fields, and they find problems, information and recognition primarily at home (Frame and Carpenter, 1979; Herzog, 1976). It should be pointed out that perhaps very applied research is not suitable for publication in journals covered by the Science Citation Index. Finally, part of the reason for the difference between the level of international collaboration in basic compared to applied science may be due to government sponsored programmes for international scientific collaboration which place a greater emphasis on basic than applied research (Frame and Carpenter, 1979).

The difference in the amount of international collaboration in basic and applied research suggests some interesting research questions about intranational collaboration. Does intranational university-university collaboration occur more frequently in basic research than in applied research? If so, are there similar/different patterns between basic and applied research at the intranational and the international research? Finally, and perhaps most important, can the individual scientific areas be legitimately categorised as basic or applied?
3.2.2 **Scientific Size and International Collaboration**

Frame and Carpenter (1979) showed that scientific size, measured by counting publication output, and collaboration exhibits a log-linear relationship; countries with small scientific output publish proportionately more of their papers with a foreign author. Others investigators (Luukonen, Person and Sivertsen, 1990) suggest that this is not a hard and fast rule because political, geographical and linguistic factors may play a dominant role.

Frame and Carpenter’s data illustrated that the relationship between international collaboration (co-authorships) \( Y \), and national scientific size (publications), \( X \), is given by:

\[
Y = 1.49X^{0.67}
\]

or

\[
\ln(Y) = 0.67 \ln(X) + 0.40.
\]

Schubert and Braun (1990) examined international collaboration for 167 countries using 1981-1985 SCI data and found a broadly similar relationship with

\[
Y = 1.35X^{0.77}
\]

or

\[
\ln(Y) = 0.77 \ln(X) + 0.30.
\]

Remember that the elasticity coefficient \( \varepsilon \) is equal to the slope. In both of the preceding instances \( \varepsilon < 1 \) and therefore a small increase in scientific size (publications) would produce a smaller increase in collaborative activity. Also, recall the previous finding (Frame, 1979) that a small increase in GNP produces a larger increase in scientific size. This is interesting because since it seems to imply that a small increase in GNP produces a larger increase in scientific
output but a smaller increase in international collaboration. Is it possible that the smaller increase in international collaboration is accompanied by a larger increase in intranational collaboration?

When Frame and Carpenter (1979) disaggregated their data by scientific field, they found that the exponents or elasticity coefficients fell into two groups. For physics, mathematics and earth/space sciences, the coefficient ranged from 0.76 to 0.84 and for the rest it varied between 0.60 to 0.65. These two groups again correspond to the more basic versus applied research dichotomy noted earlier. Thus, Frame and Carpenter conclude that

... in the applied disciplines there is a sharper drop in international collaboration than in basic disciplines, as the countries increase in research size. That is, larger countries appear to be substantially more self-sufficient in the applied disciplines than are smaller countries. [Frame and Carpenter (1979) pp 491-492]

These findings led Frame and Carpenter (1979) to two conclusions: first, scientists in smaller countries, because of limited resources, direct themselves strongly to the international scientific community for research opportunities; and second, in larger countries, basic research has a stronger international orientation than applied research.

In contrast to the preceding observations, Narin, Stevens and Whitlow's (1990) research on European Community collaboration and Luukkonen, Person and Sivertsen's (1990) research on international collaboration both yielded a somewhat different finding. They concluded that the degree of co-authorship was only weakly dependent on national scientific size and suggested that:

...the relative low percentage of variation explained by size highlights that many other factors are important influences on the propensity of countries to collaborate internationally. [Luukkonen, Person and Sivertsen (1990) p 17]
In the light of these findings about scientific size and international collaboration, intriguing questions can be posed about intra\textit{national} university-university collaboration. How does the scientific output of a university change with economic size of the university? How does scientific size of a university effect the amount of intra\textit{national} university-university collaboration? Does the effect varying across scientific research fields?.

### 3.2.3 Geographical and Sociopolitical Factors

A number of methodologies have been used to map the intensity of scientific research collaboration between countries and to investigate the effects of geographical, political and cultural factors. Most of these methodologies use a normalisation technique to remove the effect of such factors as country or institutional size. For example, in order to do cross country comparisons of university-university collaborations one would need to normalise the absolute number of collaborations to the size of the university community. A simple normalisation procedure would express the number of university-university collaborations as a percentage of the total number of university publications, a measure of the scientific size of the university community, produced by a given country.

Many normalisation procedures use complicated techniques to reduce the effect of various factors. Some of these weighting techniques are non-linear and weight values more favourably that are at one or the end of the spectrum of values. However, it seems that no one has carefully evaluated the various normalisation techniques used in collaboration analysis and therefore there is no simple way to compare research findings.

In addition, most researchers use the normalised collaboration data as input to a multidimensional scaling program to produce graphical maps of
collaboration. Finally, these maps are subjectively analysed to see if geographical, political, economical or cultural factors seem to be influencing the collaborative activity. Before we begin a discussion of the difficulties associated with comparing results from a variety of normalisation techniques and the problems with multidimensional scaling, an overview of the various normalisation techniques and resultant interpretations found in the literature will be presented. Unfortunately, most investigators did not comment on the reasons for selecting the normalisation procedure that was used.

Frame and Carpenter (1979) performed non-metric multidimensional scaling on their aggregate cross-country co-authorship data. They did not use any techniques to normalise the data. They interpreted the four clusters of collaboration that emerged to imply that there are geographically as well as political, social and economic factors involved in international collaboration.

Schubert and Braun (1990) also used multidimensional scaling and arrived at a similar conclusion. They used a relative strength measure, \( r_{ij} \), to normalise their data. This measure was given by:

\[
    r_{ij} = \frac{n_{ij}}{\sqrt{n_i n_j}}
\]

\(^{17}\)Frame and Carpenter (1979) found the following four clusters: 1) Canada, France, Italy, UK, USA, West Germany and the rest of Western Europe, 2) Eastern Europe and USSR, 3) Australia and New Zealand and 4) Asia, India and Japan. There was an unclustered group consisting of Black Africa, Israel, Latin America, Middle East, South Africa and Sweden. Luukonen, Person and Sivertsen (1990) subsequently pointed out that Sweden was only isolated because other Nordic countries were omitted from the data.

\(^{18}\)Schubert and Braun's (1990) analysis generated four clusters of unequal size: 1) Western Europe, USA and Canada, 2) Nordic countries, 3) Eastern Europe and 4) Australia and New Zealand. There was a large unclustered group consisting of Latin America, South Africa, Israel, Egypt, Greece, Japan, China and India. They claimed the clusters illustrated a significant effect of geography and sociopolitical factors on international co-authorship.
where \( n_i \) and \( n_j \) are the total numbers of papers published by countries i and j, respectively, and \( n_{ij} \) is the number of papers co-authored by i and j.

Luukkonen, Person and Sivertsen (1990) normalised their data using observed collaboration frequency versus expected collaboration frequency ratios. This ratio was given by

\[
Y_{ij} = \frac{C_{ij}T}{C_i C_j}
\]

where \( C_{ij} \) is the number of collaborations between countries i and j, \( C_i \) and \( C_j \) are the total number of collaborations each country has with all other countries, and \( T \) is the total number of collaborations among all countries. The resultant \( Y_{ij} \) matrix was used as input to a multidimensional scaling program\(^{19}\). From their maps, they concluded that regional or geopolitical factors, history, language and cultural similarity seem to be very important for shaping the collaborative networks.

In a study on scientific cooperation in Europe, Narin, Stevens and Whitslow (1990) used a different technique to normalise their data. They used what they called a country co-authorship index, \( I \), more commonly known as the inclusion index. This is given by:

\[
I = \frac{C_{ij}}{C_i}
\]

---

\(^{19}\)Luukkonen, Person and Sivertsen (1990) found well-defined clusters within Eastern Europe and one containing Australia and New Zealand. Central and southern Europe formed a slightly looser cluster than Northern and Eastern Europe. The USA had strong links with many countries but did not form a clear-cut cluster with any of them. Japan showed strong collaborative links with its big Asian neighbours: The People’s Republic of China and India.
where $C_{ij}$ is the number of papers that country $i$ co-authored with country $j$. The $C_i$ used in the equation was the smaller of $C_i$ and $C_j$, the total number of collaborations for countries $i$ and $j$, respectively. Using this measure they concluded that:

... co-authorship patterns in the Community have strong linguistic and historical components, and international cooperation within the Community is far from uniformly distributed. [Narin, Stevens and Whitslow (1990) p 5]

In contrast, Moed, de Bruin, Nederhof and Tijssen (1990) used correspondence analysis, a type of multidimensional scaling, and an unspecified normalisation technique to examine interrelationships between European Community members. This methodology seems to show a greater effect of geography than Narin, Stevens and Whitslow (1990). They concluded that there existed a stronger tendency to international scientific cooperation among the nine EC nations that shared a border.

Interestingly, in all the preceding studies, only very general statements were made about the effect of the influencing factors, and in almost every instance, the main influencing factor mentioned was geography. Perhaps, this is due to fact that the maps provide a graphical representation of collaborative activity and it is easier for the interpreter to identify geographical relationships than cultural, political or economic relationships.

Let us now examine multidimensional scaling in a little more detail. In addition to exploring collaborative activity by investigating co-authorship linkages, multidimensional scaling has been used for a variety of purposes in other bibliometric studies: (1) to display relationships between publishing and citing patterns (Inhaber and Alvo, 1978), (2) to explore the social structures of scientific specialties (Small, 1977), (3) to examine author conomination (Lenk,
P, 1983), (4) to display journal similarities (Noma, 1982), and (5) to map co-word relationships (Peters and Van Raan, 1991; Tijssen and Van Raan, 1988).

In essence, multidimensional scaling allows the investigator to explore the underlying structure of (dis)similarities between co-occurrence elements which exist in multidimensional space by projecting these relationships into a lower dimensional space (typically one-, two- or three-dimensions) using linear regression techniques. Generally speaking, in collaboration studies those collaborators that exhibit a high co-occurrence in multidimensional space are placed in the vicinity of one another in a lower dimensional space. However, the projection is seldom, if ever, perfect and frequently significant distortion occurs because of the information loss that is incurred during the mathematical compression of co-occurrence relationships from many dimensions to few dimensions. This can result in collaborators who are not near one another in multidimensional space may be placed near one another in low dimensional space or vice versa.

In addition to distortions, there do not appear to be any well-founded reasons for selecting one normalisation method over another from the wide variety of possibilities available. Peters and Van Raan (1991) explored two-dimensional maps which were produced by doing a multidimensional scaling of co-words derived from chemical engineering papers. They normalised the input data using three normalisation techniques: (1) the Jaccard index, (2) the proximity index and (3) the inclusion index. This resulted in three maps, each possessing the same words but each with entirely different spatial characteristics (see Figure 3.1). These maps were presented to experts in the

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20 Each element in a row (or column) in a co-occurrence matrix is assumed to be independent (or orthogonal) to every other element in that row (or column). Therefore, each element is considered to be a value for a vector which has a dimensionality equal to the number of elements in the row (or column).
field of chemical engineering to see if they could determine which map provided
the most realistic representation of activity in the field. There was no consensus
among the experts. Peters and Van Raan concluded that it was unclear which
index should be used.

Similar criticisms can be directed at the collaboration maps because at
least two important questions are raised. Which of the variety of normalisation
procedures is the most appropriate for examining *intranational* collaboration?
And how many of the influencing factors that have been claimed to be revealed
by collaboration maps are merely artifacts of normalisation or multidimensional
scaling?

Because of the concerns about normalisation and mapping techniques, a
decision was made to avoid procedures that required normalisation or
multidimensional scaling in this research project. This decision prompted a
number of interesting research questions. Can an empirical method be
developed to isolate individual influencing factors? More specifically, can a
methodology be developed which isolates the effects of geographical proximity
on collaborative activity? Can a distortion-free mapping technique be developed
to depict collaboration within a national university community? Can
Figure 3.1 - Multidimensional Co-Word Analysis


Fig. I.3 Jaccard-index  Fig I.4 Inclusion-index  Fig I.5 Proximity-index
such a mapping technique be designed to assist an investigator or policy analyst in visualising how collaborative activity has changed over time?

### 3.2.4 International Collaboration and Policy

Frame and Carpenter (1979) argued that effects of government policy on collaborative research, particularly in the basic sciences, should not be ignored. Only two bibliometric studies have apparently attempted to examine this effect and their results are somewhat inconclusive.

Narin, Stevens and Whitlow (1990) and Moed, de Bruin, Nederhof and Tijssen (1990) investigated the effect that policies of the Commission of European Communities (CEC) were having on collaborations within the European Community. Narin et al. concluded that international co-authorship is increasing steadily, both within and outside the Community, with some evidence that it is increasing more rapidly in scientific fields targeted by the Commission. In contrast, Moed et al. concluded that in several disciplines collaboration among European Community member states had not increased significantly faster than the general increase of international scientific cooperation.

These findings should be viewed in context. The time over which the relevant CEC policies have been operating is relatively short. Furthermore, the methodologies used in the two studies differ. Narin et al. used all *Science Citation Index* data for the years 1977-1986. On the other hand, Moed et al. examined individual years (1979, 1982, 1985 and 1988). Perhaps, the different methodologies account for some of the difference between the findings.

Based on these observations, a final research question can be proposed. Can a bibliometric analysis of *intranational* university-university collaboration reveal underlying shifts in policies targeted at collaboration?
3.3 **Summary**

Co-authored publications have been steadily increasing since the turn of the century but the rate of increase seems to vary across research fields. Collaboration is an activity commonly found among highly productive researchers which seems to increase the quality and value of research. It rewards individual researchers with increased professional recognition through improved citations rates and in some instance may bring monetary rewards.

There are strong indications that communication and physical proximity play a significant role in establishing cooperative relationships. However, collaboration seems to be critically influenced by the type of problem being addressed and the scientific field of investigation. In addition, there are indications that it can be influenced by economic, political and cultural factors.

Collaboration can take many different forms and can occur for a variety of reasons. Alone, bibliometric assessment of collaboration sheds little light on the types and motives for cooperation but it is appears to be an excellent tool for empirically evaluating the changes in cooperation and exploring the dynamics of structural linkages within and between communities.

Research investigations have revealed that international collaboration has a number of distinctive characteristics: there tend to be more collaboration in basic science areas than in applied science areas; smaller nations have a greater proportion of their scientific output in the form of collaboration than larger nations; and geographical, cultural and political factors can influence the level of collaboration. The techniques currently used for mapping the collaborative linkages between countries have limitations and a fresh approach has to be developed.
Little, if any, research effort has been devoted to the bibliometric assessment of *intranational* scientific research collaborations even though individual nations spend more of their R&D funds nationally than internationally. A bibliometric investigation of university-university collaboration activity is a starting point for this investigation. Research on the nature of collaboration in general and international collaboration in particular is a fertile source of methodological approaches and provides an excellent source of data against which to compare the results from an investigation into *intranational* collaboration.

Based on the material presented in this chapter a number of research questions have been posed and will be explored in later chapters. They are summarised as follows:

1. How does the scientific output of a university change with the economic size of the university?

2. How does scientific size of a university effect the amount of *intranational* university-university collaboration?

3. Does *intranational* university-university collaboration occur more frequently in basic research than in applied research? If so, are there similar or different patterns between basic and applied research at the *intranational* and the *international* research? Most importantly, can the individual scientific areas be legitimately categorised as basic or applied?

4. Is there a relationship between geographical proximity and the level of university-university collaboration?

5. Can a bibliometric analysis of *intranational* university-university collaboration reveal underlying shifts in policies targeted at collaboration?
6. Can a distortion-free mapping technique be developed to depict collaboration within a national university community? Can such a mapping technique be designed to assist an investigator or policy analyst to visualise how collaborative networks have changed over time?

Before proceeding to a description of the methodologies used to answer these questions we shall turn our attention in the next chapter to the university community and explore the national and historical context in which universities are situated.
4.

The University Community

Intranational university-university collaboration must be viewed within a national and historical context. This chapter provides this information in four sections: national context; history and structure of the university community; comparison of national science activity; and a summary of the main similarities and differences.

The first section compares national statistics concerning geography, population, gross domestic product related measures along with university related inputs and outputs. The second section examines the historical evolution of the university community in each country, its organisational interface with government and the mechanisms for financing scientific research. The final section provides an overview of input-output and quality measures of the scientific activity within each country that have been collected from a variety of sources.

4.1 National Context

The United Kingdom, Canada and Australia are industrialised Commonwealth nations with a high standard of living. They have similar gross expenditures on higher education R&D (HERD) supporting a publicly funded
university system providing world-class scientific research. Many factors distinguish these countries from each other. However, this discussion will primarily focus on geography, population, language and gross domestic product related measures (see Table 4.1).

Australia and Canada are primarily resource- and agriculture-based economies possessing a substantially larger land mass but smaller population than the UK, giving them a relatively low population density. The per capita gross domestic products of the UK and Australia are equivalent. Canada, on the other hand, has a per capita gross domestic product nearly 30 per cent greater, giving its citizens a higher standard of living.

Canada is more dependent on its exports as a source of national revenue than either the UK or Australia. Its major trading partner is the United States which accounts for approximately 70 per cent of its imports and exports. The geographical isolation of Australia contributes to its substantially lower import and export trade. Japan, the Far East, United States and Europe are its major trading partners. Europe is the UK's major trading partner and the UK does more trade with the developing countries than it does with the United States.

In terms of support for national scientific research (see Table 4.1), one of the features that distinguishes the UK from both Canada and Australia is the relatively high percentage of GDP it spends on research and development (GERD). In 1988 the UK spent 2.22 per cent of GDP on research and development compared to 1.38 per cent in Canada and 1.23 per cent in Australia. A larger proportion of the UK's GERD comes from industry than government. Also, a greater percentage of the UK's R&D is performed by the business sector, primarily defence related, than in Canada and Australia. On
Table 4.1

General Statistics

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Units</th>
<th>United Kingdom</th>
<th>Canada</th>
<th>Australia</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Area(^1)</strong></td>
<td>km(^2)</td>
<td>244</td>
<td>9,976</td>
<td>7,686</td>
<td>0.02:1.0,77</td>
</tr>
<tr>
<td><strong>Population(^1)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total number of inhabitants</td>
<td></td>
<td>56,890,000</td>
<td>25,803,000</td>
<td>16,249,000</td>
<td>1.0:0.45:0.29</td>
</tr>
<tr>
<td>inhabitants per sq km</td>
<td></td>
<td>232</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td><strong>Primary Languages</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>English</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>French</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GDP(^1)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>current prices using PPP's</td>
<td>Billion US$</td>
<td>702.5</td>
<td>444.5</td>
<td>204.9</td>
<td>1.0:0.63:0.29</td>
</tr>
<tr>
<td>per capita using PPP's</td>
<td>US$</td>
<td>12,340</td>
<td>17,211</td>
<td>12,612</td>
<td>0.71:1.0,73</td>
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<td><strong>Foreign Trade(^1)</strong></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>exports % of GDP</td>
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<td>19.7</td>
<td>22.8</td>
<td>13.6</td>
<td>0.86:1.0,62</td>
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<tr>
<td>imports % of GDP</td>
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<td>23.2</td>
<td>21.1</td>
<td>13.9</td>
<td>1.0:0.91:1.0</td>
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<tr>
<td><strong>GERD(^2)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of GDP</td>
<td></td>
<td>2.22</td>
<td>1.38</td>
<td>1.23</td>
<td>1.0:0.62:0.55</td>
</tr>
<tr>
<td><strong>GERD Financing(^3,(^b)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>% of GERD industry</td>
<td></td>
<td>51.4</td>
<td>41.8</td>
<td>41.1</td>
<td>1.0:0.81:1.0</td>
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<tr>
<td>government</td>
<td></td>
<td>36.5</td>
<td>44.0</td>
<td>54.6</td>
<td>0.67:0.80:1.0</td>
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<tr>
<td>other</td>
<td></td>
<td>12.0</td>
<td>13.7</td>
<td>4.2</td>
<td>0.88:1.0:0.31</td>
</tr>
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<td><strong>GERD Performance(^3,(^b)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of GERD business</td>
<td></td>
<td>66.6</td>
<td>55.7</td>
<td>41.5</td>
<td>1.0:0.84:0.62</td>
</tr>
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<td>higher education</td>
<td></td>
<td>15.1</td>
<td>23.3</td>
<td>25.7</td>
<td>0.59:0.91:1.0</td>
</tr>
<tr>
<td>government</td>
<td></td>
<td>14.4</td>
<td>19.4</td>
<td>31.4</td>
<td>0.46:0.62:1.0</td>
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<td>private non-profit</td>
<td></td>
<td>4.0</td>
<td>1.5</td>
<td>1.4</td>
<td>1.0:0.38:1.35</td>
</tr>
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<td><strong>HERD(^2)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of GDP</td>
<td></td>
<td>0.34</td>
<td>0.34</td>
<td>0.31</td>
<td>1.0:1.0:0.91</td>
</tr>
<tr>
<td><strong>University(^4,(^b)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>number of universities</td>
<td></td>
<td>52</td>
<td>47</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>expenditure (nat'l currency)</td>
<td>billion</td>
<td>£1.73</td>
<td>$7.77</td>
<td>$2.81(^a)</td>
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</tr>
<tr>
<td>academic (full-time)</td>
<td>number</td>
<td>45,878</td>
<td>35,698(^5)</td>
<td>10,569</td>
<td>1.0:0.78:2.3</td>
</tr>
<tr>
<td>students</td>
<td>number</td>
<td>305,405</td>
<td>499,177</td>
<td>134,276</td>
<td>0.61:1.0:27</td>
</tr>
<tr>
<td>full-time</td>
<td>number</td>
<td>40,706</td>
<td>306,178</td>
<td>56,679</td>
<td>0.13:1.0:19</td>
</tr>
<tr>
<td>part-time</td>
<td>number</td>
<td>54,695</td>
<td>56,843</td>
<td>10,502</td>
<td>0.96:1.0:19</td>
</tr>
</tbody>
</table>

Sources:
1. OECD Economic Surveys - Canada 1988/89
2. OECD STIID data bank
3. OECD Main Science and Technology Indicators 1991
4. Commonwealth Universities Yearbook 1990
5. Canadian World Almanac 1990

Notes:
a. All higher educational institutions
b. 1988
the other hand, the Canadian and Australian higher education sector performs almost twice as much R&D as a percentage of GERD than in the UK. Also, in Australia the government sector performs more of the R&D than the higher educational sector.

The official language in the UK and Australia is English. Although Canada is officially bilingual (English and French), most Canadian universities teach undergraduate courses and conduct their scientific affairs in English. However, many universities in Quebec, except McGill and Concordia, and a couple of small universities in the Atlantic provinces teach undergraduate courses in French.

4.2 History and Structure of The University Community

Canada has nearly as many universities as the UK (see Tables 4.3 and 4.4) but it only has one polytechnic whereas there are thirty polytechnics in England and Wales and sixteen central institutions in Scotland (Commonwealth Universities Yearbook 1990). In 1992, UK polytechnics where granted permission to call themselves universities.

Canada has 1.6 as many full-time and 7.5 times as many part-time students enroled in university than in the UK (see Table 4.1). The number of enroled graduate students is about the same in both countries. Although the statistical approach used to count for the university staff may vary across countries, it is worth noting that the ratio of full-time students to full-time academic staff is 6.7 in the UK, 12.7 in Australia and 14.0 in Canada; and the ratio of graduate student to full-time academic staff ratio is 1.2 in the UK, 1.0 in Australia and 1.6 in Canada (see Table 4.1).
The collaborative activities of a university community should be examined within the context of its historical formation, political milieu, university-government interfacing organisation and funding mechanisms. The following section provides an overview of this context for each of the three countries. A great deal of the material has been drawn from the *Commonwealth Universities Yearbook 1990* which is an excellent and up-to-date source of general history, recent university structural shifts and changes in government funding policies in Commonwealth countries.

4.2.1 **Australia**

4.2.1.1 **University Community History and Structure**

Post-school education is provided almost entirely in publicly established, financed and co-ordinated institutions. Until the end of 1988, there were three broad sectors: universities; colleges of advanced education; and technical and further education. All the universities were established under state legislation, except for the Australian National University in the national capital, and were wholly funded by the federal government (apart from relatively minor levels of endowment income).

The growth of university education in Australia followed a pattern distinctively different from the United States and Canada. The first two universities were established in Sydney and Melbourne in the 1850s. Other universities were established as the population grew. The Universities of Adelaide and Tasmania were founded near the end of the nineteenth century, and the Universities of Queensland and Western Australia were set up during the early years of this century.
With the exception of the Australian National University, which started with different aims from the others, all Australian universities pursued similar goals and have analogous organisations and teaching programmes. The universities can be conveniently divided into five groups.

First, there are the six oldest - Sydney (1850), Melbourne (1853), Adelaide (1874), Tasmania (1890), Queensland (1910) and Western Australia (1911). With the exception of Tasmania, they are all large institutions: Sydney, Melbourne and Queensland all have a total enrolments of 16,000 or more students.

The second group consists of the University of New South Wales (1949) and Monash University (1958). These universities were established after the Second World War, have a strong emphasis on technological fields and a strong commitment to graduate studies.

The third group comprises the new capital city universities established in the 1960s and 1970s - La Trobe (1964), Macquarie (1964), Flinder (1966), Griffith (1971) and Murdoch (1973). They were created as second or third universities in their cities to cope with the rapid expansion in demand for university places. They are all located in suburban areas and their main emphasis is in the basic arts, sciences, economics and education.

Five regional universities, located outside of the state capital cities, make up the next group. These are the University of New England (1954), University of Newcastle (1965), James Cook University (1970), Deakin University (1974) and the University of Wollongong (1975). Like the new capital universities, they emphasis the arts, sciences, economics and education. Four of these began as university colleges while Deakin was developed from two colleges of advanced education.
The Australian National University (ANU) constitutes a fifth and separate category. It is made up of two distinct parts, an Institute of Advanced Studies (comprised of the research schools of medical research, physical sciences, earth sciences, chemistry, Pacific studies and social sciences) and the faculties (arts, sciences, economics, Asian studies and law). The Institute, which is concerned solely with research and the training of PhD students, was established in 1946 as the original ANU, while the faculties began in 1930 as Canberra University College. They were amalgamated in 1960.

Table 4.2 lists the Australian universities that were examined in this research project, a two-letter abbreviation that will be used later and a location number indicating where the university is geographically located on the map of Australia is presented in Figure 4.1.

### 4.2.1.2 Finance and Research

From January 1, 1974 the Australian federal government accepted total responsibility for providing regular capital and recurrent funds to universities. Prior to this, the responsibility was shared between the state and federal governments. Education is still a state responsibility but the funds come to the institutions from the federal government via state treasuries.

The higher educational system provides a major part of Australia’s research effort. For many years, the bulk of the effort was conducted by universities, but over the past decade research activity in colleges of advanced education has increased, largely with support from industry. In the public sector, research is carried out by a number of organisations, the most important of which is the Commonwealth Scientific and Industrial Research Organisation (CSIRO), which has a reputation for high quality research in a variety of fields.
<table>
<thead>
<tr>
<th>UNIVERSITY NAME</th>
<th>Abbreviation</th>
<th>Map Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian National University</td>
<td>AU</td>
<td>2</td>
</tr>
<tr>
<td>Curtin University of Technology</td>
<td>CU</td>
<td>4</td>
</tr>
<tr>
<td>Deakin University</td>
<td>DE</td>
<td>5</td>
</tr>
<tr>
<td>Flinders University of South Australia</td>
<td>FL</td>
<td>6</td>
</tr>
<tr>
<td>Griffith University</td>
<td>GR</td>
<td>7</td>
</tr>
<tr>
<td>James Cook University</td>
<td>JC</td>
<td>8</td>
</tr>
<tr>
<td>La Trobe University</td>
<td>LT</td>
<td>9</td>
</tr>
<tr>
<td>Macquarie University</td>
<td>MC</td>
<td>10</td>
</tr>
<tr>
<td>Monash University</td>
<td>MO</td>
<td>12</td>
</tr>
<tr>
<td>Murdoch University</td>
<td>MU</td>
<td>13</td>
</tr>
<tr>
<td>University of Adelaide</td>
<td>AD</td>
<td>1</td>
</tr>
<tr>
<td>University of Melbourne</td>
<td>ME</td>
<td>11</td>
</tr>
<tr>
<td>University of New England</td>
<td>NE</td>
<td>15</td>
</tr>
<tr>
<td>University of New South Wales</td>
<td>NW</td>
<td>16</td>
</tr>
<tr>
<td>University of Newcastle</td>
<td>NC</td>
<td>14</td>
</tr>
<tr>
<td>University of Queensland</td>
<td>QU</td>
<td>18</td>
</tr>
<tr>
<td>University of Sydney</td>
<td>SY</td>
<td>20</td>
</tr>
<tr>
<td>University of Tasmania</td>
<td>TA</td>
<td>21</td>
</tr>
<tr>
<td>University of Western Australia</td>
<td>WA</td>
<td>23</td>
</tr>
<tr>
<td>University of Wollongong</td>
<td>WO</td>
<td>25</td>
</tr>
</tbody>
</table>

Figure 4.1 - Geographical Location of Australian Universities
Support for research equipment, special research centres and key teaching and research centres comes from a variety of sources including the Australian National Research Council, the National Health and Medical Research Council, the National Energy Research, Development and Demonstration Council, and various Commonwealth departments and agencies.

Since January 1988, major changes have taken place as a result of new policies initiated by the federal government. First, the universities and centres for advanced education have been merged. Second, the federal government is committed to fewer and larger institutions through a process of amalgamation. To qualify for membership in the unified national system, an institution must have a sustainable student load of 2000 equivalent full-time student units (EFSTU). To qualify for research funding, institutions must have 5000 to 8000 EFSTU, while 8000 EFSTU is seen as a necessary size to provide the infrastructure needed for research to be carried out over a broad range of fields. Third, the government has committed itself to a significant expansion in graduate student numbers. Fourth, the newly established Australian National Research Council plays a major role in allocating research funds. Lastly, the government favours universities having governing bodies with a smaller membership and also wishes to strengthen institutional management.

4.2.2 Canada

4.2.2.1 History and Structure

The Canadian university system has been influenced by its European forebears and American neighbours as well as the nation's own unique political, cultural and geographical character. Canada has a relatively small population
(approximately 26 million), distributed in a narrow-band along the Canada-US border, with a land mass second in area only to the former Soviet Union.

Higher education began in New France (later the province of Quebec) with the establishment in 1663 of the Séminaire de Québec (now Laval University). Subsequent universities were founded in the British colonies of Nova Scotia, New Brunswick, and Upper Canada (later the province of Ontario). These early universities were denominational and modelled on European institutions. The universities of pre-Confederation Canada reflected the character of their communities and the sectarian (Anglican, Presbyterian, Methodist, Baptist and Roman Catholic) patterns of settlement. The Anglicans had a propensity for King's Colleges and established three: one founded in 1827 which became the largest university in Canada - the University of Toronto and another established in 1828 formed the basis of the University of New Brunswick. The Presbyterians founded Dalhousie University (1818), McGill University (1821) and Queen's University (1841). In some instances, these institutions were modelled on specific ancestral universities (for example, Queen's University was modelled on the University of Edinburgh). By the time of Confederation (1867) Dalhousie, McGill, New Brunswick and Toronto were independent of denominational control while the rest continued to be church-controlled institutions.

As additional territories joined Canada after Confederation, universities were established in the new provinces based on the model of the American land-grant college. The first of these was the Ontario Agricultural College (1874) (later the University of Guelph). This model came to be seen as an attractive approach to linking higher education to nation-building and was favoured by the provincial governments.
In the western provinces, although initial support for higher education came primarily from private sources, the governments' strategy was to limit the number of degree-granting institutions to one within each province: University of Manitoba (1877), Saskatchewan (1907), Alberta (1906) and British Columbia (1908). As the population grew, these universities developed affiliations with emerging or existing denominational colleges or established branch campuses. Then during the rapid economic growth in the 1960s, the 'one university' notion came to be seen as unworkable and a number of affiliated colleges and campuses were incorporated as universities. These included the Universities of Winnipeg and Brandon in Manitoba, the University of Regina in Saskatchewan, the Universities of Calgary and Lethbridge in Alberta and the University of Victoria in British Columbia.

Degree-granting institutions must be provincial incorporated by an act of parliament. They receive recognition from the scholarly community by virtue of their membership of the Association of Universities and Colleges of Canada (AUCC), a national body with 88 member institutions, 69 of which have full degree-granting authority. This organisation has no legislative authority, but in a country with a strong provincial structure, it provides an essential national voice and perspective, and allows the higher educational community to act and speak on matters of common concern.

Rapid growth in the 1960s prompted universities and governments to consider various forms of co-operative association to conserve resources and develop plans for an efficient university system. In 1967, the provinces formed their own voluntary association, the Council of Ministers of Education Canada (CMEC). This body represents a useful arena for the exchange of information and the identification of areas of potential co-operation, as well as providing a common voice for dealings with the federal government.
The universities also established their own voluntary associations. The most developed of these is the Council of Ontario Universities. Quebec has a similar organisation, the Conférence des recteurs et des principaux des universités du Québec. British Columbia has formed a more modest Tri-University President's Council. With the two largest provinces (Ontario and Quebec) having self-sufficient, internal university associations, the east and west decided to organise, respectively, the Association of Atlantic Universities and the Council of Western Canadian University Presidents.

Table 4.3 lists the Canadian universities that were examined in this research project, provides a two-letter abbreviation for twenty universities which will be used latter and gives a location number indicating where the university is located on the map of Canada presented in Figure 4.2

4.2.2.2 Finance and Research

In 1987-88 university and non-degree granting institutions received $10.9 billion or 1.9 per cent of GNP, with $7.77 billion going to the university sector. These monies were derived from the governments (provincial governments 71.2 per cent and federal government 11.9 per cent), student fees (9 per cent) and other sources (7.9 per cent). This level of expenditure placed Canada third in terms of the proportion of GNP spent on education among the nations of the OECD.

University research programmes also derive their funding from a variety of federal government departments as well as the federally funded national research councils, including, for example, National Health and Welfare ($15.9 million in 1986-87); Agriculture ($5.4 million); National Defence ($11.4 million) and Energy, Mines and Resources ($6.9 million). During 1987-88, a total of
<table>
<thead>
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<th>University Name</th>
<th>Abbreviation</th>
<th>Map Location</th>
</tr>
</thead>
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<td></td>
</tr>
<tr>
<td>Bishops University</td>
<td></td>
<td></td>
</tr>
<tr>
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Figure 4.2 - Canadian University Geographical Locations
$105 million was contributed by federal department agencies in support of
university research, including research-related student assistance.

The principal federal contribution was channelled through the three
'arms-length' granting agencies which collectively provided $574 million to
Canadian universities: $173.6 million from the Medical Research Council; $335
million from the Natural Sciences and Engineering Research Council; and $64.6
million from the Social Sciences and Humanities Research Council.

For reasons to do with Canada's size and economic structure,
universities have been the principal performers of the country's basic research.
Although provincial governments have increasingly become direct sponsors of
research (with eight now having their own granting agencies), the federal
government is still the main source of research funds. There has been a
substantial increase in the proportion of research costs incurred directly by
government and a corresponding decline in institutional operating grants in
support of research.

In recent years, there has been increasing concern about the
comparatively low level of privately-funded research in Canada. This has
resulted in a 'matching funds' strategy which involves linking growth in operating
budgets of granting agencies to contributions to specific research projects on
the part of the private sector. Under this scheme, private-sector contributions
can be used by the councils to secure further matching funds from the federal
government, up to a specified maximum level. About $45 million were received
in matching funds from the federal government for 1987-88; and during that
year, approximately $129 million in research funds were contributed by the
private sector. The federal government expects that, with additional assistance
of the matching funds strategy, about $3.7 billion will have been made available
to university research during the five-year duration of the plan (1986-87 to 1990-91).

The three granting councils have attempted to respond to the governments' desire for more 'targeted' research by developing a category of strategic grants intended to focus attention on topics considered to be of strategic national importance to the country's development. The most recent manifestation came in the form of a federal centres of excellence program designed to foster research productivity in areas of strength and encourage efficiency through the provision for inter-institutional 'net-working'. The programme dispensed $240 million over a five-year period, and applications were open to researchers in all areas of study. While stressing excellence, the programme had an additional criterion: the financial partnership with industry and the provinces and a discernible prospect for 'innovation and commercial exploitation'. The programme emphasised collaborative 'mega-projects', involving budgets of between $10 and $20 million, a large amount in Canadian terms.

Some provinces have also created similar centres of excellence. Ontario took the lead and may have provided a model for the federal initiative. Other provinces are not far behind. A provincial research policy has been established in British Columbia, aiming to support the development of technological innovations that will help the province's export potential. Efforts to support research centres of excellence at the provincial level appear increasingly to emphasise technological development. Ontario used a $1 billion technology fund, introduced in 1986, to establish seven centres of excellence and six centres of entrepreneurship. Quebec has allocated $50 million for three new centres for research and knowledge-transfer.
At both the federal and provincial government levels, there is a desire to see the appropriate ministries more active in forging research partnerships with universities and other agencies. The Ministry of State for Industry, Science and Technology has communicated through the Natural Sciences and Engineering Research Council and the Science Council of Canada (disbanded in March 1992) with a series of reports to a major study entitled *University Science and Technology and Canadian Economic Renewal*. There are two basic themes: business and industry must align themselves more closely with postsecondary institutions in terms of research, development, teaching and continuing education; and universities must develop a more effective working relationship with other institutions of post-secondary education.

Research universities have also been able to expand their staff resources without material cost through adjunct professorships (see Commonwealth Universities Yearbook 1990). This mechanism provides additional highly qualified resources from outside the university for graduate student research supervision, joint research and teaching.

### 4.2.3 United Kingdom

#### 4.2.3.1 History and Structure

The origin of British universities in the twelfth and thirteenth century can be linked to the necessity to provide professional vocational training to meet the needs of the society. The historical origins of British universities are obscure, but there is no doubt that schools existed in Oxford in the twelfth century from which the University developed and received papal recognition in 1214. However, it was not until the thirteenth century that endowed colleges became established. The first Cambridge college was endowed towards the end of the
thirteenth century after the migration of Oxford scholars in 1209 following disturbances in that city. Before the Reformation only three small colleges were founded, all in Scotland, at St. Andrews (1411), Glasgow (1451) and Aberdeen (1495). The first post-Reformation university was founded in Edinburgh in 1583.

The nineteenth century saw the major civic universities established in England, Wales and Ireland. The University of London (1836) was created to examine and grant degrees to a variety of institutions in the capital and it was empowered to recognise new institutions in London. These institutions developed as independent colleges but were brought together into a single federal University of London in 1900.

Durham was established on a collegiate basis with an ecclesiastical bias and received its charter in 1837. It formed an association with the College of Medicine established independently in Newcastle on Tyne in 1834. Newcastle was typical of the predominantly northern civic universities founded in the latter half of the nineteenth century and early twentieth century.

With the development of technology in Europe, especially engineering and the chemical industry, government leaders and businessmen encouraged the growth of local colleges to meet the demands of local industry. The metamorphosis of these colleges into the universities of Manchester (1880), Birmingham (1900), Liverpool (1903), Leeds (1904), Sheffield (1905) and Bristol (1905) was often the result of major private benefactions from local families. It coincided with the development of faculties of science and technology in the older universities. For the first time in Britain, universities became recognised as major research institutions.

Similar developments took place in Ireland with the establishment of Queen's College, Belfast (1845), and in Wales with the amalgamation in 1893 of
the three colleges in Aberystwyth (1872), Cardiff (1883) and Bangor (1884) into the federal University of Wales.

Apart from the University of Reading (1926), the first half of the twentieth century saw the development of university colleges which were extensions of the University of London. After the Second World War, some of these colleges received university status, namely Nottingham (1948), Southampton (1952), Hull (1954), Exeter (1955) and Leicester (1957).

The Robbins Committee on Higher Education (1961) reviewed the pattern of full-time education in Great Britain and based on its advice there was a major shift from a predominantly non-governmental-funded basis to one largely dependent on government for its main activities. Furthermore, a number of universities were expanded and new ones established to specialise in teaching and research in science and technology. Two kinds of institutions were promoted. On the one hand, universities like Sussex (1961), York and East Anglia (1963), Essex, Kent, Lancaster and Warwick (1964-65) in England, Stirling (1967) in Scotland and Ulster (1968) in Northern Ireland were established. On the other hand, ten colleges of technology in England and Scotland were upgraded to provide specialist technological universities as recommended by Robins namely, Strathclyde (1964), Aston, Bath, Bradford, Brunel, City, Loughborough, Surrey and Heriot-Watt (1966) and Salford (1967).

Two other universities have been established since then. The most recent at Buckingham (1973) is Britain's only independent university. The other was the Open University, considered to be one of the most imaginative university institutions to have been developed in Britain since the thirteenth century.

Other than Buckingham, all British universities receive substantial support from government. Since 1919, the funds have been channelled to them
by the University Grants Committee (UGC) which was linked to the Department of Education and Science. The UGC was composed primarily of academics nominated by the Secretary of State for Education and Science. However, the increasing cost of universities and a growing belief that universities had failed to contribute substantially to the national economy led to more direct government intervention in the 1980s.

Apart from the four ancient Scottish universities, the others were established by royal charter as autonomous bodies and each has its own system of internal government. The UGC monitored their activities, advised them, assessed their needs, protected them from government intrusion and advised government on their needs. It had been responsible for the division and allocation of funds to the universities. In July 1981, at exceedingly short notice, the government reduced the funds available to the UGC by 17 per cent over the following three years. The UGC used their judgement to decide how to allocate these reduced funds to the universities. The reductions were not applied equally to the universities; some experienced very little reduction while others were reduced by as much as 20 per cent.

The UGC responded to Conservative government policy by becoming increasingly involved in university affairs and in the last decade, up to the establishment of the University Funding Council (UFC), the UGC seemed to many to be acting as a direct agent of government policy rather than as a traditional go-between and mediator (Commonwealth Universities Yearbook 1990). The government's eagerness to reform the universities led to the production of a 'green paper' in 1985 setting out the government's ideas. This was followed by a 'white paper' in which the Government set out its aims which were later incorporated in an Education Reform Act. The Act was passed in 1988 and the UGC was replaced with the UFC in April 1989. Unlike the UGC, it has a minority of academic members.
Two further external bodies need to be mentioned since they play an increasingly important role in the relationship between universities and government namely, the Advisory Board for the Research Councils (ABRC) and the Committee of Vice-Chancellors and Principals (CVCP). The former advises government on the objectives and funding of the research councils which are the primary source of additional, external funding for university research and the CVCP presents the views of the university.

Table 4.4 lists the United Kingdom universities that were examined in this research project and gives a two-letter abbreviation that will be used later for twenty university and a map location number indicating where the university is geographically located on the map of United Kingdom presented in Figure 4.3

4.2.3.2 Finance and Research

With the exception of Buckingham, British universities are largely financed, directly or indirectly, from government sources. Apart from Oxford and Cambridge, endowment income rarely exceeds 3 per cent of income and the average is around 1 per cent.

The major element (54.6 per cent) in university funding consists of the grants determined by the UFC or, originally the UGC. In 1988-89, £140.1 millions was provided for capital expenditure and £1584.9 million for recurrent expenditure. The second largest element (19.7 per cent) of income is external research income which comes from three sources. The main source is studentships, fellowships and grants from the five research councils - Science and Engineering (SERC), Natural Environmental (NERC), Agriculture and Food (AFRC), Medical (MRC), and Economic and Social (ESRC) - which operate under the general policy direction of the ABRC. Their funds are derived solely
### Table 4.4
United Kingdom Universities

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Figure 4.3 - United Kingdom University Geographical Locations
from government. The second source of research funds is charitable donations, the majority of which are concentrated on medical research. The last source is income derived from contract research. These funds come from a multitude of sources, with an increasing amount coming from the European Community research programmes and industry.

The third element (13.4 per cent) comprising the universities income is the revenue derived from tuition fees. For many years, it has had no relationship to the actual cost of teaching and all students where charged the same amount. With the great influx of overseas students, mostly from Commonwealth countries, the government decided that it was unfair to subsidise higher education elsewhere and differential overseas student fees were introduced in 1979.

4.3 Comparison of National Science Activity

Table 4.5 provides data derived from a variety of sources on some general input-output and quality measures of the scientific research activity in the UK, Canada and Australia. The right hand column gives the three-country ratio for each of these measures. The three-country ratios for papers published in the Science Citation Index and citations received between 1980 and 1990, the world share of 1984 Science Citation Index publications and citations are broadly similar to the three-country GDP (1.0:0.63:0.29 - Table 4.1). A small effect of size may be evident since Canada and Australia consistently perform slightly lower than might be expected from the size of their GDPs compared to the UK. However, the mean number of citations per paper was approximately the same for all three countries. On the other hand, in terms of publications per 100,000 population and publications per full-time equivalent researcher, Canada significantly out-performs both the UK and Australia.
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<td>number</td>
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<td>1.03</td>
<td>1.23</td>
<td>1.07794</td>
</tr>
<tr>
<td>Clinical Medicine</td>
<td>number</td>
<td>1.83</td>
<td>0.90</td>
<td>1.14</td>
<td>1.04962</td>
</tr>
<tr>
<td>Biomedical Research</td>
<td>number</td>
<td>1.28</td>
<td>0.81</td>
<td>0.86</td>
<td>1.06367</td>
</tr>
<tr>
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<td>0.70</td>
<td>1.10</td>
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</tr>
<tr>
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<td>1.00</td>
<td>0.81</td>
<td>1.09779</td>
</tr>
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<td>number</td>
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<td>0.74</td>
<td>0.55</td>
<td>1.08161</td>
</tr>
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</table>

Sources:
3. International Science and Technology Data Update 1991, National Science Foundation

Notes:
a. year 1978
b. year 1984
c. 1981 Citation Ratios interpolated from bar graph p. 197
d. ratios are referenced to the largest value
The bottom part of Table 4.5 gives the relative citation ratios for each country's scientific publications in the 1984 *Science Citation Index* combined and for eight individual areas. The relative citation ratio is defined as the proportion of the world's citations generated by papers from a given country divided by the proportion of the world's papers (as calculated by *CHI Research*) produced by that country. A citation ratio of 1.00 reflects no over- or under-citing of a country's scientific literature, whereas a higher ratio indicates a greater influence than would be expected from the number of articles produced by that country in a given year. Even though the relative citation ratios tend to vary from year to year, the values in the table are indicative of the relative international influence of each country's scientific effort.

As might be expected, overall the UK has a better relative citation ratio (1.20) that either Canada (0.98) or Australia (0.95) both of which are very close to the world average. In individual sciences the UK has six citation ratios above or equal to the world average (physics, chemistry, biology, clinical medicine, biomedical research, and engineering and technology), Canada has five (physics, mathematics, chemistry, biology and earth and space science) and Australia has four (chemistry, biology, clinical medicine and engineering and technology). The UK has an outstandingly high citation ratio in clinical medicine and is well above average in biology and biomedical research. All three countries performed well above the world average in chemistry.

4.4 Summary

The United Kingdom, Canada and Australia have publicly financed universities which publish world-class scientific research. As expected, the UK's age, wealth, culture and tradition make it a much stronger scientific contributor
than either Canada or Australia, although their international scientific stature is comparatively high relative to their economic size.

Historically the older universities were founded in the major urban centres and/or capital cities. As the population increased, demand for higher education increased and new universities were established either within the same cities or in other urban centres. Generally speaking, many new universities were founded either during the late nineteenth and early twenty century or during rapid the economic growth in the 1960s. The universities in the three countries can be roughly categorised according to their geographical location.

The universities in the UK fall into three main regions: universities in the south and southwest including all the universities south of Birmingham and Wales; the north and Midlands including all the universities north of Cambridge and south of Newcastle-Upon-Tyne; and the universities in Scotland.

The Canadian university community is also concentrated in three distinct geographical regions. The majority of Canadian universities are located in central Canada in the provinces of Ontario and Quebec. The remainder are situated in the prairie provinces and the province of British Columbia in the west and the Atlantic provinces in the east.

The majority of Australian universities are situated in the south eastern part of Australia and over 65 per cent of them are located in just five cities. The rest of the universities are scattered around the country, primarily on the coast.

Australia has twenty universities while Canada and the UK have about the same number, forty-seven and fifty-two, respectively. However, Canada has more undergraduate and graduate students and fewer faculty members than the UK. The percentage of GDP spent on higher education research and
development was nearly the same in all three countries, while the percentage of GDP spent on all research and development in the UK was almost twice the amount spent in Canada and Australia.

In terms of scientific output, between 1980 and 1990 the UK produced nearly twice as many *Science Citation Index* publications and citations as Canada which in turn produced nearly twice as many as Australia. However, all three countries received about the same number of mean citations per paper. On the other hand, the UK had a higher overall relative citation ratio than either Canada or Australia.

Although universities in Canada and Australia were strongly influenced by their UK predecessors, they have managed to develop their own unique character. For example, Canadian universities, unlike UK and Australian universities, evolved a strong inter-university organisational structure to provide a unified voice concerning university-related governmental affairs, to minimize duplication of expensive resources, and encourage more inter-university cooperation.

In all three countries, government funds for scientific research are primarily administered by the various research councils but some project specific-finances are awarded directly by other government agencies and departments. However, during the mid 1980s, both in the UK and Australia, the research councils were restructured through government intervention. This reorganisation redefined the relationship between the universities, the research councils, and government, as well as shifting funding priorities and levels of financial support. Very little, if any, restructuring occurred in Canada.

Canada appears to be the only one of the three countries which initiated government programmes, both at the federal and provincial government level, which directly encouraged university-university collaboration. However, it is
probable that all three countries implemented programmes which promoted industry-university collaboration and which may have had the secondary effect of stimulating university-university co-operation.

The material presented in this chapter provides the background for some research questions which will be explored in later chapters. These questions are

1. Is there a relationship between GDP and national scientific output?

2. Does the university community in each of the three countries make the same percentage contribution to the national scientific output?

3. Can regional and national collaborative networks be distinguished from each other? If so, does one type of network dominant the other and does it vary with the science area?

4. Can the impact of the different inter-university organisational structures in each university communities be discerned using bibliometrics?

5. Can the effect of the government programmes designed to encourage collaboration be detected by bibliometric assessment of university-university collaboration?

Now let us turn our attention to the bibliometric techniques that were used in this project.
This chapter is devoted to a detailed examination of the methodologies used in the bibliometric assessment of *intranational* university-university collaboration. It is divided into five sections: (1) computing resources, (2) the data sets, (3) counting collaborations, (4) mathematical techniques and (5) collaboration maps. The first section describes the computing hardware, operating system and software tools that were used for data analysis and reduction. The second section discusses the structure of the data sets, the unification procedures and other bibliometric methods that were employed to prepare bibliographic data for numerical analysis and mapping. The third section analyses the technique that was adopted for counting collaborations. The fourth section specifies the mathematical techniques that were used to produce the publication, collaboration and distance matrices and derives an indicator to measure the distribution of collaborative activity in the university community. The final section outlines a prototype mapping procedure developed to dynamically display how collaborative activity in the university community had changed over time.
5.1 **Computing Resources**

Data processing was accomplished using the UNIX-based Sequent Symmetry and Solbourne minicomputers at the University of Sussex. Data reduction and intermediate data analysis was facilitated through the use of standard UNIX operating system functions, the INGRES database and software written in 'c' and PERL\(^1\) programming languages.

Final data analysis was performed on an IBM PC running Windows 3.0 with a Microsoft EXCEL spreadsheet and a SPSS statistical package. Much of the statistical analysis, graphing and table production was done with EXCEL. Dynamic collaboration maps (to be discussed in detail later) were produced using a public-domain graphing package. The software was modified specifically for the purpose of producing and displaying maps which portray the changing collaborations between the twenty most collaborative universities in each country.

5.2 **The Data Sets**

The data source used in this study was the *ISI Science Citation Index*. The UK and Australian data was derived from 1981-1990 *Science Citation Index* tapes purchased by the Science Policy and Research Evaluation group at SPRU and the Research School of Social Sciences at the Australian National University for use in the academic research performance indicators project. Special permission was granted by ISI's UK office to download the Canadian data from the BIDS database at the University of Bath in return for feedback on

\(^1\)PERL, the Practical Extraction and Report Language (developed by Larry Wall at NASA's Jet Propulsion Laboratories) is an interpreted language optimized for scanning arbitrary text files, extracting information from those files, and printing reports based on that information. It combines some of the best features of C, sed, awk and sh (UNIX functions). PERL has a GNU General Public License.
The performance of their on-line enquiry software which was then under development. The original plan was to download the data for the same years as the UK and Australia. However, the University of Bath encountered software implementation problems and only data for 1984-1990 were available for this study.

One difficulty with comparative time-series studies using the *Science Citation Index* is that over time ISI has added new journals and deleted old ones. Earlier work by Narin (1976) showed that even though journals appeared and disappeared the most significant science journals remained relatively constant. For example, he found that the number of biomedical journals covered by the *Science Citation Index* increased from 500 in 1965 to 925 in 1972 - a net gain of 425 journals. However, a constant journal set consisting of 500 journals accounted for 89.5 per cent of the publications published in that seven-year period. *CHI Research* (CHI) and the others (e.g. Anderson, Collins, Irvine, Isard, Martin, Narin and Stevens, 1988) have concluded that basing bibliometric indicators on a constant journal-set results in more easily interpretable data.

It was decided that best strategy to adopt for this three country comparative study was to use *CHI Research* 1984 journal set, consisting of 3282 journals. Only papers published in a journal from this standard journal set have been examined. An additional advantage to using this journal set is that each journal has been classified into one of nine primary CHI science areas (physics, mathematics, chemistry, biology, biomedical research, clinical medicine, earth and space science, engineering and technology and psychology) using journal-to-journal citations and cluster analysis. This provides a means for investigating university-university collaboration at the level of individual scientific areas. Since 1977, ISI has substantially reduced the number of journals covering psychology research in the *Science Citation Index* and moved them to the *Social Sciences Citation Index*. Although psychology has
been included this research project merely for comparative purposes, little effort will be spent explaining patterns and trends in this area.

5.2.1 UK and Australian Data

The UK and Australian university addresses had previously been unified to the university department level by Jim Skea and Nigel Ling from SPRU and Paul Bourke and Linda Butler from the Australian National University. They produced a thesaurus of variations for university names and departments. All colleges of the University of London (Bedford, Berbeck, Chelsea, City University, Goldsmith, Kings, Hings, Imperial, Queen Mary, Royal Holloway) where unified under the University of London.

Australian universities have been undergoing restructuring since 1986 and the number of universities has risen from twenty to thirty-three. Upon examining the effect of this restructuring, the Australian research team concluded that more than 97% of the papers published between 1986 and 1990 were produced by the original twenty universities. Therefore, only publications from these twenty universities were used in this analysis.

Some difficulty was encountered unifying teaching hospitals (i.e. hospitals affiliated with a university). An example of one such problem is a physician working at a teaching hospital who is not a faculty member of the affiliated university. Publications from such individuals only list the hospital address and not the university address. Problems such as these prevent teaching hospitals from being categorically unified under a specific university. For simplicity, it was assumed that if the author(s) of a paper did not include a university address, then no university affiliation existed. This is not a completely satisfactory solution but short of verifying each hospital publication with the author(s), it was judged to be an acceptable technique.
The following is a sample record for a 1990 ISI publication (article number ZZDK %) from the raw data:

```
ZZDJ9V 0PHYS REV A 004089 N11 CE723 KDQS
ZZDK %11BARNETT SM 6314 6320 1 01 BARNETT SM 0631406320
ZZDK %12GILSON CR 00 GILSON CR
ZZDK %1 REPRT01 81UNIV OXFORD,DEPT ENGN SCI,PARKS RD/OXFORD OX1 3P
ZZDK %1 82J/ENGLAND/
ZZDK %1 01 81UNIV NEWCASTLE UPON TYNE,DEPT MATH & STAT/NEWCAS
ZZDK %1 82TLE TYNE NE17RU/TYNE & WEAR/ENGLAND/
```

Software written by Jim Skea processed the raw ISI data to produce one clean data set for the UK and one for Australia. These data only contained Science Citation Index publications which possessed a UK or Australian university name in the address field. One data record was produced for each university associated with a publication. No data records were produced for domestic non-university or foreign institutions. In the above example, there are two universities, Oxford and Newcastle Upon Tyne, and therefore two data records where produced. Each record contained the following information: ISI article number (6 characters), collaboration code (1 character), journal name (11 characters), publication year (2 characters), tape year (2 characters), number of collaborating institutions (2 characters), number of collaborating authors (3 characters), institution type code (3 characters), publication type (1 characters) and city, university and department (separated by commas).

Processing the example publication given above produced the following records:

```
ZZDK %3PHYS REV A 899002002age 1OXFORD,UNIV OXFORD,DEPT ENGN SCI
ZZDK %3PHYS REV A 899002002ama 1NEWCASTLE TYNE,UNIV NEWCASTLE UPON TYNE,DEPT MATH & STAT/NEWCAS
```

These data were then reprocessed to include an additional field that specified the science area to which the journal belonged as derived from the CHI journal classification scheme. Also, each field in the record was delimited...
with colons for easier visual scanning and processing by the PERL programs.

The above example was processed into the following records:


5.2.2  Canadian Data

The Canadian data were processed in a slightly different manner. For each year between 1984 and 1990, all publications in the BIDS database that contained the keyword 'Canada' in the corporate address field were selected. These publications were downloaded to a UNIX machine at the University of Sussex. One year of data typically contained 25-35,000 publications and required 20-30 hours to download. It should be noted that these data contained Current Contents publications as well as publications from the Science Citation Index journal set. The following is an example publication from the BIDS database:

Article 100 (total of 30597 in this set)

TI: DIVERSITY OF CUCUMBER CHITINASE ISOFORMS AND CHARACTERIZATION OF ONE SEED BASIC CHITINASE WITH LYSOZYME ACTIVITY
AU: MAJEAU_N, TRUDEL_J, ASSELIN_A
NA: UNIV LAVAL,FAC SCI AGR & ALIMENTAT/QUEBEC CITY G1K 7P4/QUEBEC/CANADA/
     UNIV TORONTO,DEPT BOT/TORONTO M5S 1A1/ONTARIO/CANADA/
JN: PLANT SCIENCE 1990 VOL.68 NO.1 PP.9-16
DT: ARTICLE

As can be seen from the example, each publication record contains a title field (TI:), author field (AU:), corporate address field (NA:), journal field (JN:) and publication type field (DT:). This data was converted into a format similar to that used for the UK and Australian data by parsing it with a PERL language program. The resultant data were not unified and contained publications from any Canadian institution and their foreign collaborators.

Next a PERL program was used to compile a list of Canadian institutions that contained either the keyword 'UNIV' (an ISI abbreviation for university) or a
valid university postal code in the corporate address field. A thesaurus of Canadian universities for each entry in the list was derived from the Commonwealth Universities Yearbook 1990. University-affiliated institutions where also included. Publications from the University of Quebec, which has six campuses in different geographical locations in the province of Quebec, were all unified to the University of Quebec. Again, a problem was encountered with teaching hospitals. The same technique that was used for the UK and Australia data was applied to the Canadian data.

Unlike the UK and Australia ISI data and the CHI Research Inc. journal set which uses an eleven character journal abbreviation, the BIDS database uses full journal names. A dictionary of abbreviated and full journal names therefore had to be compiled so that a CHI science area could be assigned to each Canadian publication.

Finally, a PERL program which used the university thesaurus and the journal dictionary was employed to reprocess the non-unified data to produce a data set that contained only university publication records with abbreviated journal names and the appropriate CHI journal classification. All journals not contained in the CHI standard journal list (including Current Contents journals), were assigned an 'unknown' science area classification. The following two records illustrate the result obtained by reprocessing the publication from the preceding example:

5.3 Counting Collaborations

No well-formulated methods were found in the literature for counting institutional collaborations but some productivity measures were located. These measures were examined for their suitability for counting institutional collaboration.

Price and Beaver (1966), Nudelman and Landers (1972), Lindsey (1980), and Pravidic and Oluic-Vukovic (1986), among others, have argued that productivity investigations should adjust for the number of collaborating authors. In essence, the problematic question they tried to answer was the following: 'If more than one author contributes to the publication of a single paper, should each author be allocated full credit for the paper or should the credit be equally distributed among the contributors?'.

Lindsey argued that ‘one paper is one paper’ and that an adjustment must be made so that the total credit allocated to a paper is independent of the number of authors. He adopted Narin's (1976) suggestion and defined an adjusted measure where each of n authors of co-authored paper is given a fractional credit value of 1/n. In contrast, the unadjusted measure credits each author with the whole paper or a credit value of one. Long and McGinnis (1982) compared both techniques and found that, contrary to Lindsey's findings, there appeared to be no significant difference between the results obtained with adjusted and unadjusted measures. They concluded

We believe that his (Lindsey's) theoretical argument fails to take account of the way in which the scientific community evaluates productivity. We do not pretend to know precisely how this process operates. But we do find it a bit far-fetched to think that throughout the scientific community it consists of applying a deflation factor equal to the inverse of the total number of co-authors, as Lindsey insists. [Long and McGinnis, 1982 pp 386]
Furthermore, a positive relationship has been found between citation frequency and multiple-authorship (Bayer and Folger, 1966; Garfield, 1970, Lawani, 1977; and Lawani and Bayer, 1983). This would appear to support the old adage that 'two minds are better than one'. A multiple-author paper may have a greater perceived value than a single author paper which would again suggest that Lindsey's notion is invalid. There does not appear to be a rigourously derived method for determining the true value of a multiple-author paper.

Even if there were no criticisms of the adjusted counting method, there is a major problem with using it in this study. To properly allocate the contribution of each author to the appropriate institution, one has to be able to determine which author is associated with which institution. This is not possible with the Science Citation Index data since it does not provide information on individual author-institution affiliations. Therefore, in cases where the number of authors is greater than the number of institutions, there is no way of determining which author resides at which institution.

Narin (1976) claimed that multiple-authorship problems arose less often in institutional publication counts since there are seldom more than one or two institutions involved in a publication. Consideration was given to the possibility of fractionating each paper according to the number of institutions involved. However, this seemed to be unfair in certain instances. Consider the example of a publication with 3 authors and two institutions where two authors reside at one institution and one author at the other institution. If each author participated fully in this collaboration, then it would seem unfair to allocate the institution with two authors 1/2 of the credit when its researchers actually contributed 2/3 of the effort. In addition, many of the institutional collaborations are heterogeneous and involve foreign institutions and domestic non-university institutions. In order to properly allocate credit to an institution all the institutional addresses would have to be unified and this was beyond the scope of this project.
The object of this study was to focus on collaborations within the university community and adjusted productivity measures were judged to be invalid measures of this activity primarily because of the heterogeneity problem. After careful consideration, it was decided that the counting technique should indicate how 'attractive' an university appears to be to the rest of the domestic university community for forming collaborative linkages. A university may be attractive for many different reasons ranging from the quality of its researchers to the uniqueness of its instrumentation and facilities. A technique which seemed to adequately measure the collaborative attractiveness of a university was one which counts the number of 'pairings' a university has with other universities.

Consequently, the technique which was adopted for this research project was to count the number of two-way collaborations that occur in each publication. For example, a paper listing four universities A, B, C and D would be counted as having six two-way collaborations: A-B, A-C, A-D, B-C, B-D and C-D. It will be shown later over 90% of all intranational university-university collaborations only involve two universities. The average number of two-way university-university collaborations ranged from 1.2 to 1.4 collaborations per paper.

In general, if the number of institutions, n, is greater than one, the number of two-way collaborations, c, is given by

\[ c = \frac{n!}{2(n-2)!} \]  

(5.1)

Two-way collaboration counting is relatively simple to perform and is outlined in detail in the next section.
5.4 **Mathematical Techniques**

Several mathematical techniques were used to reduce and analysis the unified data. This section details the methods used to produce the publication, collaboration and radial distance matrices and to calculate the national collaboration vector, a measure of the distribution of collaborations among the universities with a nation.

5.4.1 **Publication Matrix**

The data for each country and for each year were processed separately. One publication matrix was produced for each of the nine CHI science areas as well as for all these areas combined (which will be referred to as the aggregate). Therefore, in total one hundred publication matrices were produced for Australia and the UK and seventy (for the years 1984-90 inclusive) for Canada.

Before a publication analysis can be done, a fundamental decision has to be made as to which publications to count. In this case the question which had to answered was which publication types most accurately reflect the scientific output of the university community. A decision was made to use the article, note and review publication types only, partly because these publication categories contain substantial contributions to scientific knowledge and partly because Narin (1976) claims that these publication types accurately represent the core scientific literature and are a good measure of science output.

A publication matrix is a binary, university by publication, matrix where the entries in each cell are either a 1 or 0. Each row in the publication matrix represents one publication; each column represents one university. If a given university participates in a publication its column entry for that publication is assigned a 1, otherwise it is assigned a 0. Formally, a publication matrix can be defined as follows:
Given a set of universities, \( U = (u_1, u_2, u_3 \ldots u_n) \), and a set of publications, \( P = (p_1, p_2, p_3 \ldots p_m) \), the publication matrix \( Q \) is a \( n \times m \) binary matrix where \( Q_{ij} = 1 \) if \( u_i \) is listed in \( p_j \), otherwise \( Q_{ij} = 0 \).

By way of illustration, consider an example consisting of five publications from a community of four universities: A, B, C, and D. Assume the publications involved the following university collaborations: (1) AB, (2) AD, (3) BD, (4) ACD and (5) BCD. Using the above definition of a publication matrix, the result would be

\[
Q = \begin{pmatrix}
1 & 0 & 0 & 0 \\
1 & 0 & 0 & 1 \\
0 & 1 & 0 & 1 \\
1 & 0 & 1 & 1 \\
0 & 1 & 1 & 1
\end{pmatrix}
\]

where the columns indicate university A, B, C and D, respectively, and the rows indicate paper one to five, respectively.

### 5.4.2 Collaboration matrix

A collaboration matrix is a square, university by university, matrix that records the number of two-way collaborations that one university has with another university. This matrix is derived from the publication matrix by multiplying the transpose of the publication matrix, \( Q^T \), by the original matrix, \( Q \). Therefore, the collaboration matrix, \( C \), is given by

\[
C = Q^TQ \quad (5.2)
\]

The diagonal cells, \( C_{ij} \) where \( i=j \), in the resultant publication matrix contain the number of papers in which \( u_i \) participated; the remaining cells, \( C_{ij} \) where \( i \neq j \),
contain the number of *two-way collaborations* between \( u_i \) and \( u_j \). If we use the example publication matrix above, the resultant collaboration matrix would be

\[
C = \begin{pmatrix}
1 & 1 & 0 & 1 & 0 \\
1 & 0 & 1 & 0 & 1 \\
0 & 0 & 0 & 1 & 1 \\
0 & 1 & 1 & 1 & 1
\end{pmatrix}
\begin{pmatrix}
1 & 1 & 0 & 0 \\
1 & 0 & 0 & 1 \\
0 & 1 & 0 & 1 \\
1 & 0 & 1 & 1 \\
0 & 1 & 1 & 1
\end{pmatrix} = \begin{pmatrix}
3 & 1 & 1 & 2 \\
3 & 1 & 3 & 1 \\
1 & 1 & 2 & 2 \\
2 & 2 & 2 & 4
\end{pmatrix}
\]

In the resultant matrix, \( C \), both the rows and columns indicate universities A, B, C, and D, respectively. The diagonal elements show that A was involved in three multi-university publications, B in three, C in two and D in four. The contents of the first row indicate that A was involved in one two-way collaboration with B, one with C and two with D.

### 5.4.3 Radial distance matrix

The radial distance matrix, \( R \), is a square, university by university, matrix that contains the radial distance in kilometres between pairs of universities within a country. The diagonal cells have been set to zero; \( R_{ij} = 0 \) where \( i=j \), i.e. the distance between any university and itself is zero. The remaining cells, \( R_{ij} \) where \( i \neq j \), are assigned the distance in kilometres between \( u_i \) and \( u_j \).

Universities in the same city were arbitrarily assigned a distance of 25 km. In order to facilitate country comparisons, the inter-university distances for each country were normalised by dividing by the distance that separated the two most distant universities in that country.

The normalised radial distance matrix was used in conjunction with the collaboration matrix to determine the effect of distance on level of collaboration. A tabulation was made of the number of two-way collaborations that occurred in each 0.1 distance interval (0.000-0.099, 0.100-0.199, ..., 0.900-1.000) between 0, the minimum, and 1.0, the maximum.
5.4.4 National Collaboration Vector

The collaboration matrix was used to derive a vector-based indicator which measures how evenly the collaborations were distributed among the universities in the community. Also, this indicator was designed to determine whether the distribution of collaborations in the university community had changed over time.

A vector is a quantity with both a magnitude (size) and a direction. It is frequently represented by a straight line whose length represents the magnitude of the vector and whose angles with the x- and y- axes in two-dimensions (or with x-, y- and z-axes in three-dimensions and so on) specify its direction. The distribution indicator is only derived from the magnitude of a vector and not its direction and it is only concerned with vectors which are represented by lines which begin at the origin. Such a two-dimensional vector, \( V \), is specified by the starting-point, \((0,0)\), and the end-point, \((x,y)\), and its magnitude, \(|V|\), is given by the Pythagoras theorem

\[
|V| = \sqrt{x^2 + y^2}
\]

Similarly, a three-dimensional vector, \( V \), is specified by the starting-point, \((0,0,0)\), and the end-point, \((x,y,z)\) and its magnitude is again given by the Pythagoras theorem

\[
|V| = \sqrt{x^2 + y^2 + z^2}
\]

In the more general case, a vector, \( V \), can exist in an n dimensional euclidean space which is composed of n orthogonal axes. This vector is defined by the starting-point, \((0,0, \ldots 0)\), and end-point, \((v_1,v_2,v_3 \ldots v_n)\) and its magnitude, \(|V|\), is also given by the Pythagorus theorem.
\[ |V| = \sqrt{v_1^2 + v_2^2 + v_3^2 + \ldots + v_n^2} \]  

(5.3)

A row (or column) from a matrix or derived from a matrix can be represented by a vector, provided each element in the row (column) is independent of every other element in the row (column) - that is, the elements are orthogonal. The number of axes needed to specify this vector is equal to the number of elements in the row (column).

Consider as an example a three-by-three university collaboration matrix where the diagonal elements have been set to zero. The columns have been individually totalled to yield a row of three numbers that specify the total number of two-way collaborations for each university:

\[
\begin{pmatrix}
0 & 2 & 3 \\
2 & 0 & 4 \\
3 & 4 & 0 \\
5 & 6 & 7
\end{pmatrix}
\]

The column totals can be considered to be a vector, the *national collaboration vector*, representing the total collaborative activity of the three universities. This vector is specified by the coordinates (5,6,7) and its magnitude is

\[ |V| = \sqrt{5^2 + 6^2 + 7^2} = 10.49 \]

It is important to realise that |V| would have the same value for any arrangement of two-way collaboration totals 5, 6 and 7 among the three universities. In other words, |V| would be 10.49 if V was (5,7,6) or if V was (7,5,6), and so on. The magnitude of the national collaboration vector, |V|, is a measure of the distribution of collaborative activity among the universities in a country which is not dependent on the ordering of this collaborative activity. It will be shown that
smaller values of $|V|$ indicates a more even distribution of collaboration activity in the university community while larger values of $|V|$ indicate a concentration of collaboration activity among just a few universities.

Let us summarise the discussion to this point in a more formal manner. For a given collaboration matrix, $C$, with the $C_{ij} = 0$ when $i = j$ (diagonal elements equal zero), the national collaboration vector, $V = (\sum_{j=1}^{n} C_{1j}, \sum_{j=1}^{n} C_{2j}, \ldots, \sum_{j=1}^{n} C_{nj})$, has a magnitude, $|V|$, given by

$$|V| = \sqrt{\sum_{i=1}^{n} \left( \sum_{j=1}^{n} C_{ij} \right)^2} \quad (5.4).$$

An additional parameter that will be required is the total number of two-way collaborations. This is determined by summing all the cells in the collaboration matrix and dividing the result by two because the matrix is symmetrical and each collaboration will have been recorded twice. Formally, the number of two-way collaborations, $m$, is given by

$$m = \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij} \quad (5.5)$$

Now, in order to determine the maximum and minimum magnitude of the national collaboration vector, assume that a country has $n$ universities with a total of $m$ two-way collaborations. Consider the following two cases.

**Case 1:**

Assume that all the collaborations are equally distributed among the universities. Each two-way collaboration must be shared between two universities and therefore each university has $\frac{2m}{n}$ two-way collaborations. The magnitude of the national collaboration vector, $|V|$, is
\[ |V|_{\text{min}} = \sqrt{\frac{(2m)^2}{n^2} + \frac{(2m)^2}{n^2} + \cdots + \frac{(2m)^2}{n^2}} = \sqrt{\frac{n(2m)^2}{n^2}} = \frac{2m}{\sqrt{n}} \]

Case 2:

Assume that all the collaborations occur between only two universities, \( u_i \) and \( u_j \). Each of these universities has \( \frac{2m}{2} \) collaborations and the magnitude of the national collaboration vector, \( |V| \) is

\[ |V|_{\text{max}} = \sqrt{0^2 + \cdots + m^2 + \cdots + 0^2 + \cdots + m^2 + \cdots + 0^2} = m\sqrt{2} \]

The magnitude of the collaboration vector, \( |V| \), is bounded at the lower limited by case 1 (collaborations are equally distributed among all universities) and at the upper limit by case 2 (collaborations are concentrated in just two universities) or

\[ \frac{2m}{\sqrt{n}} \leq |V| \leq m\sqrt{2} \]

Normalising this relationship to the total number of collaborations yields

\[ \frac{2}{\sqrt{n}} \leq \frac{|V|}{m} \leq \sqrt{2} \]

In other words, when \( m \) collaborations are distributed equally among \( n \) universities \( \frac{|V|}{m} = \frac{2}{\sqrt{n}} \) and when they are concentrated in two university

\[ \frac{|V|}{m} = \sqrt{2} = 1.414 \]. Using the previous example, the national collaboration vector, \( V = (5,6,7) \), would have a normalised magnitude, \( \frac{|V|}{m} = \frac{10.49}{9} = 1.165 \) which is greater than \( \frac{2}{\sqrt{n}} = 1.15 \) and less than 1.414.
The derivation of this indicator required the assumption that each university acts autonomously\(^2\). In other words, the administrative policies of a university and the activities of individual researchers are determined within the university and not by individuals at another university. This does not imply that socio-political influences do not exist between universities but rather it assumes that the action regarding collaboration and publication is usually left in the individual researcher's hands.

### 5.5 Collaboration Maps

The distortions introduced by multidimensional scaling techniques and the difficulty of justifying the use of any given normalisation procedures (see Chapter 3 for a discussion of these issues) inspired a commitment to exploring the possibility of developing a new mapping technique - a dynamic mapping technique which might allow investigators and policy researchers to examine how collaboration patterns change over time.

The research objective was to develop a computer-based mapping program which used approximate geographical locations of the universities as a template and dynamically displayed the intensity of the collaborative activity among university community members using interconnecting lines of varying thickness. The idea for this dynamic mapping procedure was partly based on the 'flicker' technique used in astronomy to distinguish stars from planets in a series of photographs of the night sky. When the photographs are projected in rapid succession, the spots on the photograph that flickered could be

\(^2\)This derivation is based on multidimensional Euclidean geometry and assumes that the axis are orthogonal. In order for this assumption to be valid we must assume that each university acts autonomously. In formal terms, each university's collaborative involvement is considered to be a vector lying along an axis which is at right angles to all the other universities axis and from a national point of view is considered to be a component of the national vector.
interpreted as planets because they moved a small amount from frame to frame while those spots that did not flicker were stars because they did not move. Similarly, the stable linkages in densely interconnected collaboration maps shown in rapid succession will persist on the computer display while those that varied will flicker. This provides a method for easily visualising the stable collaboration linkages in a university community.

After careful deliberation, it was decided that the mapping software should run on a personal computer because these are most commonly used by policy researchers. A number of professional graphics software packages were examined but none were found to be suitable for this application. Finally, a search was made for a public domain graphing package which could be modified. After a few months of investigation, an IBM PC xy plotting program with the required features was located in a public domain software archive on a US military computer. The program was downloaded and a preliminary investigation was initiated. Although the package was not as flexible as might have been wished, it was adequate for producing a prototype dynamic mapping technique.

Approximate geographical university location maps were produced for the UK, Canada and Australia using x,y coordinates derived from maps found in the Commonwealth Universities Yearbook 1990. After experiments with these maps, it was discovered that the PC's screen resolution (for VGA screens) posed a fundamental limitation and it was decided to restrict the number of displayed universities to twenty. This is not a particularly serious limitation because there are only twenty universities in Australia and the top twenty universities in the UK and Canada account for more than 85% of university-university collaborations.
Different techniques for determining the thickness of the lines joining pairs of collaborating universities were explored. Again limitations due to the screen resolution and the inherent characteristics of the xy plotting program were encountered. However, a satisfactory prototype dynamic mapping methodology was established. It was decided that three-year running averages should be used to smooth out the uneven collaborative activity. The procedure for producing the maps for each country for each science area is described in what follows.

**Step 1.**

A set of ten collaboration matrices were selected; one for each year for a given science area. These matrices were used to produce eight running average map matrices by combining three years of data in an overlapping fashion. In others words, data for 1981 to 1983 were added together cell by cell to produce the first map matrix; data from 1982 to 1984 were combined to produce the second map matrix; and so on until data from 1988 to 1990 was added together to yield the eighth map matrix.

**Step 2**

For each map matrix, the average number of two-way collaborations, $C_{\text{ave}}$, and the pair of universities with the maximum number of two-way collaborations, $C_{\text{max}}$, were determined. In order to maximise $C_{\text{ave}}$ only universities that had at least one two-way collaboration were included in the calculation.

**Step 3**

The $x,y$ coordinates and thickness of each line joining pairs of collaborators, $C_{ij}$, were determined. The thickness was calculated using the parameters in the following table.
Table 5.1

Map Line Thickness

<table>
<thead>
<tr>
<th>Interval</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{ij} &lt; C_{ave}$</td>
<td>None</td>
</tr>
<tr>
<td>$C_{ave} \leq C_{ij} &lt; \frac{(C_{max} \cdot C_{ave})}{3}$</td>
<td>Thin</td>
</tr>
<tr>
<td>$\frac{(C_{max} \cdot C_{ave})}{3} \leq C_{ij} &lt; \frac{2(C_{max} \cdot C_{ave})}{3}$</td>
<td>Medium</td>
</tr>
<tr>
<td>$\frac{2(C_{max} \cdot C_{ave})}{3} \leq C_{ij} \leq C_{max}$</td>
<td>Thick</td>
</tr>
</tbody>
</table>

Step 4

Each of the eight maps was drawn using the xy plotting program and saved on a diskette. These maps were then used as an input to a 'map playing' program capable of displaying the maps in sequence. The software allowed the user to step forward (or backward) through the sequence slowly or to cycle them forwards (or backwards) in rapid succession.

5.6 Summary

The preceding discussion details the procedures and techniques used to process and analyse the Science Citation Index publication data, the results of which will be explored in the next chapter. The general approach involves unifying the university addresses and assigning a CHI science area to each publication in the data-set. The unified data is used to produce one publication matrix for each CHI science area for each year. These matrices are then algebraically manipulated to produce collaboration matrices. Also, the unified data is employed in the determination of other factors such as the university scientific output and the overall university collaboration activity (i.e. university collaborations with any domestic or foreign institution).
A radial distance matrix is produced for each country by measuring the geographical distance between pairs of universities within a given country's university community. This matrix is used in conjunction with the collaboration matrices to investigate the effect of geographical proximity of collaboration activity.

The collaboration matrices for the individual CHI science areas are used as the input to the mapping program which produces dynamic maps of the collaboration activity in each university community. These maps are examined visually to see which collaboration linkages are stable and which linkages change over time, and how the collaborative network pattern varies across science areas.

The magnitude of the national collaboration vector is also calculated using the collaboration matrices. This information is used to see how evenly (or unevenly) distributed the collaborations are within a university community and how the distribution varies across the individual science areas with time.
Part Two

The Bibliometric Findings and Discussion

There are three ways of arriving at truth: authority, which can only produce faith, and must, moreover, justify itself in the eye of reasoning; reasoning, the most certain conclusions of which leave somewhat to be desired, unless one verifies them; and, finally, experiment, which suffices by itself.

[Thirteenth century English monk - Roger Bacon - footnote in Compayre G. Abelard and the Origin and Early History of Universities (1893) p 300]
Part two of the thesis presents the findings and discussion of the bibliometric assessment of university-university collaborations in Australia, Canada and the United Kingdom. This part is divided into three chapters: scientific output; university collaboration; and collaboration maps.

Chapter 6, on *scientific output*, examines the national scientific output, university scientific output and the relationship between university size and scientific output using the number of published scientific research papers as a measure of scientific activity. Baseline statistics are presented which will be used in subsequent sections.

Chapter 7, *on university collaboration*, is composed of five sections each of which investigates collaboration in the university community from a different perspective. The first section looks at the overall collaborative activity in the university community without regard for the type of collaborative partner. It is here that an interesting issue is raised about the fundamental nature of institutional collaboration and in the second section this issue is analysed within the context of the number of authors and the number of institutions that are listed on a publication. The third section focuses on the growth of university-university publications throughout the decade in Australia, Canada and the UK. The fourth section uses the notion of a two-way collaboration to do the following: to examine the relationship between the average number of collaborations per paper and the science area; to perform inter-country comparisons of collaborative activity within a basic versus applied research framework; to do an *intranational* comparison by science field of university-university collaborations; to analyse the relationship between university scientific output and university-university collaborative activity; and to determine whether there is a relationship between geographical proximity and the amount of collaboration. The fifth section describes the use of a vector analysis
technique to see how the distribution of collaborations in each university community has changed with time.

Chapter 8, on collaboration maps, explores a prototype dynamic mapping technique which is used to visualise university-university collaborative linkages within the university communities. The first two sections explain how to use the map-viewing software and how to interpret the maps. The third section investigates an interesting feature of the collaboration maps that seems to be common to all three countries. (A detailed description of the collaboration maps for each CHI science area for each country is given in the appendix.) The mixture of national (or inter-regional) and regional (or intra-regional) collaborative networks in each CHI science area appears to be a broadly similar in Canada, Australia and the UK. By way of illustration we shall examine the Canadian maps for three CHI science areas - physics, earth and space sciences and clinical medicine.

The policy implications of the results described in these chapters will be presented in a separate section in the conclusions chapter.
Scientific Output

The scientific output of a country, institution, group or individual is difficult to measure because it takes a variety of forms: scientific publications; patents; new or improved instruments; trained undergraduate and graduate students; knowledge and products transferred to industry; public awareness; and even advice on science policy. The list is almost endless. The easiest component of scientific output to enumerate is scientific publications. Although it is difficult to prove that the number of publications is a valid partial indicator of scientific output, it has been argued that at least in more basic research most scientific results are published in journals or conference proceedings. However, bibliometric measures of scientific output should only be considered to be a partial indicator of scientific achievement.

The best sources of publication data are in databases such as Inspec, Biosis, Physics Briefs, Chemical Abstracts, Medline, and the Science Citation Index. However, these databases are designed primarily for bibliographic

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searches and most of them are not amenable to bibliometric assessment. The choice about which database to use for this project was restricted to the Science Citation Index because it is the only database that contains the names and full addresses of all the authors, a feature which facilitates selection and enumeration of publications by institution and country. In comparison, other databases record only the first author or do not provide information on institutional affiliations (Moed, 1991). Furthermore, unlike other abstracting or indexing sources which cover some journals completely and others selectively, the Science Citation Index indexes every entry from any journal it covers (Narin, 1976). This gives better reliability for country and institutional comparisons.

6.1 National Scientific Output

The overall scientific output from the UK, Canada and Australia had first to be measured in order to establish a baseline for comparative purpose. Some difficulty was encountered in doing this because the primary source of the UK and Australia data used in this study was the set of Science Citation Index tapes and the unified data sets contained only publications from universities. The Canadian data were derived from an on-line database which contained publications not only from the Science Citation Index journal set but also other publications listed in Current Contents.

In order to ensure comparability, the national scientific output for each country needed to be determined from the same source. The numbers of

3The UK and Australian data were derived from 1981-1990 Science Citation Index tapes purchased by the Science Policy and Research Evaluation group at SPRU and the Research School of Social Sciences at the Australian National University for use in the academic research performance indicators project.

4Current Contents covers all the journals that the Science Citation Index covers plus some others.
articles, notes and reviews published by UK, Canadian and Australian authors were counted using on-line access to the Science Citation Index via the University of Bath ISI Database Service (BIDS). At the time that these counts were made, BIDS only covered publications archived in 1984-92 tape years\textsuperscript{5}. The disadvantage of using BIDS was that the Current Contents publications could not be separated from Science Citation Index only publications\textsuperscript{6}.

Before the final counts were made, a corporate address search strategy was developed to minimise interference from such things as publications from 'New South Wales' being included in publications from 'Wales'. The UK search strategy required the construction of two sets. One set contained publications (articles, notes and reviews) which had the keywords 'England', 'Wales', 'Scotland', or 'Ireland' in the corporate address field. The other set contained publications with 'New England' or 'New South Wales' in the corporate address field. A final set was composed by selecting publications that appeared in the first set and not the second. This search strategy was not ideal because papers that were co-authored by a UK and a New South Wales author were eliminated from the final publication set. However, very little overlap was observed.

\textsuperscript{5}The tape year is the year in which the publication was recorded in the Science Citation Index whereas, the publication year is the year in which the paper was published in the journal. Usually, a publication is recorded in the database in the year in which it was published. However, in some instances a publication is published in a previous year and recorded in a subsequent year (usually the next year). This could be due to distribution or printing delays. In other instances, the publication is recorded in a tape year which precedes the publication year. This can be due to the fact that some journals are distributed prior to the indicated publication date. For example, a publisher may distribute the January issue of their journal in December of the preceding year.

\textsuperscript{6}The on-line user software for BIDS does not have an option which allows the user to discriminate between Current Contents and Science Citation Index journals. Therefore, the national scientific output counts will be slightly inflated due to the contribution from the Current Contents journals. A conversation with an ISI representative in the UK office indicated that in 1990 there were about 10 per cent more journals in Current Contents than in the Science Citation Index. The additional journals include such publications as Omni Magazine, a popular magazine, and journals that publish unrefereed papers. One could estimate that Current Contents may only contribute a 3-5 per cent inflation in the number of articles, notes and reviews that were counted using BIDS.
between the two sets resulting in a very small under estimation of the UK scientific output. The Canadian and Australian scientific output was measured simply by counting the number of publications that had the keywords 'Canada' or 'Australia' in the corporate address. A visual inspection of a few of hundred records for each of two years from each country revealed no examples of interference and therefore a fair degree of confidence can be attributed to these measurements.

Figure 6.1 depicts the national science output for each country. All three countries exhibited an increase in their published scientific output. Canada had the greatest growth at 4.5 per cent per annum, followed by Australia with 3.9 per cent and the UK with 3.2 per cent. The ratio of the scientific outputs summed over the years between 1984 and 1990 was 1.0:0.54:0.25 (UK:CANADA:AUSTRALIA). In other words, the UK produced almost twice as many publications as Canada which in turn produced a little more than twice as many publications as Australia. This was very similar to the ratio of their GDPs which was 1.0:0.63:0.29 in 1988 (see Table 3.1). This suggests that there may be a relationship between national scientific output and economic size, a observation first made by Price (1969).

6.2 University Scientific Output

The scientific output for the universities in each country was determined by counting the articles, notes and reviews in the unified Science Citation Index data sets that contained at least one domestic university name in the corporate address field. The strong growth of Canadian university scientific output is a noticeable feature of the graph shown in Figure 6.2. In 1984 Canadian
Number of Science Citation Index publications, including Current Contents, derived from the Bath University Institute for Scientific Information Data Service (BIDS) on-line service.
Number of *Science Citation Index* publications published each year that contained at least one domestic university name in the corporate address field.
universities published approximately 15 per cent less than their UK counterparts. Their output grew steadily at 5.4 per cent per annum and by 1990 it had surpassed the UK output by approximately 9 per cent. UK universities produced an almost constant number of publications from 1981 to 1984, then they experienced a growth of 2.2 per cent per annum from 1984 to 1989, followed by a decline of 5.7 per cent in 1990. Australian university output underwent a decline of 0.6 per cent per annum between 1981 and 1984, and then exhibited a growth rate of 2.1 per cent per annum between 1984 and 1989 which was followed by a decline of 6.7 per cent in 1990. Before one can attach any significance to the decline in the UK and Australian university outputs in 1990, one would have to eliminate the possibility that they were simply statistical fluctuations in the time series\textsuperscript{7}. In order to do this at least two more years of data would have to be analysed.

Now let us examine these scientific outputs in terms of productivity. First, we shall assume that the number of full-time academic staff remained constant from 1984 to 1990. Although this assumption is not completely accurate because the number of full-time academic staff increased slightly in the UK\textsuperscript{8} and fluctuated in Australia\textsuperscript{9}, it will allow us to get a sense of the relative

\textsuperscript{7}The university scientific output data for all three countries was based on the tape year. The possibility that the fluctuations may be an artifact due to such things as the UK and Australian data being derived from the publication year and the Canadian data from the tape year can be ruled out.

\textsuperscript{8}For example, if one compares the number of full-time academic staff (wholly university financed and other) in University Statistics 1985-86 and University Statistics 1988-89 produced by Universities Statistical Records, one can see that there was an increase of approximately 1 per cent.

\textsuperscript{9}Examining Figure 2.11 in Profile of Australian Science p29 produced by Australian Science and Technology Council (1989) published by Australian Government Services it can be seen that the number of full-time equivalent academic and teaching staff in Australian universities declined from approximately 3.3 per cent between 1981 and 1983 and then grew by 1.8 per cent between 1983 and 1985.
productivities. The results\textsuperscript{10} show that Australian universities had an average productivity of 0.58 publications/full-time academic staff, while for Canadian universities the figure was 0.50 and for UK universities it was 0.42. University statistical records for the UK show that in 1990 approximately 50 per cent of the full-time staff were employed in science areas\textsuperscript{11}. If the other countries have a similar percentage of their staff employed in the sciences, then universities in all three countries are producing on the average about one publication (article, note or review) per full-time scientific staff member per year. Although this estimate is very crude, it is about what one would expect, and provides additional confidence in the use of scientific publications as a partial measure of scientific output.

Figure 6.3 shows the percentage of the national scientific output that was attributable to universities scientific output. Canadian universities increased their contribution from 73 per cent in 1984 to 78 per cent in 1990 through a steady growth rate of 1 per cent per annum. Australian university scientific output accounted for 57 per cent of the national scientific output in 1984, decreased steadily until 1988 when it fell to 49 per cent in 1990; an overall drop of 16 per cent in six years. The contribution from UK universities scientific output remained a fairly constant at 44 per cent until 1989 and then it too dropped to 39 per cent in 1990. Most of this decline can be attributed to the decrease in the absolute output from UK universities in 1990.

\textsuperscript{10} The average productivity was calculated by dividing the average number of university publications produced per year between 1984 and 1990 by the number of full-time academic staff in 1990 (see Table 4.1).

\textsuperscript{11}This was estimated by summing the number full-time academic staff (wholly university financed and other) in University Statistics 1989-90 that were in the various science areas. This value was compared to the total number of full-time academic staff in UK universities.
Figure 6.3
University Contribution to National Scientific Output

CAN

AUS

UK

Article, notes & reviews

The reason for overall decline in the percentage contribution by Australian universities to the national scientific output is quite likely due to an increase in the contribution from another sector, possibly from government laboratories such as CSIRO. Clearly, a change in the university sector's relative contribution to the national scientific output can occur either as a result of a change in that sector or as a result of a change in another sector. Which sectors gained and which sectors declined is an interesting question. The answer to the question can only be obtained by unifying the data sets for each country at the sector level and this is a research project for the future.

6.3 University Size and Scientific Output

Ideally, the relationship between university size and scientific output should be investigated by analysing the relationship between the university expenditures on scientific research, or the size of the scientific research staff, and the scientific output. Accurate and internationally comparable data on expenditure and scientific research staff are not readily available, so an analysis was performed using the total number of academic staff (both scientific and non-scientific) at a given university and the published scientific output - that is, the number of articles, notes and reviews published by a university.

The average number of papers published annually between 1981 and 1990 by each UK and Australian university was plotted (see Figure 6.4) against the number of academic staff at that university in 1989. The University of London was not included in the UK analysis because of its unique character and unusual size. (This university had more than four times as many academic staff as the next largest universities, Oxford or Cambridge.) The average number of publications produced per year between 1984 and 1990 by each Canadian university was plotted against the number of academic staff at that
University Size versus Scientific Output

A. Australia

\[
\ln(\text{Publications}) = 1.23 \ln(\text{Staff}) - 3.12
\]

\[ (+0.15) \]

or

\[
\text{Publications} = 0.04 \text{ Staff}^{1.23}
\]

Two-Tailed T-Test < 0.01 and R-squared = 0.80

No. data points = 18

* Standard error of slope

Academic staff statistics source:

*Selected Higher Education Statistics 1990*, Australian Government Publishing Services
Figure 6.4
University Size versus Scientific Output

B. Canada

Ln(Publications) = 1.91 Ln(Staff) - 7.04

(±0.10)*

or

Publications = 0.001 Staff 1.91

Two-Tailed T-Test < 0.01 and R-squared = 0.90

No. data points = 40

* Standard Error of slope

Academic staff statistics source: Canadian World Almanac 1990
Figure 6.4
University Size versus Scientific Output

C. United Kingdom

\[
\ln(\text{Publications}) = 1.38 \ln(\text{Staff}) - 3.23
\]

\[\pm 0.10\]\

or

\[
\text{Publications} = 0.04 \text{Staff}^{1.38}
\]

Two-Tailed T-Test < 0.01 and R-squared = 0.84

No. data points = 45

* Standard error of slope


An initial regression analysis seemed to reveal that the relationship between university size and scientific output was linear. However, when the residuals were inspected it was found they correlated with university size - in other words, the data were heteroscedastic\textsuperscript{12}. A logarithmic transformation of both size and output produced normally distributed residuals and resulted in a good linear fit.

**Table 6.1**

Linear Regression Coefficients of University Output versus University Size

\[ Y = aX^b \]

<table>
<thead>
<tr>
<th>Country</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>0.04</td>
<td>1.23</td>
</tr>
<tr>
<td>Canada</td>
<td>0.001</td>
<td>1.91</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>0.04</td>
<td>1.38</td>
</tr>
</tbody>
</table>

* The linear form of this equation is \( \ln(Y) = b \ln(X) + \ln(a) \)

Figure 6.4 clearly illustrates that a log-linear relationship exists between university size and scientific output in all three countries. The regression coefficients are given in Table 6.1 (two tailed t-test < .01). The labelled points on each graph are universities that were excluded from the regression analysis in order to improve the regression fit. In each instance, these universities were eliminated because they either exhibited a larger (above the regression line) or smaller (below the regression line) published scientific output than would be expected for a university of that size in that country. The universities of Ulster (ULS - UK), Deakin (DE - Australia), Curtin (CU - Australia), Quebec (QUE -

\textsuperscript{12}Heteroscedasticity is a phenomenon where the residuals do not have a common variance. One of the assumptions that underlies linear regression analysis is that the variance is common or homoscedastic. Frequently, this problem can be overcome by using a suitable transformation of the variables.
Canada) and Bishop's University (BIS - Canada) are primarily teaching universities and are known to have less than scientific research activity than most universities. On the other hand, the University of Manchester (MAN - UK), Wales College of Medicine (WCM - UK), Technical University of Nova Scotia (TNS - Canada) and Nova Scotia Agricultural University (NSA - Canada) either have a strong science (eg. large medical school) or technology focus and are known to have more scientific research activity than most universities.

Caution must be exercised when interpreting the coefficients of the regression line for comparative purposes because the accounting methods used to count the number of academic staff may vary appreciably from country to country. Also, the mixture of teaching and research, and of teaching and research staff, probably differs from university to university. For certain the ratio of scientific to non-scientific academic staff will vary from university to university. A comparison can only be made after accounting for these factors. A further problem with comparing the coefficients arises because the average scientific output over a number of years was plotted against the number of staff in 1989. No doubt this introduced some error into the analysis because the number of staff will have changed over the decade.

With these cautionary notes in mind, recall that the elasticity coefficient, ε, is equal to b, the exponent in Y = aX^b, and can be used to determine how a small change in the independent variable (number staff) would affect the dependent variable (publications/year). Australia and the UK have comparable positive ε values, 1.23 and 1.38, respectively, which implies that a small increase in staff size would produce a larger increase in scientific output. Canada's ε value, 1.91, was also positive but larger than the other two suggesting that a Canadian university might experience a larger increase in scientific output for the same small increase in staff size. However, there are many more smaller universities in Canada than there are in the other two
The larger \( \varepsilon \) value may be attributable to the influence the smaller Canadian universities had on the slope of the regression line. Another noteworthy feature is the regression equation for each country has a negative y-axis intercept. This may mean that a minimum critical mass of academic staff is required before a university can produce a significant amount of scientific output.

6.4 Summary

The national published scientific output in Australia, Canada and the UK experienced a growth of 3.9 per cent, 4.5 per cent and 3.2 per cent per annum, respectively, as measured by the number of articles, notes and reviews contained in the BIDS on-line version of the Science Citation Index database.

The published scientific output from universities in the UK and Australia was reasonably constant from 1981 to 1984 and then grew at approximately 2 per cent per annum until 1989 when it fell by 5.7 and 6.7 per cent respectively in 1990. Canadian universities showed a 5.7 per cent per annum growth and in 1990 surpassed the UK university scientific output for the first time. The productivity of the university community in each country was comparable and was roughly estimated to be close to one publication per full-time scientist per year.

The university community’s contribution to the total national scientific output varied considerably among the three countries. Canadian universities accounted for 73-78 per cent of the national scientific output; the Australian universities’ contribution declined from 57 to 49 per cent over the decade; and the UK universities’ contribution also declined, in this case from 44 to 39 per cent. A detailed sectoral analysis of the Science Citation Index data would be
required to determine which sectors in the UK and Australia increased their scientific contribution to the national scientific output over this period.

University scientific output increased non-linearly with the size of the university. This implies that universities are subject to economies of scale because an incremental increase in staff seems to produce a proportionately larger incremental increase in scientific output. There is some indication that this effect was larger in Canada than in Australia and the UK.
This chapter is composed of five sections each of which investigates collaboration in the university community from a different perspective. The policy implications of the findings presented here will be discussed in a separate section in the conclusions chapter.

The first section looks at the overall collaborative activity in the university community without regard for the type of collaborative partner. The second section analyses institutional collaboration within the context of the number of authors and the number of institutions that are listed on a publication. The third section focuses on the growth of university-university publications throughout the decade. The fourth section uses the notion of a two-way collaboration to do the following: to examine the relationship between the average number of collaborations per paper and the science area; to perform inter-country comparisons of collaborative activity within a basic versus applied research framework; to do an *intranational* comparison by science field of university-university collaborations; to analyse the relationship between university scientific output and university-university collaborative activity; and to determine whether there is a relationship between geographical proximity and the amount of collaboration. The fifth section describes the use of a vector analysis
technique to see how the distribution of collaborations in each university community has changed with time.

7.1 **Overall University Collaborative Activity**

The overall collaborative activity in each university community - that is collaborations between a university and any domestic or foreign institution - was evaluated by counting articles, notes and reviews in the unified data set that contained at least one domestic university name in the corporate address field and at least one other partner. The additional partner could have been another department in the same university, or another domestic or foreign institution, organisation, company or individual. The results plotted in Figure 7.1 depicts a steady growth in university collaborations over the decade. Canada exhibited the largest growth with a 6.9 per cent per annum increase between 1984 and 1989, followed by a very large 22.7 per cent rise in 1990. During the same period, UK and Australian universities demonstrated similar and considerable collaborative growth with a 5.4 and 5.0 per cent per annum increase, respectively, followed by a slow down in 1990. Over the whole decade the UK and Australian universities displayed 4.6 and 4.1 per cent per annum growth, respectively.

Figure 7.2 portrays the overall university collaborative activity as a percentage of the total university scientific output. The growth pattern in the UK and Australia was remarkably similar. The frequency of university collaborations grew from about 35 per cent in 1981 to 50 per cent in 1990. On the other hand, the occurrence of Canadian university collaborations was greater and accounted for 46 per cent of the university scientific output in 1984, grew to nearly 50 per cent in 1989 and then jumped dramatically to 58 per cent in 1990.
In all three countries, the growth in the percentage of university collaborations making up the university scientific output was strong and
Figure 7.1
All University Collaborations

*Science Citation Index* publications that contained one domestic university and any other partner (university department, domestic or foreign institution).
Figure 7.2
Percent of University Scientific Output Involving a University Collaboration
sustained over the decade. A variety of factors could have contributed to this growth. These include an increase in interdisciplinary research, economic pressure to share resources and make joint appointments, and governmental policies to encourage university-industry linkages. A good deal more investigation would be needed to determine why such a strong and similar rate of growth occurred in these three countries. It would be particularly interesting to see if a bibliometric assessment of interdepartmental collaboration revealed an increase in the occurrence of interdisciplinary research.

7.2 Authors and Institutions

During the analysis of the overall university collaborative activity, a visual inspection of randomly selected publications revealed an interesting phenomenon. This finding raised a basic question about the nature of an institutional collaboration and is illustrated by the following three examples derived from the 1990 Canadian data set. 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 corporate addresses for two different institutions: University of British Columbia, biology department and York University, zoology department. In the second example, the author listed two corporate addresses which were two departments in the same institution: University of Manitoba, department of pathology and department of physiology. And in the third example, the author listed two corporate addresses in the same institution and another address in a different institution; Isaak Walton Killam Children's Hospital and Dalhousie University, department of pediatrics and department of microbiology. In each of the preceding examples, and any other publications which listed more corporate addresses (at least one of which was a domestic university) than authors would have been counted as a university collaboration. One might ask if these publications actually reflect an institutional collaboration and whether they should be counted as such.

Before focusing on this question, it is worth contemplating why an author might list more than one corporate address. A few obvious reasons come to mind: the author had a joint appointment in two departments or institutions; the author was a visiting fellow and listed both the home and visited institution; the author was an adjunct professor who worked primarily in another sector and did some research in conjunction with a university; or the author was a private-practice physician, with privileges to admit patients to a university-affiliated hospital (not unusual in Canada), who was involved in clinical trials and listed
both the private practice and hospital addresses on the resultant research publication.

After some consideration and discussions with colleagues, it was decided that these publications should be considered as valid institutional collaborations since they reflect a formal or informal agreement between two (or more) departments or institutions to share a single researcher. The institutional collaboration is manifested as a publication from the shared researcher.

Before too much emphasis was given to this type of collaboration, a count was made of the occurrences of one-author publications listing two (or more) institutions as well as publications listing more authors than institutions (which includes one-author publications listing two or more institutions). It should be noted that even this evaluation inherently underestimates the number of instances of this type of collaboration. For example, it is possible that 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. The Science Citation Index provides no means for determining author-institution affiliations\(^1\) so it is impossible to detect such cases.

The graphs shown in Figure 7.3 demonstrate that the number publications which involved one author listing two (or more) institutional addresses and, more generally, the number of collaborations which involved more institutions than authors occurred in a significant percentage of the university collaborations. Canadian publications with one author and two (or more) institutions accounted for 5.5 per cent of all university collaborations in

\(^1\)The Science Citation Index does not link individual authors with the institutions listed in the corporate address field. Thus, for example, if one is given a paper written by three authors which lists two institutions it is impossible to know which author is affiliated with which institution.
1984. It continuously declined to 3.5 per cent in 1989 and then rose rapidly back to the 1984 level in 1990. The UK and Australia displayed similar trends. One author publications listing two (or more) institutions occurred in 3.7 per cent of the university collaborations in 1981 but declined to approximately 2.5 per cent by 1990.

Canadian publications that listed more corporate addresses than authors (including one author papers listing two or more institutions) accounted for between 10.5 and 11.3 per cent of all university collaborations until 1989 when it rose sharply to 13.7 per cent. The percentage of UK and Australian publications with the same characteristics fluctuated between 4.5 and 6.0 per cent of the university collaborations throughout the decade. This was approximately one-half of the percentage that was seen in Canada.

A detailed investigation using the CHI journal classification scheme was carried out to determine if the occurrence of this collaboration type differed across science areas. There was some variations from country to country, but generally speaking, the highest occurrence of publications with more institutions than authors was found in clinical medicine (40-50 per cent), followed by biomedical research and physics (10-15 per cent), biology and earth and space science (5-10 per cent) and chemistry, mathematics and engineering and technology (less than 5 per cent).

The high occurrence of this type of collaboration in clinical medicine could be the result of joint appointments, especially between departments in the same hospital and between a hospital and a university. The relatively high incidence in biomedical research and physics might be partially explained by researchers who visit institutions with unique research facilities and list both
Figure 7.3
A. One Author and Two or More Institutions

B. More Institutions than Authors

* includes papers with one author and two or more institutions
institutions on their publication. No references have been found in the literature that report this phenomenon. A more detailed interview-based investigation would have to be carried out to uncover the reasons why authors list more institutions than authors and why there is such a large variation between fields.

7.3 University-University Publications

Publications in the unified data sets that contained at least two domestic university names in the corporate address field were counted. Generally speaking, the results (Figure 7.4) indicate that between 1984 and 1990 all three countries experienced a significant increase in university-university collaborations.

Australian university-university publications fluctuated a little then exhibited a steady 4.7 per cent per annum increase until 1989 which was followed by a 12.7 per cent decline in 1990. The number of UK university-university collaborations changed very little from 1981 to 1984 but then it grew rapidly at approximately 6 per cent per annum until 1989 after which there was a sharp 12.8 per cent decreased in 1990. Canadian publications showed a sustained 10 per cent per annum growth from 1984 to 1988, changed little between 1988 and 1989 and then increased by a phenomenal 35 per cent in 1990.

Figure 7.5 displays the number of university-university publications as a percentage of the total university scientific output. A notable and curious feature of this graph is the analogous percentages and growth patterns in all three countries. From 1981 to 1984, these publications accounted for an about 4.5 per cent of the university scientific output in the UK and Australia. Starting in 1984, all three countries entered a similar growth trajectory. Australian publications climbing to about 5.8 per cent of the university scientific output in
Science Citation Index publications that contained the name of at least two domestic universities in the corporate address field.
Figure 7.5

Percent of University Scientific Output Involving a University-University Collaboration
1987 and then slowly fell to 5.5 per cent in 1990. The growth in the UK was stronger and longer. By 1989 these collaborative publications accounted for 6.3 per cent of the university scientific output but fell to 5.8 per cent in 1990. The Canadian trend was similar. However, instead of declining in the last year university-university publications grew rapidly, rising from 5.8 per cent in 1989 to 7.3 per cent in 1990.

When the number of university-university publications are expressed as a percentage of the overall number of university collaborations (see Figure 7.6) the result is not quite so clear. In the UK and Australia the percentage fluctuated between 11 and 13.5 per cent over the decade showing a general tendency to decline in the early 1980s, increase from about 1984 to 1988 and then decline until the end of the decade. The percentage of Canadian university-university publications tended to increase from 10 per cent in 1984 to approximately 12.5 per cent in 1990.

Discussions with science policy analysts from Australia and the UK and correspondence with two Canadian observers has not revealed any obvious reasons for the growth of intranational university-university collaborations in the mid 1980s. One factor that was common to both the UK and Australia was the substantial amount of organisational and financial restructuring of the university community that began in the early 1980s and continued throughout the decade. There was no structural reorganisation of Canadian universities, perhaps because of the inherently strong inter-university infrastructure which may act as a partial buffer against government intervention in university affairs\(^2\) (see

\(^2\)Canadian universities have a number of inter-university organisations such as the Council of Ontario Universities, the Conférence des recteurs et des principaux des universités du Québec, Tri-University President's Council, the Association of Atlantic Universities and the Council of Western Canadian University Presidents.
Figure 7.6
Percent of All University Collaborations
Involving a University-University Collaboration
Chapter 4 for more details). However, there were significant financial cut-backs, especially in the provincial contributions, to the universities. Exactly how one would go about investigating the effect of economic cut-backs on university-university collaboration is an interesting problem that warrants more exploration.

The dramatic growth in 1990 of Canadian university collaborations, particularly, university-university collaborations and the increase in publications with more institutions than authors might be attributable to programmes which were introduced during the late 1980s. Various federal and provincial government initiatives were launched to encourage more collaboration with universities, in particular, university-industry collaboration. Some of these programmes emphasised the need for more than one university to participate. Examples of these programmes (see Chapter 4 for more details) are the federal government 'matching funds' strategy; the seven centres of excellence established in the province of Ontario; the inauguration of the national centres of excellence initiative; and individual provincial initiatives to encourage more economically relevant research. By 1990, the effect of some these programmes may have be seen in the publication data. However, it will not be until the mid 1990s that a bibliometric analysis would reveal whether or not these programmes had any real impact on university collaborations.

Some aspects of the preceding findings are indeed curious and generate more questions than they answer. What factor(s) would three countries separated by such large distances and with essentially autonomous university communities have in common that would stimulate similar growth patterns in university collaborations? Why should the percentage of the university-university publications which contribute to the national scientific output be almost the same in all three countries? Could global economic factors such as the recession in the early and late 1980s, economic growth in the mid 1980s and financial cut backs to the university community affect collaborative activity?
Was there a change in attitude within the university community that encouraged university researchers to seek more partners from within their own community? Were the trends restricted to these three Commonwealth nations or did the trends occur in other industrialised nations? Answers to these and other questions warrant more investigation because the identification of the forces which stimulate and retard *intranational* university-university collaboration, and university collaboration in general, would be valuable to policy makers.

### 7.4 Two-way Collaborations

The remainder of this section explores university-university collaborations primarily within the context of two-way collaborations. As described in the methodology, the number of two-way collaborations is determined by counting the number of pairs of domestic universities that participated in a given paper (see equation 5.1). A paper involving two universities results in one two-way collaboration, a paper involving three universities results in three two-way collaborations and one involving four universities produces six two-way collaborations.

#### 7.4.1 Collaborations Per Paper

The average number of two-way collaborations that occurred in each CHI science area was determined for each country. It is worth noting that an average of 1.0 two-collaborations per paper implies that exactly two universities participated in each paper, whereas, an average of 3.0 implies most publications involved three universities. The value of the average number of university collaborators per paper is an indicator of the distribution of the number of university participants across all university-university publications. The closer the average is to 1.0, the more frequently only two collaborators
were involved; and the larger the value, the more frequently three, four and more collaborators were involved.

The bar graph in Figure 7.7 illustrates how the average number of university collaborators varied from the aggregate level to the individual CHI science fields\(^3\) for each country. At the aggregate science level Canada and the UK had an average of approximately 1.2 two-way university collaborations per paper while in Australia it was slightly lower at 1.1. The percentage of papers that involved a specific number of universities is tabulated in Table 7.1. It provides some perspective on how these averages arose.

### Table 7.1

Percentage Distribution of University Participants in Collaborative Publications

<table>
<thead>
<tr>
<th>Country</th>
<th>Average number publications/year</th>
<th>Number of universities</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>290(^a)</td>
<td>95.4%</td>
<td>4.2%</td>
<td>0.4%</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>1123(^b)</td>
<td>92.9%</td>
<td>5.8%</td>
<td>0.9%</td>
<td>0.3%</td>
<td></td>
</tr>
<tr>
<td>United Kingdom</td>
<td>911(^a)</td>
<td>93.0%</td>
<td>5.4%</td>
<td>1.1%</td>
<td>0.5%</td>
<td></td>
</tr>
</tbody>
</table>

Notes:

- 1981-1990
- 1984-1990

More than 93 per cent of all publications involved only two universities. About 4.2 per cent of the Australian publications and more than 5 per cent of the UK and Canadian publications involved three universities. A small but

\(^3\)Throughout this section the following abbreviations have been used in the tables and figures: AGG - all CHI science fields, PHY - physics, MTH - mathematics, CHM - chemistry, BIO - biology, BMR - biomedical research, CLM - clinical medicine, ESS - earth and space sciences, and ENT - engineering and technology.
Figure 7.7

Two-Way University Collaborations Per Paper

AGG - Aggregate Science Area
MTH - Mathematics
BIO - Biology
ESS - Earth & Space Sciences
ENT - Engineering & Technology
PHY - Physics
CHM - Chemistry
BMR - Biomedical Research
PSY - Psychology
significant percentage of UK and Canadian publications involved four or more universities. This was a factor of more than three greater than in Australia. It was the distribution of university collaborators that determined the average value of number of two-way collaborations per paper and on the average, at the aggregate level, Canadian and UK university publications involved more university partners than did Australian publications.

The average number of two-way collaborations per paper for each CHI science area was broadly similar but there were a few notable exceptions. Physics in Canada and the UK, clinical medicine in Canada and earth and space science in Australia had more collaborators per paper than was the case at the aggregate science level.

7.4.2 Inter-Country Comparison

The percentage of publications in a given CHI field that involved a university-university collaboration was determined. These values are comparable across the three countries because percentages normalise for the effects caused by the scientific size of the university community in each country. In Table 7.2 the CHI science fields are ranked by the percentage of publications that entailed a university-university collaboration. Also presented in the table are the rank and percentages of the 1973 publications that Frame and Carpenter's (1979) study found involved an international institutional collaboration. Recall that they claimed there was more cooperation in the basic research areas (physics, mathematics, earth and space science and biomedical research) than in the more applied areas (chemistry, biology, clinical medicine and engineering and technology). For convenience, the more basic research fields have been italicised.
### Table 7.2
Ranking of Percentage of Publications Involving a University-University Collaboration for CHI Science Fields

<table>
<thead>
<tr>
<th>Country</th>
<th>RANK</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Australia</td>
<td>CHM</td>
<td>ESS</td>
<td>BMR</td>
<td>CLM</td>
<td>MTH</td>
<td>PHY</td>
<td>BIO</td>
<td>ENT</td>
</tr>
<tr>
<td>percent collaboration</td>
<td>10.11%</td>
<td>6.59%</td>
<td>5.29%</td>
<td>4.86%</td>
<td>4.72%</td>
<td>3.77%</td>
<td>3.62%</td>
<td>3.07%</td>
</tr>
<tr>
<td>Canada</td>
<td>ESS</td>
<td>PHY</td>
<td>MTH</td>
<td>BIO</td>
<td>ENT</td>
<td>BMR</td>
<td>CLM</td>
<td>CHM</td>
</tr>
<tr>
<td>percent collaboration</td>
<td>8.58%</td>
<td>8.47%</td>
<td>7.15%</td>
<td>6.50%</td>
<td>6.37%</td>
<td>6.34%</td>
<td>6.14%</td>
<td>4.64%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>ESS</td>
<td>PHY</td>
<td>CHM</td>
<td>BMR</td>
<td>CLM</td>
<td>MTH</td>
<td>ENT</td>
<td>BIO</td>
</tr>
<tr>
<td>percent collaboration</td>
<td>8.55%</td>
<td>7.32%</td>
<td>6.30%</td>
<td>5.71%</td>
<td>4.54%</td>
<td>4.35%</td>
<td>3.81%</td>
<td>3.55%</td>
</tr>
<tr>
<td>Frame &amp; Carpenter</td>
<td>ESS</td>
<td>PHY</td>
<td>MTH</td>
<td>BMR</td>
<td>CHM</td>
<td>BIO</td>
<td>CLM</td>
<td>ENT</td>
</tr>
<tr>
<td>percent collaboration</td>
<td>4.45%</td>
<td>4.23%</td>
<td>3.75%</td>
<td>2.63%</td>
<td>2.03%</td>
<td>1.68%</td>
<td>1.61%</td>
<td>1.46%</td>
</tr>
</tbody>
</table>

At first glance, with the noticeable exception of chemistry in Australia, it might appear that university-university collaborative activity in three countries appears to follow Frame and Carpenter’s basic versus applied dichotomy. However, a closer inspection shows that there are significant discrepancies and a different interpretation may be warranted.

Earth and space science In all three countries and physics in Canada and the UK shows a definite tendency to have more university-university collaborations than other CHI science areas. This may result from the need to share expensive, complex high energy and astronomy research facilities. The low amount of collaborative activity in Australian physics is no doubt due to the fact that there is little physics research in Australia. The Australian Science and Technology Council (ASTEC, 1989) in their report on Australian science noted that ‘physics has never been a particularly large field and has been declining in recent years’.

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There is a tendency for there to be a fair amount of collaboration in biomedical research in all countries. In Canada, even though the percentage of collaboration in biology and engineering and technology is higher than the percentage in biomedical research, the values are so similar that for all intents and purposes they are the same. An interesting observation is that clinical medicine is always ranked next to biomedical research and with the exception of the UK, both fields exhibit a similar amount of collaboration activity. It almost appears that these two research areas are inseparable and, perhaps, should be amalgamated into one medical sciences category.

Engineering and technology and biology research shows the least amount of collaboration in Australia and the UK but ranks fourth and fifth in Canada. Canadian activity in these areas may have little to do with the nature of the scientific research but rather may have resulted from a historical tradition which encouraged co-operative research in matters concerning mining, agriculture, forestry and fisheries. Canada has always assigned national priority to research in these areas because in every province a significant portion of their economic revenue comes from at least three out of four of these areas.

Australian chemistry research has by far the largest percentage of university-university collaborations, outstripping earth and space science by a large margin. Discussions with Australian policy analysts did not reveal any obvious reason for this. In fact, they were surprised by this finding, but confirmed it after they re-examined their own bibliometric data.

Why should the pattern of *intranational* university-university collaborations not conform to Frame and Carpenter's basic versus applied dichotomy? There are at least two reasons: inherent problems with the CHI journal classification scheme and a flaw in the basic versus applied research hypothesis.
First, let us examine the journal classification scheme. Frame and Carpenter analysed 1973 *Science Citation Index* data using CHI Research's 1973 journal classification scheme. Both the analysis and the journal classification were derived from publications published in the same year. This study used 1981-90 *Science Citation Index* data and CHI Research's 1984 journal classification scheme. The journal set was derived by clustering 1984 data. This bibliometric analysis examined ten years of data and used the one journal set. Over the decade some older journals disappeared and some new ones appeared. This has not been reflected in the CHI journal set. Also, some journals have shifted their focus in order to survive in a competitive and dynamic scientific world. A speciality journal with a previous basic research orientation may have evolved an applied research focus as the field matured. Similarly some journals are interdisciplinary and are located on the boundary between two or more fields; their content moves between fields and specialties over time. For example, a biophysics journal may publish more basic research articles one year and then more applied research articles the next. It is inappropriate to categorise a whole science area as basic or applied based on journal groupings because it is difficult to classify individual journals as basic or applied.

Frame and Carpenter did not give any rationalisation for dividing the various CHI science fields into basic and applied research other than prefacing their comments with the comment that 'a quick perusal of Table 1 enables us to make an obvious generalisation'. It seems they may have had some misconceptions. For example, many people think that because mathematics research can be esoteric it has few applications. In fact, much mathematics is very applied; it is the language of science. Furthermore, Frame and Carpenter's generalisation does not account for mixed basic and applied research which is the mainstay of high energy physics and radio astronomy. For example, new
instruments (such as linear accelerators, radio telescope, and nuclear magnetic resonance scanners) are designed and constructed by physicists and engineers with an excellent grasp of how to apply fundamental science and engineering principles and their tacit knowledge to building a better set of 'eyes and ears' with which to investigate uncharted research frontiers. Then applied and basic scientists and engineers, experimentalists and theoreticians, explore these frontiers side-by-side, all the while designing and redesigning, building and rebuilding their equipment and publishing their findings as they go along - basic and applied. The boundary between basic and applied is 'fuzzy' and Frame and Carpenter's definition seems very artificial. The best solution to this difficulty is to stay away from such distinctions.

Perhaps the results in Table 7.2 should be interpreted as a fingerprint of the intranational university-university collaboration activity which has been derived using a common journal classification. This fingerprint is defined by the composition of the CHI fields ranked by the percentage of publications that involve a university-university collaboration. An international comparison of the national fingerprints can be made using ranking correlation techniques.

A Spearman rank-correlation coefficient was calculated for each pair of countries and a two-tailed t-test was used to determine if the correlations were significant. There was no significant correlation between the Australian and Canadian or the Canadian and the UK fingerprints but a significant correlation was found between the Australian and the UK fingerprints (t-test < 0.05).

Each country was compared to the Frame and Carpenter science field rankings (see Table 7.2) for international collaborations. No correlation was found between these rankings and the science field rankings of collaborative activity in Australia, a small correlation existed for Canada (t-test < 0.10) and there was reasonable correlation for the UK (t-test < 0.05). In other words, a
general correlation was not found with the basic and applied categories for all three countries.

7.4.3  *Intranational University-University Collaboration*

The percentage of university-university collaborations that occurred in each CHI science field was calculated so that a *intranational* cross-field comparison could be made. In Table 7.3 each science field was ranked by this percentage. In addition, the percentage of the total number of publications that occurred in each CHI science field was calculated and the fields were ranked according to this percentage. This rank (publication rank) is also give in the table.

| Table 7.3  |

**CHI Science Areas Ranked by Percentage of Two-way Collaborations**

<table>
<thead>
<tr>
<th>Country</th>
<th>Rank</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australiaa</td>
<td></td>
<td>CLM</td>
<td>CHM</td>
<td>BMR</td>
<td>BIO</td>
<td>ESS</td>
<td>PHY</td>
<td>ENT</td>
<td>MTH</td>
</tr>
<tr>
<td>percent collaborations</td>
<td>26.7%</td>
<td>23.3%</td>
<td>16.6%</td>
<td>10.5%</td>
<td>9.5%</td>
<td>5.9%</td>
<td>2.6%</td>
<td>2.4%</td>
<td></td>
</tr>
<tr>
<td>publication rank</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Canada b</td>
<td></td>
<td>CLM</td>
<td>PHY</td>
<td>BMR</td>
<td>BIO</td>
<td>ESS</td>
<td>ENT</td>
<td>CHM</td>
<td>MTH</td>
</tr>
<tr>
<td>percent collaborations</td>
<td>29.4%</td>
<td>15.7%</td>
<td>14.8%</td>
<td>11.9%</td>
<td>8.3%</td>
<td>6.4%</td>
<td>6.0%</td>
<td>3.3%</td>
<td></td>
</tr>
<tr>
<td>publication rank</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>United Kingdomc</td>
<td></td>
<td>PHY</td>
<td>CLM</td>
<td>BMR</td>
<td>CHM</td>
<td>ESS</td>
<td>BIO</td>
<td>ENT</td>
<td>MTH</td>
</tr>
<tr>
<td>percent collaborations</td>
<td>22.4%</td>
<td>20.4%</td>
<td>17.4%</td>
<td>16.1%</td>
<td>9.6%</td>
<td>5.4%</td>
<td>4.4%</td>
<td>2.1%</td>
<td></td>
</tr>
<tr>
<td>publication rank</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
Average number of two-way collaborations/year
a. 336  b. 1258  c. 1182

A quick inspection of the table seems to indicate that there might be a relationship between the amount of university-university collaboration in a science area and the national expenditure in that science area. Establishing such a relationship is difficult and is hampered by the problem of accurately
apportioning the national scientific expenditures to individual CHI science areas. An indirect technique was developed in order to overcome this difficulty.

Recall our previous finding that there is a proportional relationship between the size of an academic institution (number of staff) and its scientific output (number of publications). The number of staff was used as a measure of the recurrent expenditure; the more staff an institution has, the larger its expenditure. We can extrapolate this to the national level and suggest that the more scientific researchers a country employs in its universities, the greater the national expenditure has to be in science.

Now, we assume that the number of staff in a given science area is directly proportional to the national expenditure in that science area. Support for this notion comes from Australian R&D expenditure data which were also broken down by science field, and the statistics on R&D staff in higher educational institutions which was broken down by science field. A comparison of the science fields ranked by expenditure and ranked by number of staff showed that there was an exact match in rankings\(^5\).

We know that the number of publications is directly proportional to the number of staff at the institutional level and we can extrapolate this relationship to the national level; the more researchers a country has, the greater its scientific output. If we assume that the number of staff is directly proportional to the national expenditure in each science area, then as a first order approximation, it follows that the number of publications in each science area is

\(^5\)See *Profile of Australian Science* p 26 produced by Australian Science and Technology Council (1989) published by Australian Government Services. A comparison of 1978-86 data found in Figure 2.8, R&D Expenditure by Field of Science, Higher Education and Figure, 2.9 Research Staff Numbers (conducting R&D) in Higher Education by Field of Science yielded the following rankings both by expenditure and by staff: 1. biological, 2. medical, 3. engineering, 4. physical, 5. agriculture, 6 chemical and 7. earth.
directly proportional to the national expenditure in that science area. This assumption, however, disregards productivity differences between science fields which can be substantial.

An examination of Table 7.3 shows that, with a few exceptions, there is a close relationship between the percentage of collaboration rank and the percentage of publication rank. This was confirmed by calculating the Spearman rank-coefficient. Australia had the best correlation at 0.96 (t-test < 0.001), followed by Canada with a coefficient of 0.78 (t-test < 0.01) and then the UK with a coefficient of 0.72 (t-test < 0.05).

Let us now examine the exceptions. Chemistry was the only exception in Australia. It was ranked fourth in publication output but was ranked first in university-university collaborative activity. Physics was ranked fourth in Canada and the UK in publication output but was ranked second in Canada and first in the UK in university-university collaborations. Earth and space science was ranked seventh in Canada and the UK in publication output but was ranked fifth in Canada and the UK in terms of collaborative activity.

The explanation for the ranking differences in physics and earth and space science in the UK and Canada may reflect the fact that their research effort in these fields focuses around centralised, expensive and complex instrumentation such as higher energy particle accelerators and radio telescopes which are known to spawn a great deal of collaborative activity. Also, facilities of this type involve large capital expenditures. Our analysis only used recurrent expenditures and perhaps these results reflect the need to account for capital costs in the analysis. Again, the reason for the anomaly in chemistry in Australia is unknown, even to science activity observers from that country, and requires further investigation.
A scatter plot (Figure 7.8) composed of the number of two-way university-university collaborations and the number of articles, notes and reviews published by each university was produced for each country. The initial regression analysis of the data suggested there was a linear relationship between collaborations and publications. However, when the residuals were examined it was found that they were correlated with the number of publications; thus again the data were heteroscedastic. A natural logarithmic transformation of both collaborations and publications removed the correlation.

### Table 7.4

**Regression Coefficients for Collaborations versus Publications**

<table>
<thead>
<tr>
<th>Country</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>1.23</td>
<td>0.71</td>
</tr>
<tr>
<td>Canada</td>
<td>0.61</td>
<td>0.83</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>0.17</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Note:
1. two tailed t-test < 0.001

The elasticity coefficient, which is equal to b (see Table 7.4), is less than one for all three countries implying that a small increase in the number of publications would produce a proportionately smaller increase in the number of university-university collaborations. There are couple of interesting points to observe. First, the elasticity coefficient for the UK is very close to one suggesting that the relationship between publications and collaborations is almost linear. Second, at least for these three countries, the smaller the country the smaller the elasticity coefficient. The reasons for this are not apparent and before such a generalisation can be made, a number of other countries of different sizes would have to be examined.
Figure 7.8
Collaborations Versus Scientific Output
A. Australia

\[ \ln(\text{Collaborations}) = 0.71 \ln(\text{Publications}) + 0.21 \pm 0.06 \]

or

\[ \text{Collaborations} = 1.23 \text{Publications}^{0.71} \]

Two-tailed t-test > 0.001 and R-squared = 0.89

No. data points = 20

* Standard error of slope
Figure 7.8

Collaborations Versus Scientific Output

B. Canada

\[ \ln(\text{Collaborations}) = 0.83 \ln(\text{Publications}) - 0.49 \pm 0.03 \]

or

\[ \text{Collaborations} = 0.61 \cdot \text{Publications}^{0.83} \]

Two-tailed t-test < 0.001 and R-squared = 0.96
No. data points = 47
*Standard error of slope
Figure 7.8

Collaborations Versus Scientific Output

C. United Kingdom

\[ \text{Ln(Collaborations)} = 0.96 \text{Ln(Publications)} - 1.76 (\pm 0.05)^* \]

or

\[ \text{Collaborations} = 0.17 \text{Publications}^{0.96} \]

Two-tailed t-test > 0.001 and R-square = 0.90

No. data points = 50

* Standard error of slope
7.4.5  **Effect of Geographical Proximity**

There have been some findings that suggest geographical proximity has an effect on international collaboration (Frame and Carpenter 1979; Luukkonen, Person and Sivertsen, 1990; Moed, de Bruin, Nederhof and Tijssen, 1990). Most of these studies used multidimensional scaling analysis which made it difficult to isolate geographical effects from other economic, political and social effects. As described in the methodology chapter, a new technique was devised to establish whether or not there was a relationship between geographical proximity and collaborative activity. Briefly, the technique involves measuring the distance between pairs of universities which is normalised to the maximum distance separating a pair of universities. The number of collaborations in each of a fixed distance interval was counted.

In Figure 7.9 the number of total number two-way collaborations in the UK and Australia between 1981 and 1990 and in Canada between 1984 and 1990 is plotted against the normalised geographical distance for each country. For convenience a fixed distance interval of 0.1 or 10 per cent of the country size was chosen and the number of collaborations that occurred within each interval were counted. A regression analysis of collaborations versus distance was performed and in each instance it was found that the number of two-way collaborations decreased exponentially with distance (two-tailed t-test < 0.01).

To put this into a geographical perspective, the furthest distance between any pair of universities is approximately 700 km in the UK, 2100 km in Australia and 4800 km in Canada; therefore each 0.1 normalised interval represents 70 km, 210 km and 480 km, respectively. It is worth noting that there is no data point plotted in the 0.60 to 0.70 interval for Australia because there are no
universities within this interval. Also, in the UK it can be seen that the number of collaborations in the 0.0 and 0.1 interval is less than might be
One Distance Interval = 10 per cent of the country size

Australia:

\[ \text{Ln(Collaborations)} = -5.0 \text{ Distance} + 9.8 \]

or

\[ \text{Collaborations} = 18034 \text{ e}^{-5.0 \text{ Distance}} \]

Two-tailed t-test < 0.01, R-squared = 0.90, S.E. = ±0.084

Canada:

\[ \text{Ln(Collaborations)} = -3.8 \text{ Distance} + 10.1 \]

or

\[ \text{Collaborations} = 24343 \text{ e}^{-3.8 \text{ Distance}} \]

Two-tailed t-test < 0.01, R-squared = 0.72, S.E. = ±0.084

United Kingdom:

\[ \text{Ln(Collaborations)} = -5.2 \text{ Distance} + 11.8 \]

or

\[ \text{Collaborations} = 133252 \text{ e}^{-5.2 \text{ Distance}} \]

Two-tailed t-test < 0.01, R-squared = 0.80, S.E. = ±0.97
expected. This can be explained by two facts. First, the radius of greater London is approximately 40 km (25 mi) or approximately one distance interval in diameter. Second, all collaborations with the individual colleges of the University of London were counted as collaborations within the University of London. If the collaborations between the individual colleges had been counted separately, the number of two-way collaborations in the first interval would have been much larger.

This analysis provides convincing evidence that university-university collaborations occur more frequently with partners who are geographically closer than those further away. In general, more than 60 per cent of all two-way university-university collaborations in Canada and Australia and more than 40 per cent in the UK occur within a collaboration radius equal to less than 20 per cent of the country size which is 140 km in the UK, 410 km in Australia and 960 km in Canada. This provides evidence to support the notion that informal, ‘face-to-face’ communication may be an essential ingredient in research collaborations and that factors such as greater geographical distances with the additional travel cost and time involved are deterrents to collaboration.

We might expect that cheaper telecommunications, fax and electronic mail would have slowly been increasing the average radius of collaboration. A regression analysis of the number of collaborations versus distance was performed on a year-by-year basis in order to see if such effects could be observed. The slope of each regression line was plotted against time (see Figure 7.10). There is a direct relationship between the slope of the regression

\[6\text{The University of London is in greater London and not only is it the largest university in the UK, it has the largest number of collaborations in the UK. With the exception of a couple of smaller universities like the Universities of Reading and Surrey, most universities are more than 70 km (43 mi) away and their collaborations with the University of London would not be counted in the 0.0 to 0.1 interval.}\]
Figure 7.10
Geographical Proximity Regression Slope Versus Time

Slope of regression line of collaborations and geographical proximity plotted over time. If the slope becomes more negative, collaborations are occurring between geographically closer partners. If the slope becomes more positive, collaborations are occurring further apart.
line and the radius of collaborations. A slope that tends to become more negative with time indicates that the collaboration radius is decreasing; in other words collaborations are becoming geographically closer. A slope that tends to become more positive with time shows that the collaboration radius is increasing; collaborations are becoming geographically more distant.

The results seem to indicate that during the early part of the decade there was a general trend in the UK and Australia for collaborations to occur between geographically more distant partners. However, by 1984 this trend had reversed and by 1990 there was a slight, but not very significant, tendency for collaboration to occur between closer partners than in 1981. In contrast, in Canada between 1984 and 1986, partners tended to move further apart but after that there was little change.

These trends are interesting but not especially significant. Roughly speaking, in Australia the percentage of collaborations that occurred in the 0.0 to 0.1 interval and in the UK the percentage of collaborations that occurred in the 0.0 to 0.2 interval had increased by approximately 4 per cent over the decade. On the other hand, in Canada, the percentage of collaborations that occurred in the 0.0 to 0.1 interval had decreased by 5 per cent between 1984 and 1986.

It is very difficult to say what caused these trends. For example, while telecommunications may have helped reduce the gap between collaborators, such factors as increasing transportation costs and travel time may have been had a more profound negative effect. These findings suggest that this is an interesting area for exploration but a great deal of care would have to be devoted to designing suitable quantitative and qualitative techniques to uncover the underlying factors.
7.5 **Distribution of Collaborations.**

The magnitude of the national collaboration vector is a measure of the distribution of collaborations in the university community. In the methodology chapter, it was demonstrated that the magnitude of the national collaboration vector, \(|V|\), is bounded by

\[
\frac{2}{\sqrt{n}} \leq \frac{|V|}{m} \leq \sqrt{2}
\]

where \(m\) is the total number of two-way collaborations and \(n\) is the number of universities. The closer \(\frac{|V|}{m}\) is to the lower bound, the more evenly the collaborations are distributed; the closer it is to the upper bound, the more the collaborations are concentrated in fewer universities.

Table 7.5 gives the upper and lower bounds of the magnitude of the national collaboration vector and the actual value of the magnitude that was determined from the collaboration data for each country. Also, it gives a ratio which indicates where in the interval between the upper and lower bound \(\frac{|V|}{m}\) is located. This ratio is determined by the following equation:

\[
\text{ratio} = \frac{\text{magnitude}}{\text{upper bound} - \text{lower bound}}
\]

The closer the ratio is to zero, the closer the magnitude is to the lower bound and the closer the ratio is to one, the closer the magnitude is to the upper bound.

**Table 7.5**

<table>
<thead>
<tr>
<th>Country</th>
<th>Lower</th>
<th>Upper</th>
<th>Measured</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>0.45</td>
<td>1.414</td>
<td>0.55</td>
<td>0.57</td>
</tr>
<tr>
<td>Canada</td>
<td>0.29</td>
<td>1.414</td>
<td>0.44</td>
<td>0.39</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>0.28</td>
<td>1.414</td>
<td>0.41</td>
<td>0.36</td>
</tr>
</tbody>
</table>
The data in Table 7.5 show that in Australia university-university collaborations are concentrated in fewer universities than in Canada or the UK. Australia has less than half as many universities and none of them are comparable to the largest universities in the other countries. This may partially account for the more even distribution of collaborations in its university community. On the other hand in the UK and Canada university-university collaborations are concentrated in a few universities. Additional confirmation of this comes from the knowledge that about 80 per cent of all university-university collaborations occurred in the top twenty universities in these countries.

In order to get a sense of how the collaboration distribution has changed over time, a regression analysis of the magnitude of the national collaboration vector was performed for each CHI science area versus time. (Note that individual linear regressions will not allows us to determine how much each science area contributed to the change in distribution.) Table 7.6 gives the sign of the linear regression slope (plus or minus) and its two-tailed t-test significance for each science area for each country. The sign of the slope indicates the direction in which the magnitude of the collaboration vector tended to change. A negative slope indicates a trend towards a more even distribution while a positive slope indicates a trend towards a more uneven distribution.

Table 7.6

Regression Analysis of Collaboration Distribution Time Trends

<table>
<thead>
<tr>
<th>Country</th>
<th>AGG</th>
<th>PHY</th>
<th>MTH</th>
<th>CHM</th>
<th>BIO</th>
<th>BMR</th>
<th>CLM</th>
<th>ESS</th>
<th>ENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>-.01</td>
<td>+.30</td>
<td>-.30</td>
<td>-.05</td>
<td>-.30</td>
<td>-.30</td>
<td>-.30</td>
<td>-.05</td>
<td>-.40</td>
</tr>
<tr>
<td>Canada</td>
<td>+.20</td>
<td>+.30</td>
<td>-.90</td>
<td>-.50</td>
<td>+.40</td>
<td>+.80</td>
<td>-.90</td>
<td>-.50</td>
<td>-.90</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>+.05</td>
<td>+.30</td>
<td>-.10</td>
<td>+.80</td>
<td>+.40</td>
<td>-.80</td>
<td>-.30</td>
<td>-.90</td>
<td>-.70</td>
</tr>
</tbody>
</table>
Since the number of years that were examined was ten or less, relatively few data points were used in the regression analysis therefore, a stringent interpretation of the significance levels was not used. A t-test value less than 0.10 was interpreted as being 'highly' significant and a t-test value of less than 0.30 but greater than 0.10 was be considered to be 'somewhat' significant.

Overall, there was a 'highly' significant trend in Australia for university-university collaborations to become more evenly distributed because the slope of the aggregate of all science areas was negative and its t-test was less than 0.01. This appeared to be a result of 'highly' significant trends in chemistry and earth and space science and 'somewhat' significant trends in mathematics, biology, biomedical research and clinical medicine to become more evenly distributed. Collaborations in physics showed a tendency to become more concentrated in fewer in universities.

Canada showed a 'somewhat' significant trend for university-university collaborations at the aggregate level to become concentrated in fewer universities as shown by the fact that the slope was positive with a t-test less than 0.20. Much of this concentration probably resulted from a tendency for physics collaborations to become concentrated in fewer universities. There was some difficulty interpreting the Canadian trends because only six data points were used in each regression analysis.

The United Kingdom also exhibited a 'highly' significant trend for university-university collaborations at the aggregate level to become more concentrated in fewer universities since the slope was negative with a t-test less than 0.05. However, only physics displayed a 'somewhat' significant trend towards concentration in fewer universities while mathematics and clinical medicine collaborations seemed to become more dispersed.
The tendency in all three countries for physics collaborations to become more concentrated in fewer universities may reflect a trend for centres of high energy physics research or other ‘big science’ research to be concentrated in fewer universities.

7.6 Summary

The number of university collaborations with all institutional types grew steadily throughout the 1980s with Canadian universities displaying the most vigorous growth. Over the decade the percentage of university published scientific output that was collaborative increased from 35 to 50 per cent in the UK and Australia while in Canada it rose from 46 to 58 per cent between 1984 and 1990.

More than 6 percent of university collaborations in the UK and Australia and as many as 12 per cent of those in Canada were composed of publications that list more institutions that authors in the Science Citation Index corporate address field. About 40-50 per cent of these occurred in clinical medicine.

The number of intranational university-university collaborations was constant during the first part of the decade, but between 1984 and 1989 it grew steadily at between 4.7 and 6 per cent per annum in Australia and the UK, respectively. Both countries exhibited a sharp decline in 1990. In Canada, the increase in university-university collaborations was much stronger at 10 per cent per annum between 1984 and 1988 and was followed by a phenomenal 35 per cent increase in 1990.

A curious finding in this study was the similar growth patterns in all three countries of the percentage of university scientific output involving a university-university collaborations. From 1984 to almost the end of the decade,
university-university collaborations increased from approximately 4.5 per cent to about 6.0 per cent of the university scientific output. There is no obvious reason why three countries separated by vast geographical distances and with autonomous university communities should experience such similar growth patterns. In contrast, the percentage of all university collaborations that involved a university-university collaboration did not exhibit very similar trends across the three countries.

Counting two-way collaborations proved to be a useful way to explore university-university collaborations within a university community. The average number of two-way collaborations per paper at the aggregate science field level was between 1.1 and 1.2 in for all three countries. The average number of two-way collaborations per physics paper in the UK and Canada and per clinical medicine paper in Canada was significantly greater than the aggregate average. The high collaborative activity in physics probably reflects a greater amount of cooperative research in high energy physics and other 'big sciences' in these countries.

A cross-country comparison of the ranking of CHI science fields by the percentage of publications that involved university-university collaboration did not reveal much correlation with Frame and Carpenter's basic versus applied research field categorisation. However, it was found that the UK and Australia had similar collaborative activities across the CHI science fields but Canada was quite different.

An *intranational* comparison of CHI science areas ranked by the percentage of the total number of two-way collaborations showed that there may be a significant relationship between the level of university-university collaboration in a scientific area and the national expenditure in that area. There were a couple of exceptions. In Canada and the UK, physics and earth and
space sciences ranked higher than expected, perhaps confirming a need to share centralised facilities, data, and personnel in these scientific areas.

A strong nonlinear relationship was found between two-way university-university collaborations and university scientific output. Larger universities have more university-university collaborations but the number of collaboration is proportionately less of the scientific output than was found for smaller universities.

A strong relationship was found between collaboration and geographical proximity. The number of two-way collaborations that a university has with other universities decreases exponentially with the distance separating the universities. This may reflect a fundamental need for informal, 'face-to-face' communications in collaborative research. An examination of how this relationship changed with time showed that in the UK and Australia, universities displayed a slight but increasing tendency to collaborate with partners that were geographically closer while the reverse trend was observed in Canada.

A technique involving the use of a national collaboration vector was designed to assess how collaborations were distributed in the university community. Two-way collaborations were more evenly distributed among Australian universities than UK or Canadian universities. Also, a time series analysis revealed that Australian university-university collaborations had became more evenly distributed over the decade while in Canada and the UK there was a tendency for them to become more concentrated in fewer universities. All three countries showed a tendency for physics collaborations to become more concentrated in fewer universities.

Now we shall turn our attention to mapping collaborative activity within the university community.
University Collaboration

This chapter is composed of five sections each of which investigates collaboration in the university community from a different perspective. The policy implications of the findings presented here will be discussed in a separate section in the conclusions chapter.

The first section looks at the overall collaborative activity in the university community without regard for the type of collaborative partner. The second section analyses institutional collaboration within the context of the number of authors and the number of institutions that are listed on a publication. The third section focuses on the growth of university-university publications throughout the decade. The fourth section uses the notion of a two-way collaboration to do the following: to examine the relationship between the average number of collaborations per paper and the science area; to perform inter-country comparisons of collaborative activity within a basic versus applied research framework; to do an *intranational* comparison by science field of university-university collaborations; to analyse the relationship between university scientific output and university-university collaborative activity; and to determine whether there is a relationship between geographical proximity and the amount of collaboration. The fifth section describes the use of a vector analysis
technique to see how the distribution of collaborations in each university community has changed with time.

7.1 **Overall University Collaborative Activity**

The overall collaborative activity in each university community - that is collaborations between a university and any domestic or foreign institution - was evaluated by counting articles, notes and reviews in the unified data set that contained at least one domestic university name in the corporate address field and at least one other partner. The additional partner could have been another department in the same university, or another domestic or foreign institution, organisation, company or individual. The results plotted in Figure 7.1 depicts a steady growth in university collaborations over the decade. Canada exhibited the largest growth with a 6.9 per cent per annum increase between 1984 and 1989, followed by a very large 22.7 per cent rise in 1990. During the same period, UK and Australian universities demonstrated similar and considerable collaborative growth with a 5.4 and 5.0 per cent per annum increase, respectively, followed by a slow down in 1990. Over the whole decade the UK and Australian universities displayed 4.6 and 4.1 per cent per annum growth, respectively.

Figure 7.2 portrays the overall university collaborative activity as a percentage of the total university scientific output. The growth pattern in the UK and Australia was remarkably similar. The frequency of university collaborations grew from about 35 per cent in 1981 to 50 per cent in 1990. On the other hand, the occurrence of Canadian university collaborations was greater and accounted for 46 per cent of the university scientific output in 1984, grew to nearly 50 per cent in 1989 and then jumped dramatically to 58 per cent in 1990.
In all three countries, the growth in the percentage of university collaborations making up the university scientific output was strong and
Science Citation Index publications that contained one domestic university and any other partner (university department, domestic or foreign institution).
Figure 7.2

Percent of University Scientific Output Involving a University Collaboration

Articles, notes & reviews
sustained over the decade. A variety of factors could have contributed to this growth. These include an increase in interdisciplinary research, economic pressure to share resources and make joint appointments, and governmental policies to encourage university-industry linkages. A good deal more investigation would be needed to determine why such a strong and similar rate of growth occurred in these three countries. It would be particularly interesting to see if a bibliometric assessment of interdepartmental collaboration revealed an increase in the occurrence of interdisciplinary research.

7.2 Authors and Institutions

During the analysis of the overall university collaborative activity, a visual inspection of randomly selected publications revealed an interesting phenomenon. This finding raised a basic question about the nature of an institutional collaboration and is illustrated by the following three examples derived from the 1990 Canadian data set. 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: ISAAC 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 corporate addresses for two different institutions: University of British Columbia, biology department and York University, zoology department. In the second example, the author listed two corporate addresses which were two departments in the same institution: University of Manitoba, department of pathology and department of physiology. And in the third example, the author listed two corporate addresses in the same institution and another address in a different institution; Isaak Walton Killam Children's Hospital and Dalhousie University, department of pediatrics and department of microbiology. In each of the preceding examples, and any other publications which listed more corporate addresses (at least one of which was a domestic university) than authors would have been counted as a university collaboration. One might ask if these publications actually reflect an institutional collaboration and whether they should be counted as such.

Before focusing on this question, it is worth contemplating why an author might list more than one corporate address. A few obvious reasons come to mind: the author had a joint appointment in two departments or institutions; the author was a visiting fellow and listed both the home and visited institution; the author was an adjunct professor who worked primarily in another sector and did some research in conjunction with a university; or the author was a private-practice physician, with privileges to admit patients to a university-affiliated hospital (not unusual in Canada), who was involved in clinical trials and listed
both the private practice and hospital addresses on the resultant research publication.

After some consideration and discussions with colleagues, it was decided that these publications should be considered as valid institutional collaborations since they reflect a formal or informal agreement between two (or more) departments or institutions to share a single researcher. The institutional collaboration is manifested as a publication from the shared researcher.

Before too much emphasis was given to this type of collaboration, a count was made of the occurrences of one-author publications listing two (or more) institutions as well as publications listing more authors than institutions (which includes one-author publications listing two or more institutions). It should be noted that even this evaluation inherently underestimates the number of instances of this type of collaboration. For example, it is possible that 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. The Science Citation Index provides no means for determining author-institution affiliations so it is impossible to detect such cases.

The graphs shown in Figure 7.3 demonstrate that the number publications which involved one author listing two (or more) institutional addresses and, more generally, the number of collaborations which involved more institutions than authors occurred in a significant percentage of the university collaborations. Canadian publications with one author and two (or more) institutions accounted for 5.5 per cent of all university collaborations in

\[ \text{1} \]

\[ \text{1} \] The Science Citation Index does not link individual authors with the institutions listed in the corporate address field. Thus, for example, if one is given a paper written by three authors which lists two institutions it is impossible to know which author is affiliated with which institution.
1984. It continuously declined to 3.5 per cent in 1989 and then rose rapidly back to the 1984 level in 1990. The UK and Australia displayed similar trends. One author publications listing two (or more) institutions occurred in 3.7 per cent of the university collaborations in 1981 but declined to approximately 2.5 per cent by 1990.

Canadian publications that listed more corporate addresses than authors (including one author papers listing two or more institutions) accounted for between 10.5 and 11.3 per cent of all university collaborations until 1989 when it rose sharply to 13.7 per cent. The percentage of UK and Australian publications with the same characteristics fluctuated between 4.5 and 6.0 per cent of the university collaborations throughout the decade. This was approximately one-half of the percentage that was seen in Canada.

A detailed investigation using the CHI journal classification scheme was carried out to determine if the occurrence of this collaboration type differed across science areas. There was some variations from country to country, but generally speaking, the highest occurrence of publications with more institutions than authors was found in clinical medicine (40-50 per cent), followed by biomedical research and physics (10-15 per cent), biology and earth and space science (5-10 per cent) and chemistry, mathematics and engineering and technology (less than 5 per cent).

The high occurrence of this type of collaboration in clinical medicine could be the result of joint appointments, especially between departments in the same hospital and between a hospital and a university. The relatively high incidence in biomedical research and physics might be partially explained by researchers who visit institutions with unique research facilities and list both
Figure 7.3
A. One Author and Two or More Institutions

B. More Institutions than Authors*

* includes papers with one author and two or more institutions
institutions on their publication. No references have been found in the literature that report this phenomenon. A more detailed interview-based investigation would have to be carried out to uncover the reasons why authors list more institutions than authors and why there is such a large variation between fields.

7.3 University-University Publications

Publications in the unified data sets that contained at least two domestic university names in the corporate address field were counted. Generally speaking, the results (Figure 7.4) indicate that between 1984 and 1990 all three countries experienced a significant increase in university-university collaborations.

Australian university-university publications fluctuated a little then exhibited a steady 4.7 per cent per annum increase until 1989 which was followed by a 12.7 per cent decline in 1990. The number of UK university-university collaborations changed very little from 1981 to 1984 but then it grew rapidly at approximately 6 per cent per annum until 1989 after which there was a sharp 12.8 per cent decreased in 1990. Canadian publications showed a sustained 10 per cent per annum growth from 1984 to 1988, changed little between 1988 and 1989 and then increased by a phenomenal 35 per cent in 1990.

Figure 7.5 displays the number of university-university publications as a percentage of the total university scientific output. A notable and curious feature of this graph is the analogous percentages and growth patterns in all three countries. From 1981 to 1984, these publications accounted for an about 4.5 per cent of the university scientific output in the UK and Australia. Starting in 1984, all three countries entered a similar growth trajectory. Australian publications climbing to about 5.8 per cent of the university scientific output in
Science Citation Index publications that contained the name of at least two domestic universities in the corporate address field.
Figure 7.5

Percent of University Scientific Output Involving a University-University Collaboration

![Graph showing percent of university scientific output involving university-university collaboration over the years from 1981 to 1990, with data points for AUS, CAN, and UK.]
1987 and then slowly fell to 5.5 per cent in 1990. The growth in the UK was stronger and longer. By 1989 these collaborative publications accounted for 6.3 per cent of the university scientific output but fell to 5.8 per cent in 1990. The Canadian trend was similar. However, instead of declining in the last year university-university publications grew rapidly, rising from 5.8 per cent in 1989 to 7.3 per cent in 1990.

When the number of university-university publications are expressed as a percentage of the overall number of university collaborations (see Figure 7.6) the result is not quite so clear. In the UK and Australia the percentage fluctuated between 11 and 13.5 per cent over the decade showing a general tendency to decline in the early 1980s, increase from about 1984 to 1988 and then decline until the end of the decade. The percentage of Canadian university-university publications tended to increase from 10 per cent in 1984 to approximately 12.5 per cent in 1990.

Discussions with science policy analysts from Australia and the UK and correspondence with two Canadian observers has not revealed any obvious reasons for the growth of *intranational* university-university collaborations in the mid 1980s. One factor that was common to both the UK and Australia was the substantial amount of organisational and financial restructuring of the university community that began in the early 1980s and continued throughout the decade. There was no structural reorganisation of Canadian universities, perhaps because of the inherently strong inter-university infrastructure which may act as a partial buffer against government intervention in university affairs\(^2\) (see

\(^2\)Canadian universities have a number of inter-university organisations such as the Council of Ontario Universities, the Conférence des recteurs et des principaux des universités du Québec, Tri-University President's Council, the Association of Atlantic Universities and the Council of Western Canadian University Presidents.
Figure 7.6

Percent of All University Collaborations
Involving a University-University Collaboration
Chapter 4 for more details). However, there were significant financial cut-backs, especially in the provincial contributions, to the universities. Exactly how one would go about investigating the effect of economic cut-backs on university-university collaboration is an interesting problem that warrants more exploration.

The dramatic growth in 1990 of Canadian university collaborations, particularly, university-university collaborations and the increase in publications with more institutions than authors might be attributable to programmes which were introduced during the late 1980s. Various federal and provincial government initiatives were launched to encourage more collaboration with universities, in particular, university-industry collaboration. Some of these programmes emphasised the need for more than one university to participate. Examples of these programmes (see Chapter 4 for more details) are the federal government 'matching funds' strategy; the seven centres of excellence established in the province of Ontario; the inauguration of the national centres of excellence initiative; and individual provincial initiatives to encourage more economically relevant research. By 1990, the effect of some these programmes may have be seen in the publication data. However, it will not be until the mid 1990s that a bibliometric analysis would reveal whether or not these programmes had any real impact on university collaborations.

Some aspects of the preceding findings are indeed curious and generate more questions than they answer. What factor(s) would three countries separated by such large distances and with essentially autonomous university communities have in common that would stimulate similar growth patterns in university collaborations? Why should the percentage of the university-university publications which contribute to the national scientific output be almost the same in all three countries? Could global economic factors such as the recession in the early and late 1980s, economic growth in the mid 1980s and financial cut backs to the university community affect collaborative activity?
Was there a change in attitude within the university community that encouraged university researchers to seek more partners from within their own community? Were the trends restricted to these three Commonwealth nations or did the trends occur in other industrialised nations? Answers to these and other questions warrant more investigation because the identification of the forces which stimulate and retard *intranational* university-university collaboration, and university collaboration in general, would be valuable to policy makers.

7.4 **Two-way Collaborations**

The remainder of this section explores university-university collaborations primarily within the context of two-way collaborations. As described in the methodology, the number of two-way collaborations is determined by counting the number of pairs of domestic universities that participated in a given paper (see equation 5.1). A paper involving two universities results in one two-way collaboration, a paper involving three universities results in three two-way collaborations and one involving four universities produces six two-way collaborations.

7.4.1 **Collaborations Per Paper**

The average number of two-way collaborations that occurred in each CHI science area was determined for each country. It is worth noting that an average of 1.0 two-collaborations per paper implies that exactly two universities participated in each paper, whereas, an average of 3.0 implies most publications involved three universities. The value of the average number of university collaborators per paper is an indicator of the distribution of the number of university participants across all university-university publications. The closer the average is to 1.0, the more frequently only two collaborators
were involved; and the larger the value, the more frequently three, four and more collaborators were involved.

The bar graph in Figure 7.7 illustrates how the average number of university collaborators varied from the aggregate level to the individual CHI science fields\(^3\) for each country. At the aggregate science level Canada and the UK had an average of approximately 1.2 two-way university collaborations per paper while in Australia it was slightly lower at 1.1. The percentage of papers that involved a specific number of universities is tabulated in Table 7.1. It provides some perspective on how these averages arose.

Table 7.1

<table>
<thead>
<tr>
<th>Country</th>
<th>Average number publications/year</th>
<th>Number of universities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>290(^a)</td>
<td>95.4% 4.2% 0.4% 0.0%</td>
</tr>
<tr>
<td>Canada</td>
<td>1123(^b)</td>
<td>92.9% 5.8% 0.9% 0.3%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>911(^a)</td>
<td>93.0% 5.4% 1.1% 0.5%</td>
</tr>
</tbody>
</table>

Notes:
\(^a\) 1981-1990
\(^b\) 1984-1990

More than 93 per cent of all publications involved only two universities. About 4.2 per cent of the Australian publications and more than 5 per cent of the UK and Canadian publications involved three universities. A small but

\(^3\) Throughout this section the following abbreviations have been used in the tables and figures: AGG - all CHI science fields, PHY - physics, MTH - mathematics, CHM - chemistry, BIO - biology, BMR - biomedical research, CLM - clinical medicine, ESS - earth and space sciences, and ENT - engineering and technology.
Figure 7.7
Two-Way University Collaborations Per Paper

CHI Science Area

AGG - Aggregate Science Area
MTH - Mathematics
BIO - Biology
ESS - Earth & Space Sciences
ENT - Engineering & Technology

PHY - Physics
CHM - Chemistry
BMR - Biomedical Research
PSY - Psychology

Two-way collaborations/

AU
CA
UK
significant percentage of UK and Canadian publications involved four or more universities. This was a factor of more than three greater than in Australia. It was the distribution of university collaborators that determined the average value of number of two-way collaborations per paper and on the average, at the aggregate level, Canadian and UK university publications involved more university partners than did Australian publications.

The average number of two-way collaborations per paper for each CHI science area was broadly similar but there were a few notable exceptions. Physics in Canada and the UK, clinical medicine in Canada and earth and space science in Australia had more collaborators per paper than was the case at the aggregate science level.

### 7.4.2 Inter-Country Comparison

The percentage of publications in a given CHI field that involved a university-university collaboration was determined. These values are comparable across the three countries because percentages normalise for the effects caused by the scientific size of the university community in each country. In Table 7.2 the CHI science fields are ranked by the percentage of publications that entailed a university-university collaboration. Also presented in the table are the rank and percentages of the 1973 publications that Frame and Carpenter’s (1979) study found involved an international institutional collaboration. Recall that they claimed there was more cooperation in the basic research areas (physics, mathematics, earth and space science and biomedical research) than in the more applied areas (chemistry, biology, clinical medicine and engineering and technology). For convenience, the more basic research fields have been italicised.
Table 7.2
Ranking of Percentage of Publications Involving a University-University Collaboration for CHI Science Fields

<table>
<thead>
<tr>
<th>Country</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>CHM</td>
<td>ESS</td>
<td>BMR</td>
<td>CLM</td>
<td>MTH</td>
<td>PHY</td>
<td>BIO</td>
<td>ENT</td>
</tr>
<tr>
<td>percent collaboration</td>
<td>10.11%</td>
<td>6.59%</td>
<td>5.29%</td>
<td>4.86%</td>
<td>4.72%</td>
<td>3.77%</td>
<td>3.62%</td>
<td>3.07%</td>
</tr>
<tr>
<td>Canada</td>
<td>ESS</td>
<td>PHY</td>
<td>MTH</td>
<td>BIO</td>
<td>ENT</td>
<td>BMR</td>
<td>CLM</td>
<td>CHM</td>
</tr>
<tr>
<td>percent collaboration</td>
<td>8.58%</td>
<td>8.47%</td>
<td>7.15%</td>
<td>6.50%</td>
<td>6.37%</td>
<td>6.34%</td>
<td>6.14%</td>
<td>4.64%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>ESS</td>
<td>PHY</td>
<td>CHM</td>
<td>BMR</td>
<td>CLM</td>
<td>MTH</td>
<td>ENT</td>
<td>BIO</td>
</tr>
<tr>
<td>percent collaboration</td>
<td>8.55%</td>
<td>7.32%</td>
<td>6.30%</td>
<td>5.71%</td>
<td>4.54%</td>
<td>4.35%</td>
<td>3.81%</td>
<td>3.55%</td>
</tr>
<tr>
<td>Frame &amp; Carpenter</td>
<td>ESS</td>
<td>PHY</td>
<td>MTH</td>
<td>BMR</td>
<td>CHM</td>
<td>BIO</td>
<td>CLM</td>
<td>ENT</td>
</tr>
<tr>
<td>percent collaboration</td>
<td>4.45%</td>
<td>4.23%</td>
<td>3.75%</td>
<td>2.63%</td>
<td>2.03%</td>
<td>1.68%</td>
<td>1.61%</td>
<td>1.46%</td>
</tr>
</tbody>
</table>

At first glance, with the noticeable exception of chemistry in Australia, it might appear that university-university collaborative activity in three countries appears to follow Frame and Carpenter’s basic versus applied dichotomy. However, a closer inspection shows that there are significant discrepancies and a different interpretation may be warranted.

Earth and space science In all three countries and physics in Canada and the UK shows a definite tendency to have more university-university collaborations than other CHI science areas. This may result from the need to share expensive, complex high energy and astronomy research facilities. The low amount of collaborative activity in Australian physics is no doubt due to the fact that there is little physics research in Australia. The Australian Science and Technology Council (ASTEC, 1989) in their report on Australian science noted that ‘physics has never been a particularly large field and has been declining in recent years’.

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There is a tendency for there to be a fair amount of collaboration in biomedical research in all countries. In Canada, even though the percentage of collaboration in biology and engineering and technology is higher than the percentage in biomedical research, the values are so similar that for all intents and purposes they are the same. An interesting observation is that clinical medicine is always ranked next to biomedical research and with the exception of the UK, both fields exhibit a similar amount of collaboration activity. It almost appears that these two research areas are inseparable and, perhaps, should be amalgamated into one medical sciences category.

Engineering and technology and biology research shows the least amount of collaboration in Australia and the UK but ranks fourth and fifth in Canada. Canadian activity in these areas may have little to do with the nature of the scientific research but rather may have resulted from a historical tradition which encouraged co-operative research in matters concerning mining, agriculture, forestry and fisheries. Canada has always assigned national priority to research in these areas because in every province a significant portion of their economic revenue comes from at least three out of four of these areas.

Australian chemistry research has by far the largest percentage of university-university collaborations, outstripping earth and space science by a large margin. Discussions with Australian policy analysts did not reveal any obvious reason for this. In fact, they were surprised by this finding, but confirmed it after they re-examined their own bibliometric data.

Why should the pattern of intranational university-university collaborations not conform to Frame and Carpenter's basic versus applied dichotomy? There are at least two reasons: inherent problems with the CHI journal classification scheme and a flaw in the basic versus applied research hypothesis.
First, let us examine the journal classification scheme. Frame and Carpenter analysed 1973 Science Citation Index data using CHI Research's 1973 journal classification scheme. Both the analysis and the journal classification were derived from publications published in the same year. This study used 1981-90 Science Citation Index data and CHI Research's 1984 journal classification scheme. The journal set was derived by clustering 1984 data. This bibliometric analysis examined ten years of data and used the one journal set. Over the decade some older journals disappeared and some new ones appeared. This has not been reflected in the CHI journal set. Also, some journals have shifted their focus in order to survive in a competitive and dynamic scientific world. A speciality journal with a previous basic research orientation may have evolved an applied research focus as the field matured. Similarly some journals are interdisciplinary and are located on the boundary between two or more fields; their content moves between fields and specialties over time. For example, a biophysics journal may publish more basic research articles one year and then more applied research articles the next. It is inappropriate to categorise a whole science area as basic or applied based on journal groupings because it is difficult to classify individual journals as basic or applied.

Frame and Carpenter did not give any rationalisation for dividing the various CHI science fields into basic and applied research other than prefacing their comments with the comment that 'a quick perusal of Table 1 enables us to make an obvious generalisation'. It seems they may have had some misconceptions. For example, many people think that because mathematics research can be esoteric it has few applications. In fact, much mathematics is very applied; it is the language of science. Furthermore, Frame and Carpenter's generalisation does not account for mixed basic and applied research which is the mainstay of high energy physics and radio astronomy. For example, new
instruments (such as linear accelerators, radio telescope, and nuclear magnetic
resonance scanners) are designed and constructed by physicists and engineers
with an excellent grasp of how to apply fundamental science and engineering
principles and their tacit knowledge to building a better set of 'eyes and ears'
with which to investigate uncharted research frontiers. Then applied and basic
scientists and engineers, experimentalists and theoreticians, explore these
frontiers side-by-side, all the while designing and redesigning, building and
rebuilding their equipment and publishing their findings as they go along - basic
and applied. The boundary between basic and applied is 'fuzzy' and Frame and
Carpenter's definition seems very artificial. The best solution to this difficulty is
to stay away from such distinctions.

Perhaps the results in Table 7.2 should be interpreted as a fingerprint of
the intranational university-university collaboration activity which has been
derived using a common journal classification. This fingerprint is defined by the
composition of the CHI fields ranked by the percentage of publications that
involve a university-university collaboration. An international comparison of the
national fingerprints can be made using ranking correlation techniques.

A Spearman rank-correlation coefficient was calculated for each pair of
countries and a two-tailed t-test was used to determine if the correlations were
significant. There was no significant correlation between the Australian and
Canadian or the Canadian and the UK fingerprints but a significant correlation
was found between the Australian and the UK fingerprints (t-test < 0.05).

Each country was compared to the Frame and Carpenter science field
rankings (see Table 7.2) for international collaborations. No correlation was
found between these rankings and the science field rankings of collaborative
activity in Australia, a small correlation existed for Canada (t-test < 0.10) and
there was reasonable correlation for the UK (t-test < 0.05). In other words, a
general correlation was not found with the basic and applied categories for all three countries.

7.4.3 Intranational University-University Collaboration

The percentage of university-university collaborations that occurred in each CHI science field was calculated so that a *intranational* cross-field comparison could be made. In Table 7.3 each science field was ranked by this percentage. In addition, the percentage of the total number of publications that occurred in each CHI science field was calculated and the fields were ranked according to this percentage. This rank (publication rank) is also given in the table.

### Table 7.3

**CHI Science Areas Ranked by Percentage of Two-way Collaborations**

<table>
<thead>
<tr>
<th>Country</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australiaa</td>
<td>CLM</td>
<td>CHM</td>
<td>BMR</td>
<td>BIO</td>
<td>ESS</td>
<td>PHY</td>
<td>ENT</td>
<td>MTH</td>
</tr>
<tr>
<td>percent collaborations</td>
<td>26.7%</td>
<td>23.3%</td>
<td>16.6%</td>
<td>10.5%</td>
<td>9.5%</td>
<td>5.9%</td>
<td>2.6%</td>
<td>2.4%</td>
</tr>
<tr>
<td>publication rank</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Canadab</td>
<td>CLM</td>
<td>PHY</td>
<td>BMR</td>
<td>BIO</td>
<td>ESS</td>
<td>ENT</td>
<td>CHM</td>
<td>MTH</td>
</tr>
<tr>
<td>percent collaborations</td>
<td>29.4%</td>
<td>15.7%</td>
<td>14.8%</td>
<td>11.9%</td>
<td>8.3%</td>
<td>6.4%</td>
<td>6.0%</td>
<td>3.3%</td>
</tr>
<tr>
<td>publication rank</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>United Kingdomc</td>
<td>PHY</td>
<td>CLM</td>
<td>BMR</td>
<td>CHM</td>
<td>ESS</td>
<td>BIO</td>
<td>ENT</td>
<td>MTH</td>
</tr>
<tr>
<td>percent collaborations</td>
<td>22.4%</td>
<td>20.4%</td>
<td>17.4%</td>
<td>16.1%</td>
<td>9.6%</td>
<td>5.4%</td>
<td>4.4%</td>
<td>2.1%</td>
</tr>
<tr>
<td>publication rank</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

**Notes:**
Average number of two-way collaborations/year
a. 336  b. 1258  c. 1182

A quick inspection of the table seems to indicate that there might be a relationship between the amount of university-university collaboration in a science area and the national expenditure in that science area. Establishing such a relationship is difficult and is hampered by the problem of accurately
apportioning the national scientific expenditures to individual CHI science areas. An indirect technique was developed in order to overcome this difficulty.

Recall our previous finding that there is a proportional relationship between the size of an academic institution (number of staff) and its scientific output (number of publications). The number of staff was used as a measure of the recurrent expenditure; the more staff an institution has, the larger its expenditure. We can extrapolate this to the national level and suggest that the more scientific researchers a country employs in its universities, the greater the national expenditure has to be in science.

Now, we assume that the number of staff in a given science area is directly proportional to the national expenditure in that science area. Support for this notion comes from Australian R&D expenditure data which were also broken down by science field, and the statistics on R&D staff in higher educational institutions which was broken down by science field. A comparison of the science fields ranked by expenditure and ranked by number of staff showed that there was an exact match in rankings⁵.

We know that the number of publications is directly proportional to the number of staff at the institutional level and we can extrapolate this relationship to the national level; the more researchers a country has, the greater its scientific output. If we assume that the number of staff is directly proportional to the national expenditure in each science area, then as a first order approximation, it follows that the number of publications in each science area is

⁵See *Profile of Australian Science* p 26 produced by Australian Science and Technology Council (1989) published by Australian Government Services. A comparison of 1978-86 data found in Figure 2.8, R&D Expenditure by Field of Science, Higher Education and Figure, 2.9 Research Staff Numbers (conducting R&D) in Higher Education by Field of Science yielded the following rankings both by expenditure and by staff: 1. biological, 2. medical, 3. engineering, 4. physical, 5. agriculture, 6 chemical and 7. earth.
directly proportional to the national expenditure in that science area. This assumption, however, disregards productivity differences between science fields which can be substantial.

An examination of Table 7.3 shows that, with a few exceptions, there is a close relationship between the percentage of collaboration rank and the percentage of publication rank. This was confirmed by calculating the Spearman rank-coefficient. Australia had the best correlation at 0.96 (t-test < 0.001), followed by Canada with a coefficient of 0.78 (t-test < 0.01) and then the UK with a coefficient of 0.72 (t-test < 0.05).

Let us now examine the exceptions. Chemistry was the only exception in Australia. It was ranked fourth in publication output but was ranked first in university-university collaborative activity. Physics was ranked fourth in Canada and the UK in publication output but was ranked second in Canada and first in the UK in university-university collaborations. Earth and space science was ranked seventh in Canada and the UK in publication output but was ranked fifth in Canada and the UK in terms of collaborative activity.

The explanation for the ranking differences in physics and earth and space science in the UK and Canada may reflect the fact that their research effort in these fields focuses around centralised, expensive and complex instrumentation such as higher energy particle accelerators and radio telescopes which are known to spawn a great deal of collaborative activity. Also, facilities of this type involve large capital expenditures. Our analysis only used recurrent expenditures and perhaps these results reflect the need to account for capital costs in the analysis. Again, the reason for the anomaly in chemistry in Australia is unknown, even to science activity observers from that country, and requires further investigation.
7.4.4 **Scientific Output and Collaborative Activity**

A scatter plot (Figure 7.8) composed of the number of two-way university-university collaborations and the number of articles, notes and reviews published by each university was produced for each country. The initial regression analysis of the data suggested there was a linear relationship between collaborations and publications. However, when the residuals were examined it was found that they were correlated with the number of publications; thus again the data were heteroscedastic. A natural logarithmic transformation of both collaborations and publications removed the correlation.

<table>
<thead>
<tr>
<th>Country</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>1.23</td>
<td>0.71</td>
</tr>
<tr>
<td>Canada</td>
<td>0.61</td>
<td>0.83</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>0.17</td>
<td>0.96</td>
</tr>
</tbody>
</table>

**Note:**
1. two tailed t-test < 0.001

The elasticity coefficient, which is equal to \( b \) (see Table 7.4), is less than one for all three countries implying that a small increase in the number of publications would produce a proportionately smaller increase in the number of university-university collaborations. There are couple of interesting points to observe. First, the elasticity coefficient for the UK is very close to one suggesting that the relationship between publications and collaborations is almost linear. Second, at least for these three countries, the smaller the country the smaller the elasticity coefficient. The reasons for this are not apparent and before such a generalisation can be made, a number of other countries of different sizes would have to be examined.
Figure 7.8
Collaborations Versus Scientific Output
A. Australia

\[ \ln(\text{Collaborations}) = 0.71 \ln(\text{Publications}) + 0.21 \pm 0.06 \]

or

\[ \text{Collaborations} = 1.23 \times \text{Publications}^{0.71} \]

Two-tailed t-test > 0.001 and R-squared = 0.89

No. data points = 20

* Standard error of slope
Figure 7.8

Collaborations Versus Scientific Output

B. Canada

Ln(Collaborations) = 0.83 Ln(Publications) - 0.49

(±0.03)*

or

Collaborations = 0.61 Publications^{0.83}

Two-tailed t-test < 0.001 and R-squared = 0.96
No. data points = 47
*Standard error of slope
Figure 7.8

Collaborations Versus Scientific Output

C. United Kingdom

\[
\text{Ln}(\text{Collaborations}) = 0.96 \text{Ln}(\text{Publications}) - 1.76
\]

\((\pm 0.05)^*\)

or

\[
\text{Collaborations} = 0.17 \text{Publications}^{0.96}
\]

Two-tailed t-test > 0.001 and R-square = 0.90

No. data points = 50

* Standard error of slope
7.4.5  **Effect of Geographical Proximity**

There have been some findings that suggest geographical proximity has an effect on international collaboration (Frame and Carpenter 1979; Luukkonen, Person and Sivertsen, 1990; Moed, de Bruin, Nederhof and Tijssen, 1990). Most of these studies used multidimensional scaling analysis which made it difficult to isolate geographical effects from other economic, political and social effects. As described in the methodology chapter, a new technique was devised to establish whether or not there was a relationship between geographical proximity and collaborative activity. Briefly, the technique involves measuring the distance between pairs of universities which is normalised to the maximum distance separating a pair of universities. The number of collaborations in each of a fixed distance interval was counted.

In Figure 7.9 the number of total number two-way collaborations in the UK and Australia between 1981 and 1990 and in Canada between 1984 and 1990 is plotted against the normalised geographical distance for each country. For convenience a fixed distance interval of 0.1 or 10 per cent of the country size was chosen and the number of collaborations that occurred within each interval were counted. A regression analysis of collaborations versus distance was performed and in each instance it was found that the number of two-way collaborations decreased exponentially with distance (two-tailed t-test < 0.01).

To put this into a geographical perspective, the furthest distance between any pair of universities is approximately 700 km in the UK, 2100 km in Australia and 4800 km in Canada; therefore each 0.1 normalised interval represents 70 km, 210 km and 480 km, respectively. It is worth noting that there is no data point plotted in the 0.60 to 0.70 interval for Australia because there are no
universities within this interval. Also, in the UK it can be seen that the number of collaborations in the 0.0 and 0.1 interval is less than might be
Figure 7.9
Geographical Proximity

One Distance Interval = 10 per cent of the country size

Australia:

\[
\ln(\text{Collaborations}) = -5.0 \text{ Distance} + 9.8
\]

or

\[
\text{Collaborations} = 18034 \ e^{-5.0 \text{ Distance}}
\]

Two-tailed t-test < 0.01, R-squared = 0.90, S.E. = ±0.084

Canada:

\[
\ln(\text{Collaborations}) = -3.8 \text{ Distance} + 10.1
\]

or

\[
\text{Collaborations} = 24343 \ e^{-3.8 \text{ Distance}}
\]

Two-tailed t-test < 0.01, R-squared = 0.72, S.E. = ±0.084

United Kingdom:

\[
\ln(\text{Collaborations}) = -5.2 \text{ Distance} + 11.8
\]

or

\[
\text{Collaborations} = 133252 \ e^{-5.2 \text{ Distance}}
\]

Two-tailed t-test < 0.01, R-squared = 0.80, S.E. = ±0.97
expected. This can be explained by two facts. First, the radius of greater London is approximately 40 km (25 mi) or approximately one distance interval in diameter. Second, all collaborations with the individual colleges of the University of London were counted as collaborations within the University of London. If the collaborations between the individual colleges had been counted separately, the number of two-way collaborations in the first interval would have been much larger.

This analysis provides convincing evidence that university-university collaborations occur more frequently with partners who are geographically closer than those further away. In general, more than 60 per cent of all two-way university-university collaborations in Canada and Australia and more than 40 per cent in the UK occur within a collaboration radius equal to less than 20 per cent of the country size which is 140 km in the UK, 410 km in Australia and 960 km in Canada. This provides evidence to support the notion that informal, ‘face-to-face’ communication may be an essential ingredient in research collaborations and that factors such as greater geographical distances with the additional travel cost and time involved are deterrents to collaboration.

We might expect that cheaper telecommunications, fax and electronic mail would have slowly been increasing the average radius of collaboration. A regression analysis of the number of collaborations versus distance was performed on a year-by-year basis in order to see if such effects could be observed. The slope of each regression line was plotted against time (see Figure 7.10). There is a direct relationship between the slope of the regression line and the average distance of collaboration.

---

6 The University of London is in greater London and not only is it the largest university in the UK, it has the largest number of collaborations in the UK. With the exception of a couple of smaller universities like the Universities of Reading and Surrey, most universities are more than 70 km (43 mi) away and their collaborations with the University of London would not be counted in the 0.0 to 0.1 interval.
Slope of regression line of collaborations and geographical proximity plotted over time. If the slope becomes more negative, collaborations are occurring between geographically closer partners. If the slope becomes more positive, collaborations are occurring further apart.
line and the radius of collaborations. A slope that tends to become more negative with time indicates that the collaboration radius is decreasing; in other words collaborations are becoming geographically closer. A slope that tends to become more positive with time shows that the collaboration radius is increasing; collaborations are becoming geographically more distant.

The results seem to indicate that during the early part of the decade there was a general trend in the UK and Australia for collaborations to occur between geographically more distant partners. However, by 1984 this trend had reversed and by 1990 there was a slight, but not very significant, tendency for collaboration to occur between closer partners than in 1981. In contrast, in Canada between 1984 and 1986, partners tended to move further apart but after that there was little change.

These trends are interesting but not especially significant. Roughly speaking, in Australia the percentage of collaborations that occurred in the 0.0 to 0.1 interval and in the UK the percentage of collaborations that occurred in the 0.0 to 0.2 interval had increased by approximately 4 per cent over the decade. On the other hand, in Canada, the percentage of collaborations that occurred in the 0.0 to 0.1 interval had decreased by 5 per cent between 1984 and 1986.

It is very difficult to say what caused these trends. For example, while telecommunications may have helped reduce the gap between collaborators, such factors as increasing transportation costs and travel time may have been had a more profound negative effect. These findings suggest that this is an interesting area for exploration but a great deal of care would have to be devoted to designing suitable quantitative and qualitative techniques to uncover the underlying factors.
7.5 Distribution of Collaborations

The magnitude of the national collaboration vector is a measure of the distribution of collaborations in the university community. In the methodology chapter, it was demonstrated that the magnitude of the national collaboration vector, $|V|$, is bounded by

$$\frac{2}{\sqrt{n}} \leq \frac{|V|}{m} \leq \sqrt{2}$$

where $m$ is the total number of two-way collaborations and $n$ is the number of universities. The closer $\frac{|V|}{m}$ is to the lower bound, the more evenly the collaborations are distributed; the closer it is to the upper bound, the more the collaborations are concentrated in fewer universities.

Table 7.5 gives the upper and lower bounds of the magnitude of the national collaboration vector and the actual value of the magnitude that was determined from the collaboration data for each country. Also, it gives a ratio which indicates where in the interval between the upper and lower bound $\frac{|V|}{m}$ is located. This ratio is determined by the following equation:

$$\text{ratio} = \frac{\text{magnitude}}{\text{upper bound} - \text{lower bound}}$$

The closer the ratio is to zero, the closer the magnitude is to the lower bound and the closer the ratio is to one, the closer the magnitude is to the upper bound.

Table 7.5

<table>
<thead>
<tr>
<th>Country</th>
<th>Lower</th>
<th>Upper</th>
<th>Measured</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>0.45</td>
<td>1.414</td>
<td>0.55</td>
<td>0.57</td>
</tr>
<tr>
<td>Canada</td>
<td>0.29</td>
<td>1.414</td>
<td>0.44</td>
<td>0.39</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>0.28</td>
<td>1.414</td>
<td>0.41</td>
<td>0.36</td>
</tr>
</tbody>
</table>
The data in Table 7.5 show that in Australia university-university collaborations are concentrated in fewer universities than in Canada or the UK. Australia has less than half as many universities and none of them are comparable to the largest universities in the other countries. This may partially account for the more even distribution of collaborations in its university community. On the other hand in the UK and Canada university-university collaborations are concentrated in a few universities. Additional confirmation of this comes from the knowledge that about 80 per cent of all university-university collaborations occurred in the top twenty universities in these countries.

In order to get a sense of how the collaboration distribution has changed over time, a regression analysis of the magnitude of the national collaboration vector was performed for each CHI science area versus time. (Note that individual linear regressions will not allows us to determine how much each science area contributed to the change in distribution.) Table 7.6 gives the sign of the linear regression slope (plus or minus) and its two-tailed t-test significance for each science area for each country. The sign of the slope indicates the direction in which the magnitude of the collaboration vector tended to change. A negative slope indicates a trend towards a more even distribution while a positive slope indicates a trend towards a more uneven distribution.

<table>
<thead>
<tr>
<th>Country</th>
<th>AGG</th>
<th>PHY</th>
<th>MTH</th>
<th>CHM</th>
<th>BIO</th>
<th>BMR</th>
<th>CLM</th>
<th>ESS</th>
<th>ENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>-.01</td>
<td>+.30</td>
<td>-.30</td>
<td>-.05</td>
<td>-.30</td>
<td>-.30</td>
<td>-.30</td>
<td>-.05</td>
<td>-.40</td>
</tr>
<tr>
<td>Canada</td>
<td>+.20</td>
<td>+.30</td>
<td>-.90</td>
<td>-.50</td>
<td>+.40</td>
<td>+.80</td>
<td>-.90</td>
<td>-.50</td>
<td>-.90</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>+.05</td>
<td>+.30</td>
<td>-.10</td>
<td>+.80</td>
<td>+.40</td>
<td>-.80</td>
<td>-.30</td>
<td>-.90</td>
<td>-.70</td>
</tr>
</tbody>
</table>

Table 7.6
Regression Analysis of Collaboration Distribution Time Trends
Since the number of years that were examined was ten or less, relatively few data points were used in the regression analysis therefore, a stringent interpretation of the significance levels was not used. A t-test value less than 0.10 was interpreted as being 'highly' significant and a t-test value of less than 0.30 but greater than 0.10 was be considered to be 'somewhat' significant.

Overall, there was a 'highly' significant trend in Australia for university-university collaborations to become more evenly distributed because the slope of the aggregate of all science areas was negative and its t-test was less than 0.01. This appeared to be a result of 'highly' significant trends in chemistry and earth and space science and 'somewhat' significant trends in mathematics, biology, biomedical research and clinical medicine to become more evenly distributed. Collaborations in physics showed a tendency to become more concentrated in fewer in universities.

Canada showed a 'somewhat' significant trend for university-university collaborations at the aggregate level to become concentrated in fewer universities as shown by the fact that the slope was positive with a t-test less than 0.20. Much of this concentration probably resulted from a tendency for physics collaborations to become concentrated in fewer universities. There was some difficulty interpreting the Canadian trends because only six data points were used in each regression analysis.

The United Kingdom also exhibited a 'highly' significant trend for university-university collaborations at the aggregate level to become more concentrated in fewer universities since the slope was negative with a t-test less than 0.05. However, only physics displayed a 'somewhat' significant trend towards concentration in fewer universities while mathematics and clinical medicine collaborations seemed to become more dispersed.
The tendency in all three countries for physics collaborations to become more concentrated in fewer universities may reflect a trend for centres of high energy physics research or other ‘big science’ research to be concentrated in fewer universities.

7.6 Summary

The number of university collaborations with all institutional types grew steadily throughout the 1980s with Canadian universities displaying the most vigorous growth. Over the decade the percentage of university published scientific output that was collaborative increased from 35 to 50 per cent in the UK and Australia while in Canada it rose from 46 to 58 per cent between 1984 and 1990.

More than 6 percent of university collaborations in the UK and Australia and as many as 12 per cent of those in Canada were composed of publications that list more institutions that authors in the Science Citation Index corporate address field. About 40-50 per cent of these occurred in clinical medicine.

The number of intranational university-university collaborations was constant during the first part of the decade, but between 1984 and 1989 it grew steadily at between 4.7 and 6 per cent per annum in Australia and the UK, respectively. Both countries exhibited a sharp decline in 1990. In Canada, the increase in university-university collaborations was much stronger at 10 per cent per annum between 1984 and 1988 and was followed by a phenomenal 35 per cent increase in 1990.

A curious finding in this study was the similar growth patterns in all three countries of the percentage of university scientific output involving a university-university collaborations. From 1984 to almost the end of the decade,
university-university collaborations increased from approximately 4.5 per cent to about 6.0 per cent of the university scientific output. There is no obvious reason why three countries separated by vast geographical distances and with autonomous university communities should experience such similar growth patterns. In contrast, the percentage of all university collaborations that involved a university-university collaboration did not exhibit very similar trends across the three countries.

Counting two-way collaborations proved to be a useful way to explore university-university collaborations within a university community. The average number of two-way collaborations per paper at the aggregate science field level was between 1.1 and 1.2 in for all three countries. The average number of two-way collaborations per physics paper in the UK and Canada and per clinical medicine paper in Canada was significantly greater than the aggregate average. The high collaborative activity in physics probably reflects a greater amount of cooperative research in high energy physics and other 'big sciences' in these countries.

A cross-country comparison of the ranking of CHI science fields by the percentage of publications that involved university-university collaboration did not reveal much correlation with Frame and Carpenter's basic versus applied research field categorisation. However, it was found that the UK and Australia had similar collaborative activities across the CHI science fields but Canada was quite different.

An intranational comparison of CHI science areas ranked by the percentage of the total number of two-way collaborations showed that there may be a significant relationship between the level of university-university collaboration in a scientific area and the national expenditure in that area. There were a couple of exceptions. In Canada and the UK, physics and earth and
space sciences ranked higher than expected, perhaps confirming a need to share centralised facilities, data, and personnel in these scientific areas.

A strong nonlinear relationship was found between two-way university-university collaborations and university scientific output. Larger universities have more university-university collaborations but the number of collaboration is proportionately less of the scientific output than was found for smaller universities.

A strong relationship was found between collaboration and geographical proximity. The number of two-way collaborations that a university has with other universities decreases exponentially with the distance separating the universities. This may reflect a fundamental need for informal, 'face-to-face' communications in collaborative research. An examination of how this relationship changed with time showed that in the UK and Australia, universities displayed a slight but increasing tendency to collaborate with partners that were geographically closer while the reverse trend was observed in Canada.

A technique involving the use of a national collaboration vector was designed to assess how collaborations were distributed in the university community. Two-way collaborations were more evenly distributed among Australian universities than UK or Canadian universities. Also, a time series analysis revealed that Australian university-university collaborations had became more evenly distributed over the decade while in Canada and the UK there was a tendency for them to become more concentrated in fewer universities. All three countries showed a tendency for physics collaborations to become more concentrated in fewer universities.

Now we shall turn our attention to mapping collaborative activity within the university community.
This chapter explores the collaboration maps which were produced from a prototype mapping technique that was developed to display the collaborative activity in each CHI science area of a university community. A detailed description of the technique used for generating the dynamic maps is given in the methodology chapter. Only the twenty universities with the most collaboration in each country are displayed on the dynamic maps because of resolution limitations of the graphics display. This was not a serious limitation because these universities account for approximately 80 per cent of all the collaborations.

It is important to remember that the object of this part of the research project was to develop a prototype dynamic mapping technique which might the assist policy analyst to visualise the collaborative activity within a research community. It was not the intention of this research project to use this mapping procedure as a tool for interpreting individual collaborative relationships in the community but rather to look for patterns. This could be a future research project. The pilot exercise has been successful from a technical point of view; however, there are many improvements which must be made before it could be considered to be a easily usable tool. These will be discussed later.
About a dozen policy analysts explored the dynamic maps. Each one of them considered the technique to be original and many of them gained new insights into the collaborative relationships within their university community. A few analysts were caught by surprise when they found collaborative relationships which they did not know or expect to exist. A couple of analysts were sceptical and thought the technique had more novelty value than utility.

The remainder of this section is divided into three parts. The first describes how to load and operate the map viewing program and how to interpret the maps that are displayed. The second part examines a feature of the collaborative networks that was broadly similar in all three countries. Finally, a brief discussion of some improvements to the mapping software is given.

8.1 The Map Viewing Program

Three diskettes, one for each country, with the dynamic maps are attached as an appendix to the inside back cover of this thesis. These maps can only be viewed on an IBM PC or an IBM PC compatible computer which has at least 640K of RAM, a VGA video graphics card, a C: hard disk drive with one megabyte of free disk space, a 3.5" double sided, double density floppy disk drive and the DOS operating system version 3.3 or higher. (Note that the map viewing software will not work under Windows or when any memory resident software such as Sidekick is installed.) The procedure for viewing the maps is as follows:

Step 1.

Once the computer has been turn on and the DOS prompt (usually a ‘>’) is visible, select a diskette which contains the collaboration maps for the desired country. Insert this diskette into the A: disk drive.
The map viewing program will *not* work if you only have a B: disk drive; it *must* be an A: disk drive.

**Step 2.**

At the DOS prompt type:

```
> a:
```

to switch to the A: disk drive. Then type:

```
> install
```

The first thing 'install' does is create a directory call MAPS on the C: hard drive. The map viewing software will *not* work if you do not have a C: hard drive. Then 'install' transfers the map-viewing programs from the A: drive to the MAPS directory. Once this is complete, a message will appear on the screen telling you to type UK_MAPS, AUS_MAPS or CAN_MAPS at the prompt depending on which country you selected.

Do *not* remove the diskette in the A: disk drive because it contains the data for the dynamic maps. (Only the map viewing software has been transferred to the hard drive.) At the DOS prompt, type the appropriate command as instructed by the message on the screen.

**Step 3.**

The map-viewing program will start and give you a menu of CHI science areas for which dynamic maps are available. Please note the commands that are listed at the bottom of the screen. These commands will be described in a moment.

Use the 'up' and 'down' cursor keys to highlight the CHI science area for which you wish to view the collaboration maps. Press the
<Enter> key once you have made a selection. The map viewing program will load the appropriate maps into the computer memory. This takes about a minute. The name of each map may be written on the screen as it is loaded into memory depending on how the configuration of the computer was setup. Once the process is complete, a dynamic cycling map series will be displayed on the screen.

Step 4.

A number of commands are available to let you change the cycling pattern or return to the CHI science field menu. These are the commands you saw listed at the bottom of the menu screen. The keys which initiates the commands and the command functions are listed below:

<table>
<thead>
<tr>
<th>Key</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enter</td>
<td>Stop and start the dynamic cycling.</td>
</tr>
<tr>
<td>R</td>
<td>Reverses the direction of cycling</td>
</tr>
<tr>
<td>Page Up</td>
<td>Manually cycle forward one map</td>
</tr>
<tr>
<td>Page Down</td>
<td>Manually cycle backward one map</td>
</tr>
<tr>
<td>ESC</td>
<td>Return to the CHI science area menu</td>
</tr>
</tbody>
</table>

For example, if you wish to change the direction in which the maps are cycling, first press the <Enter> key to stop the cycling, then press the <R> key. The maps will begin to cycle in the reverse direction. If you wish to inspect a map manually, first press the <Enter> key to stop the cycling, then use either the 'Page Up' or 'Page Down' key to select the map you want to view. Pressing the <Enter> key will start the cycling process again. If you want to return to the CHI science area menu, press the <Enter> key to stop the cycling and then press the <ESC> key. The menu will appear on the screen. Once you have finished using the map
viewing program, go to the CHI science area menu and press the <Q> key. This will returned you to the DOS prompt.

8.2 **Interpreting Collaboration Maps**

A series of eight maps depicting above average collaborators from among the top twenty UK universities in the CHI chemistry area are displayed in Figure 8.1. Thin, medium or wide thickness lines are drawn between pairs of universities that collaborated at or above the average for the top twenty universities. The method for determining the thickness is given in the methodology chapter however, generally speaking the thicker the line the more intensely a pair of universities collaborated. Located at the bottom right hand corner of each map are four lines of information that are interpreted as follows:

**Line 1** - CHI science area and the smoothing interval.

The first line of the first map in Figure 8.1 is

CHEMISTRY (1981-1983)

It indicates that this is a map of chemistry collaborations that was drawn using the combined 1981 to 1983 chemistry collaboration data.

**Line 2**: - Average number of collaborations, multiplier and cutoff value.

The second line of the first map in Figure 8.1 is

Ave Collab: 2.9 (1.0: 2.9)

The first value after the Ave. Collab.: label is the average of 2.9 number of collaborations that a university had during the three year smoothing interval. There are two value in brackets. The first value is a multiplier that could be modified during the preparation of the maps. The
Figure 8.1
United Kingdom Chemistry Collaboration Maps
Figure 8.1
United Kingdom Chemistry Collaboration Maps
1983-1985 and 1984-1986
Figure 8.1
United Kingdom Chemistry Collaboration Maps
Figure 8.1
United Kingdom Chemistry Collaboration Maps
second value is the cutoff value; it is the product of the average number of collaborations and the multiplier. Only pairs of universities that collaborate at or above the cutoff value are connected with lines. Except for the aggregate level maps the multiplier is 1.0. The multiplier is 1.5 for aggregate level maps because when 1.0 was used the maps were so densely connected that collaborative relationships was difficult to see.

**Line 3 - Maximum number of collaborations and university name**

The third line of the first map in Figure 8.1 is

Max Collab:  72 [LN]

This indicates that the maximum number of two-way collaborations that occurred with one university during the smoothing interval was 72. In chemistry research between 1981 and 1983 the University of London was the university which had this maximum. (If two or more universities were tied for maximum then the university which was alphabetically first is displayed; this very rarely occurred.)

**Line 4 - Maximum collaboration intensity**

The fourth line of the first map in Figure 8.1 is

Max Int Collab: 13 [LN-SF]

This indicates that the greatest intensity of collaboration occurred between the Universities of London and Sheffield. They had 13 collaborations in chemistry during the three year smoothing interval. (Again, if two or more pairs were tied for the maximum intensity, the pair that were alphabetically first are given on the map.)
8.3 Characteristics of the Dynamic Maps

A detailed description of the collaboration maps for each CHI science area for each country is given in the appendix. The objective of the description is only to point out some of the prominent characteristics and not to provide an interpretation or rationalisation of why various collaborations occurred. The interpretation of these maps could be the subject for a future study that would require intensive field work consulting knowledgeable observers for an interpretation of the collaborative linkages and why they changed with time.

This section investigates one interesting feature of the collaboration maps that seems to be common to all three countries. It was noticed that the mixture of national (or inter-regional) and regional (or intra-regional) collaborative networks in each CHI science area appeared to be a broadly similar in Canada, Australia and the UK. By way of illustration we shall examine the Canadian maps for three CHI science areas - physics, earth and space sciences and clinical medicine. First we will use the aggregate level map to illustrate some of the geographical features of Canada's university community.

8.3.1 Canadian University Community

The Canadian university community is concentrated in three distinct geographical regions. This can be seen by inspecting the aggregate level maps. The majority of Canadian universities are located in central Canada in the provinces of Ontario and Quebec. The remainder are situated in the prairie provinces and the province of British Columbia in the west and the Atlantic provinces in the east. With the exception of the Atlantic universities which are
among the smallest of the top twenty universities, generally speaking, at the aggregate level the most collaborative linkages were contained within the regions. However, there were some sustained ties between the western and central regions.

In central Canada the University of Toronto in the province of Ontario and McGill University in the province of Quebec are the primary collaborative hubs and strong linkages existed between them. The University of Toronto was the centre for many of the collaborations between central and western Canada. Its western partners were primarily the Universities of British Columbia, Calgary and Alberta. The University of McGill maintained a steady linkage with the University of British Columbia.

A few of the top twenty Canadian universities are located in the same city. The University of British Columbia and Simon Fraser University are situated in Vancouver on the west coast; the Universities of McGill, Laval, Montreal and Concordia are in the city of Montreal; and the Universities of Ottawa and Carleton are in the nation's capital, Ottawa. Intracity collaboration was constant but curiously the universities in the city of Montreal were not fully interconnected; the University of Concordia showed no above average collaborative activity with the Universities of Laval and Montreal which may be related to fact that it is primarily an English-speaking university located in a predominantly French-speaking city.

Two collaborative triangles existed in southern Ontario consisting of the Universities of Toronto, Guelph and Waterloo, and the Universities of Toronto, McMaster and Western Ontario. In the west, much of the collaborative activity centred on the University of Alberta which is situated in the capital of Canada's petroleum province, Alberta, and the University of British Columbia. Only
intermittent linkages were formed with an eastern university and they only involved the University of Dalhousie.

8.3.2 Collaborative Network Types

The web of collaborative activity in the individual CHI science areas is diffuse and complex. In some instances, there were predominantly regional networks which were overlaid by a web of national activity. In other cases, there was a predominantly national network under which regional networks could be identified.

Three general types of collaborative activity can be identified. First, there were the predominantly national collaborative networks. These networks exhibited a great deal of inter-regional collaboration but they also had intense intra-regional activity. However, the intra-regional linkages were less likely to be sustained over time. Second, there were the predominantly regional collaborative networks. These networks were composed of many intra-regional collaboration links but, again they also displayed intense intra-regional activity. However, these links were not always preserved over time. The finally type of collaborative network was composed of a mixture of regional and national links, neither of which is dominant over time. We shall examine one example of each of three types. However, we must keep in mind that this analysis was based on subjective observation. A more precise analytical methodology such as those used in graph theory analysis should be utilised to confirm these findings.

The network of collaborations in physics appeared to be composed of a mixture of regional networks with some strong inter-regional links. The inter-regional links centred around the Universities of British Columbia and Toronto probably because high energy particle accelerators are located there. In the west, there were sustained links between the Universities of British Columbia,
Simon Fraser, Saskatchewan, Alberta and Manitoba - partners in the accelerator located at the University of British Columbia. In central Canada, the Universities of Toronto, Carleton and McGill formed a triangle of activity joining the two provinces of Ontario and Quebec. The University of Toronto was the hub of activity in Ontario, with cooperative linkages with the Universities of Waterloo, Western Ontario and McGill. In Quebec, there was a sustained intracity link between the Universities of McGill and Montreal.

Sustained and sometimes intense intra-regional links existed between the Universities of Alberta and Calgary in the province of Alberta, the Universities of Montreal and McGill in the province of Quebec, and the University of Toronto and many universities in the province of Ontario. A number of the west-central links centred on the University of Alberta and to a lesser extent on the University of British Columbia in the west, and the Universities of Toronto, Western Ontario and to a lesser extent McGill in central Canada. Most of the activity in the east focused on Dalhousie University.

The web of clinical medicine collaborative activity spanned the country. However, the collaborative network appeared to be dominated by strong regional networks in central and western Canada. West-central links centred on the Universities of British Columbia and Alberta but included the University of Calgary in the west and the Universities of Toronto, Western Ontario and McGill in central Canada. Dalhousie University was the focus of activity in the east and it had sustained collaborations with the University of Toronto and McGill and fairly constant ties to the Universities of McMaster and British Columbia.

In central Canada, there was a backbone of intense activity between the Universities of Toronto and McGill and a less intense link between the University of Ottawa and both of these universities. Provincial networks were connected to this backbone by universities in their respective provinces. In
Quebec, the University of McGill had a strong link with the University of Montreal and less intense ties with the Universities of Laval and Concordia. Also, the Universities of Laval and Concordia had a sustained link. In Ontario, the University of Toronto had strong links with the Universities of McMaster and Western Ontario who also exhibited sustained cooperation between themselves. Queens University provided the focus for another network that was not as intense as the previous one but included many of the same partners.

In the west there was a sustained regional network which centred on the University of Alberta. This university exhibited sustained links with the Universities of British Columbia, Calgary, Saskatchewan and Manitoba.

Collaborative research networks in earth and space science appeared to have a strong national focus. One distinguishing feature was the existence of an intense east-west link between the University of Alberta and Memorial University. The hub of collaborative activity in the west was the Universities of Alberta and British Columbia. In central Canada it was the Universities of Toronto and Western Ontario. Intracity linkages were intense but again not all the universities in the city of Montreal were interconnected. The national network seemed be dominated by links between the Universities of British Columbia, Alberta, Memorial and Western Ontario, and to a lesser extent the Universities of Calgary, Toronto, Queens and McMaster.

8.3.3 Country Comparison

Although each national university community displayed its own unique characteristics, there were some similarities. A visual examination of the inter-regional (or national) and intra-regional (or regional) activity suggests there may be some common patterns. However, before too much significance is attributed
to these findings, a more detailed analysis using mathematical graph theory-based techniques should be performed.

University-university collaborations in physics and biology exhibited both strong national and regional activity. The pattern in physics might be explained by the presence of high energy particle machines and other unique 'big science' facilitates located in each region which would encourage institutions within that region to collaborate with these regional centres and might also encourage cooperation between the regional centres.

There appeared to be more regional collaboration in biomedical research and clinical medicine in Canada and Australia while both regional and national networks were strong in the UK. The larger geographical distances in Canada and Australia may account for the difference. Much of the research in the medical sciences is based in hospitals and involves patients as well as equipment and techniques. It would not be unusual for two or more hospitals to share a common patient community or to send patients to another centre which has unique diagnostic facilities as long as the geographical distances are moderate. The UK is geographically much smaller than a single region in Canada or Australia which may account for the tendency for both types of networks to be prevalent there.

The national collaborative networks in earth and space science were strong in all three countries. Perhaps the need to share observational data may partially account for this pattern of collaboration.

Collaborative networks in mathematics, chemistry and engineering and technology did not show a pattern that was common across countries. This might reflect the fact that collaboration in these area is not as dependent on some unique characteristic of the scientific research in these areas (eg. need to share national facilities or regional-based data) but is more dependent on some
social, economic or political characteristic of the scientific community in each science field. On the other hand, the trends may be too difficult to assess visually and mathematical analysis may be required to establish if there are any common patterns.

8.4 **Mapping Technique Improvements**

The public domain xy plotting software that was used to produce a prototype of the dynamic mapping system was not designed for this purpose. Some unusual procedures had to be followed to make the plotting program produce the required maps. In addition, the collaboration matrices had to be individually processed on the Solbourne\(^1\) because they were not in a format that was usable by the plotting software. The resultant files were transferred to a PC and individual maps were plotted. These maps were then stored on a new diskette in chronological order to reduce the risk of them being displayed in a random sequence.

Now that the prototype has been tested and the procedure for making the maps is fairly well understood, it may be possible to develop software that is specifically designed for this purpose. Without going into too much technical detail, it seems that user-friendly software with the following features could be developed:

1. A user-interface that is menu or icon driven to facilitate easy of use;

2. Direct input of collaboration and geographical location information matrices;

\(^1\)A great deal of numerical manipulation had to be done on the collaboration matrices in order to produce data suitable for xy plots. The Solbourne computer is a minicomputer which supports the PERL programming language which makes it more useful for performing numerical transformations.
3. The intensity of the collaborative linkages could be displayed using various coloured lines instead of lines of various thickness;

4. User-selectable features such as the ability to change the smoothing interval, to choose a subset from the complete set of universities; and to set the range of collaboration intensity that one wishes to explore (eg. below average, above average, or any desirable interval).

5. A dynamic map viewing software that is more efficient and quicker. The current system stores all the geographical locations and interconnecting lines in each map. Much of this information is redundant and results in excessively large data files. Also, the universities need only be displayed once not each time as is currently done. In addition, only information concerning the linkages that have changed needs to be stored for subsequent maps. These improvements would produce a much faster display and would result in a better approximation of the ‘flicker’ technique described in the methodology chapter.

Finally, some thought has been given to how this mapping technique can be used to explore other co-occurrence data. For example, economic trade data between countries could be dynamically displayed over time; or co-word data could be dynamically examined. In conclusion, there seems to be a research opportunity to develop software which is specifically designed for displaying and probing co-occurrence data.

8.5 Summary

A successful prototype of a dynamic mapping technique was developed and some interesting collaborative patterns were revealed. Generally speaking,
many of the policy analysts who examined the dynamic maps claimed that they gained new insights into the collaborative activity in their university community. However, a couple of the investigators thought the technique was novel but were unsure whether it provided additional information compared with conventional methods such as multidimensional scaling.

A visual inspection of the dynamic maps suggested that different scientific areas exhibited different preferences for regional and national collaborative networks. Physics and biology both had strong national and regional collaborative networks; clinical medicine and biomedical research showed a tendency towards stronger regional networks than national networks but the effect seemed to depend on the size of the country; earth and space sciences showed a propensity to favour national collaborative networks; and no common tendency to favour either type of network was found in mathematics, chemistry and engineering and technology.

These results provide enough evidence to suggest that more research into this phenomenon may be warranted. Perhaps more powerful analytical techniques such as those used in graph theory analysis could be used to investigate whether there is a tendency for certain scientific areas to favour national networks over regional ones, or vice versa.
Think of those thousands of obscure men, those successive generations of masters, who patiently tilled the field of science. They sowed, it is quite possible, only inferior sort of grain: they knew neither good processes of tillage nor good methods of scattering seed! But at least, their labour and incessant efforts kept the ground in a state of cultivation; they did not permit it to lie fallow; they did not leave the fields of thought to be overrun by thorns and briars. One may say what he likes of their sterile tasks and wasted pains. They commented, commented, commented. They invented nothing. They ground away at the empty mill of dialectic! They wore themselves out in subtleties, in fine distinctions, in quibblings.

The objective of this thesis was to perform a bibliometric assessment of intra-national university-university collaboration in the UK, Canada and Australia to determine if the patterns and trends of collaboration were similar to those previously found for international collaboration.

There were a number of reasons for embarking on this research project. For example, we suggested that there appears to be increasing emphasis by federal and regional governments on intra-national collaboration, and during the 1980s some countries developed initiatives to encourage collaboration among individual scientists. Other policies have been aimed at improving the links between science and technology by fostering research collaboration between universities and companies. Yet even with the increasing emphasis on intra-national collaboration, very little bibliometric research seems to have been performed to assess this activity. Furthermore, even though most nations spend the majority of their R&D funds internally, most of the bibliometric assessment of collaborative activity has focused on international activity.

In this thesis, we explored the bibliometric assessment of intra-national university-university collaboration in two parts. The first part, the analytical framework, which was composed of five chapters, discussed the notion of a research collaboration, examined previous investigations on the topic, provided historical and structural information on each national university community and detailed the methodology that was used in this study. In chapters three and four, a number of research questions were asked and these were summarised at the end of each chapter. The second part, the bibliometric findings and discussion, which was made up of three chapters, analysed and discussed the bibliometric results. Now, let us summarise the overall research findings before we proceed to answer the specific research questions addressed in this thesis and to discuss the policy implications. An unavoidable amount of redundant information will be encountered when the research questions are answered.
9.1 Overview of Research Findings

First and foremost, we can conclude that a bibliometric procedure can be used to carry out a partial assessment of *intranational* university-university collaboration. The basic methodology involved unifying university names derived from the corporate addresses given in the *Science Citation Index*. A university-university collaboration was identified by selecting articles, notes and reviews that listed authors from two (or more) universities in the same country.

Much of the previous work in this area has used co-authorship analysis to assess collaboration, but in this study the focus was on multiple institution papers - in other words, an inter-institutional collaboration rather than inter-individual collaboration. A significant difference was found between this approach and the co-authorship technique for studying collaboration. More than 6 percent of university collaborations in the UK and Australia and as many as 12 per cent of those in Canada were composed of publications that list more institutions than authors in the *Science Citation Index* corporate address field. About 40-50 per cent of these occurred in clinical medicine. In other words, it is quite possible for an inter-institutional collaboration to manifest itself as a formal or informal agreement between two (or more) institutions to share a single researcher.

*Intranational* collaboration in Australia, Canada and the UK occurred within a context where national published scientific output grew steadily at a rate of 3.9 per cent, 4.5 per cent and 3.2 per cent per annum, respectively, from 1984 to 1990. In addition, the published scientific output from universities in the UK and Australia remained reasonably constant from 1981 to 1984 and then grew at approximately 2 per cent per annum until 1989 when it fell by 5.7 and 6.7 per cent respectively in 1990. Canadian universities showed a 5.7 per cent per annum growth and surpassed the UK university scientific output for the first
time in 1990. Given that Canada is only half the size of the UK in terms of population and GDP, this is a somewhat unexpected finding.

The university community's contribution to the total national scientific output varied considerably among the three countries. Canadian universities accounted for 73-78 per cent of the national scientific output over the period 1984-1990; the Australian universities' contribution declined from 57 to 49 per cent over the decade; and the UK universities' contribution also declined, in this case from 44 to 39 per cent. This shows that other research performers such as hospitals, government laboratories or companies account for a significant proportion of the national scientific output, especially in the UK and Australia.

University scientific output increased non-linearly with the size of the university (expressed by the equation $Y = a X^b$ where $Y =$ scientific output and $X =$ university size ). This suggests that universities are subject to economies of scale and larger universities exhibit a proportionately larger increase in scientific output per unit increase in staff numbers compared to smaller universities. A non-linear relationship between national scientific output and country size was observed by Frame (1979) for developed and underdeveloped countries. Furthermore, the exponent $b$ in the logarithmic relationship was greater than one indicating that economies of scale are also in effect at the country level. However, Cohen (1978, 1981) found that there was a linear relationship between number of scientists in a laboratory group and the number of publications. It appears that economies of scale are in effect at the country and institutional level but may not be noticeable at the level of the research laboratory.

Intra-national collaboration also took place within an environment where university collaborations with all institutional types grew steadily throughout the decade. Canadian universities displayed the most vigorous growth at 6.9 per
cent per annum but the UK and Australia were not far behind at 5.4 and 5.0 per cent per annum, respectively. The percentage of university published scientific output that involved a collaboration increased dramatically over the decade. The growth rates in Australia and the UK were remarkably similar; in both cases, university collaborative publications accounted for 35 per cent of university scientific output in 1981 and this grew to 50 per cent by 1990. The proportion of Canadian university collaborations increased from 46 to 50 per cent between 1984 and 1989 and then jumped abruptly to 58 per cent in 1990. It appears that institutional research cooperation in the university community is becoming the rule rather than the exception. This trend is consistent with the complaints of university scientists about the shortage of funds which probably stimulates more cooperation, on the one hand, and with government policies aimed at promoting collaboration, especially university-industry collaboration, on the other.

Generally speaking, from 1984 to the end of the decade university-university collaborations grew at the same rate or even faster than overall university collaborations (with any type of institution or other university departments) - 4.7 per cent per annum in Australia, 6.0 per cent in the UK and 10 per cent in Canada. In 1990, both the UK and Australia experienced a decline and Canada exhibited a phenomenal 35 per cent increase. It is possible that the rapid increase in Canada is a product of the 'centres of excellence' and 'matching grants' programmes that were initiated in the late 1980s but more years of Science Citation Index data need to be examined before this can be confirmed.

A curious finding in this study was the similar growth patterns in all three countries of the percentage of university scientific output which involved a university-university collaborations. From 1984 to almost the end of the decade, university-university collaborations increased from approximately 4.5 per cent to about 6.0 per cent of the university scientific output. There is no obvious reason
why three countries separated by vast geographical distances and with autonomous university communities should experience such similar growth patterns.

Counting two-way collaborations proved to be a useful way to explore university-university collaborations. The average number of two-way collaborations per paper was approximately 1.2 in Canada and the UK. In Australia it was 1.1, slightly lower because fewer Australian publications involved more than two universities. This average varied across science areas. It was highest in physics in the UK (1.48) and Canada (1.43), and in clinical medicine (1.33) in Canada. It was lowest in mathematics (1.01 - 1.05) and engineering and technology (1.02 - 1.08) in all three countries. The high average in physics probably reflects a greater amount of collaborative research in high energy physics and other 'big sciences'. Perhaps the reason for the high average for clinical medicine in Canada is the relatively large number of papers in that science area that listed more institutions than authors. This in turn is apparently related to the fact that more researchers in clinical medicine appear to be affiliated in two (or more) institutions. However, a more detailed investigation would be required to uncover all the underlying reasons for this phenomenon.

A nonlinear relationship was found between two-way university-university collaborations and the volume of university scientific output. However, unlike the relationship between university size and scientific output, in this case larger universities, as measured by scientific output, had proportionately fewer university-university collaborations than smaller universities. In other words, scientists in larger universities seem to have less need to collaborate with researchers at other universities - presumably because they are more likely to find suitable collaborators within their own institution.
A comparison of the rankings by percentage of international collaboration in each CHI science field as found by Frame and Carpenter (1979) and the ranking of CHI science fields by the percentage of publications that involved university-university collaboration revealed very little correlation. In other words, at the level of domestic collaboration there was little support for Frame and Carpenter's finding that there was more collaboration in basic research than in applied research. Furthermore, it is possible that the notion that fields of science can be categorised as basic or applied may be inappropriate. For example, research in physics can range from cosmology (basic) to engineering-physics (applied) and in clinical medicine research can range from neurophysiology (basic) to public health (applied). Perhaps such broad superfluous distinctions are best avoided.

The rankings by the percentage of university-university collaboration in the CHI science fields were used as a fingerprint of the collaborative activity in each country. When these fingerprints were compared, it was found that the UK and Australia had similar collaborative activities across the CHI science fields but Canada was quite different. Perhaps the similarity in collaborative patterns across the fields of science in the UK and Australia partially reflects the similarity in inter-university organisational structures and the effects of government policy on the financial restructuring of research support in the mid 1980s. On the other hand, the difference between the collaborative habits in Canadian universities and their UK and Australian counterparts may partially be influenced by the strong association between Canadian and US universities which results from their close geographical proximity.

An intranational comparison of CHI science areas ranked by the percentage of two-way collaborations in the total number papers indicated that there may be a significant relationship between the level of university-university collaboration in a scientific area and the national expenditure in that area. There

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were a couple of notable exceptions. Physics and earth sciences in Canada and the UK, and chemistry in Australia exhibited more collaboration than expected. In the former case, this may reflect a heavy involvement in 'big sciences' such as high energy physics and astronomy.

A significant relationship was found between collaboration and geographical proximity. The number of two-way collaborations that a university has with other universities appears to decrease exponentially with the distance separating the universities. Among other things, this suggests that informal 'face-to-face' communications may be crucial for collaboration. Also, there is some evidence to indicate that over the decade there was a slight tendency for UK and Australian universities to collaborate increasingly with partners who were geographically closer while the reverse trend was observed in Canada. Whether this reflects lower cost of transportation and greater availability of intercity air flights in Canada remains to be determined.

A technique involving the use of a national collaboration vector was employed to assess how collaborations were distributed in the university community and how the distribution had changed with time. The results indicate that two-way collaborations were more evenly distributed among Australian universities than UK or Canadian universities. In addition, trend analysis revealed that Australian university-university collaborations had became more evenly distributed over the decade while in Canada and the UK there was a tendency for them to become more concentrated in fewer universities. All three countries showed a tendency for physics collaborations to become more centred in fewer universities. This is in line with the rapidly increasing costs of research in certain subfields in physics and hence the need for more specialisation.
Finally, a successful prototype of a dynamic mapping technique was developed and some interesting collaborative patterns were revealed. Generally speaking, many of the policy analysts who examined the dynamic maps claimed that they gained new insights into the collaborative activity in their university community. However, a couple of the investigators thought the technique was novel but were unsure whether it provided any additional information compared with conventional mapping methods.

A visual inspection of the maps suggested that different scientific areas exhibited different preferences for regional and national collaborative networks. The universities in each country were grouped according to traditionally recognised geo-political regions. In general, intra-regional collaboration (collaboration between universities within a region) was considered to be indicative of a preference for regional collaborative networks. A preference for national collaborative networks was indicated by the dominance of inter-regional collaboration (collaboration between universities in different regions). Physics and biology both had strong national and regional collaborative networks; clinical medicine and biomedical research showed a tendency towards stronger regional networks than national networks but the effect seemed to depend on the size of the country; earth and space sciences showed a propensity to favour national collaborative networks; and no common tendency to favour either type of network was found in mathematics, chemistry and engineering and technology.

9.2 Answers to Research Questions

Now let us return to the research questions posed in the summary section of chapters three and four (given in italics) to see whether we can
provide any answers. The questions are not dealt with in the order in which they were originally posed, so the origin of each question is given in brackets.

What is the relationship between GDP and national scientific output (C.4 - Q.1)?

Our results provide some evidence of a relationship between national scientific output and economic size, a observation first made by Price (1969). The ratio of scientific output summed over the years between 1984 and 1990 was 1.0:0.54:0.25 (UK:CANADA:AUSTRALIA) which is very similar to the ratio of their GDPs which was 1.0:0.63:0.29 in 1988.

Do the universities in all three countries make the same percentage contribution to the national scientific output (C.4.-Q.2.)?

The contribution of the university community to the total national scientific output differed markedly in the three countries. Canadian universities made a contribution (73-78 per cent) that was almost a factor of two larger than in the UK (39-44 per cent) while the contribution from Australian universities (49-57 per cent) was approximately half-way between these. This suggests that in the UK and to some extent in Australia research performers in other sectors are major contributors to the national scientific output.

How does the scientific output of a university change with the economic size of the university (C.3.-Q.1.)?

University scientific output increased non-linearly with the size of the university. In larger universities, a small increase in staff produced a proportionately greater increase in scientific output compared to smaller universities. The scientific output was compared to the number of university staff - scientific and non-scientific teaching and research, teaching, and research staff. Since, the ratio of scientific to non-scientific staff may very well differ from institution to institution and the staff accounting procedures
probably varies for each country, a cross-country comparison of the magnitude of this effect was not possible.

*How does scientific size of a university effect the level of intranational university-university collaboration (C.3.-Q.2.)*?

There is a nonlinear relationship between two-way university-university collaborations and university scientific output. Larger universities have proportionately fewer university-university collaborations than smaller universities. The size of this effect varies across the three countries. In the UK the effect is quite small as evident from the fact that the elasticity coefficient, $\varepsilon$, is close to one ($\varepsilon = 0.96$). This indicates that the relationship between publications and two-way collaborations is nearly linear. However, the nonlinear effect is more pronounced in Canada ($\varepsilon = 0.83$) and is considerably larger in Australia ($\varepsilon = 0.71$). These data appear to suggest that the size of the nonlinear relationship between university scientific output and two-way collaborations may be related to the size of the country - that is the larger the country the smaller the nonlinear effect (the closer the elasticity coefficient is to one). However, before such a generalisation can be made with any confidence, more countries would first need to be examined.

*Does intranational university-university collaboration occur more frequently in basic research than in applied research? If intranational university-university collaboration occurs more frequently in basic research than in applied research, are there similar or different patterns between basic and applied research at the intranational and the international research? Most importantly, can individual scientific areas be legitimately categorised as basic or applied (C.3.-Q.3)*?

A comparison of the ranking of CHI science fields by the percentage of publications that involved university-university collaboration with the ranking of each science field by the percentage of international collaboration as
determined by Frame and Carpenter revealed that there was very little correlation. There is little evidence at the national level of collaboration to support Frame and Carpenter's idea that there is more collaboration in basic research than in applied research. Furthermore, we would argue that the boundary between basic and applied research is rather 'fuzzy', perhaps implying that Frame and Carpenter's categorisation of entire scientific fields into basic or applied categories may be oversimplistic.

*Is there a relationship between geographical proximity and the level of university-university collaboration* (C.3.-Q.4.)?

A significant correlation was found between collaboration and geographical proximity. The number of two-way collaborations that a university has with other universities appears to decrease exponentially with the distance separating the universities. This suggests that for face-to-face contacts may be very important in developing or maintaining a research collaboration.

*Can the impact of the different inter-university organisational structures in each university communities be discerned using bibliometrics* (C.4-Q.4.)?

There is no clear indication that inter-university organisational structures have any discernible effect at least in these three countries. Recall that the number of inter-university organisations in the UK and Australia is low in comparison to that found in the Canadian university community. This may partly account for some of the similarities in trends in the UK and Australia - the decline in the contribution of universities to national scientific output in the later part of the decade, virtually the same growth in the percentage of university scientific output involving university collaboration, and tendency over time to choose collaborative partners who are geographically close. The trends in Canada are quite different - the university contribution to national scientific output increased throughout the decade, and there is a
trend to choose collaborative partners who are geographically more distant. However, a great deal more quantitative and qualitative investigative work would need to be carried out to uncover the effect, if any, of inter-university organisational structure on collaboration.

Can the effect of government programmes designed to encourage collaboration be detected by bibliometric assessment of university-university collaboration (C.4.-Q.5.)? Can a bibliometric analysis of intranational university-university collaboration reveal any underlying shift in policies targeted at collaboration (C.3.-Q.5.)?

The effects of government policy may be just detectable. Unlike in the UK or Australia, during the late 1980s federal and provincial governments in Canada introduced programmes specifically to encourage intranational collaboration. The above bibliometric analysis revealed that in 1990 the number of overall university collaborations and of university-university collaborations both increased dramatically. Perhaps some of this increase may have been influenced by these programmes. However, more years of data need to be analysed before any firm conclusions can be drawn.

Can a distortion-free mapping technique be developed to depict collaboration within a national university community? Can such a mapping technique be designed to assist an investigator or policy analyst to visualise how collaborative networks have changed over time (C.3.-Q.6)?

A successful prototype of a dynamic mapping technique was developed to illustrate how collaborative activity within a national university community varies across the CHI science areas. This technique appears to exhibit good potential to assist policy analysts to visualise how collaborative networks change over time.
Can regional and national collaborative networks be distinguished from each other? If so, does one type of network dominate the other and does it vary with the science area (C4-Q.3)?

A visual inspection of the dynamic maps suggests that regional and national collaborative networks can be distinguished and that one type of network may dominate over the other in certain science areas. However, other analytical tools need to be explored before this claim can be verified.

We are now in a position to address the primary research question of this thesis which was: Does intranational scientific research collaboration exhibit the same patterns and trends as international scientific research collaboration?

Many patterns and trends are the same in intranational and international collaborative activity. For example, just as country size is non-linearly related to national scientific output (Frame, 1979), so university size is non-linearly related to university scientific output, and both have elasticity coefficients greater than one. Similarly, just as country size is non-linearly related to international collaboration (Frame and Carpenter, 1979; Schubert and Braun, 1990), so university size is non-linearly related to two-way university-university collaborative activity, and again both have elasticity coefficients that are less than one. Among other factors, international collaboration is effected by geographical proximity (Frame and Carpenter, 1979; Luukkonen, Person and Sivertsen, 1990; Moed, de Bruin, Nederhof and Tijssen, 1990; Schubert and Braun, 1990) while university-university collaboration appears to decrease exponentially with distance.

The most noticeable difference in the patterns and trends was the finding that intranational collaboration does not conform to Frame and Carpenter's results that showed there was more international collaboration in basic
research areas than in applied areas. Furthermore, the notion that science areas can be categorised in basic or applied is questionable.

9.3 Policy Implications

A number of policy implications arise from the research findings in this project. One must remember that these findings are based on a bibliometric analysis of Science Citation Index data for only three countries. Before these results can be generalised with any confidence, more countries would first have to be examined. Nevertheless, let us look at some of the possible policy implications that are suggested by the results of this study.

It appears that the bibliometric assessment of scientific collaboration between domestic institutions can be a useful complement to other sources of information for national policy makers concerned with developing programmes directed towards cooperative scientific research. Although we have focused on university-university collaboration, it is likely that most of the methodology used here would be appropriate for assessing university-industry and university-government collaborations where these lead to published scientific output. Also, cross-country comparisons seem to add a valuable insight to this type of bibliometric investigation because they help situate national collaborative activity within a framework which reflects national collaborative activity observed around the world. However, since the economic size of the country, the national economic and science policies, the geographical distribution of the scientific community, the range of institutional sizes, and other cultural and socio-political factors can all effect the level and nature of scientific activity, the countries to be compared need to be selected with a great deal of care. Finally, times-series analysis is a good way of examining collaborative trends and may help policy
observers identify economic, political and organisational factors which affect these trends.

If all *intranational* collaborations display trends similar to those found for university-university collaboration, then presumably they too are affected by such factors such as geographical proximity, institutional size, national scientific expenditures, and scientific discipline. However, before any broad policy implications can be drawn, a detailed bibliometric investigation of inter- and intra-sectoral institutional collaborations (for example, university-industry, government-industry, and government-government collaboration) would have to be performed.

University collaboration appears to be the rule rather than the exception. It is possible that even without policies to encourage universities to collaborate, researchers may be finding that the cost, complexity and interdisciplinary nature of contemporary scientific research make collaboration with other institutions essential just to remain competitive, let alone to make major advances in scientific knowledge. Policy makers should take this into consideration because it is conceivable that few, if any, initiatives are actually required to encourage universities to collaborate. Further, it may be that only targeted programmes are required to motivate universities to collaborate with specific sectors (such as industry).

One fundamental issue which does not appear to have been addressed by science policy investigators is whether collaboration is inherently 'good' - in other words, does collaboration have some intrinsic positive value such that it should be encouraged at all cost? Some research suggests that collaboration does an intrinsic beneficial value - it apparently leads to more citations, better quality research, greater professional recognition and even more monetary rewards (see chapter 3). However, if collaboration were to become more
prevalent, how would one then evaluate individual researchers? For example, if all publications produced by scientists were prepared in cooperation with others and individual scientists did not establish a solo publication record, how can they be evaluated? Should evaluators use the number of different people, institutions, or sectors a researcher has had as collaborative partners as an indicator? Or should they seek confidential opinions from the collaborators? In other words, a policy that supports collaboration at almost any cost may have side-effects, some of them perhaps undesirable.

Collaborators appear to have a preference for partners who are located close to their home institution. There may be many factors that contribute to this effect such as the need for ‘face-to-face’ communication, the high cost of transportation, travel time, or the necessity to minimise the time away from the home institution because of teaching or family obligations. If policy makers perceive that collaborative activity is advantageous for their country, then they might have to determine how collaborators can be induced to choose more geographically distant partners without at the same time sacrificing the quality of their research.

Economies of scale seem to be at work in the university community. Large universities apparently increase their published scientific output more than small universities for a unit increase in staff. However, compared with smaller universities, proportionately fewer publications will involve an *intranational* university-university collaboration. In contrast, it may well be that publications from large universities have proportionately more intra-university, international and other domestic collaborations than those from small universities. Even though more research is required to confirm this, policy makers must decide what type of collaboration they wish to encourage because it is likely that programmes designed to encourage one type of collaboration may adversely influence another type. For example, if university-university
cooperation is seen as desirable, incentives may have to be devised to encourage larger universities to work with small universities. However, this may reduce the level of intra-university collaboration. If more intra-university collaboration is deemed necessary, then encouraging universities to become larger - that is using the benefit of economies of scale - may be one answer.

The level of collaboration varies across scientific fields. In general, this study showed that there are more *intranational* collaborations in physics and clinical medicine than in mathematics and engineering and technology. Policy decisions must be made with this in mind. Furthermore, it appears that the balance between national and regional university collaborative networks varies across scientific disciplines. Thus, some university-university collaborations lend themselves more readily to regional collaboration than to national collaboration and vice versa. Programmes designed to influence research collaboration in different areas must also take this into consideration. Not only should the focus of collaborative programmes be suited to the type of collaborative networks that are most prevalent in a given scientific research area, but programme administration might also be best performed at the regional level in some instances rather than at the national level.

To sum up, bibliometric assessment of collaboration is a valuable tool for studying the social structure of science. Databases of scientific publications are a largely untapped resource for drawing inferred relationships. However, until the cost of obtaining bibliometric access to these databases decreases, and until more user-friendly bibliometric interfaces to bibliographic data-sets are developed, bibliometric investigation of such phenomena as collaboration will remain in the hands of a few individuals who possess both the resources and the skills to explore their contents. Perhaps at some point an international organisation will be formed which will try to encourage on-line databases vendors to support widespread, low-cost bibliometric access to their electronic
archives. Then and only then will we be able to cross the threshold between the present era of ad hoc bibliometric studies and a new era of systematic electronic archaeology (Katz, 1992).
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Appendix I.

The Dynamic Maps

This appendix describes some of the interesting features that are found in the collaboration maps for each country. The object is only to point out some of the characteristics and not to provide an interpretation or rationalisation of why various collaborations occurred.
Appendix I.

The Dynamic Maps

Australia

The aggregate level map illustrates three features of the Australian university community. First, the majority of the universities are situated in the south eastern part of Australia. Second, over 65 per cent of Australian universities are found in just five cities. The Universities of Sydney, New South Wales and Macquarie are in Sydney; the Universities of Melbourne, Monash and La Trobe are in Melbourne; the Universities of Griffith and Queensland are in Brisbane; the Universities of Adelaide and Flinders are in Adelaide; and the Universities of Western Australia, Murdoch and Curtin are in Perth. Sustained collaborative linkages existed between universities located in the same city (intracity linkages). Third, the Australian National University, the largest university in Australia with a strong focus in graduate studies, had the most collaborative linkages. It had vigorous linkages with the Universities of Melbourne and Sydney, two older and geographically close institutions, and reasonably strong linkages with the University of Adelaide, also an older university but geographically more distant. In addition, it exhibited constant collaborative activity with the Universities of Monash and New South Wales. The University of Western Australia also had a large number of collaborations but, as will be seen later, much of its activity was in chemistry.
Above average collaborative activity was rare in physics. Most collaborations involved the Australian National University and the strongest linkages occurred between it and the University of Melbourne. Intracity linkages were almost non-existent with the exception of the occasional linkage between the Universities of Sydney and New South Wales and the Universities of Griffith and Queensland.

No single collaborative linkage was maintained over the entire decade in mathematics. However, a fairly constant linkage existed between the Australian National University and the University of Melbourne. Again, intracity linkages were rare except for the cluster of activity between the University of Western Australia and the Universities of Murdoch and Curtin. A burst of collaborative activity occurred in the middle of the decade between the University of New South Wales and the Universities of Adelaide and Flinders.

In chemistry the strongest collaborative linkages involved the University of Western Australia and were mainly with the Universities of Griffith Tasmania and Adelaide. The University of Adelaide also exhibited a great deal of collaborative activity. Although the Australian National University was very active in the field, it was not a dominant collaborator. Sustained intracity collaborations occurred between the University of Monash and the Universities of Melbourne and La Trobe, and the Universities of Macquarie and New South Wales.

Collaborative activity in biology was lively and diffuse. Linkages were rapidly formed across the country but most of them were short lived. Intracity linkages were strong and sustained. Much of the collaborative activity appeared to focus around the older universities of Sydney, Melbourne, Adelaide, Queensland and Western Australia. The most enduring collaborations occurred between the Universities of Western Australia and Sydney, the Universities of
Adelaide and Sydney, and the Australian National University and the University of Queensland.

Most of the collaborative linkages in biomedical research occurred in the south eastern part of Australia between the Australian National University and the universities situated in Sydney and Melbourne. Intracity linkages were particularly strong. Very few above average collaborations took place between eastern and western universities. There appeared to be a strong regional focus to collaboration in this research area.

Clinical medicine showed a collaborative pattern that was very similar to biomedical research, but intracity linkages were the strongest. Also, unlike in biomedical research, the Australian National University seemed to have fewer linkages and the dominant collaborators appeared to be the Universities of Sydney and Melbourne. The University of Adelaide, which was not a significant collaborator in biomedical research, showed sustained collaborative activity with both the previously mentioned centres.

The Australian National University was the hub of collaborative linkages in earth and space sciences. Its strongest and most sustained collaborative partners were the Universities of Sydney and Melbourne. A permanent and vigorous collaborative partnership was exhibited by the Universities of Western Australia and Wollongong. With the exception of the Universities of Western Australia and Curtin, few intracity linkages existed at the beginning of the decade but they seemed to increase with time.

University-university collaborations in engineering and technology did not exhibit any consistent pattern. Short but intense linkages existed between the Universities of Monash and Tasmania, the University of Sydney and the Universities of New South Wales and Newcastle, and the Universities of
Queensland and New South Wales. Collaborators in this scientific field seemed to prefer partners who were geographically close.

**Canada**

The Canadian university community is concentrated in three distinct geographical regions. This can be seen by inspecting the aggregate level maps. The majority of Canadian universities are located in central Canada in the provinces of Ontario and Quebec. The remainder are situated in the prairie provinces and the province of British Columbia in the west and the Atlantic provinces in the east. With the exception of the Atlantic universities which are among the smallest of the top twenty universities, at the aggregate level the most collaborative linkages were contained within the regions. However, there were some sustained ties between the western and central regions.

In central Canada the University of Toronto in the province of Ontario and McGill University in the province of Quebec are the primary collaborative hubs and strong linkages existed between them. The University of Toronto was the centre for many of the collaborations between central and western Canada. Its western partners were primarily the Universities of British Columbia, Calgary and Alberta. The University of McGill maintained a steady linkage with the University of British Columbia.

A few of the top twenty Canadian universities are located in the same city. The University of British Columbia and Simon Fraser University are situated in Vancouver on the west coast; the Universities of McGill, Laval, Montreal and Concordia are in the city of Montreal; and the Universities of Ottawa and Carleton are in the nation's capital, Ottawa. Intracity collaboration was constant but curiously the universities in the city of Montreal were not fully interconnected; the University of Concordia showed no above average collaborative activity with the Universities of Laval and Montreal which maybe
related to fact that it is primarily an English-speaking university located in a predominantly French-speaking city.

Two collaborative triangles existed in southern Ontario consisting of the Universities of Toronto, Guelph and Waterloo, and the Universities of Toronto, McMaster and Western Ontario. In the west, much of the collaborative activity centred on the University of Alberta which is situated in the capital of Canada's petroleum province, Alberta, and the University of British Columbia. Only intermittent linkages were formed with an eastern university and they only involved the University of Dalhousie.

As one can see, the web of collaborative activity in the individual CHI science areas is diffuse and complex. In some instances, there were predominantly regional networks which were overlaid by a web of national activity. In other cases, there was a predominantly national network under which regional networks could be identified. Only some of the prominent features will be highlighted here.

The network of collaborations in physics appeared to be composed of regional networks with some strong inter-regional links. The inter-regional links centred around the Universities of British Columbia and Toronto probably because high energy particle accelerators are located there. In the west, there were sustained links between the Universities of British Columbia, Simon Fraser, Saskatchewan, Alberta and Manitoba - partners in the accelerator located at the University of British Columbia. In central Canada, the Universities of Toronto, Carleton and McGill formed a triangle of activity joining the two provinces of Ontario and Quebec. The University of Toronto was the hub of activity in Ontario, with cooperative linkages with the Universities of Waterloo, Western Ontario and McGill. In Quebec, there was a sustained intracity link between the Universities of McGill and Montreal.
In mathematics there was a confusing array of national and regionally focused networks that changed over time. However, noticeably strong linkages existed between the Universities of Waterloo and Manitoba, and the Universities of Toronto and Dalhousie. In central Canada, the hubs of collaborative activity appeared to be the Universities of Waterloo, Toronto and Ottawa. In the west, it was the Universities of Alberta, Manitoba and British Columbia.

Chemistry collaborations had a strong regional focus which dominated until the 1987-89 smoothing interval, by which time the University of Alberta and to a lesser extent the University of British Columbia had developed a wide national collaborative network. Intracity linkages in Vancouver and Montreal were intense throughout. However, above average collaborations were not exhibited between the University of Laval and the Universities of McGill and Concordia. McMaster University had close ties to the Universities of Toronto and Queens. Collaborations between the Universities of Guelph and Waterloo were apparent in the first smoothing interval and expanded to include the University of Toronto by the third interval.

The biology collaborations showed a mixture of regional and national collaborations. This may be a by-product of the national and regional emphasis Canada has always given to agriculture. Strong west-central linkages can seen between the Universities of Guelph, Saskatchewan and British Columbia - universities well-know for their agricultural research. Intracity linkages existed but they fluctuated in intensity. However, no above average collaborative activity was observed between the University Concordia and any of the other universities in Montreal. In the west, there was a sustained collaborative network that involved the Universities of Saskatchewan, Manitoba, Alberta and British Columbia. The most noticeable networks in central Canada were in the province of Ontario and involved the Universities of Toronto, Guelph and Waterloo, and the Universities of Toronto and Western Ontario.
The web of biomedical collaborative activity spanned the country. However, there were also strong regional networks in central and western Canada. Sustained and sometimes intense intra-regional links existed between the Universities of Alberta and Calgary in the province of Alberta, the Universities of Montreal and McGill in the province of Quebec, and the University of Toronto and many universities in the province of Ontario. A number of the west-central links centred on the University of Alberta and to a lesser extent on the University of British Columbia in the west, and the Universities of Toronto, Western Ontario and to a lesser extent McGill in central Canada. Most of the activity in the east focused on Dalhousie University.

Collaborative activity in clinical medicine was very similar to that in biomedical research. West-central links again centred on the Universities of British Columbia and Alberta but included the University of Calgary in the west and the Universities of Toronto, Western Ontario and McGill in central Canada. Again Dalhousie University was the focus of activity in the east and it had sustained collaborations with the University of Toronto and McGill and fairly constant ties to the Universities of McMaster and British Columbia. In central Canada, there was a backbone of intense activity between the Universities of Toronto and McGill and a less intense link between the University of Ottawa and both of these universities. Universities in their respective provinces were connected to the terminal ends of the backbone; the University of McGill with the University of Montreal, and the University of Toronto with the Universities of McMaster and Western Ontario. Queens University provided the focus for another network that was not as intense as the previous one but included many of the same partners.

Research in earth and space science did not exhibit quite as much regional focus as some of the other science areas. One distinguishing feature was the existence of an intense east-west link between the University of Alberta
and Memorial University. The hub of collaborative activity in the west was the Universities of Alberta and British Columbia. In central Canada it was the Universities of Toronto and Western Ontario. Intracity linkages were intense but again not all the universities in the city of Montreal were interconnected. The national network seemed be dominated by links between the Universities of British Columbia, Alberta, Memorial and Western Ontario, and to a lesser extent the Universities of Calgary, Toronto, Queens and McMaster.

Engineering and technology collaboration was unusual because it exhibited a some intense west-central links, no east-west or east-central links, almost no regional links within the western region and a few sustained and intense links in the central region. The strongest west-central collaborative activity occurred between the University of British Columbia and McGill University, and the University of Alberta and the Universities of Waterloo and Toronto. The central Canadian network had three foci situated at the Universities of Toronto, McGill and Waterloo. The greatest intensity of collaboration in the Ontario portion of this network included the Universities of Waterloo, McMaster, Western Ontario and Queens. In the province of Quebec it involved the intracity collaborations between the Universities of McGill, Montreal and Concordia.

**United Kingdom**

The universities in the UK fall into three fairly distinct regions: universities in the south and southwest including all the universities south of Birmingham; the north and Midlands including all the universities north of Cambridge and south of Newcastle-Upon-Tyne; and the universities in Scotland. The aggregate level maps show distinctly that although there are strong regional networks, particularly in the south, the University of London dominates the picture. Inter-regional collaboration seemed to be centred on the Universities of Glasgow and
Edinburgh in Scotland, the Universities of Manchester, Liverpool, Birmingham and Sheffield in the north, and the Universities of London, Oxford and Cambridge in the south.

The strongest intra-regional link in Scotland occurred between the Universities of Glasgow and Stirling with a sustained link between the Universities of Glasgow and Edinburgh. There were no intense linkages in the north but there were constant linkages between the University of Sheffield and the Universities of Liverpool and Manchester. As expected in the south the Universities of London, Cambridge and Oxford showed intense collaboration. The University of Bristol exhibited strong links with the Universities of London and Oxford. The most noticeable inter-regional links were the intense links between the University of London and the Universities of Sheffield and Birmingham, and the Universities of Liverpool and Oxford.

Inter-regional linkages dominated the activity among the above average collaborators in physics. The Universities of London and Oxford were the primary foci. Interestingly, the Oxford-Cambridge link was sporadic and not very intense. The most intense links occurred between the University of London and the Universities of Oxford, Birmingham, and Bristol, and between the University of Oxford and the Universities of Liverpool and Bristol. A reasonably constant and strong link existed between the Universities of Liverpool and Sheffield. In Scotland, the University of Glasgow sustained collaborative links with the Universities of Sheffield and Manchester and to a lesser extent with the Universities of Liverpool and Birmingham. At the beginning of the decade, it had no above average links with the University of Edinburgh, but starting with the 1986 smoothing interval, this changed and the intensity grew up until the last smoothing interval.
In mathematics the collaborative links were infrequent and not sustained for very long. The longest duration collaborations occurred within the regions and existed between the Universities of Liverpool and Newcastle-Upon-Tyne, the Universities of London and Sussex, and the Universities of London and Cambridge. There were numerous short-lived inter-regional links but interestingly there were none between Scotland and the south.

The dominant centres of chemistry collaboration were the Universities of London, Sheffield and Edinburgh. A very strong link was maintained between the Universities of London and Sheffield throughout the decade. At the beginning of the decade, the University of Edinburgh had continuous and some time strong links with the Universities of Liverpool, Bristol and Sussex, but by the beginning of 1984 smoothing interval they had all disappeared. Towards the middle of the decade the Universities of Newcastle-Upon-Tyne and Durham established collaborative links which became intense and were sustained throughout the remainder of the decade. Generally speaking, it appeared that inter-regional links were more numerous and showed more strength than intra-regional links.

There seemed to a similar amount of above average collaborative intra- and inter-regional links in biology. The most intense intra-regional links in the south occurred between the Universities of London and Oxford and in the north between the Universities of Liverpool and Manchester, and to a lesser extent between the Universities of Nottingham and Leeds, and the Universities of Durham and Leeds. Scotland had no intense intra-regional collaborations but it had intense inter-regional collaborations with universities in the north. In particular, there were strong links between the Universities of Edinburgh and Newcastle-Upon-Tyne, and the Universities of Glasgow and Durham. The University of London was not a very dominant collaborator in biology. This role
appeared to be filled by the University of Bristol through most of the decade and by the University of Glasgow towards the end of the period.

Biomedical research seemed to dominated by intra-regional collaborations between Scotland and the north, Scotland and the south and the north and the south whereas there were strong inter-regional collaborations in the south. The obvious south region links were between the Universities of London, Cambridge, Oxford and to a lesser degree Bristol. None of the links between the north and the south had any sustained intensity. However, there were a number of other links that were maintained over a long period. For example, collaborations between the University of London and the Universities of Liverpool, Newcastle-Upon-Tyne, and the University of Cambridge and the University of Birmingham. On the other hand, there were some intense collaborations between Scotland and the other regions. They existed between the Universities of Edinburgh and Birmingham, the University of Glasgow and Cambridge, and the Universities of Dundee and Cambridge.

The trend in clinical medicine seemed to be largely reverse of that found in biomedical research. There appeared to be a fair amount of intra-regional collaborations in Scotland and the north as well as a reasonable amount of inter-regional collaboration. Also, the number of above average collaborations increased substantially between the beginning and the end of the decade.

The strongest link was between the Universities of Glasgow and Stirling and there were sustained links between the University of Glasgow and the Universities of Edinburgh and Dundee. In the north, there were sustained collaborative links between the University of Birmingham and the Universities of Manchester, Leeds, Sheffield and Liverpool. In the south, there was an intense link between the Universities of London and Oxford and, except in the first smoothing interval, between the Universities of London and Cambridge, and the
Universities of Cambridge and Oxford. The main inter-regional links occurred between the University of Glasgow and the Universities of London and Manchester, the Universities of Dundee and London, the University of Birmingham and the Universities of London and Bristol.

Most of the collaborative activity in earth and space sciences was centred in the south of the UK. There was no above average intra-regional collaboration in Scotland and very little in the north. In the south, there was an intense sustained network between the Universities of London, Cambridge, Oxford, and sustained links between the University of Sussex and the Universities of London and Cambridge. The Universities of Manchester, Durham, Leeds and Edinburgh maintained reasonably constant links with the Universities of London and Cambridge.

In engineering and technology there was no intra-regional collaboration in Scotland. However, there was a reasonable amount in the south and the north, although none of these linkages were sustained. Inter-regional collaborative activity was brisk with much of it focused on the Universities of London and Cambridge.