HEFCE Fundamental Review of
Research Policy and Funding

Collaborative Approaches to Research

Final Report

April 2000

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Acknowledgements

The authors and project team would like to acknowledge the extensive help and co-operation of the many individuals in higher education and other research institutions that participated in this research. Guarantees of anonymity prevent us from identifying people or institutions by name, but particular thanks are due to those who took on responsibility for putting together the comprehensive programmes for each of our institutional case study visits. The task was often mammoth but critical to the success of the study. Finally, we would like especially to thank Isabella Peter-Liburd whose liaison and organisational skills (and considerable patience) at the HEPU in Leeds were instrumental in enabling the study (and several other related projects) to come to fruition in such a short time scale.

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Introduction

This report presents the findings from a research project commissioned by the Higher Education Funding Council for England (HEFCE) as part of the fundamental review of research policy and funding. The project focuses on collaborative approaches to research and is set in the context of the changing dynamics and institutional bases of research. Its primary purpose is both to review and contribute to the evidence-base on institutional and individual researcher approaches to collaborative research with particular reference to the relationship between collaboration and mission in higher education institutions (HEIs).

The research used three methods. First, it reviews literature on the current state of understanding about the concept, nature and driving forces behind collaboration. Second, through bibliometric analysis it provides a comprehensive account of the principal types and levels (ranging from inter-individual through inter-institutional to inter- sectoral and international collaboration) of research activity. Third, from case study anlysis it examines how higher education institutions (HEIs) and individual researchers from a range of disciplinary fields approach research collaboration in both strategic and operational terms. The consultants carried out the study during the period November 1999 to March 2000.

Concepts of collaboration

The benefits of collaboration in research have been widely signalled - both by the Dearing and Garrick reports into higher education and by government, funding bodies and the research councils. Collaboration is now actively promoted with a view to breaking down the barriers between universities and between universities, industry, commerce, government and the public services. Specific driving factors include: the growth of the knowledge economy and attempts to strengthen the economic and social contribution of research; a shift towards more applied research in collaboration with other knowledge creators and users; greater concentration of research activity and partnership in the use of plant, equipment and expertise; the growth of the directed mode of funding based on priority areas and problem oriented project funding; and, the shift towards a mass higher education system and lifelong learning.

However, despite policy enthusiasm, research collaboration is difficult to define. The concept is neither well understood nor applied with any consistency. It has multiple meanings in practice and has developed in a complex environment of drivers and barriers. Collaboration occurs at various levels including individuals, groups, departments, institutions, sectors and countries. Some collaboration is formal, much more is informal.

Patterns of collaborative activity

The main findings from the bibliometric analysis indicate:

- Collaboration is the rule not the exception. By 1994 88% of all UK HEI papers involved two or more authors and 55% involved two or more institutions.
- HEIs collaborated with other domestic institutions on 34% of their papers and with international partners on 20% of their papers.
- The life sciences exhibited the highest percentage of multiple author papers and the multidisciplinary sciences the lowest.
- The natural sciences exhibited the highest percentage of institutional collaboration and the engineering & material sciences exhibited the lowest.
- There is a distinct non-linear relationship between institutional publishing size and the amount of institutional collaboration. On average, institutional collaboration showed a strong non-linear relationship with the publishing size of the institutions.
- A greater proportion of publications from smaller institutions than from larger institutions involved domestic, intra-sectoral, inter-sectoral and industrial collaboration. On the other hand a greater proportion of the papers from larger institutions than from smaller institutions involved international or intra-institutional collaborations.
- 50% of institutional collaborations occurred within a radius of 60-80 km. For institutions outside of greater London the radius was 80-100 km. The life sciences showed the largest change in their geographical collaboration pattern, the average distance between collaborating institutions increasing over the time period. The pattern of geographical collaborations in the natural sciences remained quite constant over time.

Institutional context

Three models of collaboration - corporate partnership, team and personal collaboration - are identified which seek to differentiate between level, rationale, structure, ownership and benefits. The principal division is between those operating at corporate level and those at team and personal level. The principal driver of corporate partnerships is access to external resources, whereas team and personal collaborations are mainly research problem and people focused.

In practice, institutional profiles of collaborations incorporate more than one model. However, it is not possible from data currently available to quantify the relative amount of different types of collaboration. Institutions rarely monitor collaboration as part of the research process. Nor is it possible to compare the success of one model over another in facilitating the achievement of institutional mission.

Pressures to work collaboratively challenge institutions to devise clear strategies that give room to individualism at the same time as encouraging the sort of collaborations necessary to promote excellent, leading edge knowledge production. This encompasses not just capacity to mould the

internal architecture of institutional organisation to fit the changing shape of research, but broader articulation with higher education's collective contribution to research and innovation locally, nationally and internationally.

Collaboration and HEI mission

The relationship between collaboration and the achievement of mission is pivotal. Evidence from the study provides the following headline findings:

- Collaboration is an essential feature of the HE research base.
- Collaboration is vital to the achievement of HEI mission.
- Strengthening the economic and social contribution of research through collaboration is now a major strategic goal of HEIs
- The type, nature and reputation of the university influences the profiles of partnerships and collaborations.
- There are important tensions in the system
- People and skill issues are being tackled collaboratively but ad hoc rather than strategically.

Policy implications

Four policy implications flow from the research:

- The importance of institutional autonomy in supporting and facilitating collaboration is reinforced, although collaboration often involves difficult institutional decisions on which areas to support, which to cut and which to develop.

- Working collaboratively facilitates involvement in areas not otherwise possible, but it implies active management of research and awareness of the strengths and weaknesses of one's own institution as well as partner organisations. There is no evidence of any strong or consistent support for funding initiatives specifically targeted on research organised collaboratively.

- Knowledge of how to fund, manage, facilitate, and conduct collaborative research will become core scientific and policy competencies in this century (see Hicks and Katz 1996).

- The importance of programmes and policies specifically designed to encourage collaboration may dwindle as collaboration is accepted as the norm. However, attention may need to be refocused on the robustness of peer review processes as the means of encouraging research excellence in collaborative environments.

Chapter 1: Issues, Models and Reflections

Introduction

1. This report presents the findings from a research project commissioned by the HEFCE as part of the fundamental review of research policy and funding. The project focuses on collaborative approaches to research and is set in the context of the changing dynamics and institutional bases of research. Its primary purpose is both to review and contribute to the evidence-base on institutional and individual researcher approaches to collaborative research with particular reference to the relationship between collaboration and mission in higher education institutions (HEIs). The report draws on a combination of literature, bibliometric and case study research and analysis carried out by a team of consultants during the period November 1999 to March 2000.

2. The importance of collaboration to the development of a high calibre research system is widely acknowledged in the UK and beyond. The signals-to-the-system sent by government, funding councils, research councils, major research charities and other parties to knowledge production incorporate the explicit aim of breaking down the barriers to collaboration, particularly between universities, industry, commerce, government and the public services. These messages reflect a number of pressures for change which have characterised the relationship between higher education and society in recent years. They include:

- The growth of the knowledge economy and attempts to strengthen the economic and social contribution of research. The policy issue addressed in this report is whether and how collaboration can enhance the capacity for innovation and engagement with local, regional, national and global economies.
- A shift in emphasis in key parts of research system - research funding, research councils and universities - towards more applied research conducted in collaboration with a wider range of other knowledge creators and users. This is linked to the emergence of new contexts and approaches to research captured in the idea of Mode 1/Mode 2 research (Gibbons et al 1994a).
- Selective funding of research, greater concentration of research activity and increased requirements for collaboration, as well as a need for stronger co-operation and partnership in the use of plant, equipment and expertise.
- The growth of the directed mode of funding based on priority areas, joint funding and applied or problem oriented project funding (exemplified in, but not confined to, EU Framework Five funding which is explicitly collaborative).
- The shift towards a mass higher education system and lifelong learning and the tensions this creates between institutional mission, diversity, autonomy and the teaching/research interface.

3. The importance of collaboration in higher education was flagged formally in the Dearing Committee report. This was echoed in the Garrick report for Scotland. Both reports identified the need for a climate that would facilitate collaboration. Dearing was concerned in particular that concentration of research effort (and facilities) should not imply exclusivity. The report argued that those with the privilege of working in a unit selectively funded for research had an obligation to allow individuals based in other institutions to benefit not just from access to equipment but from wider interaction with and contribution to the life of the research community. Implicit in this conclusion is a concern for the relationship between research funding policies and opportunities for the development of skilled people, the latter being one of the main outputs of the research base. Dearing made two specific recommendations (68 and 75) about future arrangements for dealing with collaboration suggesting that the Funding and Research Councils:

- ensure that funding arrangements do not discourage collaboration between institutions and where appropriate encourage collaboration;

- explore the possibility of setting aside some of the total grant to fund collaborative projects likely to facilitate regional access to teaching and research facilities not otherwise provided on a viable basis.

4. Allied to these issues are two further developments that have influenced the modes of thinking and operation of higher education. The first is the growth of the 'partnership movement' which has characterised public both policy making and other key relationships in the broader landscape of economic and social activity. This movement reflects a growing consensus that the scale, complexity and interrelatedness of so many public policy problems in advanced industrial societies demand multi- and inter-organisational approaches which are able to draw on a variety of public and private, government and agency, voluntary and community contributions.

5. The second is the (renewed) political focus on the regional dimension of governance and economic development. The creation of the Regional Development Agencies (RDAs) in the English regions (as well as devolution in Scotland and Wales) has already delivered some important strategic and structural changes to the availability and deployment of resources; more are likely in the future.

Study focus and research questions

6. Closely related to these overarching processes and the specific recommendations of Dearing is a widely shared perception that it is through various forms of collaboration and partnership that universities are best able to define and operationalise their research strategies and

broader missions. However, collaboration is delicately linked to broader questions about the institutional management of research, the diversity of institutional activities, institutional autonomy and, of critical importance, the role of collaboration in the processes of academic research.

7. In the broader signals to the system there are also some largely untested perceptions that collaboration is intrinsically superior to unrestrained competition; that it offers greater efficiency and value-for-money in the use of public funds; and, that it adds value to academic research. This research project provides a more critical review of these assumptions. Two broad sets of questions are explored:

Collaboration and institutional mission:

- To what extent can collaboration support the missions of HEIs?
- To what extent can HEIs support the intrinsic collaborative nature of research?
- What is the potential for research collaboration between HEIs and can collaboration facilitate their different missions?
- In what areas should research collaboration be promoted and how is it most effectively promoted?

Creating and sustaining collaborations:

Underpinning these questions are a sub-set of related issues concerning how and why collaboration is approached both at institutional level and by individual researchers across a range of academic disciplines:

- Why do researchers collaborate and are the drivers of collaboration the same across all disciplines?
- Do institutional strategies connect selectively with particular areas of research and sets of researchers?
- What is the role of funding and research assessment?
- How are potential collaborators (partners) identified and what is the 'cement' that binds collaborations together?
- What are the benefits and costs of collaboration and how are they assessed?
- How are competitive forces in research processes accommodated within frameworks of collaboration?

Report structure

8. The report is structured around findings and evidence. Chapter 1 provides an overview of the key themes, findings and policy implications of the research. Subsequent chapters then deal in more detail with the evidence base. Chapter 2 focuses on the literature of research collaboration; Chapter 3 details the bibliometric evidence; Chapters 4 and 5 switch to the

institutional dimensions of collaboration. The overview in the present chapter reflects this structure. It commences with a discussion of the concept of research collaboration and establishes the main outlines of the current state of understanding revealed by the literature review. This is followed by the headline findings of the bibliometric analysis of the patterns and practice of the concept as revealed through collaborative academic publishing. Attention is then switched to the institutional dimension of collaborative research. The main models of collaboration revealed in the case studies are outlined as a prelude to a more detailed assessment of the relationship between collaboration and institutional mission. The final section discusses the policy implications of the research.

Concepts of collaboration

9. There is considerable policy enthusiasm for collaboration. However, collaboration is difficult to define. Partly, this is because the notion of a research collaboration is largely a matter of social convention among scientists. There is little consensus on where other, less formal links between researchers end and collaboration begins. What some might deem a collaboration, others may merely regard as a loose grouping or a set of informal links. In reality, the concept of collaboration is not well-understood: it has multiple meanings in practice and is a complex phenomenon.

10. Collaboration occurs at several levels of the research system and it is not easy to distinguish between different types of collaboration. Collaboration occurs between individuals, groups, departments, institutions, sectors and countries. The latter may emerge from political memoranda of understanding between nations[1] [Beatty, 1993], although definitions of higher levels of collaboration are no easier to arrive at than for inter-individual collaboration. Nevertheless, it is important to make this distinction between the different levels because an inter-institutional or international collaboration may not necessarily entail an inter-individual collaboration. What constitutes a collaboration varies across institutions, fields, sectors and countries, and changes with time.

11. Collaboration is often loosely defined in the context of research and embraces several symbolic and concrete meanings in both policy documentation and day-to-day operation. It is often conflated with partnership and a variety of formal and informal research networks, alliances, pacts and understandings. All may be ‘collaborative’ in intent although the precise nature, purpose and configuration of the resulting collaborations may vary considerably.

12. In practice, the term ‘partnership’ has been defined as the existence of ‘formalised bodies established by two or more autonomous partners, none of whom is under contract to another,

with the purpose of attaining substantive or symbolic goals that no partner could achieve independently' (DETR 1998: 16). This more formal definition undoubtedly captures some of the key, largely corporate, collaborative activities of the higher education sector.

13. On the other hand, much collaborative activity is less formal, some of it very informal. For this reason, this report also uses the definition of collaboration (adopted in a recent SHEFC funded study of collaborative use of research facilities) as 'working with someone else for a special purpose' (SURPC 1999: 7). This dictionary based definition of collaboration captures much of the activity found in the sector particularly where it is not defined by formal partnership.

14. In higher education, the term collaboration typically embraces a range of functions, including teaching, student participation and progression (for example, compacts, franchising and validation relationships), lifelong learning, research commercialisation and intellectual property (IP), technology transfer, consultancy as well as research. Formal relationships based purely on research are a key element of collaborative activity, but even in research-led institutions may form only a part of the broader spectrum of activity. However, systematic central monitoring of collaborative activities by institutions is rare. Moreover, even if it did take place monitoring of collaboration would need to capture the full diversity and scale of informal collaborations. Formal agreements between universities and their partners as much as the research process itself are underpinned by the numerous informal collaborations between researchers.

15. At the core of the research base are vast and only partially mapped (through bibliometric techniques) networks of researchers working in various forms of collaboration. Although some may be stable, long term and highly productive collaborations, they are characterised by strong elements of temporality and change as careers develop and contacts come and go. Although the partnership route has become a favoured policy mechanism for tackling a range of problems in higher education and beyond, it would be a grave mistake to ignore such informal arrangements. Across all disciplinary areas, they are the key to unlocking the creativity and talent of individuals, although their very informality and personal (often social) basis defies other than sensitive external or managerial intervention. Such personal collaborations, however, remain within the frame of reference of the present study since invariably they are created and sustained for the purposes of either securing research funding, carrying out the research process and/or the production of research outputs (usually publications but including other outputs such as patents).

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1 For example, the Atomic Bomb Causality Commission study to observe the effects of Hiroshima is an international scientific collaboration derived from a political activity [see Beatty, 1993 p. 205].

Patterns of collaborative publishing activity

16. The bibliometric component of the study explored collaboration patterns for UK higher educational institutions. It examines scientific publications indexed between 1981-1994 in the Science Citation Index. All UK institutional addresses on the papers were unified to a set of standard institutional names and each standard name was assigned to an institutional sector. The bibliometric analysis involved examining the patterns of various types of collaboration in four scientific disciplines. Also, the effect of geographical proximity of institutions on the amount of collaboration was explored.

17. Collaboration is the rule not the exception. By 1994, 88 per cent of all UK HEI papers involved two or more authors and 55 per cent involved two or more institutions. These percentages had increased significantly from 76 per cent and 35 per cent, respectively, in 1981. HEIs collaborated with other domestic institutions on 34 per cent of their papers and with international partners on 20 per cent of their papers. The life sciences exhibited the highest percentage of multiple author papers and the multidisciplinary sciences the lowest. The natural sciences exhibited the highest percentage of institutional collaboration and the engineering & material sciences exhibited the lowest.

18. There is a distinct non-linear relationship between institutional publishing size and the amount of institutional collaboration. On average, institutional collaboration showed a power law relationship with the publishing size of the institutions. A greater proportion of publications from smaller institutions than from larger institutions involved domestic, intra-sectoral, inter-sectoral and industrial collaboration. This effect was most pronounced in the engineering & material sciences. On the other hand a greater proportion of the papers from larger institutions than from smaller institutions involved international or intra-institutional collaborations. For international collaboration the non-linear effect was strongest in the natural, life and engineering & material sciences and for intra-institutional collaboration it was most prominent in the life and multidisciplinary sciences. Industry collaboration showed a mixture of the two non-linear effects. Larger institutions published fewer collaborative papers with industry in the life and natural sciences and more in the engineering & material sciences and multidisciplinary sciences than did smaller institutions.

19. 50% of institutional collaborations occurred within a radius of 60-80 km. For institutions outside of greater London the radius was 80-100 km. The life sciences showed the largest change in their geographical collaboration pattern. The three-year average percentage of collaborations that occurred within the 60-80 km radius decreased from 56 to 42 per cent over the time period i.e. the average distance between collaborating institutions in the life sciences increased with time. Half of all collaborations in the natural sciences occurred within a 100-120 km and it remained quite constant over time.

20. The bibliometric evidence indicates that the majority of scientific research is collaborative. The size and geographical location of an institution influences its collaboration profile. An institution and it researchers do not work in isolation; they work within broad and extensive research networks. The implications of the findings suggest that evaluation activities may need to make adjustments for the non-linear effect of institutional size when making comparisons. They also suggest we need a better understanding of how much collaboration policy actually influences a science system where the emerging nature and culture of scientific research appears to encourage collaborative activity.

21. However, we need to be aware of the limitations of using co-authorship as the basis for assessment of collaboration. Four key limitations of bibliometric analysis need to be born in mind:

- It can only be used to measure collaboration where the authors put their names on joint papers and succeed in getting them published.
- Although such papers can be used as a proxy measure for collaboration among groups of researchers it does not provide a complete description of the dynamics and activities of the collaborative relationships through which such outputs are produced.
- Bibliometric measures are limited to the disciplinary areas (mainly science and technology with some social science) covered by the databases of research outputs. They do not capture the breadth of research activity in the arts, humanities and borderlands with the social sciences.
- Other forms of institutionally based collaborations, that may have important research components, are not captured by bibliometric techniques.

22. The case study component of the research was intended to elaborate the essential institutional and researcher dimensions of collaboration which are not readily amenable to quantification.

Institutional context

Models of collaboration

23. The complex and multi-layered nature of so many collaborative partnerships in higher education makes categorisation and identification of salient features an inevitable simplification of practice on the ground. However, it is possible to generate three somewhat different or 'ideal-typical' forms of collaboration. In practice, most institutions will provide variations of these forms, with all three co-existing to varying degrees as an integral part of the institutional research base. However, the models provide a heuristic tool with which to demonstrate basic differences between collaborative activities in terms of structures, roles, objectives and modes of operation.

Type A: Corporate Partnerships

These can be characterised as 'means to an end' collaborations. They are corporately initiated and ‘owned’. The driver is principally (but not exclusively) access to external resources. Examples include collaborative bids for funding sometimes with other universities and sometimes with industry. Key features include:

- Formalised network providing coordinated and forum for the development of joint strategic goals.
- Structures vary but typically may include formal boards or even companies responsible for the implementation and delivery of the partnership strategy.
- Target funding sources may include Funding Bodies or Research Council/Charity competitive funds, European funds as well as private sector/industrial funding.
- Scale and purpose of funding may vary from the creation of new ICT infrastructure, research facilities and equipment, teaching/training/technology transfer arrangements including collaborative schemes to fund studentships/research fellowships, usually but not exclusively with industry.

Benefits of corporate partnerships include:

- Identification of institutional complementarities and pooling of resources.
- Access to external resources, otherwise unavailable.
- Build capacity to work strategically and impact on key areas of joint interest.
- Promote cultural transformation and new synergies among partners with other potential spin offs.
- Achievement of mission and strategy including new knowledge; economic, social or cultural benefits through collaboration with industry/other partners; development of high skills/human resources
- A route to critical research mass, typically but not exclusively at local or sub-regional level.

Type B: Team Collaboration

- The second model exists below the corporate level. These are collaborations that also have a formalised existence though they are not defined as formal partnerships. Teams retain ‘Ownership’ and control since these are high skill/discretion areas. The driver is principally the need for multi-disciplinary skills and experience. Key features include:

- Research-focused collaborations involving teams of researchers based in various departmental, research centre or other units at two or more institutions.
- Teams involving universities, industry, government laboratories or professional practice.

- Symbiotic relationship with funding streams with competition for funding simultaneously a stimulant and problem for longer-term group stability.
- Outcomes/practitioner focused, problem and task-based.
- Structured loosely often as joint research award holders with operational responsibilities tacitly rather than formally defined.
- Predominantly, though not exclusively, science-based disciplines, especially involving access to appropriate research environments/equipment, though may characterise some specialist, often interdisciplinary, research centres.

Benefits of team collaborations include:

- Development of appropriate skills/expertise.
- Advancement of knowledge/understanding and the research agenda.
- Stable existence but collaborations generally have a life cycle which prevents ossification
- High university-user interfacing.
- Often high-profile cutting edge research with potential for research excellence

Type C: Inter-Personal Collaboration

This model contains the greatest diversity but constitutes the 'ballast' of university research activity. Collaboration is intellectually driven and discipline-based and sometimes, in larger collaborations, discipline organised. However, it is dependent on essentially personal relationships between two or more university based individuals, sometimes groups. Institutional affinity is rarely a relevant factor since many collaborations endure changes associated with career moves. The key features are:

- Successful collaborations are bottom-up and people driven.
- Based on personal relationships, trust and ability to work together.
- No formal structure to individual collaborations although many develop initially from formal research mentor/training relationships.
- Essentially university based but can include industry-based researchers especially holders of joint appointments.
- Can be remarkably enduring and capable of organic growth with collaborators joining/leaving.
- Task focused with high discretion for setting/meeting goals and targets e.g. development of research grant proposals, publications.
- Facilitated by regular face-to-face contact but can be sustained by the development by other forms of contact most recently by the development of email.
- Characterise research activity across a broad spectrum of disciplines, including interdisciplinary research.

Benefits of personal collaborations include:

- Key to disciplinary development/intellectual curiosity.
- Enhance personal and joint capacity.
- Essential to leading edge/blue skies research.
- Provide the vibrancy necessary for the growth and sustenance of research networks
- The social basis of research: collaboration is fun.
- Publication output and intellectual/RAE kudos is critically dependent on collaboration.
- High personal investment in the development of the research base.
- Benefits for teaching and research training.

Collaboration and institutional mission

24. The models both simplify and generalise the complexity of collaborative activity. However, they encapsulate the key characteristics of each type of collaboration and enable a more systematic assessment of the relationship between the different models and their respective contribution to the achievement of institutional mission. The precision of bibliometric analysis of collaboration is not replicated in the context of institutional strategy and day-to-day management. Evidence from the HEIs suggests that senior managers see support for collaboration as synonymous with support for research. The two are inseparable (with the odd caveat) and there is no evidence of any *special* support for collaborative links. To the extent that research *is* collaborative, senior managers do not appear to treat it separately. Collaboration was often explicitly referred to as 'not an issue,' it was 'taken for granted', or 'part of our way of doing things here'.

25. Management teams interviewed see their task largely as creating infrastructure and support systems for faculty/operating unit creativity in the development of collaborations. Strategies for achieving these goals vary and relate to organisational structures and missions. Active monitoring of research and research activity across institution takes place, but the evidence suggests that there is no specific focus in the institutional monitoring process on collaboration or collaborative activity. Senior managers engage in developing relationships with a number of major agencies and institutions with which the university would like to enter into partnerships and collaborations. It is important to note, however, that these relationships may not be primarily research-driven, although there may be research-related outcomes.

26. Faculties, departments and/or other operating units play a key role in developing and supporting collaborative links. However, patterns of research collaboration, and collaborating partners, differ across institutions. Organisational arrangements and cultural expectations also vary considerably between disciplines. Evidence from the study provides the following headline findings:

Collaboration is an essential feature of the HE research base

27. Collaboration in research is pervasive throughout the HE sector. The fieldwork revealed considerable diversity of activities. These are captured in the three models of collaboration - corporate, team, and personal - which operate at different levels within the research system. Examples of the three models were found in all case study institutions.

28. In all the HEIs the basic building block is inter-personal collaboration - in two senses. First, they are based on individual researchers, who work collaboratively in a climate of shared intellectual interest and trust: “the best academics will want to work with each other” (vice-chancellor). Networks of academic researchers working at the frontiers of knowledge comprise the essence of the academic labour process. They are essential to creativity, problem solving and new knowledge production. Second, the development of team collaboration and corporate partnerships are contingent on the existence of the informal and voluntaristic networks of coalface researchers.

29. Although we have suggested that inter-institutional or international collaboration may not necessarily entail inter-personal collaboration, evidence from the case studies suggests that a strong collaborative research base is an important success factor in the operationalisation of higher levels of aggregation. Developing *horizontal* integration between the HEI and a range of external partners is a key element of institutional strategy. But this external dimension has to be accommodated within the *vertical* structures of the institution. Managing and integrating the interface between these horizontal and vertical dimensions of research collaboration is a key management task and requires an environment conducive to strong researcher based collaborative activity. These personal networks are difficult to manage or produce artificially. There has to be a purpose to collaboration. Without shared interest and clear purpose higher level collaborations can easily become paper collaborations.

30. Bibliometric evidence suggests that there has been a long-term trend towards collaborative activity. This implies that the driver is located principally in the nature of the research process rather than specific policy interventions. Nevertheless, the promotion of collaboration has undoubtedly been a feature of Funding Bodies and Research Councils as well as the broader public policy environment. There are now a variety of top-down incentives to work collaboratively at different levels. The formation of corporate partnerships (Model A) and team collaborations (Model B) may be more directly attributable to changes in funding arrangements, the need for access to external sources of funding and/or equipment as well as other policy shifts towards working in partnership.

Collaboration is vital to the achievement of HEI mission:

31. HEI research strategies include specific (documented) goals to facilitate both intra- and inter-institutional collaboration. These include inter-disciplinary links within the institution, links between different research units, with affiliated institutions (including where appropriate NHS Trusts) and with other HEIs. Collaborations with industrial partners are seen as critical to finding new sources of external resources. This is fuelled by a widely shared perception in higher education that research in general and fundamental research in particular is chronically under-funded across all public sources.

32. Corporate partnerships with other HEIs are designed to advance both individual and group interests by harnessing various areas of strength and expertise to common purpose. These are predominantly **Model A** models of collaboration. Such partnerships serve a range of purposes. Examples include: strategic partnerships with one or more HEIs; preferred partner arrangements with a specific partner; and sub-regional partnerships

33. Top level corporate partnerships involving significant levels of long term investment can be difficult deals to strike. Negotiations can be complex because the relationship tends to be at the meta rather than detailed operational level. Time horizons are multiple and unpredictable. Longer-term benefits to the parties can be difficult to specify. The ultimate success factor is mutual trust and overlapping interests rather than legal contract. Forced or overly restrictive partnership conditions are unlikely to be successful.

34. Corporate level collaboration can serve either defensive or offensive goals (see DETR 1998). Defensive partnerships between HEIs enable intelligence and expertise to be shared in response to a rapidly changing funding/political environment. The regional dimension of government is a specific concern, and the research revealed resistance in the system to any significant shift of powers over HE to the regional dimension. There are concerns that the regional (and local) focus, though important, should not be to the detriment of wider UK and international collaborations.

35. Offensive partnerships serve different purposes. They enable groups of HEIs to assemble the critical mass necessary to compete with competitors in an increasingly global HE market. The driver is the desire to compete for resources otherwise unobtainable. For example, sub-regional partnerships between research-led HEIs provide scale and depth of expertise sufficient to match the leading national and overseas competitor HEIs. Conversely, there is some evidence that the top research HEIs try to provide sufficient internal critical mass to reduce the need for external collaboration. There is an awareness that collaboration costs can be higher than often perceived.

36. Corporate partnerships may connect only selectively with operating units in the HEI, typically in areas of cutting edge scientific and technological research. Research in arts, humanities and the social sciences may be untouched directly by corporate partnerships. Researchers may have only a vague awareness of the existence of the partnerships and do not connect with them in any meaningful way. Even in areas subject to 'strategic' corporate partnerships between HEIs there is evidence that researchers continue to work within their own webs of collaboration across the institutions concerned unaware that a higher level agreement is in place.

Strengthening the economic and social contribution of research through collaboration is now a major strategic goal of HEIs.

37. New knowledge and economic/quality of life benefits are key outputs of the research base. Model A type corporate partnerships in conjunction with other HEIs and a range of other external partners are able to strengthen HEI contribution to these outputs. Some are bilateral agreements between the HEI and the external partner. Others can involve consortia of HEIs acting collectively in partnership with the external body. Partnerships facilitate intellectual and disciplinary development in an applied base. Leaders and researchers emphasised corporate partnership should contribute to fundamental research. Solving specific industrial problems is not seen as the draw or purpose of such link-ups.

38. Where fundamental research is a beneficiary of the corporate partnership, then collaboration is not necessarily inimical to high performance in the RAE. There is a flow of outputs from new knowledge production, to publishing and through to application. There are also potential synergies between partners leading to two way flows of information, people and skills. For industrial partners the collaboration offers an inside track to where research and techniques will be in 10-20 years time.

The type, nature and reputation of the university influences the profiles of external partnerships.

39. Top research-led HEIs are setting up/seeking to develop partnership links with leading edge (in technology terms) global industrial players. HEIs with less intense research missions tend to develop corporate links with smaller industrial players often in more local/sub-regional contexts. Such collaborations, however, can be important in facilitating HEI-SME links. Position in the HE research system, exemplified in RAE rankings, is used by business and industry as a 'directional indicator' in the search for HEI partners. The pursuit of excellence defined in RAE was seen as an important facet of securing/maintaining relationships with external partners.

40. These 'excellence' factors are mediated by collaboration. Webs of collaborations link HEIs via all three models of collaboration. Research projects derived from HEI-industry links at the top

of the system often flow to a series of secondary partners at other HEIs involving team and/or inter-personal collaborations. Indeed, it is often the existence of informal/social relationships between researchers in different parts of the system which influence the direction and strength of these flows. The point was made by several HEIs that such linked research provides a toehold on the research base. Researchers based in top research institutions do work collaboratively with colleagues in lower ranked HEI departments, although these may not be their only collaborations. For the secondary partner retaining this toehold can be difficult. Heavy teaching loads and the absence of any 'slack' in the system mean that additional research commitments are difficult to accommodate.

There are important 'tensions' in the system

41. Despite the benefits from corporate partnerships, this is not always shared at the level of heads of research units and front line researchers. The need for a balance of fundamental, strategic and applied research is accepted, but they retain some suspicion of industrial and applied research. Concerns were expressed about the objectivity and independence of 'sponsored' research and possible constraints on academic freedom. This is linked to a perception (widely shared at all levels of the system) that the research base is being impoverished for the want of adequate resource in the system. Researchers fear that fundamental breakthroughs in scientific discovery or originality are starved of the necessary long-term and unconstrained resources. There is a widely shared view that the dual support system is becoming less and less able to provide for this critical element in the research system.

42. Generally the RAE was not seen as a major obstacle to working collaboratively with researchers in other HEIs or in partnerships with industrial and other external collaborators (except where research was too heavily tilted towards applied or industrial problem solving). Researchers recognise the pressures created by the changing nature of research, the need for critical mass and assembly of so many different skills in order to tackle problems at the highest levels. But the need to retain strong disciplines is also recognised (continuity of academic achievement and skills development).

43. HEIs face a difficult problem in combining funding and evaluation structures and the increasingly fluid divisions between disciplines with the internal walls and social architecture of the institution. Facilitating collaboration within the institution is seemingly almost more difficult than engaging in external collaboration. Researchers acknowledged that senior managers are addressing these issues, but consider that basic structural, organisational and cultural blocks remain.

People and skill issues are being tackled collaboratively but ad hoc rather than strategically

44. The production of skilled people in terms of research and related skills is one of the key outputs of the research system. It is of interest and relevance to HEIs (as a source of the leading researchers of the future) and the wider economy. The scope to develop collaborative approaches to graduate research training has been the subject of a separate interim report prepared for the Funding Council by the consultants. The findings are referred to in more detail in Chapter 5 of the present report. Here we refer to the most important features of activity in this area.

45. The people and skill dimensions of the research base point up the difficulty of separating out research from teaching and other functions. For example, schemes developed by HEIs to serve the learning needs of particular industries or businesses are often closely linked with the research (or at least development end of the research spectrum) activity of the HEI.

46. The development of collaborative (i.e. inter-institutional) approaches to different forms of graduate education appears to be overwhelmingly driven at the level of disciplines and by academic units. Researchers often display considerable enthusiasm for developing collaborative ventures with colleagues in other HEIs. Such schemes offer scope to enhance disciplinary development and standards as well as the standing and viability of the academic units involved. Some disciplinary-based schemes certainly come about in order to provide the breadth of expertise, rigour and consistency of quality thought necessary to achieve recognition from Research Councils for student funding purposes. However, there is evidence to suggest that collaborative approaches are not always successful in achieving the goal of recognition.

47. Collaborative teaching activity of this sort (although closely related to the research process) appears to suffer from a number of frictions. Institutional competition for students, strong (though unwritten) territorial ambitions and monopolies, problems of subsidy and resource transparency appear to provide particularly strong disincentives to the development of more strategic approaches to HEI level collaboration in this area.

48. Much of the activity in this area appears to be unmapped and the success factors only partially understood. At one end of the spectrum are the ad hoc arrangements devised for the joint supervision of Ph.D. students by researchers based in different institutions; at the other are more formalised corporately organised collaborative schemes.

49. Collaboration in the area of graduate education offers potential to add value from the pooling of resources, complementary expertise and critical mass. It is clear, however, that for schemes to be successful requires equal commitment from all the partners and a culture of

strategic collaboration in all the host HEIs. Specific attention would need to be given to removing the factors that cause friction between HEIs. Where these conditions are met, then there is evidence from the research that the schemes can be a major source of supporting the HEI mission as well as enhancing the quality of the student experience.

Summary

50. Collaboration is difficult to define. Co-operative and competitive forces co-exist within the research system and it is difficult to determine exactly how each of these influence researchers working alone and in groups. Extensive, often informal or semi-formal individual research collaborations, form the foundations of the research system. Bibliometric analysis enables us to at least map this activity partially. However, it is mainly the researchers themselves who are concerned with and understand the dynamics of their collaborations and how they contribute to new knowledge production. HEIs have a real interest in understanding and facilitating collaboration, but rarely monitor collaborative activity as a component part of the institutional research base.

51. HEIs embrace various forms of collaboration in their strategic planning statements. The evidence suggests they are willing to collaborate with a range of external partners in order to achieve ends collectively (either with other HEIs or a range of external partners) that they would not be able to achieve acting individually. However, where HEIs feel pressured into acting collaboratively (by formal prescriptions of funding bodies or informal political persuasions by regional or other tiers of government) then there is evidence that collaboration may be seen less positively. Meaningful collaborations are almost always driven from the bottom-up and from within the research process itself. Collaboration does not appear to respond well to top-down policy drivers particularly if they are detached from the pattern of activity on the ground. Meaningful collaborations are difficult to stimulate and manage.

52. Four policy implications flow from the research:

- The importance of institutional autonomy in supporting and facilitating collaboration is reinforced, although collaboration often involves difficult institutional decisions on which areas to support, which to cut and which to develop.

- Working collaboratively facilitates involvement in areas not otherwise possible, but it implies active management of research and awareness of the strengths and weaknesses of one's own institution as well as partner organisations. There is no evidence of any strong or consistent support for funding initiatives specifically targeted on research organised collaboratively.

- Knowledge of how to fund, manage, facilitate, and conduct collaborative research will become core scientific and policy competencies in this century (see Hicks and Katz 1996).

- The importance of programmes and policies specifically designed to encourage collaboration may dwindle as collaboration is accepted as the norm. This will refocus attention on the robustness of the peer review process as the means of encouraging research excellence within collaborative environments.

Chapter 2: Characteristics of collaboration: Literature Review

Introduction

53. There have been many previous studies of research collaboration but comparatively little attention has been given to the concept of collaboration and the methods by which it can be measured. This chapter reviews the current literature on research collaboration with particular reference to the current state of thinking about the nature and driving forces behind collaboration. It aims to:

- Explore the different levels of collaboration and show that co-authorship is only a partial indicator of collaboration.
- Develop a better understanding of the costs and benefits of collaboration.
- Identify the factors that encourage collaboration.
- Discuss issues concerning the measurement of collaboration and its practice as a precursor to the quantitative and qualitative investigations in the following chapters.

54. Over recent years, there has been increasing interest among researchers and within science and higher education policy circles about the notion of research collaboration.[2] It is widely assumed that collaboration in research is a good thing and that it should be encouraged. Numerous initiatives have been launched with the aim of developing collaboration among individual researchers. There have also been policies aimed at improving the links between science and technology through fostering research collaboration across sectors - in particular, between university and industry. Furthermore, most governments have been keen to increase the level of international collaboration engaged in by the researchers whom they support in the belief that this will bring about cost savings or other benefits.

55. Implicit in this enthusiasm for research collaboration and in policies aimed at fostering it are a number of assumptions [Katz and Martin, 1997]:

- that the concept of research collaboration is well understood;
- that we are dealing with essentially the same phenomenon, whether we are concerned with collaboration between individuals, groups, institutions, sectors or nations;
- that we can in some way measure the level of collaboration and hence determine whether or not it is changing as a result of a particular policy;

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2 In what follows, we are concerned primarily with collaboration in science, although some of the arguments may also apply to collaboration in the social sciences. They are probably less relevant to the humanities where collaboration is apparently less common [see Meadows, 1974].

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

Our current understanding about the nature of collaboration

56. There are many issues examined in the extensive literature on research collaboration and they fall into some general categories:

- there is the question of how one can measure research collaboration, and in particular the value of using bibliometric analysis of multiple-author (or multiple-address) papers.
- there are concerns about the factors and driving forces that encourage research collaborations.
- there is interest in the role of communication and the effects of physical and social proximity on propensity to collaborate, and
- there is the literature analysing the effects of collaboration on productivity and on the impact of joint research.

Each of these categories will be considered in turn.

Multiple Authorship and Collaboration

57. For decades the multiple-author publication, frequently referred to as a co-authored publication, has been used as a basic counting unit to measure collaborative activity. Smith was one of the first researchers to observe an increase in the incidence of multiple-author papers [Smith, 1958] and to suggest that such papers could be used as a proxy measure for collaboration among groups of researchers. However, he warned that nothing short of a complete description of the kinds of relationships and activities of all persons concerned in the final product would give an approximation of the amount of group effort going into the papers presented. Subramanyam (1983) took the argument further and suggested that one needs to adopt a holistic perspective when evaluating collaboration because the nature and magnitude of collaboration cannot be easily determined by the usual methods of observation, interviews or questionnaire. The complex nature of human interaction that takes place between or among collaborators over a period of time and the nature and magnitude of contribution of each collaborator will change during the course of a research project. Furthermore, only some of the more tangible aspects of a collaborative piece of work can be quantified while others most certainly cannot.

58. Even a qualitative assessment of collaboration is extremely difficult because of the indeterminate relationship between quantifiable activities and intangible contributions. For example, Subramanyam notes that

a brilliant suggestion made by a scientist during casual conversation may be more valuable in shaping the course and outcome of a research project than weeks of labour-intensive activity of a collaborating scientist in the laboratory. [Subramanyam, 1983, p.35]

59. Despite the limitations of co-authorship measures, many studies have used this technique to investigate collaboration. For example, de Solla Price was an early advocate of the use of multiple-author papers as a measure of changes in collaboration. He produced evidence to support Smith's observation that multiple-authorship has been increasing [Price, 1963], a trend since confirmed by several other investigators [Balog , 1979/80; Beaver et al, 1978, 1979a, 1979b; Hicks and Katz, 1996; Meadows, 1974; Merton 1965].[3] However, such studies have also shown that the rate of increase in multiple-authorship varies with subject area [Hicks and Katz, 1997; Meadows, 1974; Stefaniak, 1982].

60. There is general consensus that the observed growth in multiple-authorship is evidence of an increase in collaboration [Beaver et al, 1978, 1979a, 1979b; Clarke, 1964; Gilvarry et al, 1959; Meadows et al, 1971]. However, the assumption that multiple-authorship and collaboration are synonymous must be qualified with the recognition that in some instances not all those named on a paper are responsible for the work and should not share the credit accorded to it. For example, Hagstrom found evidence that some publications listed authors for purely social reasons [Hagstrom, 1965]. More recently, the investigation of several instances of scientific fraud has revealed how common the practice of making colleagues honorary co-authors has become [Follette, 1992].

61. Although the assessment of collaboration using co-authorship is by no means perfect, it nevertheless has certain advantages [Subramanyam, 1983]:

- it is invariant and verifiable; given access to the same data-set, other investigators should be able to reproduce the results;
- it is a practical method for quantifying collaboration;
- due to the size of sample that it is possible to analyse using this technique the results should be statistically more significant than those from case-studies;

62. Some argue [Subramanyam, 1983] that bibliometric studies are unintrusive and non-reactive - that is, the measurement does not affect the collaboration process. This may be true in terms of an immediate effect but others have suggested that the results from a bibliometric investigation may influence collaboration practices over the longer term [Martin, 1992].

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[3] Beaver and Rosen [1978, 1979a, 1979b;] examined the *Royal Society Catalogue of Scientific Papers* over the years between 1800 and 1960. They concluded that during the nineteenth century teamwork exhibited a very slow and steady growth from about 2 percent of all research in 1800 to about 7 percent in 1900. However, at the beginning of the century, a significant upward change in the rate of growth occurred. By the beginning of World War I the growth rate had slowed down, but jointly authored research was still increasing at a rapid rate. Since then, the proportion of multi-authored publications has continued to expand.

63. The complex nature of collaboration is perhaps not as readily amenable to assessment as previous authors have assumed. Bibliometric analysis of multiple-author papers can only be used as a partial indicator of collaborative activity [Katz and Martin, 1997]. More specifically, it can only be used to count collaborations where the collaborating participants have put their names on a joint paper.

Factors Contributing to Collaboration

64. Numerous investigators have studied collaboration. A wide range of factors apparently contribute to collaborative activity but few specific reasons have been clearly established to explain how and why it occurs. Collaboration can take various forms ranging from offering general advice and insights to active participation in a specific piece of research. These collaborative contributions can also vary in level from the very substantial to the almost negligible. Sometimes a researcher may be seen as a collaborator and listed as a co-author simply because they provide material or performed a routine assay [Stokes, 1989]. In other cases, researchers may collaborate by sharing data or ideas through correspondence or discussions at conferences, by visiting each other, or by performing parts of a project separately and then integrating the results.

65. Previous investigators have proposed a great many factors to account for the increase in collaborative research. These include the following [Katz and Martin, 1997]:

- changing patterns or levels of funding [Clarke, 1967; Heffner, 1981; Smith, 1958];
- the desire of researchers to increase their scientific popularity [O'Connor, 1970], visibility and recognition [Beaver et al, 1978, 1979a, 1979b; Crane, 1972];
- escalating demands for the rationalisation of scientific manpower [Beaver et al, 1978, 1979a, 1979b; Price, 1963];
- the requirements of more complex and large-scale instrumentation [Meadows et al, 1971; Meadows, 1974];
- increasing specialisation in science [Bush, 1956; Jewkes et al, 1959; Smith, 1958];
- the advancement of scientific disciplines which means that a researcher requires more and more knowledge in order to make significant advances, a demand which often can only be met by pooling one's knowledge with others [Goffman et al, 1980; Maanten, 1970];
- the growing professionalisation of science, a factor which was probably more important in earlier years than now [Beaver et al, 1978, 1979a, 1979b];
- the need to gain experience or to train apprentice researchers in the most effective way possible [Beaver et al, 1978, 1979a, 1979b];
- the increasing desire to obtain cross-fertilisation across disciplines [Beaver et al, 1978, 1979a, 1979b];

- the need to work in close physical proximity with others in order to benefit from their skills and tacit knowledge [Beaver et al, 1978, 1979a, 1979b].
- cheaper and faster modes of transportation and communication that facilitate co-operative activity [Katz and Hicks, 1995].

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

67. Does collaboration vary with the nature of the research? Smith was one of the first to observe that theoretical work generally produces papers with fewer co-authors than experimental work [Smith 1958, pp.598-99]. Later evidence has supported this finding and now it is generally accepted that experimentalists tend to collaborate more than theoreticians [Gordon, 1980; Meadows, et al, 1971; Price ,1963]. Collaboration is particularly common in experimental research involving the use of large or complex instrumentation such as telescopes, particle accelerators or CT scanners [Mulkay, 1972; Price, 1963]. Besides the obvious economic benefits, one reason postulated for this high degree of collaboration is the need for a formal division of labour.

68. Collaboration may also depend on how basic or applied is the research. For example, Hagstrom [1965] has argued that applied research, like experimental research, tends to be more interdisciplinary, and research on a particular problem may therefore require a wider range of skills than any single individual, or even a single institution, is likely to possess. However, this is somewhat at odds with the findings of Frame and Carpenter and others who conclude that the more basic the research area, the greater the proportion of international co-authorships [Frame et al, 1979; Luukkonen, 1992].

The Role of Communication and the Effects of Physical and Social Proximity

69. Views on the role of social or intellectual forces stimulating collaboration vary widely. On the one hand, Price [1986] claimed that collaborative authorship "arises more from economic than from intellectual dependence and ... the effect is often that of squeezing full papers out of people who only have fractional papers in them at that particular time". 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 et al, 1966] that then lead to increasing commitment to co-operate.

70. Spatial proximity seems to encourage collaboration since it tends to generate more informal communication [Hagstrom, 1965; Kraut, 1988]. The closer two potential collaborators are, the

more likely they are to engage in informal communication. This is consistent with the results of a study that shows co-authorship decreases exponentially with the distance separating pairs of institutional partners [Katz, 1993].[4] However, this does not rule out the possibility that, in cases where the potential collaboration involves a clear division of labour, scientists may be more concerned with seeking the most appropriate expert partners, even if they have to travel some distance to find them.

71. Collaboration frequently occurs between teachers and students [Crane, 1972]. Even where there is no formal collaboration, the teacher who supervises the training of a student may retain a close relationship with that student over later years. Sometimes this is part of the process associated with the development of an invisible college [Price at al, 1966]. Invisible colleges are a form of network and represent a good source of potential collaborators.

72. Social distance between individuals is also apparently a factor influencing whether collaborations develop [Hagstrom, 1965]. In general, collaboration between peers (i.e. scientists of similar standing) is more likely than collaboration between individuals of unequal rank but this is by no means always the case. In this connection, Hagstrom made a curious observation about the relationship between teachers and students - namely, that in some teachers' minds students do not count as collaborators.

Collaboration, Productivity and Impact

73. Some investigators have tried to determine if prolific authors[5] tend to collaborate more than less prolific authors. Research into this question seems to indicate that high productivity (in terms of published output) is indeed correlated with high levels of collaboration [Balog, 1979/80 Beaver et al, 1978, 1979a, 1979b; Hodder, 1979/80; Lawani, 1986; Pao, 1980 & 1981; Pravdic et al, 1986; Price, 1963; Price et al, 1966]. Furthermore, the most prolific authors seem to collaborate most frequently and authors at all levels of productivity tend to collaborate more with highly productive authors than lower-productivity authors.

74. Besides enhancing personal productivity, collaboration appears to offer authors another advantage when it comes to a paper being submitted for publication. Gordon found a significant relationship between levels of multiple authorship for papers submitted to a leading astronomy journal, and their frequency of acceptance for publication [Gordon, 1980]. Other research has shown that there are further advantages to multiple-authorship. A study by Nudelman and Landers suggested that the total credit given by the scientific community to all the authors of a jointly authored paper is greater on average than the credit allocated to the author of a single-author paper [Nudelman et al, 1972]. The number of co-authors also

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4 This study [Katz, 1993] focused on intra-national university-university collaboration - that is, collaboration between universities within the same country.

appears to be strongly correlated with the impact of a paper. In his study of cancer research, Lawani demonstrated that, as the number of authors per paper increases, the proportion of high-impact papers (i.e. papers earning a high number of citations) also increases [Lawani, 1986]. Similarly, Crane [1972] and Goffman and Warren [1980] have shown that research by larger groups tends to be more influential, while Narin and Whitlow [1990] have found evidence that internationally co-authored papers are cited up to twice as frequently as single-country papers. Furthermore, it has been demonstrated that impact can increase with the type of collaboration [Katz and Hick, 1997]. A calibrated bibliometric model has demonstrated that collaborating with an author from the home institution or another domestic institution increases the average impact by 0.75 citations while collaborating with an individual from a foreign institution increases the impact by 1.6 citations. However, adding two authors from the same institution or another domestic institution increases the impact by 1.6 citations and from two foreign institutions by 3.2 citations.

75. The increased average impact of co-authored papers is frequently attributed solely to self-citations (i.e. authors citing their own papers, colleagues cite colleagues or countryman citing countryman over foreign researchers). It seems rather strange to think that citing one's past work or actively disseminating it to into other social networks through collaborative research should discount the impact of research. After all, a basic tenant in the research process is to build upon past research and this naturally implies citing past work. It might be justified to discount *excessive* self-citations but the definition of excessive could be rather illusive.

Gaps in the literature of collaboration

76. Although there is considerable literature on the phenomenon of research collaboration stretching back over 30 years or more, in much of this work collaboration has been simply equated with co-authored papers. In particular, the increase in the incidence of multiple authorship has been seen as evidence of growth in collaboration. Other aspects extensively investigated include: the factors encouraging collaboration and accounting for the increase in multi-authored papers; the sources of collaboration and the role of communication; and, whether collaboration is associated with greater productivity and impact. However, the survey of the literature suggests that there has been very little work on other important aspects of collaboration such as:

- how to define collaboration and what it means;
- the adequacy of measuring it through co-authorship;
- how to distinguish and categorise different levels of collaboration (ranging from inter-individual through inter-departmental and inter-institutional to international collaboration); and

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5 For example Lotka [1926] see footnote 5.

- the additional costs of collaboration.[6]

These are some of the gaps in the literature that the rest of this paper will attempt to fill.

What is a collaboration and where is the boundary?

77. Few attempts have been made to examine the question of what constitutes a research collaboration.[7] The meaning of the term tends to be taken for granted. Yet is the concept of collaboration so obvious and unproblematic? The dictionary definition of collaboration suggests the working together of individuals to achieve a common goal. Thus, a research collaboration could be defined as the working together of researchers to achieve the common goal of producing new scientific knowledge. However, exactly how closely do researchers have to work together in order to constitute a collaboration? It could be argued that the international research community is one big collaboration [Subramanyam, 1983] - that all researchers work together to advance scientific knowledge. They exchange ideas, hypotheses, instrumentation, experimental results, theoretical models, and so on. And they seek advice and help from others.

78. A *weak* definition of a collaborator could include anyone providing an input to a particular piece of research. However, it would bring in such large numbers of collaborators that it would be too unwieldy for all practical purposes. A *strong* definition might include those scientists who contributed directly to all the main research tasks over the duration of the project. This is problematic because no single individual could possess all the knowledge required to contribute to all aspects of a complex piece of research. We are therefore left with the rather unsatisfactory conclusion that a research collaboration lies somewhere between these two extremes. All that we can do is suggest some criteria for distinguishing collaborators from other researchers.

79. The collaborators will normally include the following:

- those who work together on the research project throughout its duration or for a large part of it, or who make frequent or substantial contributions;
- those whose names or posts appear in the original research proposal;[8]
- those responsible for one or more of the main elements of the research (e.g. the experimental design, construction of research equipment, execution of the experiment, analysis and interpretation of the data, writing up the results in a paper).

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6 An exception here is Turney [1991].

7 One exception is Edge [1979].

In some cases, the list of collaborators may also include

- those responsible for a key step (e.g. the original idea or hypothesis, the theoretical interpretation);
- the original project proposer and/or fund raiser, even if his or her main contribution subsequently is to the management of the research (e.g. as team leader) rather than research *per se*.

80. The group of collaborators will generally exclude those who make only an occasional or relatively minor contribution to a piece of research and those not seen as, or treated as, proper researchers (e.g. technicians, research assistants).

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

What Motivates Collaboration?

82. There are several factors that have increased the level of research collaboration over the last 30 to 40 years. This can be attributed to five general factors:

- escalating cost of state-of-the-art equipment and facilities required to work at the research frontier [Price, 1963];
- cheaper and faster modes of transportation and communication, especially with the advent of the fax and electronic mail [Katz and Hicks, 1995];
- science is a social institution thus thrives and grows with the interaction of individuals [Kuhn, 1970; Peters et al, 1989; Stokes et al, 1989];
- increasing specialisation, that is instances were no single individual can perform all the specialist tasks in a research project and were a team approach is essential with a fairly formal division of labour fields [Edge et al, 1976; Gordon, 1980; Price, 1963];
- growth in interdisciplinary research such as biosensors and opto-electronics [Katz, 1987; Martin, 1989];
- various political factors such as the EU and recent changes in Eastern Europe [Moed et al, 1991; Narin et al, 1991].

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8 One obvious criterion for defining collaborators would be those who are listed as co-authors on papers. However,

Who are the Research Collaborators?

83. At the most basic level, it is people who collaborate, not institutions (institutional collaborations and institutional-researcher relationships are explored further in Chapter 4). Co-operation between two or more researchers is the fundamental unit of collaboration. However, we often talk about collaboration at other levels - between research groups within a department, between departments within the same institution, between institutions, between sectors, and between geographical regions and countries. Indeed most policies are aimed at fostering collaboration at these higher levels rather then inter-individual collaboration.

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

85. The more formal forms of working together of institutions are generally perceived by the researchers involved as representing a collaboration, while the less formal and lower-level interactions going on between institutions all the time are usually judged not to constitute a collaboration.[9] However, as with collaboration between individual researchers, we must recognise the near-impossibility of specifying where a collaboration between two or more institutions ends and the less formal interactions begin.

How Can One Measure Collaboration?

86. The idea that a unit of collaboration can be adequately defined in terms of a multi-authored paper, and that it can be used to measure collaborative activity has pervaded the literature on the subject for thirty years. Consequently, when interest emerged in the phenomenon of international collaboration [Braun et al, 1992; Frame, 1979; Lewison et al, 1991; Luukkonen et al, 1992; Luukkonen et al, 1993; Moed, 1991; Moed, 1992; Narin et al, 1990; Narin et al, 1991; Okubo et al, 1992; Schubert et al, 1990], it was sometimes assumed that it could simply be equated with papers listing addresses in two (or more) countries. Similarly, studies of inter-institutional collaboration generally take as their starting point the belief that this can be measured by examining papers listing two (or more) institutional addresses.

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as explained elsewhere, we prefer to maintain a conceptual distinction between collaboration and co-authorship.

9 Some empirical evidence on scientists' perceptions of collaboration comes from a survey of the authors of university-industry collaborative papers in Japan - [see Heffner, 1981].

87. However, Katz and Martin [1997] argued that collaboration and co-authorship are not interchangeable and that co-authorship can only be a partial indicator of collaborative activity. For example, it is possible to conceive of two researchers collaborating closely but publishing their results separately, or the instance when two researchers did not collaborate during the research phase but decided to pool their results in a jointly authored paper. In fact about 5-8% of SCI papers list more institutions that authors suggesting that at least one author resides at two or more institutions [Katz, 1993]. This could indicate that there may be a formal or informal agreement between two institutions to collaborate by sharing a researcher. For these reasons, bibliometric measures can only be a partial indicator of collaborative activity.

What are the Benefits and Costs of Collaboration?

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

Benefits

89. Modern research is increasingly complex and demands an ever-widening range of skills. Often, no single individual will possess all the knowledge, skills and techniques required. In principle, he/she might be able to learn or acquire, say, all the techniques needed to solve a particular problem, but this can be very time-consuming. If two or more researchers collaborate, there is a greater probability that between them they will possess the necessary range of techniques.

90. The first type of benefit from collaboration is therefore the **sharing** of knowledge, skills and techniques. In collaborations, there may be a fairly formal division of labour. For example, one person may be good at constructing, operating and maintaining scientific instrumentation and another at analysing the data produced. Collaboration thus ensures a more effective use of their talents.

91. A second and closely related type of benefit is the **transfer** of knowledge or skills. As noted earlier, it can be time-consuming for an individual to update his/her knowledge or to retrain. Furthermore, not all the details concerning new advances are necessarily documented. Much of the knowledge may be tacit [Collins, 1974; Senker, 1993] and remains so until researchers have had the time to deliberate and set out their findings in a publication. Frequently, considerable time elapses before the knowledge appears in written form. Collaboration is one way of transferring new knowledge, especially tacit knowledge. Furthermore, research requires not only scientific and technical expertise, but also the social and management skills needed to work as part of a team. These cannot be readily taught in the classroom - they are best learned on the job by engaging graduate students or young postdoctoral researchers in collaborative activities.

92. A third benefit of collaboration may result from a clash of views, a cross-fertilisation of ideas which may in turn generate new insights or perspectives that individuals, working on their own, would not have grasped (or grasped as quickly) [Hoch, 1987; Mulkay, 1972]. The act of collaborating may thus be a source of stimulation and creativity. Hence, collaboration is greater than the sum of its parts. Such benefits are likely to be largest when the collaboration involves partners from more divergent scientific backgrounds. However, the difficulties in working productively together may then be greater. This is one of the costs of collaboration discussed below.

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

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

95. In addition, collaboration can enhance the potential visibility of the work. Using their network of contacts, one's collaborators can diffuse the findings, either formally (e.g. through pre-prints, seminars or conference presentations) or through informal discussions. Together, collaborators are likely to arrive at a more informed decision as to the best journal in which to publish the results (or the one most likely to accept the paper). Once published, the paper may be picked up in library searches by scanning for work produced by any of the collaborating authors, multiplying the chance that it will be located and used by others. On average, it is therefore likely to be cited more frequently and to have greater impact.

Costs

96. The result of all these benefits from collaboration is that research can, in principle, be carried out more effectively. However, collaboration also entails certain costs. These can take a variety of forms.

97. First, in financial terms, although collaboration may result in savings for research funding agencies, it nevertheless entails some additional costs. For inter-institutional, inter-sectoral and international collaborations, travel and subsistence costs are incurred as researchers move from one location to another. Equipment and material may also have to be transported [Schild, 1996]. Once moved, the instrumentation may need to be carefully set up again,

perhaps requiring the assistance of technicians from the original institution, incurring further costs.

98. Second, collaboration brings certain costs in terms of time. Indeed, for many researchers, these may be more important since time is now in certain respects a more valuable resource than funding.[10] Time may have to be spent in preparing a joint proposal or securing joint funds from two or more sponsors, and in jointly defining the research problems and planning the approach. Different parts of the research may be carried out at different locations, again introducing time costs. Time must be spent keeping all the collaborators fully informed of progress as well as deciding who is to do what next. Differences of opinion are almost inevitable and time will be needed to resolve these amicably. Writing up results jointly may also take more time where there are disagreements over the findings and their significance, or over who should be included among the co-authors and in what order they should be listed. Moreover, besides these direct time costs, there are also such indirect time costs as recovering from the effects of travel (e.g. jet lag), working in an unfamiliar environment, and developing new working and personal relationships with one's collaborators.

99. Third, collaboration brings certain costs in terms of increased administration. With more people and perhaps several institutions involved, greater effort is required to manage the research. If the collaboration is large or spans a considerable distance, it might need more formal management procedures which may create problems of bureaucracy. Even when this is not the case, when difficulties arise, they may nevertheless be blamed on bureaucracy and foster a sense of grievance against other collaborators which needs to be sorted out by the project management. A more formal management structure may also stifle the creativity of the researchers, offsetting the benefits of cross-fertilisation outlined above.

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

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[10] In interviews with 120 scientists and engineers working in British university departments, the availability of time to conduct research was ranked as the second most important factor determining the research performance of departments, after the calibre of the staff but some way ahead of funding [see Martin et al, 1990].

Summary

101. Although there have been many studies of collaboration, little has been published on what exactly is meant by the concept of collaboration or on the adequacy of attempting to measure it through co-authorship. Likewise, little consideration has been given to distinguishing different forms of collaboration or to analysing the additional costs it entails.

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

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

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

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

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

would appear to be to distinguish inter-institutional collaboration from inter-individual collaboration and to recognise that the former need not always involve the latter.

107. Finally, we identified the main types of benefit from collaboration and the associated costs. Some costs are financial, others more to do with the time requirements, the management of the collaboration, and with reconciling different cultures and value systems of researchers. When considering collaboration, researchers, funding agencies and policy-makers have often previously tended to see only the benefits and consequently to view collaboration as a good thing that should be universally encouraged. In future, we would argue, a more symmetrical approach should be adopted to assessing the potential costs and benefits. We must recognise that, in some circumstances, the costs may very well outweigh the benefits.

108. Unfortunately, at present there is no means of systematically appraising all the costs and benefits of collaboration, and therefore no way of establishing whether the benefits do actually outweigh the costs. Nevertheless, policies for research which assume that more collaboration should be encouraged may need to be re-examined in the light of these factors.

Chapter 3: Patterns of collaboration: bibliometrics and practice

Introduction

109. This chapter focuses on the measurement of collaboration in the UK science system through the use of bibliometric methods. It is arranged in two sections:

- an overview of the BESST[11] database that was used as the data source for the study, and
- the bibliometric analysis of co-authored publications produced by authors residing in UK higher educational institutions (HEI).

110. The overview of the database outlines the methodology used to create the database and unify UK institutional names. It describes how journals were assigned to four scientific disciplines: natural sciences, life sciences, materials & engineering sciences, and interdisciplinary sciences.

111. The bibliometric analysis was based on refereed papers published by at least one author residing in a UK institution between 1981 and 1994 and indexed in the *Science Citation Index*. There are two main subsections in this section:

- a UK institutional sector analysis, and
- a HEI analysis.

112. The sectoral analysis provides counts and percentage shares for all papers and co-authored papers produced by authors from various UK institutional sectors: education, medical, research council, industry, government, non-profit, and other. The HEI sector analysis is a detailed analysis of the amount and growth of various types of institutional collaboration over the 1981-1994 time period for 95 HEIs. It also provides an analysis of the effect of geographical proximity on collaboration.

An overview of the BESST database

113. This section discusses the creation of the BESST database. It discusses how collaborations were analysed, specifically the conventions used to define and count collaborative papers and the categories into which the counts are subdivided. There are two types of categories: institutions were classified into sectors, and papers were classified into

[11] Bibliometric exploration of scientific sectoral trends database

scientific fields based on the journals in which they were published. This section is not meant to be detailed or complete in itself[12].

114. The bibliometric methods used in this study adhered to *de facto* standards in the bibliometric community. The difference between this and previous work is that every UK address on the 500,780 papers we processed was assigned to one of approximately 6,000 unified institutional names. Thus, for every paper produced in the UK between 1981 and 1994 and indexed in the *Science Citation Index* (SCI), we know with which institutions its authors were affiliated. Put another way, we know which institutions produced peer reviewed, publicly available (i.e. published) knowledge during this period, and how many papers each produced. Each of the institutions was assigned to a sector.

115. It is important to note that research council laboratories and hospitals are counted separately from educational institutions. This significantly reduces the distorting influence that these institutional sectors have on the analysis of HEI publication and citation counts. In addition it provides a means for exploring the collaborative interaction between HEIs, research councils and medical institutions. For this and other reasons it would not be possible to perform the analysis presented in this report using ISI's UK University Indicators on diskette.

Construction of database

116. The data were derived from the Science Citation Index. Information on all 1981-1994 papers indexed in the SCI and listing a UK address was purchased from the Institute of Scientific Information. Three document types were extracted from these data - articles, notes and reviews as these tend to report original, substantial research results; conference proceedings, biographies, software views, etc. were not counted. Each paper was then processed to unify the institutional addresses and to assign each institution to a sector. In some cases a clean institutional name could not be identified, but the sector could be inferred from keywords in the 'dirty' name. In this case the institutional name "unknown" was used, and the appropriate sector was assigned.

117. In general, laboratories were assigned the clean name of the parent organisation. Thus, company laboratories were unified to the name of the parent company using 1992 *Who Owns Whom*. The Imperial Cancer Research Fund units were unified to the ICRF. In general, ministerial laboratories were unified to the name of the ministry. Several exceptions were made to this policy of unifying to the parent organisation: research council laboratories were

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[12] For a detailed description of the construction of the database see *The Changing Shape of British Science*, Appendix A, "Desktop Scientometrics II". For a detailed description of the field classification of journals, see *The Changing Shape of British Science*, Appendix B, "A Classification of Interdisciplinary Journals: A New Approach", STEEP Special Report #3, SPRU, 1997.

unified to the laboratory name; and the Universities of London and Wales were also split into their constituent institutions.

118. The method of assigning papers to institutions was based upon respect for the choices made by authors when they write their addresses on papers. Authors can sometimes be ambiguous, however. Two sectors were particularly afflicted with ambiguities - research councils and hospitals. With research councils we attempted to assign all papers containing the keywords MRC, AFRC, NERC, and SERC to a research council institution name, even if they were located on a university campus, and the university name was the first listed in the address. However, if an MRC paper did not contain the keyword UNIT or contained the keyword GRP (group), it was assigned to the institution whose name appeared in the first part of the address, usually a hospital or university. All AFRC publications that did not designate an AFRC institution but contained the keywords UNIT or GRP were assigned to the institution listed first - usually a university.

119. An author sometimes can have more than one institutional affiliation, for example when s/he has a joint appointment. In most cases, such authors seem to list two addresses on the paper, and these papers are counted as institutional collaborations in our analysis. Sometimes, however, authors named two institutions in one address line, for example "HOSP xxx & yyy", or "UNIV xxx, HOSP yyy", or "HOSP yyy, UNIV xxx". These were assigned to the institution whose name appeared first. This rule was devised to handle an inherently ambiguous situation, and was based on respect for the author's choice of which institution to list first. Such papers were found only among hospitals, and constituted a small percentage of their total.

Classification of institutions into sectors

120. Institutions were classified into the following sectors: education, medical, research council, industry, government, non-profit, and other. Table 1 displays notes on the definition of these sectors.

Table 1 - List of sectors and notes on their definition

Sector name	Notes on definitions
Education	'Old' universities, 'new' universities (polytechnics) and other educational institutions
Medical	Hospitals (including those with 'university' in their names), Special Health Authority and British Postgraduate Medical Federation research institutes, medical centres and surgeries
Research council	Intra-mural laboratories, excluding 'groups' at universities, but including 'units' at universities
Industry	Including all government laboratories privatised during the 1980s
Government	Departmental laboratories and local governments, excluding those privatised during the 1980s (see industry)
Non-profit	Laboratories as opposed to research funded by charities
Other	Comprising institutions from unknown sectors that participate in less than 1% of UK publications

Classification of Papers into Scientific Fields

121. In addition to being assigned a clean institutional name and an institutional sector, each paper was assigned a scientific field. However, whereas the institutional and sectoral assignment was performed on a paper-by-paper basis, this was not possible for scientific fields. In large-scale studies, bibliometricians assign journals to fields and then assign all papers published in a journal to its field. This method was used here. The publications have been classified into 17 scientific fields based on the journals in which they were published.[13] The fields are further classified into four disciplinary groups: life, natural, engineering & materials and inter-disciplinary.

122. This study will only use the four disciplinary groups classification. The classification scheme is derived from previous studies, and so is similar to others. However, it is unique in how it handles journals that are not easily classified into one field. In some schemes such journals are fractionated across two or more fields; in others journals are forced into one primary field. In this scheme, journals not classified into a single field are placed in categories

[13] The classification scheme is described in greater detail in *The Changing Shape of British Science,* Appendix B - "A Classification of Interdisciplinary Journals: A New Approach", STEEP Special Report #3, SPRU 1995.

containing other journals that spanned field boundaries. These inter-field and multidisciplinary categories are unique to this study.

123. The fields are grouped by discipline[14]:

- Life sciences containing the fields of medicine, biology, agriculture and inter-field life (containing journals that span two of the other life fields).
- Natural sciences containing the fields of chemistry, physics, earth and space sciences, mathematics and inter-field natural.
- Engineering & material sciences containing of engineering, materials, information & communication and inter-field applied.
- Multidisciplinary sciences consisting of three fields containing journals that span two disciplines (inter-disciplinary life-natural; inter-disciplinary life-engineering & materials; inter-disciplinary natural-engineering & materials) and a multidisciplinary field that contains environmental sciences (which we felt could not be classified into even two of the three disciplines) as well as *Nature*, *Science*, *Proceedings of the National Academy* and other high prestige journals that publish papers from a range of disciplines.

Counting method

124. Collaborative papers were "whole counted", meaning that the figures reported for a sector are based on counts of papers that list an address from at least one institution in that sector[15]. The figures should be interpreted as the number or percentage of papers in which a sector *participated*. This is a straightforward and intuitive method of interpreting publication figures in an age of increasing inter-sectoral collaboration. This method does not involve auxiliary, unproven assumptions about the amount of work represented by authorship on a paper and it is a method that facilitates analysis of this most important component of national scientific output by making it visible.

125. In tables produced by whole counting, all papers are counted once in the national total, but papers that involve collaboration between sectors are included in two or more sectoral counts. For example, a paper that lists a university address and a company address contributes one to the national total, one to the university total and one to the company total. The arithmetical consequence of this is that figures for two sectors or two institutions cannot be added together.

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[14] Figure 1 in Appendix B, *The Changing Shape of British Science,* STEEP Special Report #3, SPRU 1995 illustrates the relationship between the fields, disciplines and "inter-" categories.

[15] Alternatively, papers could be fractionated among participating institutions. In this case, if there were two addresses listed on a paper, each institution would be credited with half a paper.

International comparisons

126. Before we examine the collaborative patterns derived from the BESST database let us compare the publishing size and amount of domestic and international collaboration for UK researchers to researchers in other countries. Table 2 gives the annual number of refereed papers published in the sciences, social sciences and arts & humanities by the world's research community[16]. It also gives the percentage of papers produced by authors from selected countries and regions. UK researchers authored or co-authored 8.3% of the world's research papers in 1981 and this amount rose to 9.3% by 1998. The US share of publications dropped from 39.9% in 1981 to 34.8% and the European share of publications increased from 30.6% to 37.3%.

Table 2: Percentage of world's research papers[a] published by various countries

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
World[b]	*435,967*	*446,287*	*454,979*	*454,794*	*486,356*	*504,113*	*502,444*	*522,269*	*543,866*	*558,082*	*570,959*	*609,378*	*600,253*	*635,189*	*666,216*	*674,765*	*677,407*	*701,526*
Australia	2.4	2.3	2.3	2.4	2.3	2.4	2.3	2.3	2.3	2.3	2.4	2.4	2.5	2.6	2.7	2.8	2.8	2.9
Canada	4.5	4.5	4.6	4.8	4.8	4.9	5.0	5.0	5.0	5.0	5.1	5.2	5.2	5.1	5.0	4.9	4.7	4.5
France	5.3	5.3	5.2	5.1	5.1	5.4	5.4	5.4	5.5	5.5	5.6	5.8	5.9	6.1	6.2	6.2	6.4	6.5
Germany	7.7	7.7	7.6	7.4	7.6	7.5	7.6	7.4	7.6	7.6	7.7	7.7	7.7	7.9	8.0	8.2	8.6	8.9
Italy	2.2	2.3	2.4	2.5	2.5	2.5	2.6	2.8	2.9	3.0	3.2	3.4	3.4	3.6	3.7	3.9	4.0	4
Japan	6.2	6.4	6.5	6.7	7.0	7.1	7.2	7.7	7.7	7.9	8.1	8.6	8.7	8.8	8.8	9.1	9.1	9.5
Netherlands	1.7	1.7	1.8	1.9	1.9	1.9	2.0	2.0	2.2	2.2	2.2	2.4	2.5	2.5	2.5	2.5	2.6	2.6
UK	8.8	8.8	8.9	8.7	8.9	8.8	8.8	8.5	8.3	8.4	8.6	8.8	8.9	9.2	9.3	9.5	9.2	9.3
US	39.9	39.7	39.2	39.4	39.2	39.0	38.9	38.7	38.6	38.7	39.2	38.3	38.7	37.6	37.4	36.3	35.8	34.8
Europe	30.6	30.9	31.1	30.9	31.3	31.6	31.8	31.5	31.9	32.2	32.7	33.5	34.1	35.1	35.4	36.2	36.7	37.3
Asia Pacific	13.1	13.3	13.3	13.7	13.8	14.1	14.4	15.1	15.3	15.7	16.2	16.9	17.4	17.9	18.5	19.2	19.8	20.7
Latin America	1.3	1.4	1.4	1.4	1.4	1.5	1.6	1.5	1.6	1.7	1.8	1.9	2.0	2.0	2.2	2.4	2.6	2.8

source: ISI®'s National Science Indicators on Diskette (NSIOD) version 1.5 1981-1998

[a] science, social science and arts & humanities publications

[b] number of article, note, review, and proceeding papers

[16] These data were derived from ISI's 1981-1998 National Science Indicators on Diskette. The counts include refereed papers (articles, notes, reviews and proceedings) indexed in the SCI, SSCI and AHCI.

127. Table 3 gives the percentage of 1981 and 1995 science and engineering papers that involved two or more domestic and/or foreign institutions and the percentage that involved a foreign institution. CHI Research, Inc prepared the data in this table for the National Science Board's 1998 Science and Engineering Indicators. While the percentages are not directly comparable with the percentages derived for the UK from the BESST database they provide an approximate overview of the collaboration activity for various countries[17]. For example, in 1981 32% of UK papers involved two or more domestic and/or foreign institutions while 13% involved a foreign institution. By 1995 these percentages had risen to 55% and 29%, respectively. In general it has been established that smaller and non-English speaking countries tend to collaborate more internationally than larger and English speaking countries.

Table 3: Coauthored scientific articles[a] for selected countries:

	Multi-institution articles (% articles)		Internationally coauthored (% articles)	
Country	**1981**	**1995**	**1981**	**1995**
World	33	50	6	15
Australia	32	54	12	26
Canada	40	59	17	31
France	44	64	15	34
Germany	31	54	14	33
Japan	30	53	5	14
Netherlands	35	65	17	35
UK	32	55	13	29
United States	43	58	8	19

source: National Science Board's Science and Engineering Indicator 1998

[a] The publication counts excludes letters to the editor, news pieces, editorials, and other content whose central purpose is not the presentation or discussion of scientific data, theory, methods, apparatus, or experiments

[17] For example, CHI Research publication counts were prepared using a 1985 journal set while the BESST publication counts were prepared using ISI's 1994 journal set. In addition the BESST database only counts refereed publications (i.e. articles, notes and reviews) while CHI includes other publication types.

Sectoral analysis

128. Tables 4, 5 and 6 provide an overview of the total number of papers and institutionally co-authored papers that were indexed in the SCI between 1981 and 1994 by various institutional sectors in the UK science system. The values are also expressed as percentages. Table 6 focuses specifically on the education sector that includes HEIs. It gives the number of institutionally co-authored papers this sector had with the other UK sectors.

Table 4 - UK institutional sector SCI publication counts

Table 4 gives the annual number of refereed papers and the percentage of total UK papers that each institutional sector participated in.

Number of papers published

Sector	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Total
Education	18461	18926	19118	19065	20589	20145	20668	20580	21186	22135	23022	24912	25687	27686	302180
Medical	7576	7771	8006	8277	9290	9212	9344	9686	10242	10737	10688	11412	11417	11634	135292
Research Council	3569	3673	3936	3704	4041	4269	3959	3804	3857	4123	4054	4345	4398	4368	56100
Industry	2547	2582	2710	2606	2771	2682	2660	2936	3001	3160	3180	3412	3351	3380	40978
Government	1397	1260	1340	1236	1322	1355	1272	1255	1258	1348	1384	1457	1490	1523	18897
Non-profit	484	556	570	632	621	633	628	683	708	844	848	958	937	1018	10120
Unknown	108	140	136	142	135	104	92	110	114	91	162	179	156	217	1886
Total	31167	31746	32425	32142	34875	34355	34227	34581	35677	37165	37866	40503	41001	43050	500780

Percentage of UK publications

Sector	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Total
Education	59.2	59.6	59	59.3	59	58.6	60.4	59.5	59.4	59.6	60.8	61.5	62.6	64.3	60.3
Medical	24.3	24.5	24.7	25.8	26.6	26.8	27.3	28	28.7	28.9	28.2	28.2	27.8	27	27
Research Council	11.5	11.6	12.1	11.5	11.6	12.4	11.6	11	10.8	11.1	10.7	10.7	10.7	10.1	11.2
Industry	8.2	8.1	8.4	8.1	7.9	7.8	7.8	8.5	8.4	8.5	8.4	8.4	8.2	7.9	8.2
Government	4.5	4	4.1	3.8	3.8	3.9	3.7	3.6	3.5	3.6	3.7	3.6	3.6	3.5	3.8
Non-profit	1.6	1.8	1.8	2	1.8	1.8	1.8	2	2	2.3	2.2	2.4	2.3	2.4	2
Unknown	0.3	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.4	0.4	0.4	0.5	0.4
Total	109.5	110	110.5	111	111.2	111.8	112.8	112.9	113.1	114.2	114.5	115.2	115.7	115.7	112.9

Table 5 - UK institutional sector co-authored SCI publication counts

Table 5 gives the annual number of collaborative (institutionally co-authored) papers and the percentage of the total number of papers for each institutional sector.

Number of collaborative papers

Sector	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Total
Education	5728	6050	6244	6598	7263	7537	8111	8341	8834	9763	10562	12183	12626	13814	123654
Medical	3016	3101	3269	3466	3887	3924	4116	4296	4674	4997	5102	5749	5942	6108	61647
Research Council	1315	1418	1573	1622	1685	1887	1961	1964	2035	2303	2348	2646	2703	2851	28311
Industry	899	979	1080	1045	1156	1173	1340	1426	1522	1705	1809	1976	2063	2125	20298
Government	432	404	442	453	485	527	520	565	568	685	709	772	815	833	8210
Non-profit	204	252	274	329	328	329	358	391	412	506	512	647	606	718	5866
Unknown	40	45	46	66	60	43	48	57	61	46	102	103	98	141	956
Total	8659	9088	9537	10059	10970	11375	12058	12567	13417	14732	15674	17904	18418	19814	184272

Percentage of Sector Papers

Sector	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Total
Education	31	32	33	35	35	37	39	41	42	44	46	49	49	50	41
Medical	40	40	41	42	42	43	44	44	46	47	48	50	52	53	46
Research Council	37	39	40	44	42	44	50	52	53	56	58	61	61	65	50
Industry	35	38	40	40	42	44	50	49	51	54	57	58	62	63	50
Government	31	32	33	37	37	39	41	45	45	51	51	53	55	55	43
Non-profit	42	45	48	52	53	52	57	57	58	60	60	68	65	71	58
Unknown	37	32	34	46	44	41	52	52	54	51	63	58	63	65	51
Total	28	29	29	31	31	33	35	36	38	40	41	44	45	46	37

Table 6 - UK education SCI co-authored publications by sector

Table 6 gives the annual number of papers published by education sector institutions in collaboration with other institutional sectors. This is also expressed as a percentage of the total number of education sector papers. The number of domestic (any UK sector) and international institutional sector collaborations is also provided.

Number of education sector papers produced in collaboration with another sector

With Sector	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Total
Education	1072	1088	1154	1143	1402	1441	1568	1656	1698	1856	1982	2510	2555	2868	23993
Medical	1085	1115	1157	1230	1432	1502	1569	1639	1726	1846	1922	2199	2395	2493	23310
Research Council	533	593	650	682	746	805	918	840	885	1043	1043	1229	1299	1356	12622
Industry	453	548	594	547	623	638	772	832	897	1031	1122	1184	1241	1312	11794
Government	186	180	185	221	228	246	263	269	266	335	344	408	413	425	3969
Non-profit	52	70	73	98	124	90	121	114	108	154	147	211	209	265	1836
Domestic[1]	3889	4112	4402	4542	5179	5318	5813	5978	6295	6927	7425	8393	8780	9495	86548
International	2226	2402	2563	2692	3026	3144	3455	3522	3718	4191	4350	4930	5236	5514	50969
Total	5728	6050	6244	6598	7263	7537	8111	8341	8834	9763	10562	12183	12626	13814	123654

1. Domestic counts include intra-institutional (e.g. inter-departmental) collaboration counts

Percentage of education sector publications produced in collaboration with another sector

With Sector	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Total
Education	5.8	5.7	6	6	6.8	7.2	7.6	8	8	8.4	8.6	10.1	9.9	10.4	7.9
Medical	5.9	5.9	6.1	6.5	7	7.5	7.6	8	8.1	8.3	8.3	8.8	9.3	9	7.7
Research Council	2.9	3.1	3.4	3.6	3.6	4	4.4	4.1	4.2	4.7	4.5	4.9	5.1	4.9	4.2
Industry	2.5	2.9	3.1	2.9	3	3.2	3.7	4	4.2	4.7	4.9	4.8	4.8	4.7	3.9
Government	1	1	1	1.2	1.1	1.2	1.3	1.3	1.3	1.5	1.5	1.6	1.6	1.5	1.3
Non-profit	0.3	0.4	0.4	0.5	0.6	0.4	0.6	0.6	0.5	0.7	0.6	0.8	0.8	1	0.6
Domestic[1]	21.1	21.7	23	23.8	25.2	26.4	28.1	29	29.7	31.3	32.3	33.7	34.2	34.3	28.6
International	12.1	12.7	13.4	14.1	14.7	15.6	16.7	17.1	17.5	18.9	18.9	19.8	20.4	19.9	16.9
Total	31	32	32.7	34.6	35.3	37.4	39.2	40.5	41.7	44.1	45.9	48.9	49.2	49.9	40.9

1. Domestic counts include intra-institutional (e.g. inter-departmental) collaboration counts

HEI analysis

Publication and collaboration counts for all fields of science

129. Table 7 (see Appendix 2) provides details of the total number of papers and collaboration of various types for all HEI institutions. It needs to be read in conjunction with Table 8 below which gives a list of the column headings and definitions used in used in Table 7.

Table 8- Definitions of collaboration types

Collaboration type	Definition
papers	Number of papers published by a HEI
multiple author	Number of papers involving two or more authors published by a HEI
all types	Number of papers involving a HEI and another institution (domestic or international)
domestic	Number of papers involving a HEI and another UK institution
international	Number of papers involving a HEI and at least one non-UK institution
intra-institution	Number of papers involving two departments in the same HEI
intra-sectoral	Number of papers involving two or more HEIs
inter-sectoral	Number of papers involving a HEI and an institution in another institutional sector
industry	Number of papers involving a HEI and at least one industrial institution

Methodology for analysing co-authored publications

130. Only collaboration for HEIs that published *at least* one paper *each* year during the fourteen-year time interval were examined in this analysis. Of the 116 HEIs in the BESST database only 96 of them met this criterion in the analysis of collaboration activity across all scientific disciplines. The amount of collaboration and the time trends for the various collaboration types were analysed using a three step method. This method is described in Appendix 1. Readers unfamiliar with the concept of a power law and non-linear functions are recommended to read Appendix 1 before proceeding with this section of the research.

Results of analysis by collaboration type

131. A graphical display of the analysis of collaboration for various scientific disciplines is given in Figures 1-40 and a tabular summary of the findings is provided in Table 9 (Figures 1-8 are reproduced below, but for convenience Figures 9-40 have been placed in Appendix 2 at the

end of the report). In Table 9, columns 3, 4 and 5 give the regression type, the slope of the regression and the goodness of fit (R^2 values). The regression analysis was done using the total number of papers containing a collaboration of a given type and the total number of papers published in the 1981-1994 period. Columns 6, 7 and 8 give the regression type, the maximum and minimum slope of the regression in the time period and the goodness of fit of the time regression for the annual slopes calculated using the regression type given in column 3. The results of the analysis are described in the following two sections.

Figures 1-8 - All disciplines: analysis of collaboration types

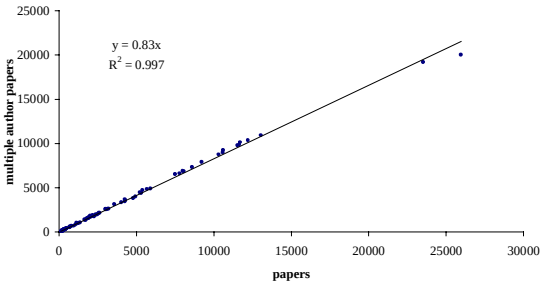

Figure 1a

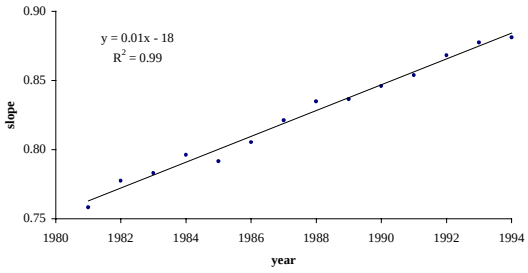

Figure 1b

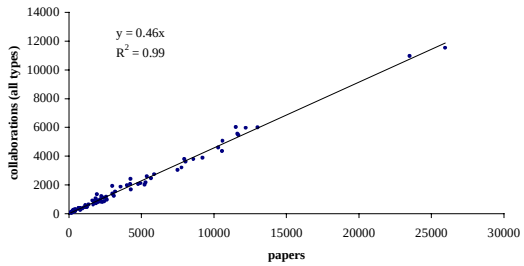

Figure 2a

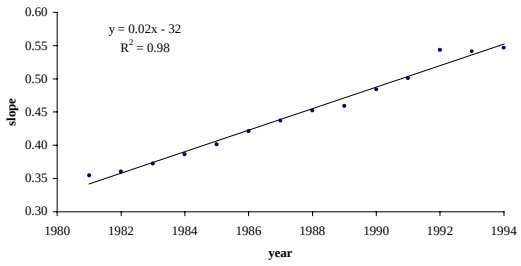

Figure 2b

Figures 1 - 8 (continued)- All disciplines: analysis of collaboration types

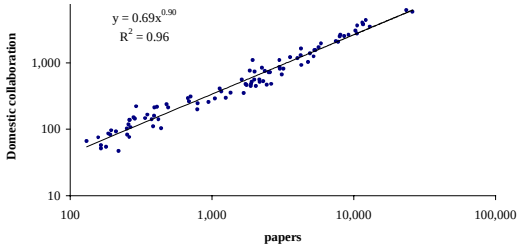

Figure 3a

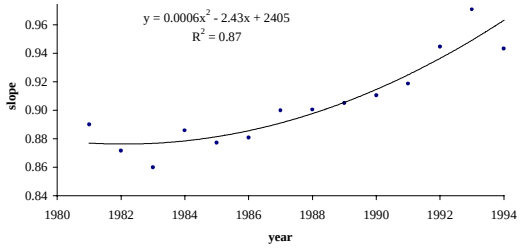

Figure 3b

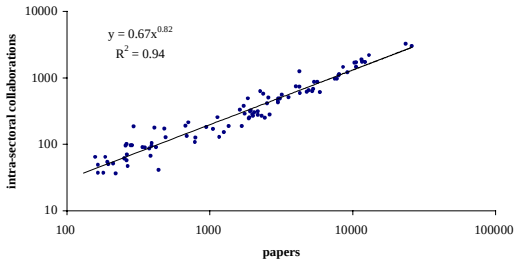

Figure 4a

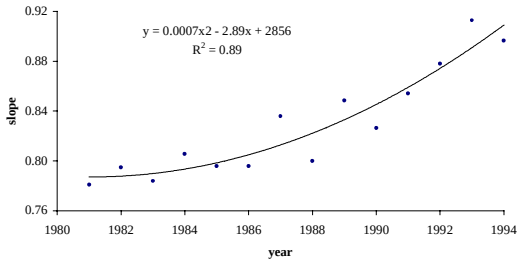

Figure 4a

Figures 1 - 8 (continued)- All disciplines: analysis of collaboration types

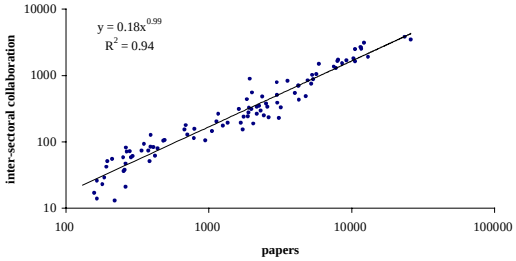

Figure 5a

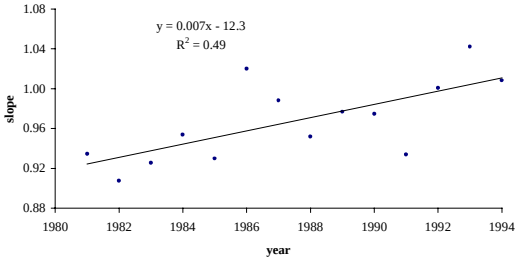

Figure 5b

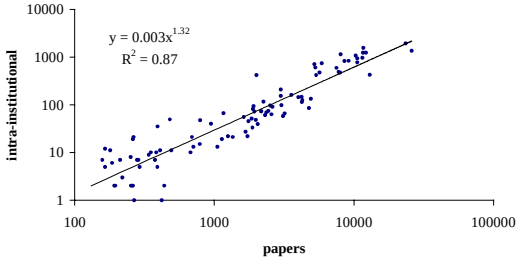

Figure 6a

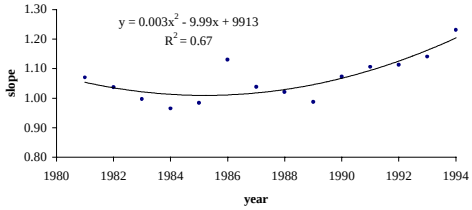

Figure 6b

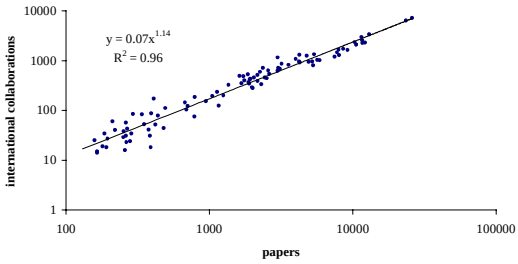

Figure 7a

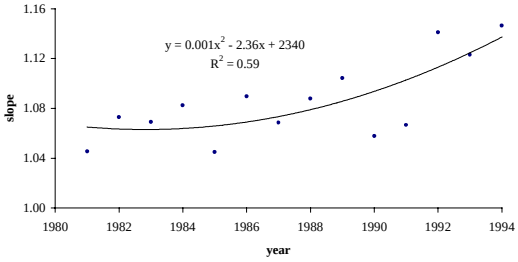

Figure 7b

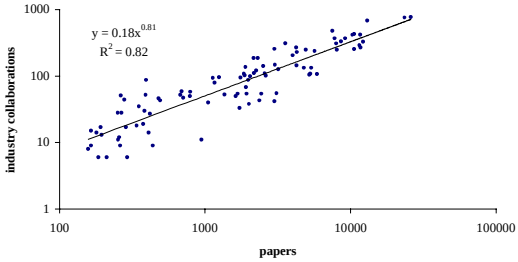

Figure 8a

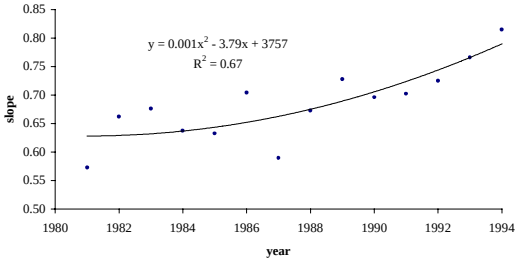

Figure 8b

Table 9 – Summary of collaboration type analysis for various disciplines

Collaboration type	Field	overall regression type	slope	R^2	time regression type	min. & max. slope	R^2
Multiple author	All fields	linear	0.83	1.00	linear	0.76-0.88	0.98
	Life	linear	0.86	1.00	linear	0.79-0.91	0.95
	Natural	linear	0.82	1.00	linear	0.75-0.87	0.97
	Engineering & Materials	linear	0.81	1.00	linear	0.73-0.89	0.93
	Multidisciplinary	linear	0.76	0.99	linear	0.70-0.83	0.92
All institutional type	All fields	linear	0.46	0.99	linear	0.35-0.55	0.98
	Life	linear	0.46	0.99	linear	0.35-0.55	0.99
	Natural	linear	0.48	0.99	linear	0.37-0.58	0.95
	Engineering & Materials	linear	0.33	0.96	linear	0.25-0.40	0.87
	Multidisciplinary	linear	0.44	0.99	linear	0.35-0.53	0.87
International	All fields	power law	1.14	0.96	polynomial ↑	1.04-1.15	0.59
	Life	power law	1.10	0.95	polynomial ↑	0.87-1.01	0.79
	Natural	power law	1.16	0.94	polynomial ↑	0.96-1.15	0.38
	Engineering & Materials	power law	1.14	0.90	polynomial ↑	0.68-1.00	0.32
	Multidisciplinary	power law	1.03	0.92	polynomial ↑	0.73-1.02	0.37
Domestic	All fields	power law	0.90	0.96	polynomial ↑	0.86-0.97	0.87
	Life	power law	0.91	0.98	polynomial ↑	0.81-0.96	0.64
	Natural	power law	0.89	0.94	polynomial ↑	0.79-0.99	0.68
	Engineering & Materials	power law	0.78	0.90	polynomial ↑	0.54-0.88	0.62
	Multidisciplinary	power law	0.91	0.90	polynomial ↓	0.70-0.94	0.25
Inter-sectoral	All fields	power law	0.99	0.94	linear	0.91-1.04	0.48
	Life	power law	0.98	0.95	linear	0.85-1.01	0.05
	Natural	power law	0.99	0.94	linear	0.68-0.91	0.79
	Engineering & Materials	power law	0.89	0.89	linear	0.36-0.72	0.45
	Multidisciplinary	power law	0.99	0.82	linear	0.61-0.84	0.34
Intra-sectoral	All fields	power law	0.82	0.94	polynomial ↑	0.78-0.91	0.89
	Life	power law	0.78	0.94	linear	0.61-0.82	0.77
	Natural	power law	0.88	0.92	linear	0.72-0.95	0.78
	Engineering & Materials	power law	0.76	0.67	linear	0.27-0.75	0.80
	Multidisciplinary	power law	0.88	0.88	linear	0.52-0.93	0.66
Intra-institutional	All fields	power law	1.32	0.87	polynomial ↑	0.97-1.23	0.67
	Life	power law	1.44	0.92	linear	1.06-1.41	0.11
	Natural	power law	1.02	0.78	polynomial ↑	0.38-0.84	0.56
	Engineering & Materials	power law	1.01	0.68	polynomial ↑	0.13-0.52	0.42
	Multidisciplinary	power law	1.27	0.83	polynomial ↑	0.54-1.04	0.39
Industry	All fields	power law	0.81	0.82	polynomial ↑	0.57-0.81	0.69
	Life	power law	0.92	0.78	linear	0.36-0.64	0.82
	Natural	power law	0.91	0.75	polynomial ↑	0.44-0.74	0.88
	Engineering & Materials	power law	1.01	0.81	linear	0.32-0.65	0.51
	Multidisciplinary	power law	1.04	0.68	polynomial ↓	0.27-0.79	0.32

Note: ↑polynomial increases with time;↓ polynomial decreases with time

All scientific disciplines

132. In 1994 88% of all HEI papers involved two or more authors and 55% involved two or more institutions. These percentages had increased significantly from 76% and 35%, respectively, in 1981. Collaboration is the rule not the exception.

133. In 1994 educational institutions collaborated with other domestic institutions on 34% of their papers and with international partners on 20% of their papers (see Table 6).

134. At the beginning of the fourteen year time period on average larger HEIs had proportionally fewer domestic, intra-sectoral, inter-sectoral and industry collaborations than smaller ones (see Figure 1-8). However, over the time period larger HEIs increased their participation in these types of institutional collaboration, particularly with industry. On the other hand larger HEIs had more international and intra-institutional collaborations than smaller ones and this trend increased over the time period.

135. Multiple author (Figure 1b) and 'all types' (i.e. institutional collaboration of all types - Figure 2b) increased linearly with time. One might expect that if the nature of the overall collaborative activity had been significantly influenced by policy factors collaborative activity should have increased and/or decreased with time under the influence of various policies.

136. Although the time interval for this analysis is relatively short, the evidence suggests that since the growth in overall collaboration was relatively constant over time the primary drivers for the increased collaboration may be intrinsic to the nature and culture of scientific research rather than due to the effect of policy. This finding is consistent an earlier report that domestic and international institutional collaboration in the US and UK has been growing at a steady and constant rate since the late 1960s[18].

137. On average, the amount of most types of institutional collaboration exhibited a power law and non-linear relationship with the publishing size (i.e. number of refereed publications indexed in the SCI) of the institutions (Figure 3-8). A greater proportion of publications from smaller (also defined in terms of publishing size) institutions had domestic, intra-sectoral, inter-sectoral and industrial collaborations than publications from larger institutions. On the other hand a greater proportion of the papers from larger institutions involved international or intra-institutional collaborations than the papers from smaller institutions.

138. These findings are consistent with the notion that researchers in smaller institutions have a smaller internal resource pool to draw upon. They need to look outside their institutional boundaries for the skills and equipment in order to achieve or maintain high quality research competence. The higher level of international collaboration for larger institutions is consistent

with the finding that on average recognition (citations) increases in a power law relationship with publishing size[19,20,21]. In other words larger institutions have a higher international profile than smaller institutions and this probably attracts more foreign collaborators

139. In general, the change in the exponent of the power law relationship for these collaboration types increased slowly or not at all in the early 1980s and then increased more rapidly thereafter. Recall that most of the papers published in this time period were probably supported from research grants and programs that were influenced by economic and political events that occurred between 1979 and 1991. It is possible the growth pattern for UK collaboration may be unique to the UK science system. However, without access to similar bibliometric data for other countries there is no way to confirm this hypothesis.

140. If the pattern is unique to the UK system, then a primary driving force for the change may have been the significant reduction of funding to HEIs that started in late 1970s and continued through the 1980s. This could have lead to a reduction in the pool of skilled resources internal to the institutions and in the nation as whole. No doubt an increased emphasis on the need for collaborative partnerships for UK and EU research grants was a contributing factor. However, what we might be seeing in these data is the signature of how the intrinsic nature and culture of scientific research responded to both the changing economic climate and the increasing complexity in the nature of scientific research. There may be no way to determine how much of the change was influenced by policy and how much was influence by the changing and complex nature of the research process.

Comparison across scientific disciplines

141. Through out the time period the life sciences exhibited the highest percentage and growth rate of multiple author papers. The percentage grew from 76% in 1981 to 91% in 1994 (Table 8). The amount and growth rate in the natural sciences and engineering & material sciences was nearly but not quite as high. In contrast, the multidisciplinary sciences had the lowest percentage and growth rate.

142. On the other hand, the natural science papers exhibited the highest percentage and growth rate of multiple institution papers. The amount grew from 37% to 58% over the time period. The percentage and growth rate in the life and multidisciplinary science was nearly the same as the natural sciences. However, the engineering & material sciences exhibited a

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[18] Katz, JS and Hicks D, (1995). "Questions of collaboration", *Nature,* vol. 375, p.99

[19] Katz ,J.S. (1999) “The self-similar science system”, *Research Policy*, 28, pp. 501-517, 1999

[20] Katz, J.S. (1999) "Bibliometric indicators and the social sciences" prepared for ESRC, available at http://www.sussex.ac.uk/spru/jskatz

[21] Katz, J.S. (1999) "A question of impact: is citations per paper a reliable measure of impact?", work in progress, , available at http://www.sussex.ac.uk/spru/jskatz

significantly lower percentage and growth rate in institutional collaborations over the time period.

143. By analysing the total number of papers published over the whole time period in each discipline we see that on average the amount of international and intra-institutional collaboration increased in a power law relationship with increasing institutional size. As described before, larger institutions had proportionately more collaborations of this type than smaller ones. This effect was most pronounced for international collaboration in the natural, life and engineering & material sciences but not as pronounced for multidisciplinary science papers.

144. In comparison, the non-linear size effect for intra-institutional collaboration was most prominent in the life and multidisciplinary sciences but not nearly as significant in the natural sciences and engineering & material sciences. For both collaboration types analysing small numbers of publications made it difficult to assess accurately how the trends changed over time. However, the general impression is that the power law exponent increased with time and the non-linear effect became more predominant between 1981 and 1994.

145. Again using the total number of papers published over the whole time period we see that on average in all scientific disciplines the amount of domestic, intra-sectoral and inter-sectoral collaboration increased in a power law relationship with publishing size of the institution. The non-linear effect was greater in the engineering & material sciences. Again the time trends are difficult to establish precisely. However, it appears that generally for these collaboration types the non-linearity between number of collaborations and publishing size diminished somewhat over the time interval.

146. Industry collaboration showed a mixture of the two non-linear effects. Using the total number of papers over the time interval it appears that the proportion of papers that involved an industry collaboration increased with the publishing size of the institution in engineering & material sciences and multidisciplinary sciences. The proportion decreased with publishing size in life and natural science papers. This effect seemed to have become a little less non-linear with time in the life and natural sciences. However, it is difficult to assess how it changed in multidisciplinary and engineering & material sciences due to the problem of analysing small numbers of papers.

Collaboration and geographical proximity

Methodology

147. In order to determine the effect of geographical proximity on collaboration the longitude and latitude was determined for each institutional location (city, town or village) listed in the BESST database. Since there were numerous errors in the location information such as spelling errors and city names mixed with postcodes, each location was unified to a standard name and stored in a unified location file that had the form

ISI city name:unified name:longitude:latitude

148. The following is an example extracted from the unified location file that contains approximately 2220 entries

ABIGDON:ABINGDON:-1.28:51.68
ABINGDON:ABINGDON:-1.28:51.68
ABINGDON OX:ABINGDON:-1.28:51.68
ABINGDON THAMES:ABINGDON:-1.28:51.68
ABINGTON:ABINGDON:-1.28:51.68
LODON:LONDON:-0.17:51.50
LONDN:LONDON:-0.17:51.50
LONDON:LONDON:-0.17:51.50

149. The great circle distance (i.e. the shortest distance between two points on a sphere) was calculated for each pair of collaborating institutions listed on each paper. The distance between pairs of institutions was determined for more than 95% of the co-authored papers. Only collaborations between different institutions were used in the analysis; in other words collaborations within the same institution were not included. For simplicity collaborations were counted in distance increments of 20 km. In other words the cumulative percentage of the collaborations that occurred with an institutional separation of 0-20 km, 20-40 km, 40-60 km, etc was calculated.

All scientific disciplines

150. Figure 41 is a graphical representation of the results of the geographical proximity analysis across all scientific disciplines. Figure 41a is a plot of (1) the cumulative percentage of research papers involving an institutional collaboration and (2) the cumulative percentage of pairs of institutional collaborations versus geographical proximity measured in kilometres. Figure 41b is the same plot but institutions located in London and Greater London area have not been included.

Figure 41 - All disciplines: collaboration and geographical proximity

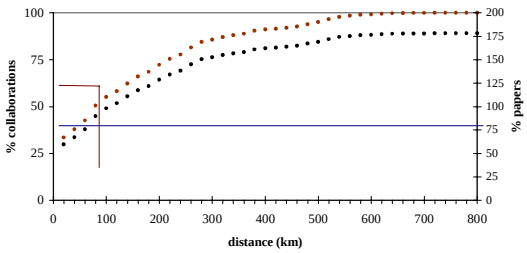

Figure 41a

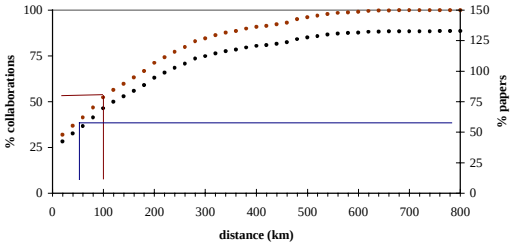

Figure 41b

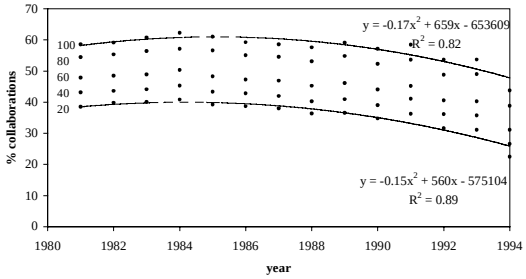

Figure 41c
including London and Greater London insitutions

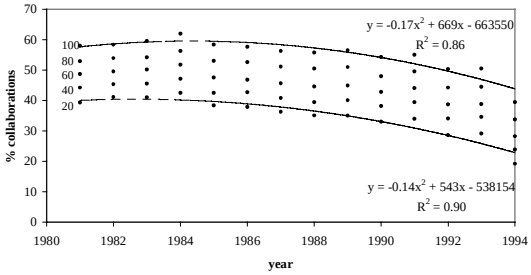

Figure 41d
excluding London & Greater London insitutions

151. From Figure 41a it can be seen that 50% of all collaborative papers involved at least one pair of institutions that were less than 20 km away from each other. 50% of all pairs of collaborations occurred between institutions that were separated by less than 60-80 km. This distance will be called the **median collaboration radius** (mcr). Figure 41b shows the effect of removing London-based institutions from the analysis. We can see that 50% of all collaborative papers involved at least one pair of institutions that were less than 20-40 km away from each other. 50% of all pairs of collaborations occurred between institutions that were separated by less than 80-100 km.

152. Figures 41c and 41d explore how the cumulative percentage of collaboration involving pairs of institutions within various distances (0-20 km, 20-40 km, 40-60 km, 60-80 km, 80-100 km) changed over the time interval. For simplicity only the upper value in the range is used in the label on the graph i.e. 20 means 0-20 km. It can be seen that the average distance between collaborating pairs of institutions increased with time. For example, the percentage of pairs of collaborations that occurred between 0-20 km decreased from 39% in 1981 to 22% in 1994. However, if the London-based institutions are removed the decrease is slightly larger and changed from 39% to 19%.

153. In summary, we see that the number of collaborations decreases with distance. Collaboration tends to occur more frequently between institutions that are geographically close to each other. Also we see that the distance between collaborating institutions tended to increase between 1981 and 1994.

Comparison across scientific disciplines

154. Figure 42-45 (see Appendix 2) is a graphical representation of the results of the geographical proximity analysis for the life sciences, natural sciences, engineering & material sciences and multidisciplinary sciences. As before Figures 42a-45a are plots of (1) the cumulative percentage of research papers involving an institutional collaboration and (2) the cumulative percentage of pairs of institutional collaborations versus the geographical proximity measured in kilometres. Figure 42b-45b is the same plot but institutions located in London and Greater London are excluded.

155. Table 10 below summarises the findings from an analysis of the effect of geographical proximity and collaboration in the various scientific disciplines. Columns 2 and 6 give the mcr in kilometres calculated using papers published over the whole time period. Columns 3, 4, 7 and 8 give three-year average percentage of pairs of institutions that collaborated within the mcr (given in columns 2 and 6) at the beginning of the period and the end of the period. In other words, the percentage for the beginning period is determined by taking the average of the 1981 to 1983 percentages. The end of the period percentage is determined by taking the

average of the 1992 to 1994 percentages. Columns 5 and 9 give the change between the beginning and the end of period percentages.

Table 10 - Summary of collaboration activity and geographical proximity by discipline

	including London*				excluding London*			
Discipline	mcr (km)	1981-83 (ave. %)	1992-94 (ave. %)	□	mcr (km)	1981-83 (ave. %)	1992-94 (ave. %)	□
Life	60-80	56	42	-16	60-80	60	42	-18
Natural	100-120	52	49	-3	120-140	50	49	-1
Engineering & material	80-100	53	53	0	80-100	53	50	-3
Multidisciplinary	80-100	56	52	-3	100-120	57	52	-5

Notes:

*including or excluding London-based institutions

□ = 1992-94 average percentage - 1981-83 average percentage

mcr = median collaboration radius

156. The greater London institutions seemed to have had a marginal effect on the mcr and at most decrease it by 20 km. Over the 14-year time period of all the disciplines the life sciences showed the largest change in its geographical collaboration pattern. This is illustrated by the fact that between 1981-83 and 1992-94 the average percentage of collaborations that occurred within the mcr decreased from 56% to 42% across all institutions and from 60% to 42% for non-London based institutions.

157. Natural sciences collaboration between institutions outside of London had the largest mcr and they showed a relatively small change in this pattern over the time period. The mcr value may reflect the fact that researchers in the natural sciences need to collaborate with institutions that have sophisticated and expensive instrumentation and laboratory facilities. The stability of this pattern might reflect the fact that many of the well-equipped facilities have been established for a considerable period of time.

158. Engineering & material sciences and multidisciplinary sciences showed an intermediate mcr. The scattering of the data points about the time regression lines (see Figures 44c, 44d and 45c, 45d) is too large to come to a confident conclusion about how the patterns changed with time in these two disciplines. However, it appears that the pattern in engineering & material sciences was fairly stable over time while the multidisciplinary sciences might have shown a slight decline.

Summary

159. Across all scientific disciplines research collaboration is the rule not the exception. By 1994 88% of all UK HEI papers involved two or more authors and 55% involved two or more institutions. They collaborated with other domestic institutions on 34% of their papers and with international partners on 20% of their papers.

160. Most types of institutional collaboration exhibited a power law relationship between the amount of collaboration and the publishing size of the institutions. On average, a greater proportion of publications from smaller institutions than from larger institutions had domestic, intra-sectoral, inter-sectoral and industrial collaborations. On average a greater proportion of the papers from larger institutions than from smaller institutions involved international or intra-institutional collaborations.

161. There is evidence to show that the publishing size is linearly related to funding[22] suggesting that the amount of funding an institution receives affects the nature of its collaboration profile. Also, the power law relationship between recognition (citations) and papers can influence an institution's international research impact and visibility that in turn influences the amount of international collaboration it has. Finally, institutional collaboration is related to geographical proximity and it appears that over time the average distance between collaborating institutions has been increasing.

[22] Hart P.W. and Sommerfeld J.T., (1998) "Relationship between growth in gross domestic product (GDP) and growth in the chemical engineering literature in five different countries", *Scientometrics*, 41, 3, 299-311.

Chapter 4: Institutional Context: Models of Collaboration

Introduction

162. In the previous two chapters the pervasiveness of collaboration in the research system was emphasised. The argument, briefly, was that collaboration has been extensively studied but remains an elusive concept both to define and to measure. Despite evidence of a shift in funding towards the large, research intensive HEIs (see report on selectivity and excellence), the production of knowledge or 'research' is mediated through various forms of collaboration between individuals, groups, departments, institutions, sectors and countries. Bibliometric measures of research give some indication of the pattern of collaborative activity within and between sectors through the analysis of multi-author or multi-address papers. This evidence indicates that the size and geographical location of institutions shape their collaboration profiles. However, we stressed that such measures need to be treated with caution since, for a variety of reasons, co-authorship can only be considered a partial indicator of collaboration.

163. The focus in this chapter is switched from the broader trends in collaborative activity indicated by bibliometric evidence, to the institutional context of collaboration. This context demands attention not just as a basic unit of analysis (through institutional address in bibliometrics), but because it is a critical site in the sociology of research. Institutions are integral to understanding the broader social organisation of research and the relationship between science, technology, art and society. They are also key to divisions of labour, management structures and as a workplace in the academic research process. The role of the institution in facilitating collaboration is highlighted by this sociological perspective and relates to broader questions about the ability of institutions to manage the research process and to change the structure, priorities and even content of research (Helvy 1992: 358-60).

164. Understanding the operating paradigms of collaborative research at institutional level is an important issue, with the potential to yield insights into the delicate relationships between the institutional managment of research, institutional diversity and autonomy. With a research system becoming more permeable, 'the task facing policy makers and institutional leaders is how to reconcile the institution's increasingly open intellectual engagement with its enveloping environment(s) and its need to retain normative focus and managerial coherence' (Bargh *et al* forthcoming 2000). The questions of interest to the Funding Council - whether and how collaboration should be supported, how to fund, assess and quality assure research increasingly done in collaboration with other institutions (or countries) - flow from these initial understandings of the collaboration-institution bases to the research process. This chapter, then, seeks to broaden the perspective on the dynamics of collaboration through an analysis of the relationship between institutional and researcher collaborative practices. It seeks to identify the characteristics of different types of collaboration, the collaborative processes

involved and the ways benefit is derived in the different institutional environments of higher education.

165. To tackle these questions and to make sense of the complexity of collaboration within institutional contexts, the research identifies three broad types or models of collaborative research activity. The models are constructed from detailed empirical evidence collected from a series of intensive institutional case study visits conducted during the winter 1999-2000 (further details of the case study methodology are given in Appendix 3). Although an ideal-typical presentation of the range and purposes of collaboration, these models are used to locate the detailed institutional context-dependent findings of the research to broader features in the research landscape. The components of the models serve to highlight the key features of collaborative activity and relate them to the role of collaboration in supporting institutional mission.

166. The chapter is divided into four main sections. The first sets out the policy signals-to-the-system that have propelled collaboration onto institutional research agendas. Although we have already identified from the literature (see Chapter 2) at least eleven different factors which may account for the increase in collaborative research, the purpose in this section is to relate such factors more specifically to the current policy environment of research and its relationship to achievement of institutional mission. The second section develops the institutional perspective by examining the spectrum of activity embraced by research collaboration. This is followed in the third section by an exposition of the different models of collaborative research in terms of their characteristics, benefits and success factors. The final section summarises the main points of the chapter.

Signals-to-the-system: the impact of the changing research and policy landscape

167. Since collaborative research activity is both cause and effect of change in the structure, shape and purpose of research institutions, it needs to be considered within a broader policy context. In recent years the shift towards collaborative ways of thinking and organising in higher education has received forceful backing in the alternative visions of a learning society (and how to achieve it) set out in the Kennedy, Fryer and Dearing reports. Although the present study focuses on collaborative approaches to research, it can scarcely ignore these wider signals-to-the system.

168. The message, articulated in recent Green and White Papers on Lifelong Learning, is that the nation has a choice - either it faces a reduction in economic activity, dampening down economic growth to match the skills of the workforce, or it can expand skills to match decent economic growth whilst maintaining stability in the economy. This message takes its cue from

competitiveness through skill (rather than price) as a key strategy of government economic policy. From this perspective lifelong learning is presented as a challenge to achieve an appropriate match between skills and economic growth (although the balance between the demand and supply elements of skills production is a matter of some debate between economists and policy makers).

The Dearing and Garrick Reports

169. The role of collaborative partnership in the supply side of both skilled people and new knowledge (research) is closely connected to the traditional teaching and research roles of higher education and the interface with business and industry[23]. The Dearing Report was specifically concerned with 'people' issues in its references to collaboration and partnership. It acknowledged that the limits of public funding of research implied selective allocation, but was concerned that concentration of research effort (and facilities) should not imply exclusivity. The Report argued that research groups needed to develop 'a stronger sense of co-operation and partnership' if the benefits of plant, equipment and expertise were to be maximised. It also stated its belief that those with the privilege of working in a unit selectively funded for research had an obligation to allow individuals based in other institutions to benefit not just from access to equipment but from wider interaction with and contribution to the life of the research community (Dearing 1997: 185).

170. Implicit in this conclusion is a concern for the relationship between research funding policies and opportunities for the development of skilled people, the latter being one of the main outputs of the research base. But Dearing also recognised that collaboration should be seen as a corollary of greater institutional diversity in the sector. To accommodate diversity, institutions would serve their mission better by seeking to form strategic alliances in order to meet both research and wider educational needs. Such needs, including greater collaboration (with industry in particular) in research and the use of large scale equipment, would be better met through the extended use of communications and information technology, credit accumulation and transfer arrangements within the context of the framework of higher education qualifications, further and higher education partnerships for widening participation, and the joint purchasing and sharing of resources.

171. Having cited evidence from both the OECD, CVCP and individual institutions in favour of the need for and importance of collaboration, Dearing noted:

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[23] Although focused on the further education sector, the Kennedy Report, *Learning Works*, provided a strong pointer to the progression of people through the hierarchies of learning with its recommendation for the establishment of a national system of permanent local strategic partnerships to widen participation. To this local focus, the Fryer Report *Learning for the Twenty-First Century* added the region as the key level for the co-ordination of strategic planning led by local authorities, working in partnership with other local stakeholders, including the new Regional Development Agencies. In declaring the need to put 'people before structures' Fryer also looked to effective partnership as a solution to the need for co-ordinating initiatives, pooling resources, auditing provision and

> Collaboration matters. It may, in some instances, make the difference between institutional success and failure. But it needs to apply throughout institutions, from individuals to management teams. There needs to be more encouragement within institutions, for example to support faculty teams to develop their ideas and evaluate the costs and potential of collaboration, and incentives to staff. At institutional level too, governing bodies should include a review of collaboration in the review of performance (Dearing 1997: 261).

172. Dearing's findings on the scope and importance of collaboration were echoed in the Garrick report for Scotland which argued that, encouraged by the size of its higher education sector, Scotland was ahead of the rest of the UK in identifying the mutual benefits and advantages of collaboration. Both reports, therefore, identified the need for a climate that would facilitate further collaboration. Dearing made two specific recommendations about future arrangements for dealing with collaboration.

173. The first (Recommendation 68) was that the Funding and Research Councils ensure that funding arrangements do not discourage collaboration between institutions and where appropriate encourage collaboration.

174. The second (Recommendation 75) suggested that the Funding Councils explore the possibility of setting aside some of the total grant *inter alia* to fund collaborative projects likely to facilitate regional access to teaching and research facilities not otherwise provided on a viable basis.

175. The Dearing findings and recommendations reflect a broader consensus and discourse of partnership and collaboration shared by politicians, policy makers and education professionals alike. Participation in partnership by HEIs needs to be viewed against both this specific educational backcloth as well as other developments in the policy and research environment. Five separate but related issues can be identified.

The knowledge economy and the economic contribution of research

176. The first is the growth of the knowledge economy and attempts to strengthen the economic contribution of research. This goal is informed by an (often uncritical) acceptance of the view that whatever the spectacular individual successes of 'fundamental' or 'blue skies' research in UK universities, there has been a continuous failure to translate the benefits of excellence in research into 'useful' economic activity, that is, jobs.

177. This view is frequently portrayed as a failure of 'transfer' or 'innovation' and is associated with a more general perception of the failure of science to engage with the knowledge

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establishing agreed targets and plans for action. In both reports, partnerships are promoted as one of the main guarantors of the sustainability of lifelong learning.

economy, regionally or nationally. Such perceptions, of course, are historically rooted, but arguably have become more policy 'critical' as notions of global competitiveness based essentially on the capacity of the 'knowledge economy' to innovate and reach the market have entered the discourse of political and economic decision making.

178. Whatever the accuracy of these perceptions, the consequence has been explicit policy attempts to shift the emphasis of key parts of the science system - research funding, research councils and universities - towards more applied research conducted in collaboration with a wider range of other knowledge creators and users. The approach is exemplified in the UK Foresight programme with its explicit aims of pooling knowledge and promoting collaboration 'not just between industry scientists and government, but across all sectoral and disciplinary boundaries' (Foresight Link, Summer 1999). Research and the science system, therefore, are now intimately connected with capacity for innovation and engagement with the global economy. Stimulating collaboration is seen as a tool for transforming the research and innovation enterprise.

New knowledge production

179. A further stimulus to working collaboratively is derived from new contexts of knowledge production. Now well documented in the concept of Mode 1/Mode 2 research (Gibbons et al 1994a), the emergence of not just inter- or multi-disciplinary, but transdisciplinary, forms of research is a growing requirement as research questions become increasingly complex.

180. Cutting edge research in key areas whether in the life or natural sciences, engineering, computing, social sciences and parts of the arts and humanities is increasingly arranged in this transdisciplinary mode, although it may involve and demand both interdisciplinary methods and/or multi-disciplinary teams of researchers.

181. As the intellectual landscape changes and research divisions become increasingly fluid serious questions are posed about the structural and organisational arrangement of the research infrastructure. Once taken-for-granted notions of disciplinary empires and boundaries, still used predominantly in the organisation of academic employment and teaching, make far less sense in several research contexts.

Research Councils and the 'users' of research

182. These shifts in the application mode of new knowledge production are captured in the reconfiguration of the relationship between research councils and the universities. In managing the interface between their customers (the users of knowledge) and the providers (the universities) the Research Councils (and other research project funders) have made increasing use of the directed mode of funding based on priority areas (often reflecting the

results of Foresight), joint (public and private) funding, and applied or problem oriented project funding (reinforced by the growth of EU Framework initiatives).

183. Directed funding often brings with it implicit and sometimes explicit requirements for collaborative activity involving a wide range of partners. In this climate, research agendas are influenced by the collaborative, top-down and bottom-up, processes associated with the identification of new areas of knowledge and techniques. Funding is then explicitly directed towards those alliances or collaborative groups able to demonstrate the range of competencies and partners necessary to solve the key tasks associated with the research agendas. For example, EPSRC, as the largest of the seven research councils, articulates its approach to promoting the flow of knowledge and people to be based on fostering 'a climate where partnerships can develop and be maintained continuously' and defines its role in relation to collaborative research as 'catalysing partnerships between the users of research (e.g. industry) and the providers of research (e.g. academia).

Access to research equipment and facilities

184. There is a further stimulant to collaboration in the form of various funding partnership initiatives designed to rebuild the nation's research equipment and infrastructure. For example, the Joint Research Equipment Initiative (JREI) run jointly by the HEFCE, DENI, the Research Councils and the Office of Science and Technology (OST) states specifically that its objectives include the promotion of partnership and equipment sharing between departments and institutions and to promote partnership between HEIs and external sponsors of research, such as industry and commerce, charities, Government bodies and NHS trusts (HEFCE Report 99/06).

185. While the degree of encouragement given to collaborative applications varies between funding councils and specific schemes (see SURPC 1999), there is little doubt that both research councils and funding agencies have responded positively to the Government's aim of encouraging greater interaction and partnership between universities, other knowledge producers and commercial users of research.

A mass HE system and selectivity of funding

186. A hundred or so universities plus a range of other institutions providing higher level education now operate in an increasingly competitive environment in which there is pressure to be excellent in all things. Diversity of mission is held to be a key feature of a mass higher education system. Despite selectivity in research funding, the UK system continues to operate on the basis that teaching can benefit from a broad range of research and other scholarly activity (see report on the relationship between teaching and research paras 1.17-1.19).

187. There is evidence that a wide range of institutions seek to widen and enhance their research activities and remain active in a broad spectrum of research areas. Nor, conversely, is there any substantial evidence to suggest that the majority of large research-led institutions necessarily want to reduce their commitments to more social or vocationally oriented missions with respect to widening participation. On the contrary, the goal of remaining 'comprehensive' remains an important part of institutional mission across the sector.

188. Given the competitive pressures in the system there is clearly a driver to accommodate diversity internally within HEIs. An important issue here appears to be a widely shared perception of a positive relationship between research and teaching (see interim report on the relationship between teaching and research).

189. There are important tensions here. Given the strength of attachment to research as a defining feature of higher education teaching and learning, the role of collaboration takes on an added, yet somewhat paradoxical, significance since competition to be top class, both between institutions and between individual researchers, co-exists with the development of a wide range of collaborative initiatives and partnerships.

190. The competition-collaboration paradigm is exemplified in the existence of the RAE. Although essentially a device for competitive resource allocation, there is evidence that the RAE is not inimical to widespread intra and inter-institutional collaboration in the production of publishable research output. Arguably, collaboration has become the key method of coping with diversity in a mass system. It has also become a strategy for managing the impact of greater selectivity of research funding.

The spectrum of activity

191. Policy enthusiasm for partnership and collaboration often makes assumptions that the concept is well-understood, that it is dealing with the same phenomenon whether collaboration is between individuals, groups, institutions, sectors or nations, that it can be measured in some way and that more collaboration is better. Our survey of the collaboration literature in Chapter 2, however, suggests that the concept of collaboration is neither well understood nor applied with any consistency. It has multiple meanings in practice and is a complex phenomenon.

192. Nomenclature is a problem associated with the term collaboration. The case studies found that collaboration is often loosely defined in the context of research and embraces several symbolic and concrete meanings in both institutional policy documentation and day-to-day operation. In practice, collaboration is often conflated with partnership and a variety of formal and informal research networks, alliances, pacts and understandings. All may be

'collaborative' in intent although the precise nature, purpose and configuration of the resulting collaborations may vary considerably.

193. In higher education institutions, collaboration typically embraces a range of functions, including teaching, student participation and progression (for example, compacts, franchising and validation relationships), lifelong learning, research commercialisation and intellectual property (IP), technology transfer, consultancy as well as research. Formal relationships based purely on research are a key element of collaborative activity, but even in research-led institutions may form only a part of both individual collaboration arrangements and the broader spectrum of activity.

194. At one of the case study HEIs (a leading research institution) a recent 'audit' of formal collaborations across all departments, faculties and other units of the institution enumerated a total of 188 formal arrangements involving a range of university and non-university partners. Of these, just less than half (49 per cent) were focused purely on research, the remainder typically being multi-purpose collaborations involving partners at local, national and international level in various combinations of teaching, consultancy, research and other activities.

195. There is no evidence to suggest that this pattern of multi-dimensional collaborative activity including, but not always confined to, the research mission of the HEI is untypical of the sector as a whole, although the balance between pure research and other activities might be influenced by position within the hierarchy of research funding. This is a qualitative judgment, since systematic central monitoring of collaborative activities by institutions is rare. Moreover, such monitoring would fail to capture the full diversity and scale of informal collaborations that underpin both the formal agreements as well as the knowledge production process of the research base.

196. Institutional documentation and the views of senior managers confirm that the partnership route has become a key imperative of research strategy across a broad range of HEIs. It is seen as a policy mechanism for tackling a range of research goals, from achieving excellence and concentration of expertise, transforming the internal organisational structure and culture of the institution, to addressing the broader system-wide agendas of the contribution of research to the economic and social vitality of localities, regions and the nation.

197. By any standards this is an ambitious, multi-layered agenda. It follows that collaboration, if it is to contribute to the achievement of institutional mission, has to be more than merely a symbolic gesture to the particular policy goals of the moment. It is not so much the collaboration intent that needs to be understood, therefore, but the specific partnership arrangements through which it is operationalised. If the sector shares an interest in developing

strategies that support collaboration then it needs to be able to distinguish between different forms and of collaborative activity. The range of collaborative links identified in the case study HEIs include:

- External agencies e.g. the RDAs which are pulling different partners together to support/foster collaboration (formal structures externally initiated and managed).
- Other external agencies which put people in touch with each other (informal networking).
- Formal links with external companies or agencies based on work commissioned by them (typically they approach departments/schools or research groups).
- Formal contacts with external agencies initiated by the university (seeking access to facilities or a 'context' for research work - initiated perhaps by research groups). Usually no contract is involved but some mutual understanding is necessary, for example, the spin-off for the business or industry.
- Informal, often individually initiated, researcher contacts based on reputation or meetings at conferences or having previously worked together which result in collaborative work often not underpinned by formal contractual arrangements but with a view to joint benefits (e.g. publications) or on a quid pro quo basis.
- External approaches from other universities seeking individuals/groups with particular expertise or access to specific facilities to join a bid for funding. If successful then formal contractual arrangements may be required.
- Occasional secondments to external collaborators.
- Joint support for research students – e.g. where the university matches external funding from an outside agency.

198. The scale and range of collaborative partnerships make comparisons difficult. The pervasiveness of collaboration may be common across the sector, but the rationales for involvement in the partnerships, their operational details and management structures present a complex reality that is unlikely to be captured either by institutional documentation or even bibliometric indicators. The latter may capture the specific outputs of a partnership arrangement, but it tells us nothing of the genesis, growth, operation and management: the very dynamics of the partnerships operation are lost in the sterility of the output measure. Nor, of course, do bibliometrics reveal anything like the whole picture of collaborative partnerships forged at strategic levels between institutions and sectors or between research units, teams and individuals. The reality is a complex mesh of formal and informal partnerships, with the latter predominating.

199. Across all disciplinary areas, these different levels and types of collaborations are the key to unlocking the creativity and talent of individuals, although their very informality and personal (often social) basis defies other than sensitive external or managerial intervention. Such informal, essentially personal, collaborations, however, remain within the frame of reference of

the present study since invariably they are created and sustained for the purposes of either securing research funding, carrying out the research process and/or the production of research outputs (usually publications but including other outputs such as patents).

Models of collaboration

200. The complex and multi-layered nature of so many collaborative partnerships in higher education makes categorisation and identification of salient features an inevitable simplification of practice on the ground. However, it is possible to generate from the empirical evidence of the case studies three somewhat different or 'ideal-typical' forms of collaboration. In practice, most institutions will provide variations of these forms, with all three co-existing to varying degrees as an integral part of the institutional research base. However, the models provide a heuristic tool with which to demonstrate basic differences between collaborative activities in terms of structures, roles, objectives and modes of operation.

Model A: Corporate Partnerships

201. These can be characterised as 'means to an end' collaborations. They are corporately initiated and 'owned' by the university and its senior managers. The driver is principally (but not exclusively) access to external resources. Typically the partnership will be constructed to enable collaborative proposals for funding to be submitted on behalf of the member institutions. The partnership provides a formalised network within which arrangements are made to co-ordinate and discuss the development of joint strategic goals. Partnership structures include formal boards or even companies responsible for the implementation and delivery of the partnership strategy. Target funding sources are Funding Bodies or Research Council/Charity competitive funds, European funds as well as private sector/industrial funding.

Model B: Team Collaboration

202. The second model exists below the corporate level. These are collaborations that have a semi-formalised existence though they are not defined as formal partnerships. The driver is principally the need for multi-disciplinary skills and experience since these are research-focused collaborations involving researchers based in various departmental, research centre or other units at two or more institutions. The teams may involve combinations of researchers based in universities, industry, government laboratories or professional practice. They exist in a symbiotic relationship with funding streams, with competition for funding simultaneously a stimulant and problem for longer-term group stability. 'Ownership' and control is retained by teams since these are high skill/discretion areas with outcomes practitioner focused, problem and task-based.

Model C: Inter-Personal Collaboration

203. This model contains the greatest diversity but constitutes the 'ballast' of university research activity. Collaboration is intellectually driven and discipline-based and sometimes, in larger collaborations, discipline organised. However, it is dependent on essentially personal relationships between two or more university based individuals, sometimes groups. Institutional affinity is rarely a relevant factor since many collaborations endure changes associated with career moves. These are invariably bottom-up and people driven collaborations based on personal relationships, trust and ability to work together. Collaborators may work together through the whole of the research process from the initial development of the research idea, its funding, results and dissemination, or may come together more selectively at key parts of the process perhaps sharing data from several projects in order to devise new tests or write joint articles.

Benefits and success factors

204. The patterns of activity and outcomes associated with the three models tend to be different. Each type has a different set of dynamics and there are also strong disciplinary variations in the degree of external engagement - and therefore funding - associated with each category. For example, some disciplines have little or no industrial, business or government collaboration; others may have significant volumes. In general, corporate partnerships are aimed at providing resources and a strategic framework within which to support ongoing or new areas of research work. The latter may itself be conducted in some form of collaboration with partners or may be located within the institution itself. Team and inter-personal collaborations are the basic units of university research activity and the boundary between these models may be difficult to define with precision. Although an inevitable simplification of practices on the ground the models enable us to clarify the main characteristics of research collaboration and to identify their main benefits and success factors.

Corporate partnerships

205. Corporate partnerships with other HEIs are designed to advance both individual and group interests by harnessing various areas of strength and expertise to common purpose. They may take different forms such as strategic partnerships with one or more HEIs, preferred partner arrangements with a specific partner, or sub-regional partnerships designed merely to facilitate a higher level of communication and information sharing between institutions.

206. The funding secured through corporate level co-operation can serve a range of purposes including the creation of new ICT infrastructure, research facilities and equipment, teaching/training/technology transfer arrangements including collaborative schemes to fund studentships/research fellowships, usually but not exclusively with industry. The case studies

gave access to several successful examples of corporate partnership. Not surprisingly, examples of failed or unsuccessful partnership models were less visible.

207. The most high profile (in media terms) of corporate partnerships are those linked with the achievement of significant research funding from leading business, industrial and research charity organisations. However, such partnerships may only become visible after long periods of often protracted negotiations. They can be difficult deals to strike, not least because the projected relationships tend to be at the meta rather than detailed operational level. Time horizons are multiple and unpredictable. Longer-term benefits to the parties can be difficult to specify. The ultimate success factor is mutual trust and overlapping interests rather than legal contract. Forced or overly restrictive partnership conditions are unlikely to be successful.

208. Fieldwork evidence concurs with a recent DETR report on regional partnerships that corporate partnerships can serve either defensive or offensive goals (see DETR 1998). Defensive partnerships between HEIs provide a mechanism with which to marshal intelligence and expertise in response to a rapidly changing funding/political environment, for example where RDAs and devolved 'national' governments acquire new powers over research agenda setting and control of significant research budget allocations. Not surprisingly perhaps, there is resistance in the system to any significant shift of powers over HE to the regional dimension. HEI perceptions of the enhanced regional role in Scotland were ambivalent. There were concerns that such intervention should not be to the detriment of wider UK and international collaborations.

209. Offensive partnerships are designed to provide the level of critical mass necessary to compete with other players in the market. The driver in these cases is provided by the emergence of global markets for research and innovation and the desire to compete for resources with the elite players. Examples include sub-regional partnerships between research-led HEIs that enable them to assemble scale and depth of expertise sufficient to match the leading national and overseas competitor HEIs.

210. Corporate partnerships may benefit the HEI resource base but the more tangible elements of the research collaboration may connect only selectively with the broader research activities of comprehensive institutions. Inevitably these connections tend to be in areas of cutting edge scientific and technological research, typically those requiring access to specialised equipment and facilities. Large swathes of institutional research will be untouched by corporate partnerships. This is particularly true of HEI-industry collaborations but can also characterise sub-regional HEI consortia, preferred and strategic partner collaborations. Researchers may have only a vague awareness of the existence of the partnerships and do not connect with them in any meaningful way.

211. Nevertheless the great strength of corporate partnerships lies in the identification of institutional complementarities and the pooling of resources they make possible. Perhaps inevitably, success tends to be defined initially by the ability of the partnership to access external resources, otherwise unavailable. However, longer term, though less predictable, benefits include building capacity to work strategically and impact on key areas of joint interest. Internally, the partnership may also promote longer-term cultural transformation and new synergies among researchers with other potential spin offs.

Team collaborations

212. The rationale, structure and success criteria of this model of collaboration are very different to the previous model. The best-known pattern is the hierarchically organised team most commonly associated with certain areas of large-scale science. Extensively studied and documented, these teams are led by principal investigators and co-principal investigators and include senior and junior researchers, postgraduate students, technicians, administrators and secretaries (Kargon et al 1992). We define a team collaboration as a group of researchers from two or more institutions working together to prosecute a specifiable research project for which funding has been sought and achieved on a joint basis. Also included in this definition are inter team collaborations involving two or more institutionally based teams working collaboratively on a specifiable research episode.

213. The teams themselves may form the communities of researchers working in particular areas of research. For example, in the world of high energy physics, the community is relatively stable with a well-articulated hierarchical structure across countries, facilities, HEIs and research specialities (Traweek 1988). Such communities can exhibit increasingly specialised divisions of labour in the face of the growing complexity of science. They have also developed, over long periods of time, sophisticated and dynamic cultures, customs and practices which embrace methods of working including rules of collaborative authorship (Galison 1997:626-7).

214. Case study visits to publicly owned science facilities confirmed that HEI teams in different scientific fields 'plug' into not just the pieces of (often expensive and globally distributed) equipment essential to the research, but into broader networks of researchers and technicians[24]. These science sites, although off-campus, may also include key researchers who also work collaboratively with colleagues in a number of HEIs and who may hold joint academic/facility appointments. These researchers may also publish jointly with the HEI members of the team.

[24] These networks include intergovernmental bodies such as the European Laboratory for Particle physics (CERN), the International Thermonuclear Experimental Reactor (ITER) and the European Space Agency (ESA). Consultations

215. Research team reputation is a key element in securing access to facilities and equipment and various inter-team collaborations may be put together in order to obtain funding and the necessary access. Teams located at the facilities themselves may also compete for funding often in collaboration with researchers from other institutions. This can mean exposure to the same competition-collaboration continuum as HEI based researchers since the teams compete for resources from the same funding bodies (though scientists at the CSL felt they were hugely disadvantaged because of their preclusion from bidding for Research Council funds).

216. Although pre-eminently a model of large-scale science, collaborative research teams are also to be found in other disciplinary areas. Not all scientists require specialist, collaboratively accessed, equipment and facilities. Social science researchers often work in team collaborations, though these tend to be much smaller in scale and formality than in the sciences. They may also be found in emerging (often inter-disciplinary) areas of research based in research centres and units working at the boundaries and spaces between disciplines. Teams may involve researchers from a range of disciplinary (though usually cognate) backgrounds, including social sciences and those working in the spaces between social science/arts and humanities. There is evidence that researchers working in novel combinations of disciplines (for example, music and science) may find funding for research difficult to secure.

217. The case study interviews with researchers in the arts and humanities suggest that the advent of the AHRB has led to an increase in team based approaches to research activity. Several felt this dimension of arts/humanities research was likely to increase. This has the potential to transform both the scale and focus of research endeavour. However, this is also likely to impact on the teaching-research interface since successful funding applications often involve collaborators' being 'bought-out' of teaching in order to concentrate on research.

218. Unlike science, where there is a much more established practice of appointing post-docs to engage in research, the arts and humanities (and even some of the social sciences) have less elaborate team hierarchies and traditionally are much more reliant on the teacher-researcher (with research assistants) in the production of new knowledge. Where such researchers are bought out of teaching it is invariably from under-graduate programmes. The Funding Council may wish to consider the likely effects on the teaching-research nexus of any significant shift in the future towards a more collaborative team based model of research activity in the social sciences/arts/humanities.

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between the various scientific communities and policy makers are facilitated by the Global Science Forum (formally the Megascience Forum), see Baruch 1999.

219. In general (and leaving the large-scale science areas aside for a moment), team collaborations tend to be loosely structured often as joint research award holders with operational responsibilities tacitly rather than formally defined. The teams are not formal associations of partners along the lines of Model A. However, they are defined both structurally and in success terms by the achievement of funding for specific 'episodes' of research. The collaboration exists because it adds value to the conduct of the research, principally though the assembly of ideas, creativity, skills/expertise.

220. There is some evidence from the research that funding opportunities that include collaboration as a pre-condition of success (such as EU funding) can lead to the construction of 'artificial' collaborative teams across several countries. Some respondents commented that such collaboration does not produce good research, is likely to be relatively short-lived and can be problematic to manage. As one vice-chancellor commented: 'The important thing is that there has to be a real advantage in collaboration - not just paper agreements.' Where research teams are founded on longer-term associations between researchers and/or are genuinely complementary in expertise and personality terms, then the collaboration can produce significant added value.

221. The success of team collaborations also lies in the scale and breadth of perspectives they bring to the investigation of research problems. This can lead not just to a significant advancement of knowledge/understanding, but of the research agenda itself. However, there is a delicate balance to be struck between stability and 'creative' instability in the existence of research teams. Most researchers agree the need for a certain minimum level of stability - researchers need employment and income security in order to feel commitment and loyalty to team, research and broader institutional life. Equally, there is a danger of ossification if the teams are not infused with new ideas and perspectives, or challenged by the creation of new teams or combinations of new and old teams.

222. There are funding and research career issues to this. Some research centres operate with very 'lean' structures of permanent staff and tackle specific research problems by bringing in external expertise by appointing associates to the centre over fixed periods of time. For this reason, however, it can be very difficult to define with any precision the existence of teams. In some research areas this approach is forced on centres because of the difficulty of recruiting researchers of sufficiently high calibre (mainly experienced post-doctoral researchers) to an academic career. This is a potentially important influence in some disciplinary areas on the capacity of the team element of the research system to produce excellent, leading edge, research.

Inter-personal collaboration

223. Inter-personal collaboration spreads across an extremely broad base of research activity. It is the essential foundation or ballast of the research system. All the evidence confirms that the most successful collaborations are bottom-up and people-driven. Some areas are difficult to manage and if researchers are not interested in collaborating it simply does not occur in any meaningful sense.

224. Across all the case studies, researchers and institutional managers concurred that successful collaboration at this level depends upon mutual trust and agreement. Co-operation requires complementary expertise, a partnership of equals and the partners have to enjoy the collaboration. As one researcher commented: 'Collaboration is fun'. Such collaborations are intensely task focused with high discretion for setting/meeting goals and targets, for example, the development of research grant proposals or publications. They are facilitated by regular face-to-face contact but can be sustained by the development by other forms of contact most recently by the development of email. Such activity characterises research activity across a broad spectrum of disciplines, including interdisciplinary research.

225. Inter-personal collaborations are easily distinguishable from corporate partnership, rather less so from team collaboration. The cement is not contractual, but social since they are in essence informal and voluntaristic arrangements. However, they may take on semi-formal or team like characteristics where two or more researchers successfully apply for project research funding. For the duration of the project the partners may act as the core of a team (with the addition of research assistants or fellows) but there may be periods between when there is no project or funding base to the relationship. Some partnerships survive long term along these lines, adding and dropping members over time and a succession of funded projects. Others will be shorter lived, surviving only the duration of the funding episode or falling into disuse as partners' careers and interests develop in new directions.

226. The genesis of these collaborations can be varied. Many are based on people's academic history: they work with people they met doing their doctorate, whether other postgraduates or former supervisors; others arise out of relationships developed as teaching colleagues, those developed at seminars and conferences or through disciplinary networks, Conferences play an important role in developing and maintaining contacts. They provide forums for keeping up-to-date with people's research, initiating and developing links and opportunities for dispersed collaborators to meet informally to discuss and review progress on a specific research collaboration. In some research areas, a similar function is performed by regular meetings at scientific facilities where researchers are able to exchange information and pick up skills and knowledge of ongoing findings.

227. Our sampling methodology in the case study HEIs yielded a broad selection of active collaborators across four disciplinary fields (see Appendix 3). Interviews with these researchers revealed a multi-layered pattern of collaborations in different stages of their life cycle. It follows that researchers are often simultaneously engaged in a number of collaborations. Some are short lived, others more enduring. Collaborations that have yielded a major collaboratively written refereed journal paper, although only recently published, may have long since faded as an active collaboration. New collaborations may be developing based on current interests and may be working up a grant proposal or comparing research results.

228. Inter-personal collaboration is not, of course, always plain sailing. Some collaborations encounter (yet survive) formidable problems. Researchers talked freely about specific collaborations indicated initially by joint authorship of research papers[25]. In some cases these were not seen as their principal collaborating colleagues - it is not unusual for researchers never to have met some of those whose names appear on a collaborative paper (perhaps the person performed a particular task or contributed a key idea). Behind each publication generally is a tale of the human interaction of research and the inevitable problems, pitfalls and unexpected glitches that accompany any social process. Life events, career and professional moves will all intervene in the collaborative process and only the most enduring survive over many years.

229. The success of inter-personal collaboration is defined (paradoxically) by the contribution it makes to the advance of individual research activity. Hence, the collaboration can be a key to personal development and/or the satisfaction of intellectual curiosity in the chosen disciplinary field. It may enhance personal and joint capacity with publication output and intellectual/RAE kudos being critically dependent on collaboration. Success can also be defined in the contribution collaboration makes to the overall development of the research base. It is essential to leading edge/blue skies research. It can provide the vibrancy necessary for the growth and sustenance of research networks and it can have obvious benefits for teaching and research training.

Summary

230. Collaboration in research is pervasive throughout the HE sector. The case studies revealed considerable diversity of activities. These are captured in the three models of collaboration - Model A Corporate, Model B Team, and Model C Inter-Personal. These models operate at different levels within the research system. Examples of the three models were found in all case study institutions.

231. The basic building block is inter-personal collaboration. It is based on individual researchers, who work collaboratively in a climate of shared intellectual interest and trust. These collaborations and broader inter-personal networks are only partially mapped (through bibliometric techniques). Although some may be stable, long term and highly productive collaborations, they are characterised by strong elements of temporality and change as careers develop and contacts come and go. It is through the capacity to forge new and creative relationships with researchers in and across disciplines and institutions that the strategic goals of the institution are achieved.

232. The development of team collaboration (Model B) and corporate partnership (Model A) are contingent on the existence of the informal and voluntaristic networks of coalface researchers. These ever-changing personal networks are difficult to manage or produce artificially.

233. Across all the models there has to be a purpose to collaboration. Without shared interest and clear purpose they can easily become unproductive 'shells'. And, without a strong foundation of inter-personal collaborative activity there is unlikely to be successful collaboration at higher levels of aggregation.

234. The main benefits and success factors of each model were identified as follows:

A Corporate: Partnerships provide HEIs with offensive or defensive capability in a turbulent policy and research environment. They can benefit the HEI resource base by pooling and developing complementary institutional capacity. Success is contingent on the ability of the partnerships to secure access to external resources otherwise unavailable.

B Team: Essential to securing access to significant levels of research funding. Pre-eminently a model found in large-scale science and related areas, but the team approach to research is spreading through the social sciences, arts and humanities. Team approaches bring scale, breadth of perspectives and different combinations of expertise to research problems.

C Inter-Personal: Networks of academic researchers working at the frontiers of knowledge comprise the essence of the academic labour process. They are essential to creativity, problem solving and new knowledge production. Inter-personal collaboration contributes to individual research activity (and research career advancement) and enhances the overall development of research capacity. It is essential to all types of research, particular leading edge/fundamental research.

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[25] In some cases multi-authored papers had been identified prior to the interview (for the methodology, see Appendix 3).

Chapter 5: Collaboration and the HEI mission

Introduction

235. The final chapter considers the role of collaboration in relation to the achievement of the different missions of HEIs. The rationale is provided by the HEFCE's interest in the role of collaboration in supporting institutional mission. The key questions investigated are

- To what extent can collaboration support the missions of HEIs?
- To what extent can HEIs support the intrinsic collaborative nature of research?
- What is the potential for research collaboration between HEIs and can collaboration facilitate their different missions?

236. The diversity and complexity of collaborative approaches to research makes comparison difficult, but by using the three broad analytical models described in the previous chapter it is possible to draw together the main threads of the relationship between collaboration and mission. The analysis is structured in four parts. The first attempts to capture from the case study investigations the key strategic dimensions of institutional support for collaboration. Two dimensions are investigated: vertical integration within institutions, and horizontal integration with a range of external partners from business, industry, government and other service users of research. The second section considers the main tensions-in-the-system which impact on the relationship between HEIs and collaboration. Attention is focused on the influence of research ranking on collaboration and issues related to fundamental and applied research. The third section switches to the role of collaboration in facilitating the output of skilled people. The final section summarises the main elements of the relationship between collaboration and HEI mission including the main policy implications arising from the research.

Supporting the collaborative nature of research

237. Locating collaboration within institutional strategy is an appropriate departure point for description and analysis of its role in facilitating the achievement of the different missions of HEIs. Statements of mission and strategy at institutional level reveal that collaboration in some form has become a pivotal policy mechanism for tackling the institutional and system drivers described in the previous chapter. Documentary analysis and the views articulated by senior managers confirm that there are multiple rationales for involvement in collaboration. Collaboration is perceived both as an end and as a means to an end in institutional strategy. Two dimensions of collaboration appeared to be particularly important in facilitating the achievement of specific strategic goals (and mission).

Vertical integration

238. The first is internal to the institution and concerns the social or organisational processes by which new knowledge is produced and the role of management (and leadership) in these processes. This internal dimension is concerned essentially with the *vertical* integration of research within the academy.

239. It is evident that research (particularly in big science and other areas of science) involves self-generating patterns of organisation typically organised in hierarchical teams. However, institutional interest in the vertical integration of research clearly extends to devising collaborative structures that both respond and contribute to the development of new knowledge as disciplinary boundaries become more fluid. It also reflects a need for institutional cultures that encourage an open rather than closed model of information sharing across the boundaries that still condition, if not separate, the disciplinary based hierarchies[26].

240. The research found that appointing (or retaining) the highest quality people and providing the freedom to let them get on with their research is a key part of institutional strategies. This is linked to the provision of an appropriate environment in which excellent research can flourish. Resources are a decisive factor in the competitive battle for top research personnel - the top research-led HEIs are clearly in pole position in this context. However, there is evidence that access to leading edge research made possible by inter-institutional collaboration can be a factor in recruiting good researchers to institutions lower down the research intensity league.

241. It was also found that specific targets for promoting flexible collaborative working between research units and disciplinary areas are frequently included in corporate strategic planning statements. The formation of various inter- and multi-disciplinary research centres is a typical institutional response, although there is evidence that these do not always solve the broader management problem of matching formal structures, resource flows and accountabilities to the informal linkages and new research directions that researchers themselves are already rapidly forging. Resource driven strategies are clearly designed to support collaboration, but cannot guarantee it, particularly at the disciplinary boundaries where much of the most innovative and potentially ground breaking work is taking place.

242. Some institutions are engaged in capital spending designed to provide new physical spaces in which researchers in emerging areas of research can work together[27]. New

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[26] Models of openness, closure (and branching) are intended to provide a specification of the main features of scientific communities and the processes by which science develops (see Mulkay 1991: 51-61).

[27] Top American universities are also investing heavily in support of interdisciplinary science. For example, University of California (UC), Berkeley, projects a total investment of $500 million in buildings, programmes and staffing for two new research premises housing researchers from a range of departments including physics, chemistry, molecular biology and public health. See *Science* 1999 286 8 October, 226-227.

buildings are intended to minimise costs yet provide supportive environments, particularly where new configurations of knowledge and disciplinary fields are occurring. This is linked to recognising these emerging areas by encouraging, supporting and pump priming wherever appropriate. There is evidence that some of the top research-led HEIs consciously try to minimise some forms of external collaboration by having large departments. On site-collaboration is then possible between colleagues (who may be in different departments) in daily contact with each other.

243. Creating an appropriate institutional culture with a clear sense of institutional goals and priorities is the priority. In management terms this does not mean a laissez-faire approach. But it does mean learning to accommodate the 'managerial and administrative nightmares' where the research and collaboration (particularly in multi-disciplinary cost centres) does not match existing resource centre models.

244. However, the problem is a wider one than merely supporting collaborative research. It concerns core-periphery relationships within the organisational structure and the deeper issue of managing the creative, bottom-up, processes of research and new knowledge production within a centrally determined framework. As one HEI strategic statement expressed it, research is both an individual and a team effort as well as a principal source of academic job satisfaction. It is vital that academics feel ownership of their research activity and the management of research needs to take account of such personal commitment issues. We detail how some case study institutions have attempted to translate strategic statements on collaboration into action later in the chapter.

Horizontal integration

245. The second strategic dimension of collaboration is *horizontal* integration with a broader community of interests in the research endeavour. Partly this is a product of resource dependency and recognition of the escalating costs in some academic (predominantly scientific) areas of research. In expensive areas, research has to be conducted within frameworks of collaboration with those in industry and government (including the military) whose purses are big enough to sustain the long-term resource implications of leading edge research.

246. Collaboration with business and industrial partners in order to find new sources of external resources is fuelled by a widely shared perception in HEIs that research in general and fundamental research in particular is chronically under-funded. Corporate partnerships developed sometimes in conjunction with other HEIs but designed to link up with external partners are a fundamental part of the resource-dependency model. However, they are also a critical part of the response of HEIs to pressures to develop research that links to economic and social priorities. HEIs are incorporating these horizontal linkages within their strategic

goals, although there is recognition that their operationalisation ultimately depends on the successful management of the vertical linkages internal to the research endeavour identified above[28].

247. Partnerships can strengthen the HEI research base by facilitating (and resourcing) intellectual and disciplinary developments in an applied base. According to one recent study, the linkages between HEIs and industry (including research collaboration, consultancy, commercialisation of research and teaching) have undergone 'spectacular growth' in recent years with access to funding being a prime motivating factor for HEIs (PREST 1998). In another study of industrial research it was found that UK collaborative papers with industrial partners are key indicators of informal networks through which knowledge and information flow and that it is these networks which can stimulate innovation (Hicks and Katz 1997).

248. The emphasis of the present study has been on understanding how these and other collaborative links support institutional mission. The evidence confirms that research-intensive HEIs are setting up/seeking to develop partnership links with leading edge (in technology terms) global industrial players. In strategic terms these links are seen as key to levering up the volume of research funding from non-public sources. Most research intensive HEIs in the study have specific targets for increasing such funding and have well-defined structures for mobilising the full panoply of linkages identified in the PREST report cited above. Becoming more business-like in the ways in which research is managed, conducted and marketed is now a facet of HEI strategy.

249. Although targeted on obvious areas of science and technology with the largest spin-off and commercial opportunities, there is a raft of activity in the social science, arts and humanities which is also being developed (or re-engineered) in line with user community requirements. Collaboration is a key part of this process. The case studies found numerous examples of innovative and extensive partnerships designed to develop academic research relevant to practitioners and service users across a range of social, economic and cultural activities. Examples include formal agreements between groups of researchers in economics, geography and related areas and regional tiers of government and its agencies; partnerships between researchers engaged in social work related research and local authority social work departments; and, partnerships in the field of film and media studies which bring together several academic departments in the arts and humanities and leading organisations in the film industry.

250. Academic researchers in the non-science areas spoke with enthusiasm about their existing multi-lateral partnerships and the vast potential that exists for much more innovative

[28] The idea of vertical and horizontal integration is adapted from the investigation of big science and the organisation of research by Kargon *et al* 1992.

research in applied settings. Just as in science, the importance of disinterested and fundamental/original research remains paramount, but the possibilities for developing balanced portfolios of pure and applied research, much of it collaboratively organised and conducted in conjunction with user communities should not be under-estimated. Far from being cocooned in ivory towers, the research found extensive examples of researchers actively engaged in broader communities through a wide range of collaborations of direct relevance to the achievement of institutional missions and broader social, cultural and quality of life policy objectives.

251. Leaders of HEIs stressed that involvement in external partnership should contribute to broader strategic goals, including support for fundamental research. Solving specific industrial problems *per se* is not seen as the draw or purpose of such link-ups. Where fundamental research is a beneficiary of the corporate partnership, then collaboration is not necessarily inimical to high performance in the RAE. There is a flow of outputs from new knowledge production, to publishing, through to application and development. There are also potential synergies between partners leading to two way flows of information, people and skills. As we have already stressed, such networks are the key to innovation, even though they are only imperfectly mapped, particularly in areas outside the scope of bibliometric measurement.

252. For industrial and service practitioners and users partnership with academic researchers offers the potential of an inside track to new combinations of knowledge. Working with a research excellent HEI(s) offers the prospect of participation in cutting edge research agendas, privileged access to where research and techniques will be over longer time horizons. For both partners there is scope to shape specific research projects and agendas in the light of new knowledge production. The prospect of more immediate payoffs may be an important attractor for longer-term industrial investment, but the longer-term view is paramount. However, if the scope of external collaborations is to be extended to new populations of partners, then there may be considerable work to be done in educating and stimulating the market for research, particularly the value of longer-term perspectives within a broader range of user communities. Such perspectives are essential if research supply and demand factors are to be brought into a more even balance.

Tensions-in-the-system

253. Evidence from the case studies suggests that horizontal integration is being approached selectively. Some HEI leaders are choosing to resist pressures to collaborate when it serves no strategic purpose. This is a more tendentious part of institutional action. While institutional leaders and managers recognise the policy (and political) signals-to-the system about collaboration, there is a perception that almost all agencies underestimate the costs involved. There is evidence also that top research-led HEIs are opposed to agency interventions that

are designed primarily to satisfy other policy considerations. Researchers on the ground were also suspicious of over-zealous promotion of collaboration, particularly where it was seen to clash with perceptions of research excellence and rating.

254. This element of institutional strategy has to be set in the broader policy context. Research funding and policy are producing considerable mission drift with institutional documentation addressing essentially similar strategic research goals. Typically the message includes reference to 'world-class' and 'excellence' in terms of research quality to be achieved within a collaborative framework by working in some form of strategic partnership with a range of organisations and sectors at all levels of engagement, from the global and national, to the regional and local. Privately, however, institutional leaders and researchers acknowledge that research orientations may be more heavily loaded in particular directions and at different levels. The specificity of research collaboration in different types of HEI is a theme to which we return below.

255. Institutional managers recognise the drivers of collaboration but are well aware of some of the problematic tensions between policy initiatives. They are also cautious about their ability to 'manage' the intrinsic collaborative nature of the research process. Collaboration and institutional mission co-exist in a symbiotic but ambiguous relationship and this demands sensitive managerial strategies. This relationship is illustrated in the following examples of tensions in the system which impact on collaborative activity.

The influence of research ranking

256. Mission and position in the HE research system appear to be critical factors in determining the profile of external partnership activity. Less research intensive HEIs tend to develop corporate links with smaller industrial players and (in general) confine their sphere of influence to local/sub-regional contexts. Such collaborations, however, can be important in facilitating HEI-SME links. There is some evidence (not always consistent) that RAE rankings are used by industry and other external research sponsors as a directional indicator in the search for HEI partners. Some institutions/units are effectively ruled out of participation in partnerships with world and even national leaders by virtue of the notions of excellence implied by the RAE.

257. New universities and/or lower ranking (in RAE terms) departments complained that they are often the only ones with serious linkages with SMEs in the their local areas. Yet their RAE ranking means they cannot bid for research studentships and grants. There are policy implications arising from this problem. Collaboration may be a way of ensuring linkages to the hubs of (RAE) excellence within disciplinary fields. However, we were informed by one PVC of a top research institution that in his field (chemical engineering) not only was there almost no contact with SMEs but attempts to put together joint bids with another new university with well developed SME linked had failed to materialise, primarily for lack of time.

258. Although researchers across all disciplines were focused on RAE requirements, generally this was not seen as a major obstacle to working in partnerships with industrial and other external collaborators unless the focus of the research was too heavily tilted towards applied or industrial problem solving. However, we found three important exceptions to this general picture.

259. First, novel combinations of disciplines, even when working towards specific economic/social/cultural benefits, may find funding from research council sources difficult to secure and/or RAE reward elusive. Specific examples include music and disability; applied maths and computing. Even more conventional areas of linkage, for example art historians and national galleries, may have to work together in the knowledge that the chances of research funding/RAE recognition will be remote despite the benefits to the user community being generated.

260. Second, although we have noted that there is some evidence that the RAE provides a disincentive to collaboration between certain types of institutions (and that links with SMEs may be the loser), this is to some extent offset by the existence of webs of collaborations linking institutions via all three models of collaboration. At the apex, the top research HEI may work collaboratively with a major industrial partner formalised in Model A corporate partnership agreement. Specific research projects may flow from this link and these can involve a series of secondary partners at other HEIs. Some lower ranked (in RAE terms) units can in effect 'coat-tail' on the higher ranked. These projects may involve Model B team collaborations and/or Model C inter-personal collaborations. For lower ranked research units the indirect access to such research is a toehold on the research base. We found numerous examples of this process particularly at the level of personal collaborations. These can include researchers based in top research institutions working collaboratively with colleagues in post-1992 universities.

261. Although such linkages offer a number of benefits, they are not without disadvantages, however. There is a danger that secondary partners can feel that tasks are 'dumped' and their presence exploited. This view was expressed by several researchers particularly in new university departments with collaborative links to higher ranked departments in partner institutions. For HEIs in this category, heavy teaching loads and the absence of any 'slack' in the system mean that additional research commitments are difficult to accommodate.

262. Third, HEIs focusing selectively on strategies to develop research activity in semi-autonomous centres run the risk of divorcing research from teaching. Our evidence comes primarily, but not exclusively, from less research intensive HEIs, particularly those only recently engaged in the competition for RAE derived grading and funding. For example, in one of the case studies the official or corporate strategy is to develop a research culture in which

teaching and research are complementary elements of the learning environment. Although the institutional mission is oriented towards teaching, the strategic goal is to obtain research recognition by developing excellence in certain selected areas of activity through the concept of research centres. These are based on UoAs and may be co-terminous with departmental boundaries, but can be inter-departmental and inter-faculty.

263. Respondents at the level of head of department and dean in this HEI felt the strategy is fundamentally flawed and is failing. The creation of 'separate' research centres has meant that in some cases they do not contribute to the teaching environment and disciplinary culture within the institution, contrary to the strategic intent. It was also felt that while HoDs are responsible for the development of the discipline internally, stripping them of responsibility for research turns them into programme managers rather than disciplinary leaders. It also tends to leave the non-research centre staff impoverished in terms of contact with disciplinary developments. Research centre managers and researchers are more positive, but emphasise that the inter-disciplinary/faculty centres are much more difficult to manage because of the horse-trading required with other resource centres. We are sure these problems are not confined to the less research-intensive HEIs (and have already referred to potential problems in arts and humanities research areas), but the net effect is to render collaboration much more difficult to disentangle from broader influences on research policy.

264. Finally, anecdotal evidence was presented in some HEIs that research 'stars' given their chance in the lower tiers of the system are identified and enticed away to the higher-ranking departments. In one sense this reflects a plus point for the centre of excellence model since the collaboration clearly facilitates skill development. But in another it leaves the 'feeder' institution exposed if the lead researcher is tempted away, particularly if the research base is short of critical mass.

Collaboration and fundamental research

265. Although senior managers in HEIs may perceive clear benefits from corporate partnerships, we have suggested that this is not always shared at the level of heads of research units and front line researchers. Most readily accept the need for a balance of fundamental, strategic and applied research in their unit/personal research activities, but there is undoubtedly a degree of suspicion of too much emphasis on industrial and applied research. Among scientists, concerns were expressed about public perceptions of science too closely identified with specific commercial interests, about the implications of politician driven research agendas and constraints on academic freedom.

266. Many researchers felt that the quality of fundamental science is threatened by a lack of balance between pure and applied research and by excessive emphasis on narrowly focused economically 'relevant' research. There is a widespread perception that the research base is

being impoverished for the want of adequate resource in the system to let people develop research, either individually or in collaboration with others, in directions that are not necessarily based in the huge (conventional) infrastructure or on commercial applications. We were referred to several examples to confirm that fundamental breakthroughs in scientific discovery or originality in the arts/humanities frequently involve long term, undirected research effort. These prove key to subsequent innovation and adaptation, but the pathbreaking research is unlikely to be funded in purely applied contexts. Some researchers linked this problem to grave misgivings about a system increasingly reliant on directed sources of (largely Foresight linked) funding which, as one senior government scientist observed, "is quite idiosyncratic in its distribution".

267. There is also a widely shared view that the dual support system is becoming less and less able to provide for this critical element in the research system. A senior life sciences researcher lamented: "Whether HEFCE accepts this or not, the reality is that we don't have a proper dual support system." Researchers undoubtedly recognise the pressures created by the changing nature of research, the need for critical mass and assembly of so many different skills in order to tackle problems at the highest levels. This problem is particularly acute in (but not confined to) the life sciences and biomedical areas. As another (veterinary science) researcher observed: "We've got to survive by collaboration.... We're getting closer and closer to the engineers, to computing science, to informatics, to socio-economics, telecommunications and to industry - it's a shifting situation."

268. However, the need to retain strong disciplines was also recognised, not just as the basis for creative collaboration but for reasons of continuity of academic achievement and skills development. The problem was seen as how to combine the structures of the funding and evaluation of research with the internal walls and social architecture of the institution in ways that provide greater flexibility within and across disciplines. Although research strategies are clearly focused on developing the sort of internal structures required, the reality is that the system is still a long way off removing some of the basic structural, organisational and cultural blocks to greater transdisciplinary or Mode 2 collaboration. It was recognised that HEIs, as autonomous entities, have the primary role in devising this vertical integration. It is important that research funding and policy does not impede the institutional freedom necessary to support these key changes in the structure and organisation of the research endeavour.

People and skill issues

269. The difficulty of separating out research from teaching and other functions of collaborations was noted above. Perhaps the clearest examples are joint teaching schemes in which expertise at different institutions is combined to develop provision for postgraduate research training.

270. At one end of the spectrum are the ad hoc arrangements devised for the joint supervision of Ph.D. students by researchers based in different institutions. Such arrangements are of value in providing the student with complementary expertise and enhanced resources. Their success depends on the capacity of the supervisors to work together and a willingness by institutions to provide access to information resources and other facilities. There is a multiplicity of such individualised arrangements. Most seem to work well although we have encountered evidence of problems arising from institutional decisions to impose charges for joint supervision arrangements and withdrawal of access to facilities and resources. In one case this was imposed by a top research ranked university on a much lower ranked local institution.

271. At the other end of the spectrum, still limited in number but likely to grow in the future, are more formalised corporately organised collaborative schemes. These can include provision for joint development and delivery of training/lifelong learning packages specifically tailored to the needs of industrial/commercial clients. For example, a group of four research led HEIs has recently concluded a deal with a major overseas high 'tech' industrial corporation to deliver a collaboratively taught and awarded MSc programme. The programme is considered a prime example of collaboration with strategic economic significance since it builds capacity not just in the partner HEIs but in the regional skills infrastructure as a whole. Control of the scheme is vested in a new joint company and delivery of teaching is located at a new purpose-built site. The creation of the partnership was, in the words of one of the participants "a miracle", but proof that even the most apparently intractable incompatibilities of degree regulations and operational cultures can, with determination, be swept aside.

272. The fieldwork uncovered numerous examples of collaborative approaches to research training which lie between these two extremes. They cover a wide range of disciplines and specialisms and can in general be described under two broad models of provision.

Strategic partnerships.

273. These exist as a semi-formalised network of diverse HEI departments. The primary purpose of the network is to provide a strategic context for the organisation and delivery of *part* of research training programme on a collaborative basis. Typically, the collaborative element provides a strategic context for the development of common elements in the disciplinary field. However, responsibility for the delivery of research training programmes is retained by each partner department and collaboration is reserved for sessions (often organised on a residential basis) designed to enrich/widen the postgraduate experience. Collaborative activities tend to be voluntary and organisation ad hoc. Resources are retained by partner institutions.

Executive partnerships.

274. These are formalised networks of relatively equal and geographically adjacent partner HEI departments. The primary purpose of the network is to provide a framework within which to organise and deliver *the entire* research training programme on a wholly collaborative basis. Such schemes require delegated authority from the partners for the delivery of the training. Partners meet together on a regular basis to oversee the policy, development and work of the network. However, authority for the implementation and operational elements of the scheme is delegated to an executive body led by a scheme directorate. The scheme needs a substantial element of executive capacity because key elements of delivery are organised on a shared basis. The teaching team is drawn from partner HEI departments on the basis of expertise in particular areas of the programme(s). Resources are shared between the partners in order to ensure the partnership achieves its aims and objectives.

275. These models are intended to simplify the range of structures and approaches found across the sector. The vast majority, however, fall into the first category of provision. Much of this is dependent on good will, hidden subsidy and a series of ad hoc, voluntaristic arrangements. This is both a strength and a weakness of the provision. Where there is rapid turnover of staff, or lack of managerial oversight, it is easy for collaborative schemes to expire or run along without any real strategic view of the purpose and value of the provision. Equally, where partners do not share equal commitment or circumstances and mutual interests are no longer evident, there is a danger that programmes become moribund.

276. The great strength, on the other hand, is the added value to be achieved from pooling resources, complementary expertise and critical mass. It is clear, however, that for schemes to be successful requires equal commitment from all the partners and a culture of collaboration in all the host units of research. Where these conditions are met then there is strong evidence that the schemes can be a major source of supporting the HEI mission as well as enhancing the quality of the student experience. There can be other spin-offs in the form of new research collaborations based around the network as well as new avenues of recruitment to research and teaching posts. When they fulfil these basic conditions, collaborative approaches to graduate research training can enhance the output of skilled people from the research base.

Conclusions and implications for policy

277. This report has examined collaborative approaches to research using a combination of literature review, bibliometric analysis, and institutional case studies. Our review of the current literature in Chapter 2 suggests that much of the research into collaboration is based on case studies of limited size, small numbers of questionnaires and bibliometric data. It also suggests that collaboration is difficult to define. Factors which might account for the increase in

collaborative research include changing patterns of funding, the desire of researchers to increase their visibility and recognition, the rationalisation of research and new divisions of labour, increasing specialisation, the need to work in close physical proximity with others in order to benefit from their skills and tacit knowledge, and cheaper and faster modes of transportation and communication that facilitate co-operative research.

278. Some research collaborations emerge from political memoranda of understanding between nations, some collaborations result from a formal requirement of funding agencies for partnerships and still others evolve from the growth of professional respect and trust. The factors that drive research collaboration are numerous and difficult to quantify. The fact that the research system has many interacting political, economic, social and cultural processes makes matters even more complicated. It is difficult to determine exactly how each of these influence the co-operative and competitive forces that are intrinsic to researchers working alone and in groups.

279. The bibliometric evidence presented in Chapter 3 suggests that there has been a long-term trend towards collaborative activity, that the majority of scientific research is collaborative and that the size and geographical location of an institution influences its collaboration profile. An institution and its researchers do not work in isolation; they work within broad and extensive research networks. The bibliometric analysis also reveals a significant non-linear effect of institutional size on collaboration. For example, the amount of international collaboration and research impact an institution has increases non-linearly with its size. However, our analysis of the institutional dimensions of collaboration in Chapters 4 and 5 showed that awareness of the spectrum of collaborative activity conducted within each HEI is perceived with much less precision. There appear to be two main reasons for this.

280. The first concerns the different levels of collaboration. Bibliometrics measure the outputs of collaboration in the form of multi-authored refereed papers. Whilst HEIs are interested in this output for evaluation (RAE) purposes, it is largely for reasons of mapping quality and research excellence rather than the processes by which the outputs were derived. It is mainly the researchers themselves who are concerned with the dynamics of their collaborations and how they contribute to new knowledge production. These are predominantly issues to do with the research process (ideas, hypotheses, testing, analysis, writing) and the social dimensions of making the collaboration work (tasks, time, communication, travel, deadlines, reliability, trust). It is for this reason that we distinguished between inter-personal, team and corporate models of collaboration. HEIs may be able to map with reasonable precision the high level, corporately sponsored and driven, collaborative partnerships or even the formation and maintenance of the primary teams associated with large-scale scientific research, because these are often associated with significant volumes of funding sometimes from highly prestigious sources. But they are much less able (or interested?) to do this for the extensive,

often informal or semi-formal, individual research collaborations, even though these form an integral part of the very foundations of the research system.

281. The second reason for the lack of precision mapping of collaboration patterns stems from the lack of central HEI monitoring. In part this is because there is, as we have implied, no funding imperative to do this. But it is also a product of the multi-faceted nature of collaboration itself. Frequently research is only one element in a multi-dimensional set of activities developed out of collaboration that typically may include elements of teaching, lifelong-learning, consultancy and a range of activities to do with the commercialisation of research. Specifying this activity is difficult and it is rarely monitored. Linked to this, it is clear that while collaboration involves costs and benefits, there is no systematic means of appraising all of these, and therefore no reliable method of establishing whether the benefits do actually outweigh the costs.

282. The fact that almost universally HEIs embrace various forms of collaboration in their strategic planning statements seems to reflect almost an act of faith that collaboration is a good thing rather than any rigorous test of its costs and benefits. In this the HE sector is probably not alone, but it needs to be born in mind when assessing the role collaboration plays in achieving the different missions of HEIs. The evidence suggests that HEIs are willing to collaborate in order to achieve ends collectively (either with other HEIs or a range of external partners) that they would be unable to achieve acting individually. Where this is driven by the institution's own assessment of the competitive advantage and benefits to be derived from the strategy then collaboration seems likely to be viewed positively. However, where HEIs feel pressured into acting collaboratively (by formal prescriptions of funding bodies or informal political persuasions by regional or other tiers of government) then there is evidence that collaboration may be seen less positively.

283. At all levels sampled within the case study institutions respondents agreed that artificial or contrived research collaboration is unlikely to be productive or enduring. This is reinforced at the level of individual researchers where there is some cynicism about the current enthusiasm for collaboration, particularly where they are artificially driven by the need to have a partner to meet funding requirements, or where separate projects are brought together under one heading. Meaningful collaborations are almost always driven from the bottom-up and from within the research process itself. Although there are strong policy signals-to-the-system encouraging more collaborative approaches to research, the evidence from within the sector is that collaboration does not respond well to top-down policy drivers particularly if they are detached from the pattern of activity on the ground.

284. Meaningful collaborations are difficult to stimulate and manage through internal institutional strategies. The problem is exemplified in the tensions that exist at the interface between the corporate model of collaboration and the broader base of collaboration captured

in the team and inter-personal models. Corporate activity is focused on expanding horizontal linkages, potentially the most profitable collaborative activity, with business and industry (applied research, technology transfer etc.). Researchers fear that excessive focus on business linkages in particular risk further erosion of the capacity for conducting fundamental and original research and expose the HEI to the charge of being a 'company university' without independence and objectivity. Economic and intellectual benefits of horizontal collaboration are sometimes opposed but it is important they are disentangled.

285. These are formidable challenges to institutional managers and policy makers. It follows that striking deals with external sponsors of research which fulfil the broader needs of institutional mission can be complicated and time-consuming exercises. It also requires sensitive attention to the vertical integration of the HEI in order to accommodate other changes in the research landscape, including new linkages between disciplines in emerging areas of inter- and multi-disciplinary research. High calibre research, particularly in a Mode 2 environment, demands the capacity to mould the organisation of research to fit the problem and not the other way around (Gibbons 1994b). Corporate leaders have to devise satisfactory internal arrangements which give 'room' to individualism at the same time as encouraging the sort of research collaborations necessary to promote excellent, leading edge knowledge production. These internal arrangements also need to mesh with the external contributions of higher education in the contexts of innovation and technology transfer as well as broader social and vocational aspirations of lifelong learning and mass participation.

286. Four policy implications flow from these findings:

First, the importance of institutional autonomy in supporting collaboration is reinforced. Articulating collaborative activities within mission and strategy may be institution specific, but can scarcely be achieved without reference to the broader picture of higher education's *collective* contribution locally, nationally and internationally. As a report on university research in Scotland has noted, how to respond to and/or encourage inter-institutional research and how to overcome intellectual, individual and organisational barriers to such research make for tough institutional decisions on which areas to support, which to cut and which to develop (SURPC 1997).

Second, working collaboratively facilitates involvement in areas not otherwise possible, but it implies active management of research and awareness of the strengths and weaknesses not just of one's own institution but those who are or may be research partners. We share the view that there is no simple recipe for achieving an increase in productive research collaboration but it is ultimately an issue of institutional autonomy and diversity. We did not encounter any strong or consistent support for funding initiatives specifically targeted on collaboration. Indeed our findings suggest that such initiatives may run the risk of undermining institutional autonomy and distorting the formation of mutually supporting co-operative action.

Third, since collaboration is the rule not the exception, knowing how to fund, manage, facilitate, and conduct collaborative research will become core scientific and policy competencies in this century (see Hicks and Katz 1996). Evaluation methods must adapt. Methods based on examining one's *own* research output in comparison with others will not work when individuals, groups, departments or institutions do not have their *own* research output because more than 50 percent of their research is collaborative. As digital communications improve and software tools designed to facilitate the management of collaborative activities improve, research groups will become more amorphous than they already are. We can speculate that in time the notion of a national institution may be become more permeable across international boundaries. Disciplinary and inter-disciplinary groups from many nations may co-operate to prepare and present undergraduate and graduate course material as well as perform research. If research is already performed on a collaborative basis, it follows that there is considerable scope for teaching and learning to follow a collaborative pattern.

Fourth, the importance of programmes and policies specifically designed to encourage collaboration may dwindle as collaboration is accepted as the norm. It is possible that the complex and emergent nature and culture of scientific research process has internal dynamics that self-encourage collaborative activity. The corollary is that attention will need to be re-focused on the robustness of peer review processes as the means of encouraging research excellence in collaborative environments. It is possible that within such a policy environment collaborative research will naturally develop as an optimum research approach.

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Appendix 1: Bibliometric method

The bibliometric analysis of co-authored publications involved was designed to quantify the amount of collaboration and the time trends of various collaboration types. The following methodology was used:

Step one:

For each HEI a regression analysis was performed using the total number collaborations of a given type in the 1981-1994 time period and the total papers published in the 1981-1994 time period. For example, Figure 1 is a plot of the total number of multiple authored papers versus the total number of published papers by HEIs. In this instance the best fit was given by linear regression as indicated in Figure 1a. The linear relationship between multiple author papers and total papers published is given by equation (1)

$$y = 0.83x \qquad (1)$$

where y is the number of multiple authored papers and x is the total number of refereed papers. The goodness of the fit was determined using the coefficient of determination, R^2, which in this instance was equal to 0.997. Equation (1) tells us that over the time period, on average, 83% of all HEI papers involved two or more authors.

Step two:

If a good fit was found in step one, that is $R^2 > 0.80$, a regression analysis was performed on the *annual* collaboration and publication counts using the best fit regression type determined in step one. The slopes for each annual regression analysis are used in step three. In all of the analyses presented in this report the best fit was either a linear[29] or a power law[30] regression. It is worth explaining what is meant by these terms. A power law is the common signature of a scale independent process that can be typified by a geometric fractal and other self-similar properties. A self-similar property is a property that exhibits a statistically similar characteristic when examined at the level of the individual, collection of individuals or the system as a whole. In other words there is no characteristic size to the distribution of the property and the property is considered scale-independent. A fractal has a self-similar geometric property; for example the jaggedness of a coastline or the branchiness of a tree are self-similar properties.

[29] A linear relationship is a unique form of a power law relationship ($y=ax^n$) were the exponent, n, is equal to 1.00 (i.e. $y = ax$)

[30] For a description of the use of power law analysis see Katz J.S. and L. Katz, (1999) "Power laws and athletic performance", *Journal of Sport Science*, 17, pp. 467-476 and Katz J.S., (1999) "The self-similar science system", *Research Policy*, 28, pp. 501-517

Step three:

Using the annual slopes determined in step two a time regression analysis was done. Figure 1b is a plot of the slopes versus time for multiple author collaborations. A linear regression gave the best fit and is given by equation (2)

$$y = 0.01x - 18 \quad (2)$$

where y is the slope and x is the year. In this case $R^2 = 0.99$. This equation and the graph tell us that the percentage of multiple authored papers increased in a linear manner by approximately 1% per year from 76% in 1981 to 88% in 1994.

In contrast to the example of multiple author collaborations given above, Figure 3 depicts the findings for the analysis of domestic collaborations. Here a power law relationship was found between the total number of domestic collaborations and the total number of papers. This is illustrated in Figure 3a by the fact that a log-log plot of the power law regression is linear and is given by equation (3)

$$y = 0.69x^{90} \quad (3)$$

where y is the number of domestic collaborations and x is the total number of papers in the 1981-1994 time period ($R^2 = 0.96$).

Since the exponent of the power law (i.e. the slope of the linear line on the log-log plot) is less than 1.00 then on average over the total time period larger HEIs had fewer domestic collaborations than smaller HEIs. Next, the exponent or log-log linear slope of the power law was determined on an annual basis and a time regression analysis was performed. Figure 3b is the result of this analysis and the best fit is given by equation (4)

$$y = 0.0006x^2 - 2.43x + 2405 \quad (4)$$

where y is the slope and x is the year ($R^2 = 0.87$). This analysis indicates that over the time interval the power law exponent increased, first slowly and then more rapidly, from around 0.88 to about 0.96. In other words the non-linear difference between the amount of collaboration in larger HEIs compared to smaller HEIs became less. In fact the relationship between domestic collaborations and papers began to approach a linear relationship by the end of the time interval.

When examining these graphs it is important to remember that most papers that are indexed in the SCI in a given year were probably funded 2-3 years earlier. Thus most of the data presented in the figures represent publications that resulted from research funds awarded approximately

between 1979 and 1992. Equally as important to note is the fact that in general power law distributions are robust and fairly impervious to moderate economic and political changes.

Appendix 2: Tables and Charts

Table 7: All disciplines: total number of publications and collaboration of various types in the 1981 - 1994 SCI

	papers	number of collaborations by type								proportion of papers by collaboration type							
Institutions	(1981-94)	multiple author	all types	domestic	inter-national	intra-institutio	intra-sectoral	inter-sectoral	industry	multiple author	all types	domestic	inter-national	intra-institutio	intra-sectoral	inter-sectoral	industry
University of Cambridge	25950	20037	11534	5849	7177	1348	2991	3450	773	0.77	0.44	0.23	0.28	0.05	0.12	0.13	0.03
University of Oxford	23501	19185	10973	6209	6394	1914	3253	3801	758	0.82	0.47	0.26	0.27	0.08	0.14	0.16	0.03
Imperial College of Science, Technology and Medicine	13018	10943	5995	3492	3395	423	2189	1896	683	0.84	0.46	0.27	0.26	0.03	0.17	0.15	0.05
University of Edinburgh	12192	10372	5969	4392	2291	1238	1721	3109	329	0.85	0.49	0.36	0.19	0.10	0.14	0.26	0.03
University of Glasgow	11689	10148	5455	3813	2275	1541	1763	2518	270	0.87	0.47	0.33	0.19	0.13	0.15	0.22	0.02
University of Manchester	11636	9885	5541	3795	2563	1232	1736	2637	420	0.85	0.48	0.33	0.22	0.11	0.15	0.23	0.04
University College London, University of London	11516	9808	6016	4000	2962	957	1869	2673	290	0.85	0.52	0.35	0.26	0.08	0.16	0.23	0.03
University of Birmingham	10592	9272	5062	3631	2112	922	1712	2488	428	0.88	0.48	0.34	0.20	0.09	0.16	0.23	0.04
University of Bristol	10571	8988	4341	2758	2098	767	1456	1619	255	0.85	0.41	0.26	0.20	0.07	0.14	0.15	0.02
University of Liverpool	10302	8755	4594	3032	2342	1072	1686	1810	418	0.85	0.45	0.29	0.23	0.10	0.16	0.18	0.04
University of Leeds	9206	7899	3885	2624	1627	827	1204	1674	370	0.86	0.42	0.29	0.18	0.09	0.13	0.18	0.04
University of Sheffield	8583	7355	3797	2531	1713	821	1446	1517	332	0.86	0.44	0.29	0.20	0.10	0.17	0.18	0.04
University of Newcastle upon Tyne	8047	6852	3615	2622	1285	1136	1130	1724	250	0.85	0.45	0.33	0.16	0.14	0.14	0.21	0.03
King's College London, University of London	7972	6921	3787	2502	1655	474	1079	1652	309	0.87	0.48	0.31	0.21	0.06	0.14	0.21	0.04
University of Southampton	7770	6643	3205	2052	1456	483	963	1289	369	0.85	0.41	0.26	0.19	0.06	0.12	0.17	0.05
University of Nottingham	7495	6561	3028	2120	1199	591	964	1354	478	0.88	0.40	0.28	0.16	0.08	0.13	0.18	0.06
The Queen's University of Belfast	5891	4930	2731	1941	1009	732	609	1493	107	0.84	0.46	0.33	0.17	0.12	0.10	0.25	0.02
University of Wales Cardiff	5668	4864	2451	1704	1026	474	865	1040	238	0.86	0.43	0.30	0.18	0.08	0.15	0.18	0.04
University of Leicester	5378	4745	2583	1552	1339	418	862	873	133	0.88	0.48	0.29	0.25	0.08	0.16	0.16	0.02
University of Aberdeen	5295	4409	2169	1546	804	598	679	1019	108	0.83	0.41	0.29	0.15	0.11	0.13	0.19	0.02
University of Dundee	5215	4473	2015	1240	959	702	628	748	105	0.86	0.39	0.24	0.18	0.13	0.12	0.14	0.02
University of Reading	4926	3999	2105	1378	951	133	651	840	248	0.81	0.43	0.28	0.19	0.03	0.13	0.17	0.05
University of Sussex	4780	3832	2063	1021	1252	85	614	484	133	0.80	0.43	0.21	0.26	0.02	0.13	0.10	0.03
University of Manchester Institute of Science and Technology	4274	3590	1677	919	918	125	586	428	229	0.84	0.39	0.22	0.21	0.03	0.14	0.10	0.05
Queen Mary and Westfield College, University of London	4251	3465	2422	1629	1311	114	1253	701	144	0.82	0.57	0.38	0.31	0.03	0.29	0.16	0.03
University of Strathclyde	4233	3699	2064	1292	953	146	730	700	269	0.87	0.49	0.31	0.23	0.03	0.17	0.17	0.06
University of Durham	4011	3342	1979	1172	1084	144	739	546	205	0.83	0.49	0.29	0.27	0.04	0.18	0.14	0.05
University of Surrey	3567	3130	1860	1213	819	161	510	827	311	0.88	0.52	0.34	0.23	0.05	0.14	0.23	0.09
University of Warwick	3192	2649	1538	816	870	65	555	330	127	0.83	0.48	0.26	0.27	0.02	0.17	0.10	0.04
University of St Andrews	3104	2603	1241	661	684	58	486	229	55	0.84	0.40	0.21	0.22	0.02	0.16	0.07	0.02
University of East Anglia	3023	2545	1402	812	714	97	489	387	148	0.84	0.46	0.27	0.24	0.03	0.16	0.13	0.05
University of Bath	3004	2602	1374	863	627	153	427	509	256	0.87	0.46	0.29	0.21	0.05	0.14	0.17	0.09
London School of Hygiene and Tropical Medicine	2996	2612	1913	1099	1151	208	456	787	42	0.87	0.64	0.37	0.38	0.07	0.15	0.26	0.01
University of Wales Swansea	2619	2175	968	478	537	90	280	233	101	0.83	0.37	0.18	0.21	0.03	0.11	0.09	0.04
University of York	2572	2149	1177	717	630	63	504	337	110	0.84	0.46	0.28	0.24	0.02	0.20	0.13	0.04
University of Exeter	2516	2061	1089	720	441	96	411	376	141	0.82	0.43	0.29	0.18	0.04	0.16	0.15	0.06

	papers	number of collaborations by type								proportion of papers by collaboration type							
Institutions	(1981-94)	multiple author	all types	domestic	inter-national	intra-institutio	intra-sectoral	inter-sectoral	industry	multiple author	all types	domestic	inter-national	intra-institutio	intra-sectoral	inter-sectoral	industry
University of Wales	2438	1967	863	467	460	74	251	251	54	0.81	0.35	0.19	0.19	0.03	0.10	0.10	0.02
Lancaster University	2364	2000	1109	749	712	69	574	479	43	0.85	0.47	0.32	0.30	0.03	0.24	0.20	0.02
Loughborough University	2308	1898	809	525	334	61	267	295	186	0.82	0.35	0.23	0.14	0.03	0.12	0.13	0.08
Royal Holloway, University of London	2253	1770	1209	838	592	116	627	349	121	0.79	0.54	0.37	0.26	0.05	0.28	0.15	0.05
University of Hull	2172	1796	822	512	387	73	313	265	111	0.83	0.38	0.24	0.18	0.03	0.14	0.12	0.05
University of Salford	2164	1908	988	556	515	73	274	337	187	0.88	0.46	0.26	0.24	0.03	0.13	0.16	0.09
Heriot-Watt University	2047	1705	855	445	457	39	301	188	99	0.83	0.42	0.22	0.22	0.02	0.15	0.09	0.05
University of Wales College of Medicine	2005	1843	917	734	281	418	267	550	38	0.92	0.46	0.37	0.14	0.21	0.13	0.27	0.02
Aston University	1986	1745	777	557	291	48	283	310	87	0.88	0.39	0.28	0.15	0.02	0.14	0.16	0.04
University of London, Miscellaneous	1937	1627	1334	1093	431	72	323	886	54	0.84	0.69	0.56	0.22	0.04	0.17	0.46	0.03
Brunel University	1913	1621	793	516	416	93	310	327	68	0.85	0.41	0.27	0.22	0.05	0.16	0.17	0.04
University of Bradford	1896	1597	776	480	343	81	254	274	137	0.84	0.41	0.25	0.18	0.04	0.13	0.14	0.07
University of Kent at Canterbury	1878	1616	728	444	369	33	245	241	103	0.86	0.39	0.24	0.20	0.02	0.13	0.13	0.05
Birkbeck College, University of London	1853	1571	1056	760	533	51	489	438	109	0.85	0.57	0.41	0.29	0.03	0.26	0.24	0.06
University of Essex	1757	1518	789	461	400	45	286	238	95	0.86	0.45	0.26	0.23	0.03	0.16	0.14	0.05
The Open University	1731	1354	847	476	484	22	378	153	33	0.78	0.49	0.27	0.28	0.01	0.22	0.09	0.02
University of Wales, Aberystwyth	1677	1372	627	351	348	27	187	193	54	0.82	0.37	0.21	0.21	0.02	0.11	0.12	0.03
Keele University	1627	1388	912	559	496	55	331	311	50	0.85	0.56	0.34	0.30	0.03	0.20	0.19	0.03
The University of Stirling	1360	1077	621	352	327	21	187	194	53	0.79	0.46	0.26	0.24	0.02	0.14	0.14	0.04
Cranfield University	1254	999	456	296	199	22	152	175	96	0.80	0.36	0.24	0.16	0.02	0.12	0.14	0.08
Royal Veterinary College	1165	948	458	371	125	66	129	263	79	0.81	0.39	0.32	0.11	0.06	0.11	0.23	0.07
School of Pharmacy, University of London	1133	1028	575	410	233	19	253	203	94	0.91	0.51	0.36	0.21	0.02	0.22	0.18	0.08
City University	1052	840	441	289	194	13	169	145	40	0.80	0.42	0.27	0.18	0.01	0.16	0.14	0.04
University of Ulster	948	696	373	257	153	40	181	105	11	0.73	0.39	0.27	0.16	0.04	0.19	0.11	0.01
University of Portsmouth	792	669	397	244	185	47	126	157	58	0.84	0.50	0.31	0.23	0.06	0.16	0.20	0.07
University of Wales Institute of Science and Technology	788	688	261	199	75	15	108	113	50	0.87	0.33	0.25	0.10	0.02	0.14	0.14	0.06
University of North London	708	568	387	310	123	13	213	128	47	0.80	0.55	0.44	0.17	0.02	0.30	0.18	0.07
University of Plymouth	692	588	337	262	103	21	133	178	59	0.85	0.49	0.38	0.15	0.03	0.19	0.26	0.09
Liverpool John Moores University	677	539	377	294	144	10	189	153	52	0.80	0.56	0.43	0.21	0.01	0.28	0.23	0.08
University of Hertfordshire	492	429	271	213	111	11	127	106	43	0.87	0.55	0.43	0.23	0.02	0.26	0.22	0.09
Sheffield Hallam University	481	420	266	237	44	49	171	104	46	0.87	0.55	0.49	0.09	0.10	0.36	0.22	0.10
Wye College, University of London	439	350	168	103	78	2	41	80	9	0.80	0.38	0.23	0.18	0.00	0.09	0.18	0.02
London Guildhall University	420	333	182	140	52	1	90	62	27	0.79	0.43	0.33	0.12	0.00	0.21	0.15	0.06
University of Central Lancashire	410	381	293	216	172	11	177	83	14	0.93	0.71	0.53	0.42	0.03	0.43	0.20	0.03
Manchester Metropolitan University	393	343	261	212	87	35	104	127	87	0.87	0.66	0.54	0.22	0.09	0.26	0.32	0.22
The Nottingham Trent University	391	336	172	159	18	5	94	84	52	0.86	0.44	0.41	0.05	0.01	0.24	0.21	0.13

Institutions	papers (1981-94)	number of collaborations by type: multiple author	all types	domestic	inter-national	intra-institutio	intra-sectoral	inter-sectoral	industry	proportion of papers by collaboration type: multiple author	all types	domestic	inter-national	intra-institutio	intra-sectoral	inter-sectoral	industry
Coventry University	385	277	133	110	31	10	67	51	30	0.72	0.35	0.29	0.08	0.03	0.17	0.13	0.08
De Montfort University	377	315	172	141	41	7	86	74	19	0.84	0.46	0.37	0.11	0.02	0.23	0.20	0.05
University of Greenwich	352	283	204	165	53	10	89	93	35	0.80	0.58	0.47	0.15	0.03	0.25	0.26	0.10
Oxford Brookes University	339	274	207	146	83	9	90	74	18	0.81	0.61	0.43	0.24	0.03	0.27	0.22	0.05
Scottish Universities Research & Reactor Centre	293	274	262	220	84	5	186	61	6	0.94	0.89	0.75	0.29	0.02	0.63	0.21	0.02
University of Sunderland	286	233	167	144	34	7	96	58	17	0.81	0.58	0.50	0.12	0.02	0.34	0.20	0.06
University of Northumbria at Newcastle	280	241	169	150	24	7	96	72	44	0.86	0.60	0.54	0.09	0.03	0.34	0.26	0.16
University of Westminster	267	236	139	107	43	1	47	71	28	0.88	0.52	0.40	0.16	0.00	0.18	0.27	0.10
Napier University	264	237	154	138	23	21	70	82	51	0.90	0.58	0.52	0.09	0.08	0.27	0.31	0.19
The Robert Gordon University	262	237	154	138	31	19	100	47	9	0.90	0.59	0.53	0.12	0.07	0.38	0.18	0.03
Goldsmiths College, University of London	262	164	123	76	57	2	57	21	0	0.63	0.47	0.29	0.22	0.01	0.22	0.08	0.00
South Bank University	258	180	127	118	16	2	95	38	12	0.70	0.49	0.46	0.06	0.01	0.37	0.15	0.05
Kingston University	253	196	105	83	38	2	61	36	11	0.77	0.42	0.33	0.15	0.01	0.24	0.14	0.04
University of Brighton	252	205	124	102	29	8	61	58	28	0.81	0.49	0.40	0.12	0.03	0.24	0.23	0.11
London School of Economics and Political Science, University of	220	104	76	47	40	3	36	13	0	0.47	0.35	0.21	0.18	0.01	0.16	0.06	0.00
University of Paisley	211	173	121	92	60	7	51	55	6	0.82	0.57	0.44	0.28	0.03	0.24	0.26	0.03
University of Wolverhampton	195	174	114	96	27	2	50	51	13	0.89	0.58	0.49	0.14	0.01	0.26	0.26	0.07
University of the West of England, Bristol	192	144	93	83	18	2	54	42	17	0.75	0.48	0.43	0.09	0.01	0.28	0.22	0.09
Glasgow Caledonian University	186	155	107	86	34	6	64	29	6	0.83	0.58	0.46	0.18	0.03	0.34	0.16	0.03
University of Glamorgan	180	150	70	54	19	11	37	23	14	0.83	0.39	0.30	0.11	0.06	0.21	0.13	0.08
University of Huddersfield	165	131	63	51	14	5	37	26	15	0.79	0.38	0.31	0.08	0.03	0.22	0.16	0.09
University of Teesside	165	107	68	57	15	12	49	14	9	0.65	0.41	0.35	0.09	0.07	0.30	0.08	0.05
Staffordshire University	158	139	94	75	25	7	64	17	8	0.88	0.59	0.47	0.16	0.04	0.41	0.11	0.05
Leeds Metropolitan University	131	99	73	66	19	3	46	28	7	0.76	0.56	0.50	0.15	0.02	0.35	0.21	0.05
University of East London	116	96	55	45	19	2	28	22	6	0.83	0.47	0.39	0.16	0.02	0.24	0.19	0.05
Middlesex University	106	68	38	31	9	1	21	15	6	0.64	0.36	0.29	0.08	0.01	0.20	0.14	0.06
University of Abertay Dundee	99	72	39	16	28	1	12	7	1	0.73	0.39	0.16	0.28	0.01	0.12	0.07	0.01
University of Buckingham	75	39	30	21	11	0	14	9	1	0.52	0.40	0.28	0.15	0.00	0.19	0.12	0.01
University of Lincolnshire and Humberside	69	63	40	35	9	0	29	9	8	0.91	0.58	0.51	0.13	0.00	0.42	0.13	0.12
Institute of Education, University of London	69	47	32	24	11	0	13	19	0	0.68	0.46	0.35	0.16	0.00	0.19	0.28	0.00
St David's University College	48	28	27	19	8	0	17	3	1	0.58	0.56	0.40	0.17	0.00	0.35	0.06	0.02
Anglia Polytechnic University	32	25	22	18	6	0	17	7	2	0.78	0.69	0.56	0.19	0.00	0.53	0.22	0.06
School of Oriental and African Studies, University of London	24	6	3	1	2	0	1	0	0	0.25	0.13	0.04	0.08	0.00	0.04	0.00	0.00
University of Central England in Birmingham	22	19	12	11	1	1	7	7	1	0.86	0.55	0.50	0.05	0.05	0.32	0.32	0.05
London Business School, University of London	16	5	5	3	3	0	1	2	2	0.31	0.31	0.19	0.19	0.00	0.06	0.13	0.13
Queen Margaret University College	10	8	6	6	1	1	2	5	0	0.80	0.60	0.60	0.10	0.10	0.20	0.50	0.00
Bournemouth University	8	7	5	4	2	0	2	3	1	0.88	0.63	0.50	0.25	0.00	0.25	0.38	0.13
Thames Valley University	1	1	1	1	0	0	0	1	0	1.00	1.00	1.00	0.00	0.00	0.00	1.00	0.00

Figures 9 - 40, 42 - 45

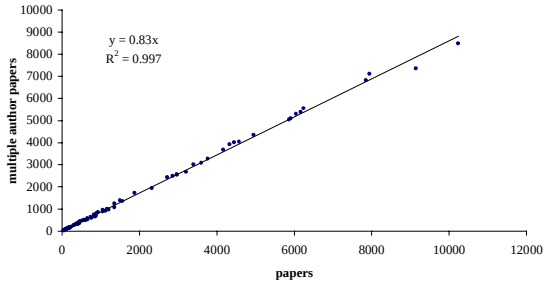

Figure 9a

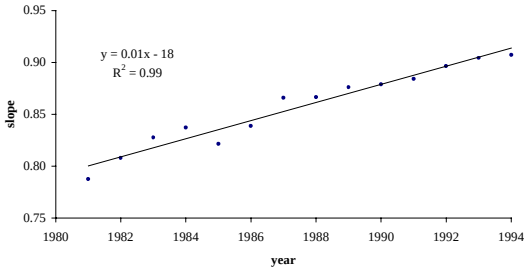

Figure 9b

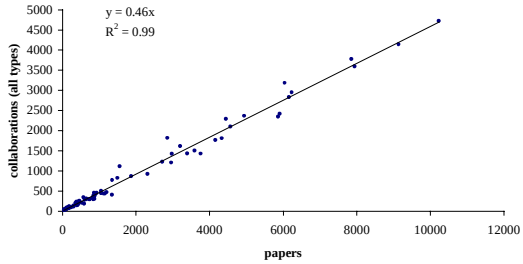

Figure 10a

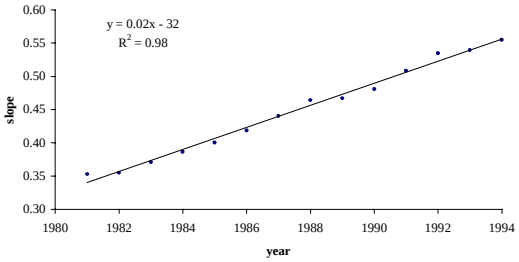

Figure 10b

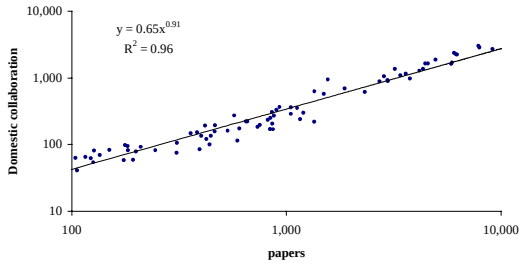

Figure 11a

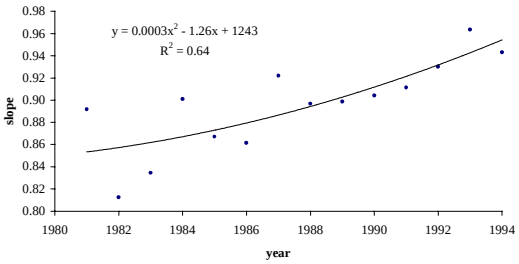

Figure 11b

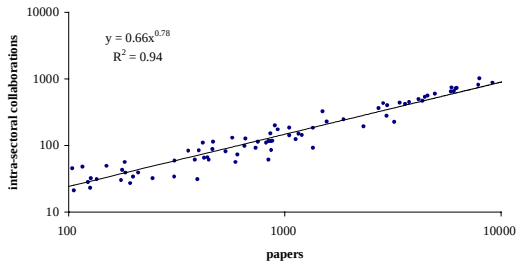

Figure 12a

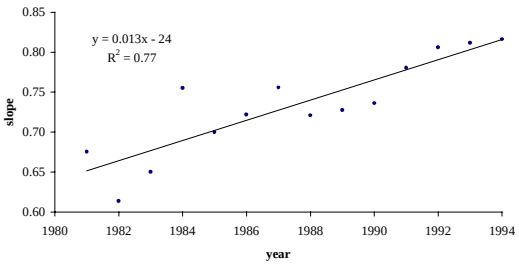

Figure 12a

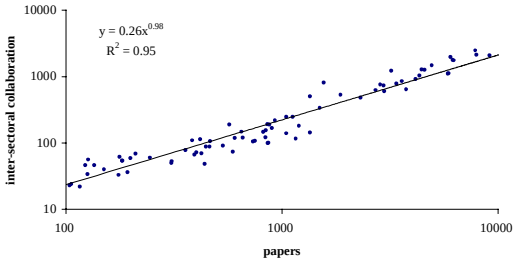

Figure 13a

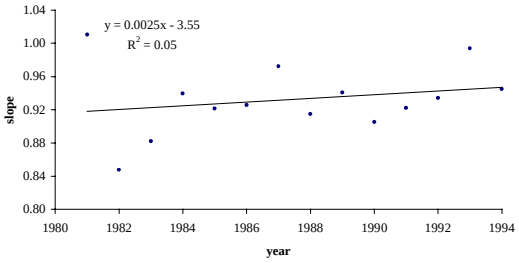

Figure 13b

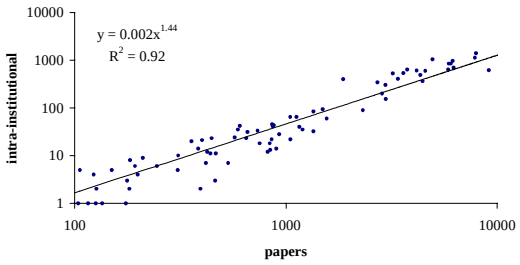

Figure 14a

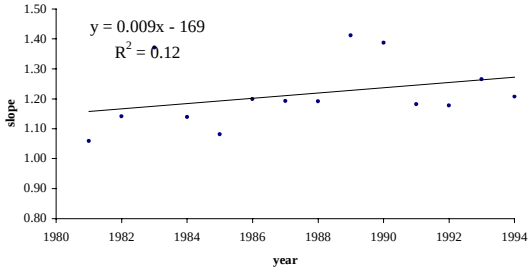

Figure 14b

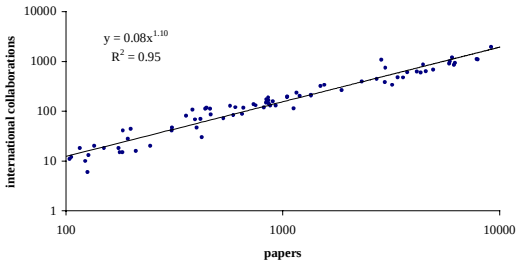

Figure 15a

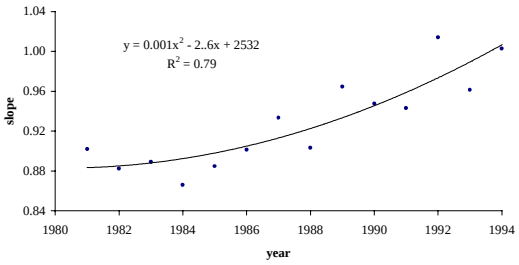

Figure 15b

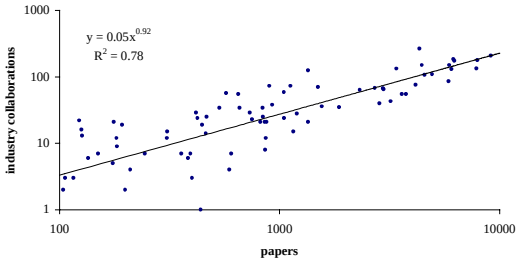

Figure 16a

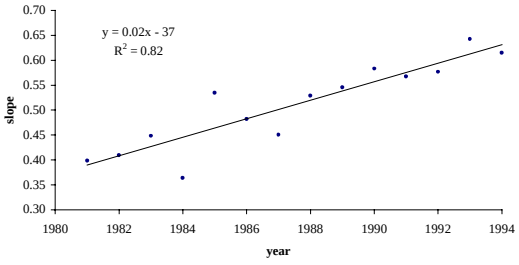

Figure 16b

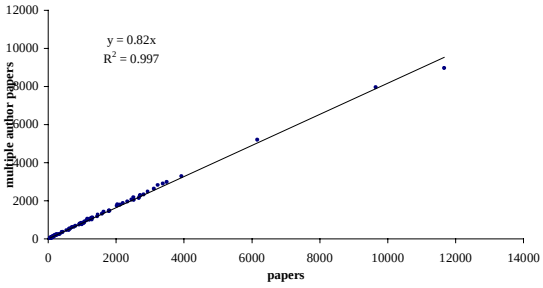

Figure 17a

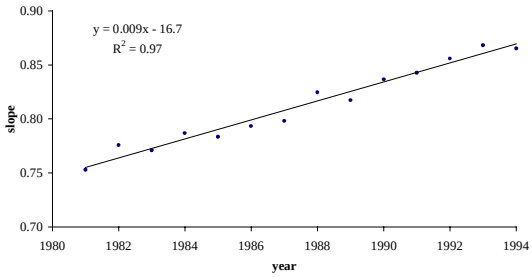

Figure 17b

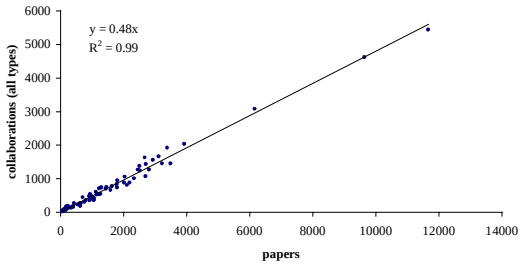

Figure 18a

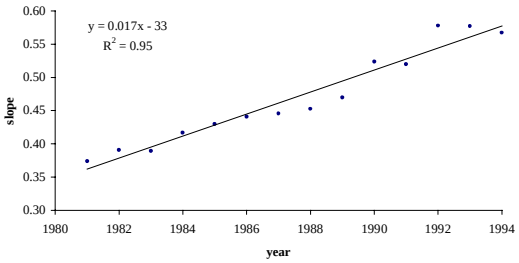

Figure 18b

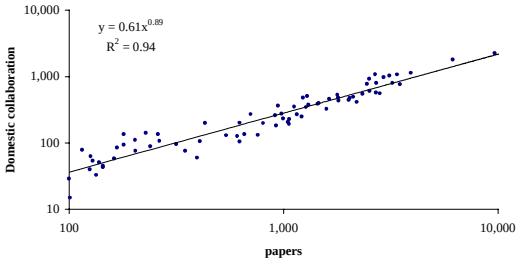

Figure 19a

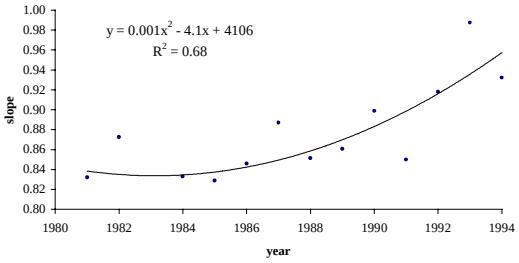

Figure 19b

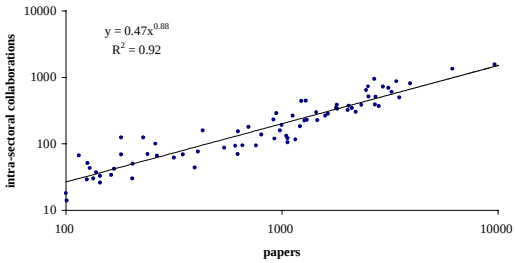

Figure 20a

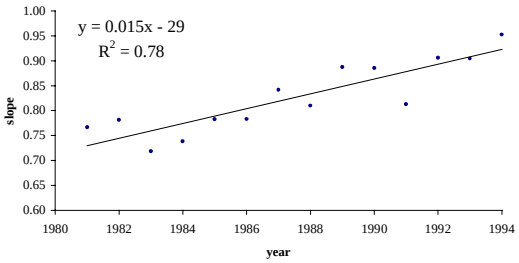

Figure20a

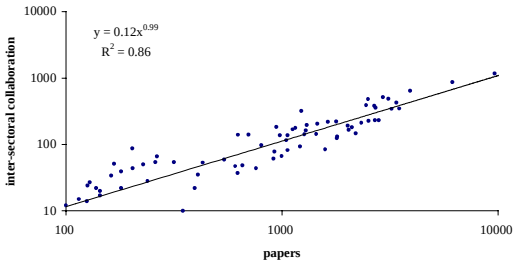

Figure 21a

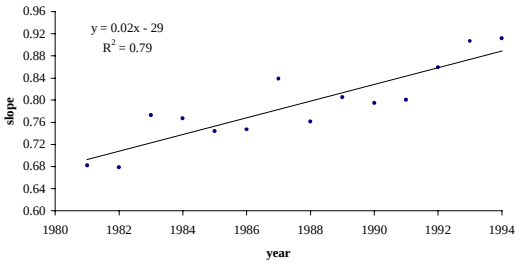

Figure 21b

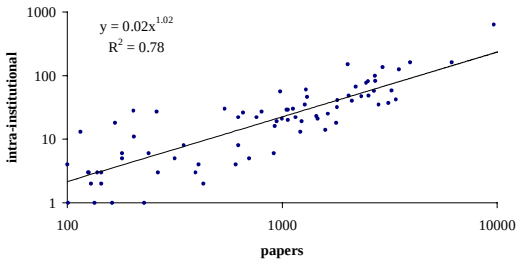

Figure 22a

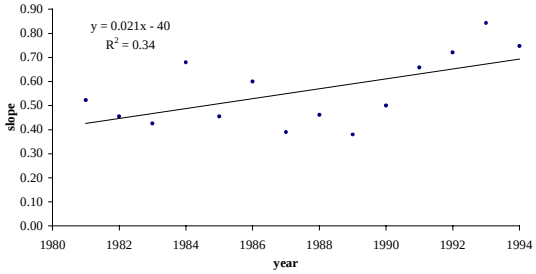

Figure 22b

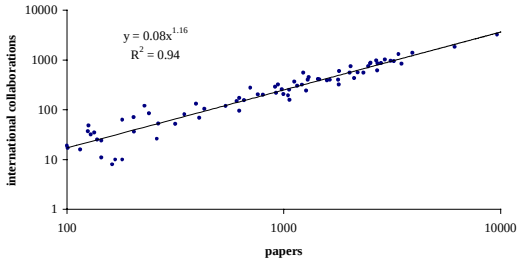

Figure 23a

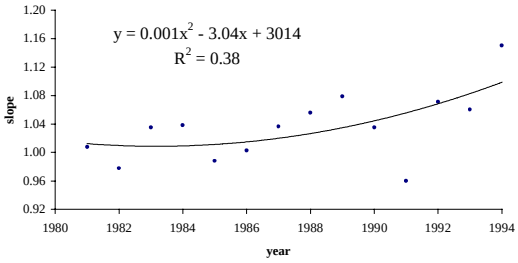

Figure 23b

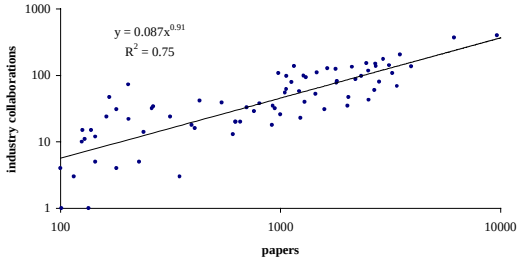

Figure 24a

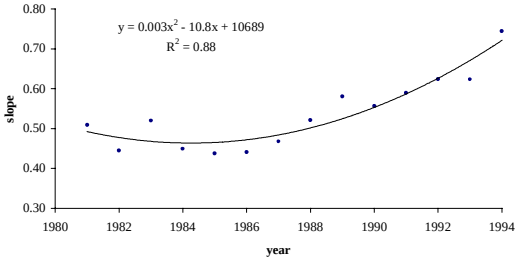

Figure 24b

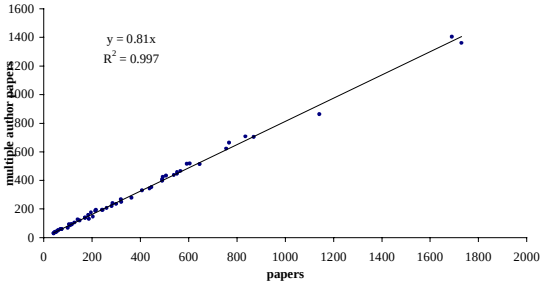

Figure 25a

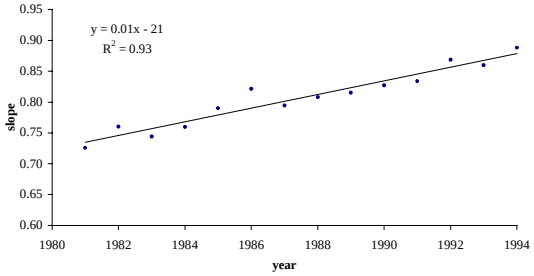

Figure 25b

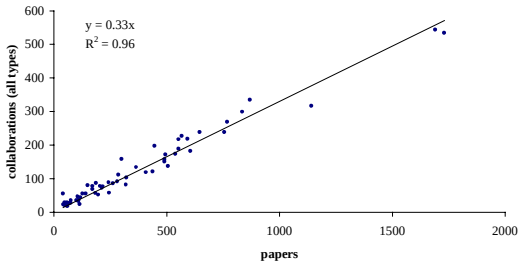

Figure 26a

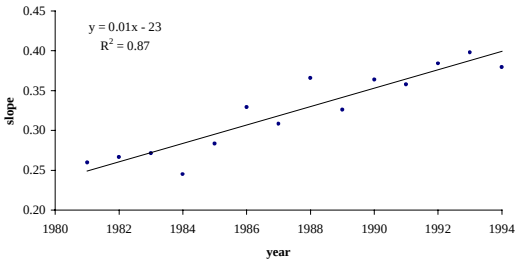

Figure 26b

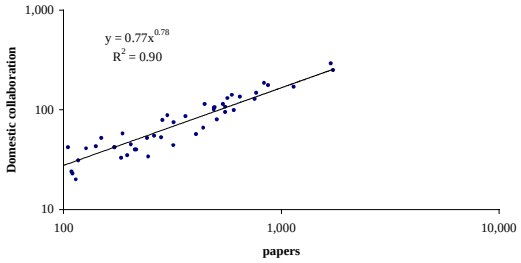

Figure 27a

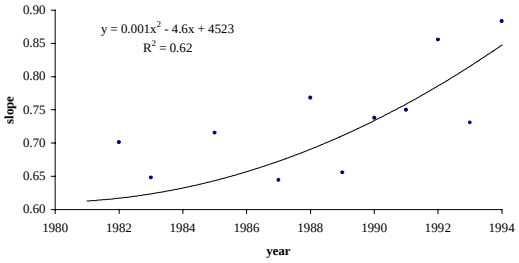

Figure 27b

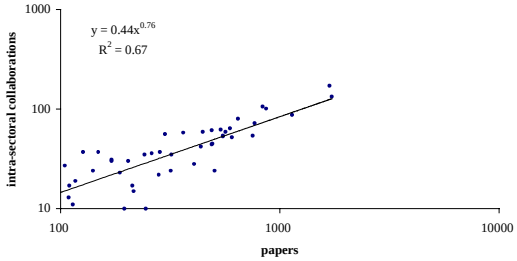

Figure 28a

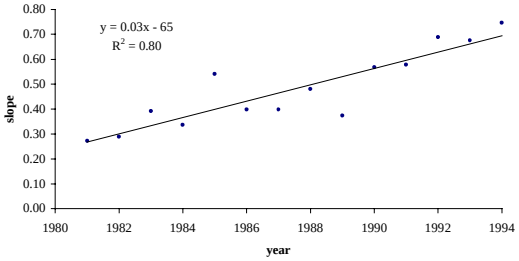

Figure 28a

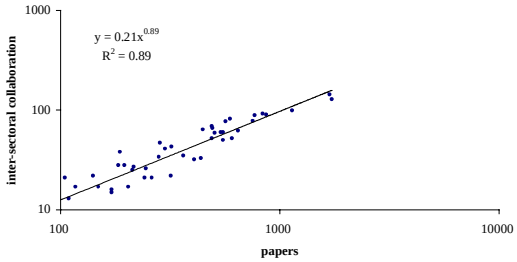

Figure 29a

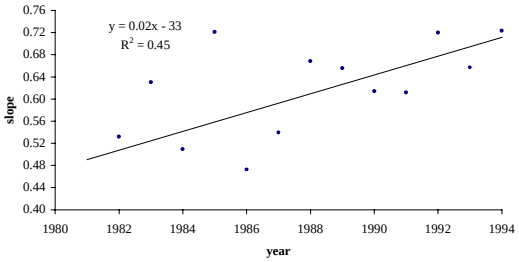

Figure 29b

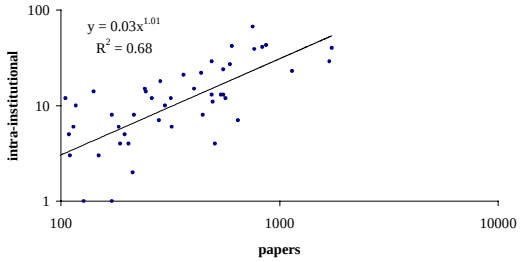

Figure 30a

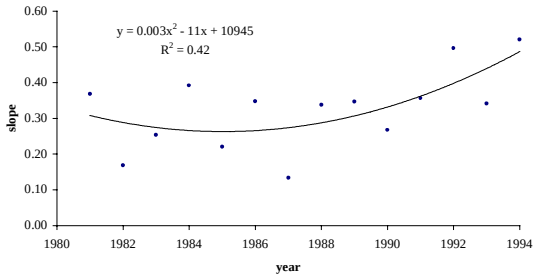

Figure 30b

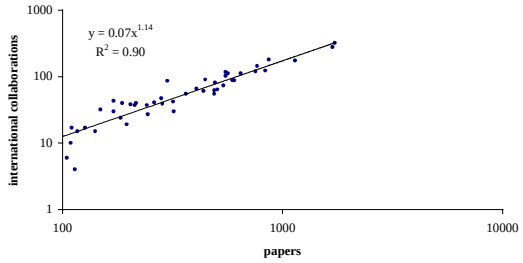

Figure 31a

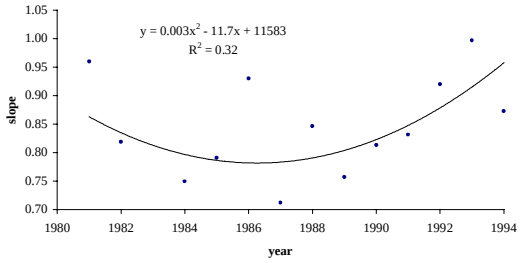

Figure 31b

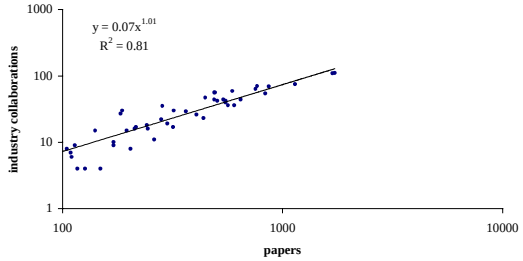

Figure 32a

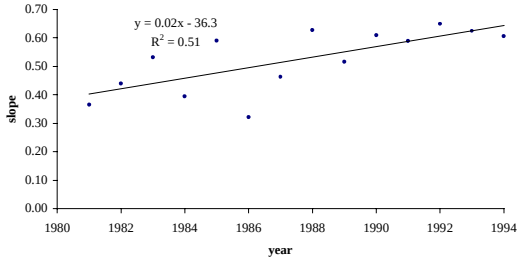

Figure 32b

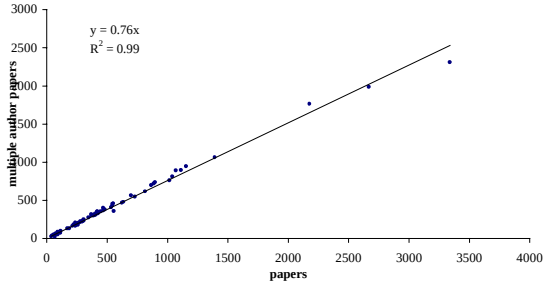

Figure 33a

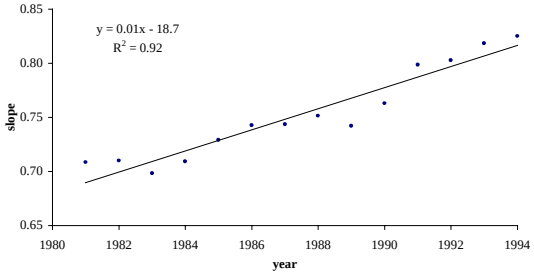

Figure 33b

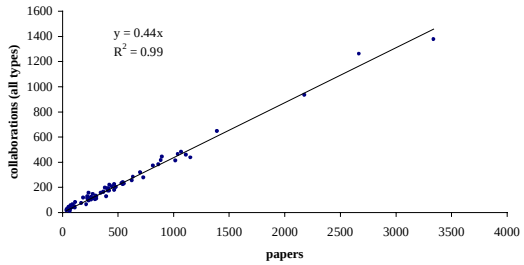

Figure 34a

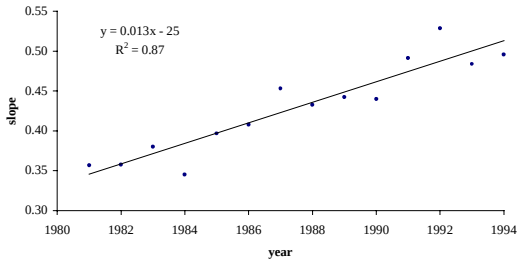

Figure 34b

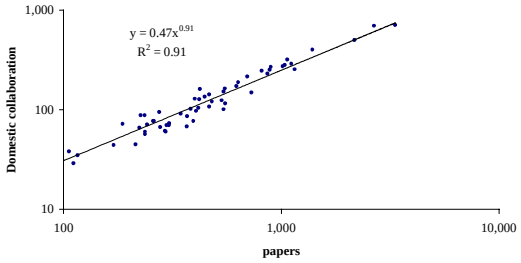

Figure 35a

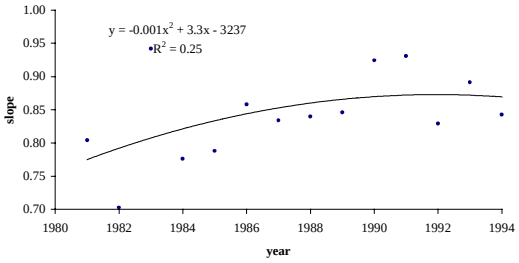

Figure 35b

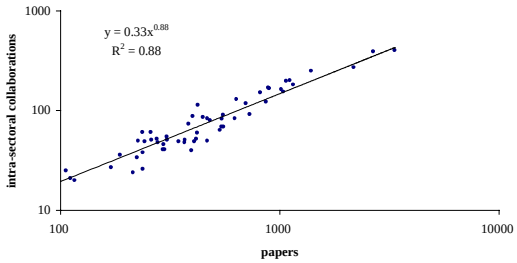

Figure 36a

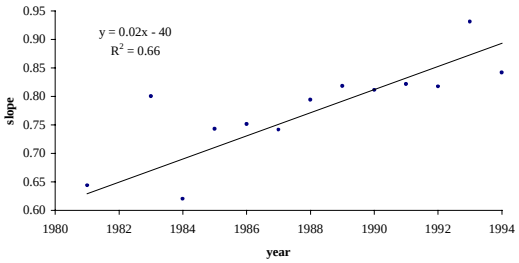

Figure 36a

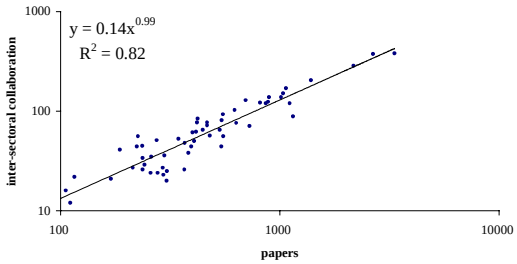

Figure 37a

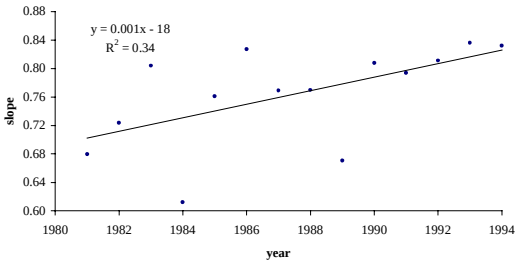

Figure 37b

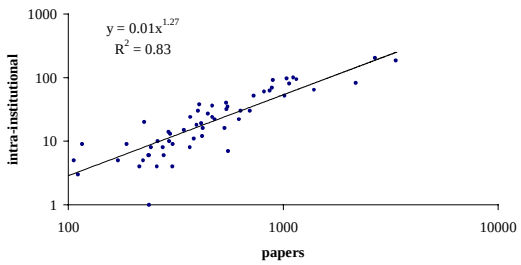

Figure 38a

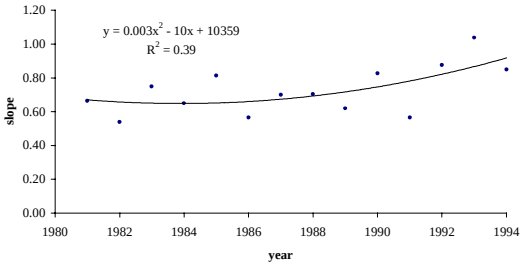

Figure 38b

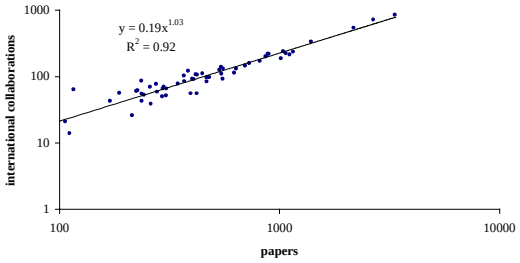

Figure 39a

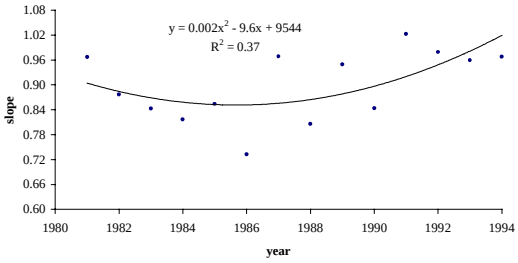

Figure 39b

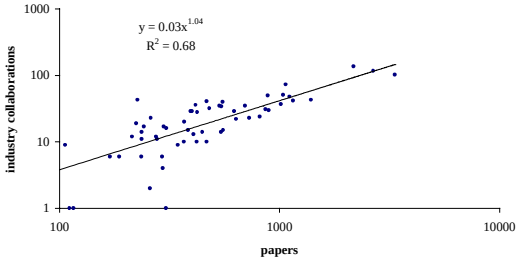

Figure 40a

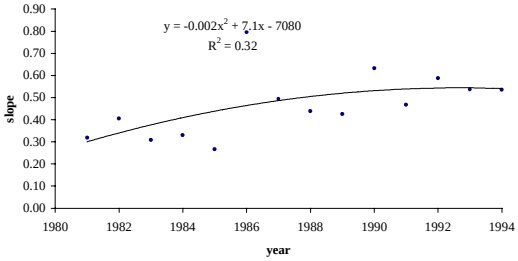

Figure 40b

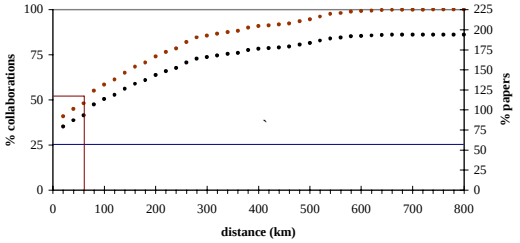

Figure 42a

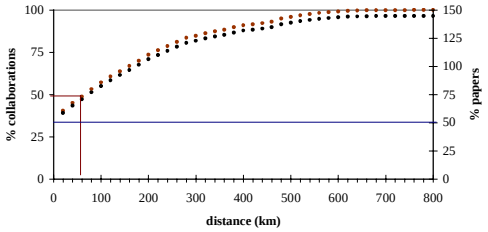

Figure 42b

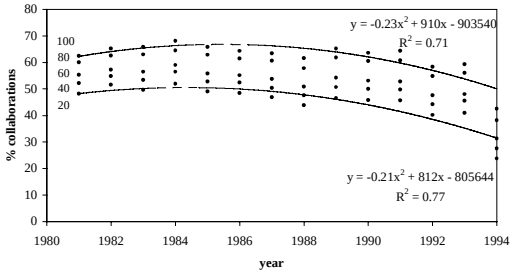

Figure 42c
including London and Greater London insitutions

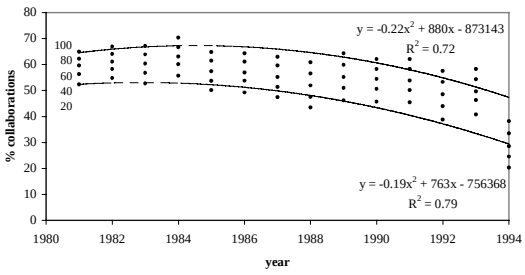

Figure 42d
excluding London & Greater London insitutions

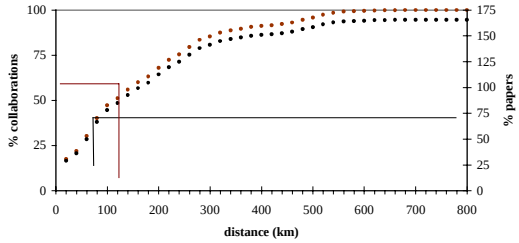

Figure 43a

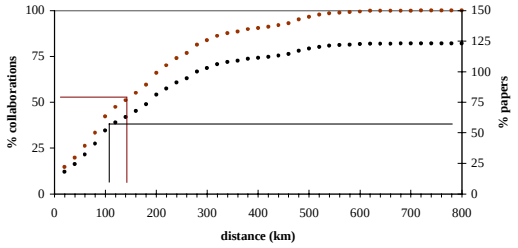

Figure 43b

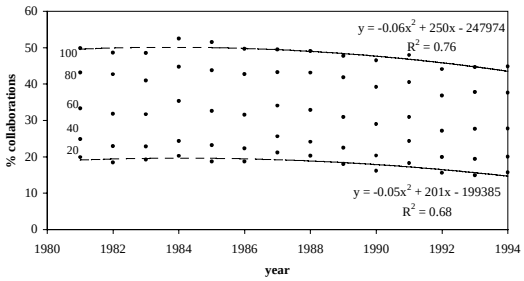

Figure 43c
including London and Greater London insitutions

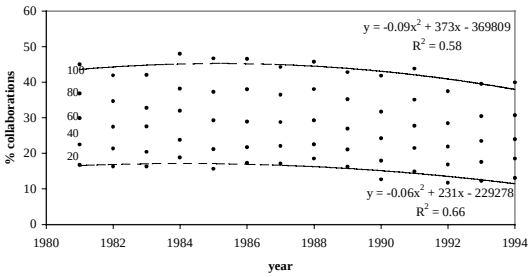

Figure 43d
excluding London & Greater London insitutions

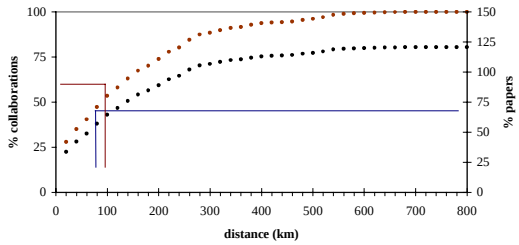

Figure 44a

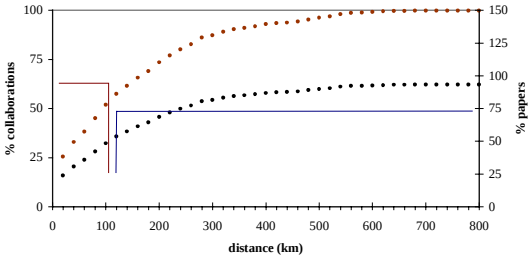

Figure 44b

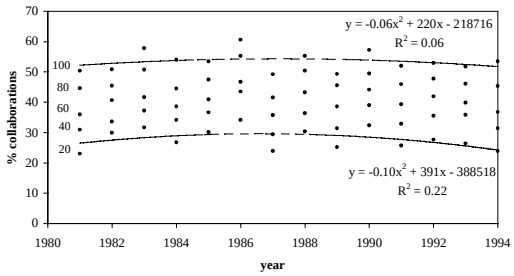

Figure 44c
including London and Greater London insitutions

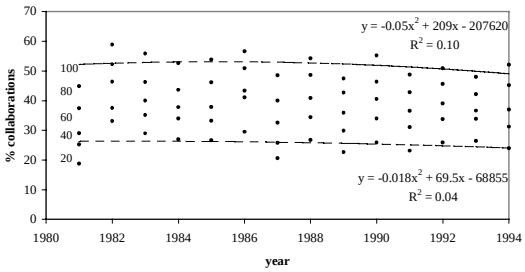

Figure 44d
excluding London & Greater London insitutions

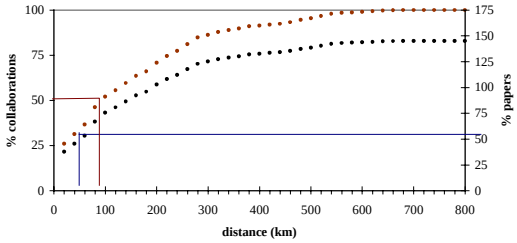

Figure 45a

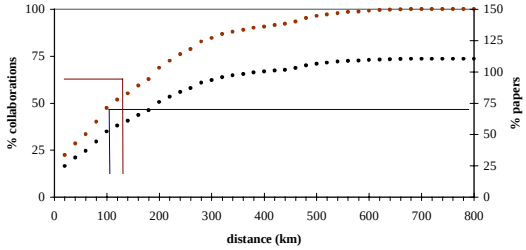

Figure 45b

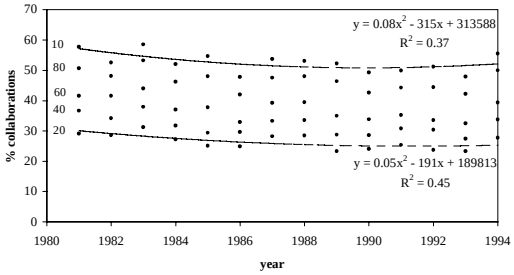

Figure 45c
including London and Greater London insitutions

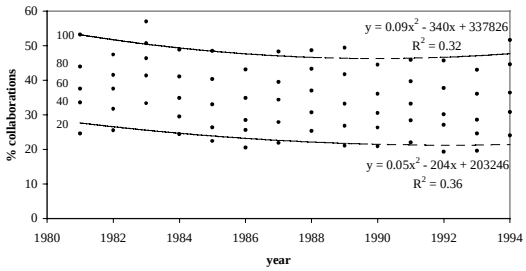

Figure 45d
excluding London & Greater London insitutions

Appendix 3: Case study methodology

Institutional case studies

The case studies were designed to provide detailed empirical evidence about institutional and researcher policy and practice in relation to collaborative approaches to research. The HEIs and individual researchers from a range of disciplines were selected to be as representative of the sector as possible. This facet of the research was conducted by means of a combination of qualitative methods. The main elements were:
policy review and evaluation;
analysis of institutional strategic and mission related documentation;
extensive semi-structured interviews with senior institutional leaders and managers as well as practising researchers involved in a wide range of collaboration activities;
reviews of published and web-based literature and previous research.

The case studies concentrated on establishing current attitudes among key players in the research system towards the changing nature of research activity, collaboration and creativity, funding and assessment, incentives and barriers. These qualitative data afforded alternative perspectives on some of the key issues tackled through bibliometric analysis, particularly the different meanings attached to the concept of collaboration. They also enabled evidence-based examination of institutional and personal approaches to the organisation, management and practice of collaboration in a range of HEI and disciplinary case study settings.

The case study sites were selected to reflect differences across the sector in terms of research intensity, regional groupings of institutional collaborators, institutional type, size and specialisation, university/industry/government collaborations. Institutions selected were:

North East: Durham*, Newcastle, Northumbria
Yorkshire and the Humber: Leeds, Sheffield, York
North West: Manchester, Manchester Metropolitan, UMIST
West Midlands: Coventry
East: Cranfield*, UEA
London: Imperial College
Scotland: Edinburgh, Glasgow
Wales: Cardiff
Government research establishments: CLRC; CSL

(* Although included in the initial selection these HEIs did not participate in the project)

Selection procedures for individual researchers

The strategy in each case study site was to cover a range of levels and disciplines: Vice-Chancellors: Pro Vice-Chancellors with research responsibility; Directors of research office or equivalent; Deans and Heads of Resource Centres; individual researchers across a range of disciplines.

Selection of researchers was based on two approaches. First, for researchers in science, engineering and social sciences we selected four units of assessment (UOAs) from the list consolidated across several projects. These include Chemistry (UOA 18), Computer Science (UOA 25), Civil Engineering (UOA 28) and Sociology (UOA 42). For each of these UOAs we then selected the highest overlap sub-field in the ISI's bibliometric database. These were:
Chemistry (UOA 18): 1996 RAE had 5,685 articles in 525 journals. This overlaps the ORG organic chemistry field in ISI's database with 1,041 of those articles in common journals.
Computer Science (UOA 25): 1,910 articles in 507 journals. ISI's CTA category captures 545 of these articles.
Civil Engineering (UOA 28): 1,304 in 343 journals. The category CIV captures 388.
Sociology (UOA 42): 1,122 in 393. S/A captures 387.

For each of these ISI fields we selected authors of collaborative articles/papers registered in the ISI/BIDS 1998 (or 1997) database of publications whose institutional address accords with the case study HEIs. In cases where more than one article has been identified with authors from the case study institution then highest journal impact factor was used as the selection criterion.

This procedure generated collaborative papers/authors published in a range of higher and medium impact journals. The intention was to hold disciplinary factors constant across the case studies and to concentrate on exploring the dynamics of specific researcher/institutional collaborations within the chosen academic fields. The method generated a wide range of collaborations across the case study HEIs including joint and multiple authored papers, intra and inter-regional, and international institutional papers, as well as example of university-industry collaborations. The method also produced co-authors from a range of disciplinary units, research centres and industrial partners including professors, senior lecturers, lecturers and members of research staff at various levels.

Equivalent data is less comprehensive for arts and humanities (including the performing arts) disciplines. For researchers in these fields the procedure was to ask HEIs to nominate individuals involved in active, externally funded research collaboration with colleagues based in other institutions.