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INDICATORS FOR SYSTEMS OF INNOVATION

- *a bibliometrics-based approach*

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ABSTRACT

In bibliometric data lie opportunities to develop indicators relevant to central concerns of new theories of innovation, specifically networks within and between national systems, and variety and diversity of capability. The data can make a unique contribution to pictures compiled from multiple sources, providing an unrivalled objective, disaggregated and internationally comparable time series signature of networks and capabilities. In this paper, we present what we call *systemic bibliometric indicators* to distinguish our disaggregated, network-focused, time series approach from classical bibliometrics.

On average, the British innovation system participates in 9% of the publications produced by the global innovation system and 28.5% of those publications involving an EU institution. Its participation is approximately 20% greater than the German innovation system and 70% greater than the French system.

UK innovation system papers have slightly less impact on the global innovation system than US innovation system papers but more impact than any of the other innovation systems we have examined. The growth in impact of UK research on the global world-wide research system is the same as the Germany system, less than the US system and greater than the remaining innovation systems.

The distribution of the top twenty scientific subfields world-wide is quite different from the distribution in the global system and other innovation systems. Five of the world's top twenty subfields (*applied physics, condensed matter physics, analytical chemistry, physiology* and *cardiovascular systems*) are not ranked in the top twenty UK subfields. The size distribution of scientific subfields suggests that the British innovation system has its own unique characteristics.

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INTRODUCTION

This report develops an indicator approach for the analysis of systems of innovation. The evolution of European economies and our advancing understanding of technological innovation has led to a call for new types of statistical data and indicators. The argument of this report is that bibliometrics, so successful at portraying research output and impact, can be used to develop new indicators with great potential to address emerging concerns such as institutional level analysis of capabilities and networks; that is, it can give us key insights into the structure and dynamics of national innovation systems. Bibliometric indicators have been used for policy purposes for 20 years, since about 1976 (Narin, 1976) and were developed to address central concerns of classical science policy - level of research output and its impact. In this sense they have been so useful that they are incorporated in regular statistical series such as the National Science Foundation's (NSF) science indicators and are used in high profile analyses by leading scientists and policy makers (May, 1997).

Somewhat unfortunately, bibliometric practitioners and their indicators are so firmly associated with these classical uses, that often no further potential is seen. In contrast, we believe that in bibliometric data lie opportunities to develop indicators relevant to central concerns of new theories of innovation, specifically networks within and between national systems, and variety and diversity of capability. As with any type of data, bibliometric indicators will not provide a perfect, all encompassing, ideal picture of the processes we seek to understand. However, they can make a unique contribution to pictures compiled from multiple sources, providing an unrivalled objective, disaggregated and internationally comparable time series signature of networks and capabilities.

In this paper, we attempt to hint at some of these possibilities. We present what we call *systemic bibliometric indicators* to distinguish our disaggregated, network-focused, time series approach from classical bibliometrics. However, we begin with the classical indicators and develop the new system from there. We do this at three levels of aggregation:

1. national - comparing national systems;
2. sectoral - comparing UK research sectors;
3. intra-sectoral - comparing UK industrial sectors.

Classical bibliometrics focuses on the national level and international comparisons. Even with the emerging emphasis on disaggregation, international comparison and analysis of interdependencies will be required, and we illustrate the ease with which national systems can be set in an international context bibliometrically. The sectoral and intra-sectoral level data we have developed are possible due to recent advances in desktop computing. These data can make their most powerful contribution in the context of the new approaches to innovation - although we do not make those connections here (for more detailed efforts in this direction see Hicks and Katz, 1997).

For each level, we propose four general types of indicators:

1. *size* or number of papers, the classical measure of research output;
2. *impact* or number of citations, again a classical bibliometric indicator;
3. *diversity* in capabilities derived from size, impact, size growth and impact growth distributions across scientific fields;
4. *interaction* in research networks as evidenced by collaborative research output and derived using size, impact and diversity measures of co-authored papers.

Before exploring the indicators, we provide a basic introduction to bibliometric analysis: the state-of-the-art in government-produced bibliometric indicators, limitations of the indicators, advantages and disadvantages of data sources, and method - *i.e.* how to produce the indicators.

We place two caveats on this paper. First, many well-informed observers (Gibbons, *et al*., 1994; Price, 1963; Ziman, 1994) of science and technology systems believe that science is an international system. We take it as a fact that science is international. Furthermore, we believe that this *global science system* is one foundation on which a *global innovation system* has evolved and it is a product of the dynamic interaction between national systems that partially moulds this meta-system of innovation.

And secondly, we can only provide a *glimpse* of the value of bibliometric indicators for exploring innovation systems. For example, using the UK bibliometric data we have produced hundreds of indicators. In this paper we provide only a few graphs and tables as evidence of the value of bibliometric indicators. In order to provide more definitive evidence we would have to provide the reader with a database of indicators data so that the reader could search for answers to specific questions. We have constructed a prototype of such a database with a graphical interface for the British science system (Hicks and Katz, 1997).

AN OVERVIEW OF BIBLIOMETRIC ANALYSIS

The state-of-the-art in bibliometric indicators

For more than twenty years, bibliometric indicators have been published by the US NSF in their *Science and Engineering Indicators* (National Science Board). Bibliometric indicators were included in the European Union's first science and technology indicators report (European Commission, 1994). These bibliometric indicators along with patent and R&D expenditure data provide a good basis from which the state-of-the-art can be extended.

Most bibliometric indicators are compiled at the national level. For each country several statistics are produced: the amount a nation publishes, the amount that their researchers collaborate internationally and the extent to which their papers are cited. Sometimes these indicators are provided as a time series for a few science fields (biology, physics, chemistry, etc.). Using these indicators, policy makers can assess whether the quantity and impact of their country's research output is increasing or decreasing relative to that of other countries.

Data concerning the internal dynamics of national systems are more limited. For the first time, the NSF incorporated one table of sectoral publication and citation counts with its recent indicators. This provides some simple overview indicators of the size and impact of the US knowledge base. The only subnational indicator provided in the EU report was a table listing the largest publishing institutions in a few member states.

It seems to us that the lack of regularly published indicators examining the internal dynamics of national science systems is unfortunate. We believe that carefully designed systemic bibliometric indicators can build on the standard indicators to portray dynamics within a national system of innovation (Nelson, 1993, Lundvall, 1992) and reveal its interactions with other systems of innovation.

What bibliometric indicators do and do not indicate

Papers are particularly valuable as the basis for indicators because they not only represent an increment to publicly available knowledge (indicating output), they can be graded by impact (a proxy for quality), and they contain traces of linkages between institutions and nations. Jointly authored papers reflect collaborative research, for example, between industry and universities and are one indicator of links between researchers (Katz and Martin, 1997). The cited references in papers indicate use of research by others enabling analysis of the extent to which, for example, industry relies on domestic and foreign sources of knowledge (Hicks *et al.*, 1994). Potentially, the publishing archive can even reveal the movement of researchers among institutions and sectors. Thus bibliometric indicators can track the institutional linkages crucial to realising spillovers and the possibly strong multiplier between public institution research and commercial industrial development (OECD, 1992, p127). Bibliometric indicators allow us to examine the development and flow of research-based knowledge thus enabling us to map the structure and changing shape of knowledge resources in the economy and society as a whole.

However, bibliometric indicators cannot capture all knowledge production in a society and inform us of its quality. As with any indicator, they fall short of the ideal in several ways. First, papers represent the published output of laboratory-based activity. They will not, for example, capture the innovative contributions made by software development and database construction which is a large and growing segment of knowledge production.

Second, there is not a one-to-one match between publication output and R&D expenditure. University faculties have incentives to publish while industrial researchers do not. Publication takes second place to secrecy or appropriation in industrial and military research and to production of maps, reference works or service to industry in some government research. On the other hand, our data indicate that papers are produced from settings where no formal R&D is recorded by statisticians. Thus publication output by no means equates to R&D activity. Rather publishing equates to producing publicly available, research-based, codified knowledge.

Published information is but one component of knowledge which also has tacit and material elements. The codified element has the advantage of being easily distributed and so diffuses far and wide. Thus papers help diffuse knowledge by conveying useful information but this is not all; they also act as signals. Neither the material nor tacit components of knowledge can be communicated in a publication. However, a paper describing research points to these other elements and thus indicates that the authors possess certain tacit knowledge, materials and devices. Readers learn the area in which the researchers work, the names of the materials used, the techniques used to manipulate them, and the astute reader assesses the technical quality of the work. Readers are alerted to the existence of underlying tacit knowledge, skills, substances and so on possessed by the authors. Published papers thus point to unpublishable resources, so papers indicate both the production of new information and presence of scientific and technical capability residing in tacit knowledge, skills, materials and devices (Hicks, 1995).

Third, bibliometric indicators do not represent all publishing. The indicators are usually based on one American produced database, the *Science Citation Index* (SCI) (for reasons explained below). Although the SCI is international in coverage, it has a certain amount of bias. It contains more minor US journals than minor European journals, and non-English language journals are not as comprehensively indexed. The SCI also does not go into great depth in the trade and technical literature. The 3,200 or so SCI journals were selected in the first instance because they have a high international impact. Indeed, coverage of the database has been criticised because the criteria for the inclusion of second-rank journals are inconsistent and applied fields are not well covered (European Commission 1994, pp 33-34). In addition, only articles, notes and reviews are usually counted in bibliometric indicators, because they are most likely to report substantial research results and be peer reviewed; discussions, letters, editorials and meeting abstracts are excluded. From a non-English speaking world perspective bibliometric indicators represent only international level, predominantly English language, higher impact, peer-reviewed, publicly available scientific and technological research output.

Finally, citation counts, that is the number of references to a publication, cannot tell us about the "quality" of a piece of research. Ideally, we would like to be able to know which work is of high quality and which is not. Citation counts can only give us a indication of the "impact" research has had on work that follows. Since knowledge is produced by communities however (Kuhn, 1962), impact is precisely what counts. As Latour says:

> *There is something still worse, however, than being either criticised or dismantled by careless readers: it is being* ignored. *Since the status of a claim depends on later users' insertions, what if there are* no *later users whatsoever? This is the point that people who never come close to the fabrication of science have the greatest difficulty in grasping. They imagine that all scientific articles are equal and arrayed in lines like soldiers, to be carefully inspected one by one. However, most papers are never read at all. No matter what a paper did to the former literature, if no one else does anything with it, then it is as if it never existed at all. You may have written a paper that settles a fierce controversy once and for all, but if readers ignore it, it cannot be turned into a fact; it simply* cannot. *You may protest against the injustice, you may treasure the certitude of being right in your inner heart; but it will never go further than your inner heart; you will never go further in certitude without the help of others. Fact construction is so much a collective process that an isolated person builds only dreams, claims and feelings, not facts. (Latour, 1987, pp. 40-41)*

Bibliometric indicators are not perfect, but they do permit us to examine several key facets of an important part of knowledge production in modern society.

Data sources: advantages and disadvantages

There are many databases indexing the scientific and technical literature: *Chemical Abstracts*, *Medline*, *Biosis*, *Forestry Abstracts*, *Physics Abstracts* to name but a few. Bibliometric indicators are primarily based on one: the SCI produced by the Institute for Scientific Information (ISI) in Philadelphia, USA. This section explains why the SCI is so heavily relied upon and its advantages and disadvantages.

The first advantage is that the SCI covers all science fields. This is a necessity if one is looking at whole research systems. In addition, SCI coverage is unambiguous because every item from every journal is indexed. Coverage in other databases is ambiguous for indicator purposes because although they include all items from core journals, only items considered relevant to the subject of the database are included from secondary journals. There are about 100,000 scientific journals; of these the ISI has selected 10-12,000 for indexing in their various products. More than 90% of the citations in these journals are made to a more limited set of about 3,200 journals and these are indexed in the SCI. Thus, the SCI covers literature seen as important by researchers. Furthermore, the SCI’s wide use for indicators means that its coverage has been well studied.

The second advantage is that all author addresses listed on the paper are included in the SCI. This is a necessity for studying institutional output as collaboration is so extensive. Only first addresses are included in other databases, and so papers on which an institution’s address was not listed first cannot be credited to the institution. This source of error is substantial and growing as the rate of institutional collaboration increases. Only the first address is needed to contact authors of a paper, so listing only the first address is not a problem from the perspective of scientists searching the literature. From the policy perspective, the address that happens to be listed first is a social artefact and not of great policy interest in comparison to the total output of the institution. Of course, only if all addresses are listed can collaboration be studied.

The third advantage is that references are included in the SCI and only the SCI. Citation counts can be derived from these references and used as a partial indicator of the impact previous research has had on succeeding work. Citation counts are such a useful adjunct to policy analysis that almost by themselves their presence justifies using the SCI for policy analysis.

Coverage and cost are the disadvantages of the SCI. Because it indexes all science, its coverage of a single area is not as broad or deep as specialist databases such as Medline, Chemical Abstracts, or Biosis. However, often a higher percentage of an institution's high impact papers in, for example, chemistry, may be found in SCI than in Chemical Abstracts because the SCI lists all addresses (Russell *et al*., 1995). Thus, more comprehensive subject coverage does not necessarily equate to superior retrieval for institutions.

The database is relatively costly to use since it is produced by a private company. In comparison, patent databases are produced by government agencies and thus the American data are available for the media cost. Any large scale development of bibliometric indicators would have to budget several hundred thousand dollars to obtain the data which would be usable under a license subject to copyright and intellectual property restrictions.

Domestic Sectors

In general, sectoral indicators are based on institutional data, that is bibliometric data which are disaggregated below the national level, but not to the level of the department or individual. Institutional level data unification is needed even if results are to be reported at the sectoral level since each institution has to be assigned to a sector. This provides additional value since institutional interactions can be tracked providing more detailed national systemic analysis - that is of small as well as large organisations. Comprehensive indicators include all institutions, not just the biggest. Often studies of innovation at the institutional level, whether of companies or public sector laboratories, have looked at large institutions. Thus we can end up believing, for example, that the British science system is comprised of Oxford, Cambridge, Imperial College, ICI, Glaxo-Wellcome and GEC. Understanding the role of these institutions is important because they are so large, however they have been relatively well studied because they are so visible. To complete our knowledge of the British system we needed to understand the role and status of the other 5,900 institutions that have published scientific papers in the UK since 1981.

Other Considerations

In order to capture the dynamic characteristics of an innovation system, bibliometric indicators should be longitudinal. A one year snapshot of the system may seem to be an economical way to obtain most of the information. However, in some ways, the first year of data is the most expensive to generate. Once the system is in place to produce one year of systemic indicators, only research assistant time is needed to generate a decade or more of data. One year of data leaves ambiguity and open questions, whereas a decade or more of data enable accurate interpretations of trends. The effect of policy on systems remains an open question, with systemic data the extent of path dependence in the system and thus the scope for policy action can be probed. With long time series the balance between self-organisation and policy management can be investigated.

Systemic indicators should be capable of tracking interactions between researchers as evidenced in collaborative papers. In producing jointly authored scientific papers, researchers exchange tacit and embodied elements of knowledge. In fact these elements are most effectively exchanged in networks based on long term relationships between experts such as those that result in collaboration (OECD, 1992, pp 70-71). Bibliometric indicators can track these interactions over time and across an organisation or sector or nation. This enables us to ask questions such as: who does industry collaborate with more than expected? How is this changing over time? How does this differ by industrial sector? It has enabled us to identify the weakening links between industry and hospitals in the UK (Hicks and Katz, 1995). No other indicator or research method can provide such a longitudinal overview of institutional links in knowledge production.

Systemic bibliometric indicators track a dynamic system generating and diffusing scientific and technical knowledge through publishing. They map one facet of the structure and circulation of knowledge resources throughout the economy and society. Scientific and technical knowledge is advanced by all sectors. Since many institutions publish we can get a glimpse into research activity wherever it takes place. Bibliometric indicators allow us to see some of the complementarities, synergies and exchanges manifested in research collaboration. Finally, they indicate how much an institution’s or sector’s published research output is used by others, and who is using what. With decades of data, stable bibliometric indicators can be constructed allowing the evolution of the system to be understood.

Method for producing systemic bibliometric indicators

Indicators can be produced from the SCI at various levels: the database as a whole, nations, institutions, departments or individuals. Movement from one level down to the next level entails an increase in difficulty and computational requirement of more than an order of magnitude to clean up the data. Publication databases were set up to serve scientists searching for literature not policy analysts wishing to construct indicators. "Raw" databases are suitable for some types of analysis. For example, since journal names are controlled terms and kept standard, simply counting occurrences of the number of articles published in a particular journal in a particular year is easy to do. Unfortunately, these easy counts have no policy interest. National indicators, being of more interest, are well established, as mentioned earlier. However, they can only be produced today because many years of development were undertaken. Originally country names were not standardised because they were not crucial to the database users, scientists searching for literature. Thus natural variety and errors meant that fairly sophisticated searching was needed to count, for example all UK papers (*i.e.* from England, Scotland, Wales, Northern Ireland, UK, or Britain but not New England, New South Wales etc.). Country names are now standardised and the techniques for producing reliable national counts are well known. However, since institutional names are not standardised, counting institutional publications are problematic. Now, we will explain how we overcame some of these limitations.

In June 1992, the Science Policy Research Unit at the University of Sussex launched the *Bibliometric Evaluation of Sectoral Scientific Trends* (BESST)[1] project. Its aim was to advance the state of indicators by producing systemic bibliometric indicators of the British R&D system. More specifically, the objectives were (a) to determine the share of national scientific output in various scientific fields contributed by

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[1] The Bibliometric Evaluation of Sectoral Scientific Trends (BESST) was funded by the UK Office of Science and Technology, the Department of Trade and Industry, the Medical Research Council, the Engineering and Physical Science Research Council, the Department of Health, and the Economic and Social Research Council. The international publication data was purchased for the BESST project by the Natural Environment Research Council.

different institutional sectors (*e.g.* universities, industry, research councils, government laboratories, hospitals, etc.), (b) to map the changes during the 1980s in patterns of inter- and intra-sectoral collaboration in different scientific fields, (c) to investigate changes in the patterns of international collaboration with UK institutions, and (d) to use the data to investigate policy-relevant questions.

The first step was to unify variations of each institutional name recorded in the SCI to a standard name, and then assign each standard name to an institutional sector. This problem involved the manipulation of hundreds of megabytes of original SCI bibliographic text data, the development of techniques to construct a thesaurus[2] of variant and standard institutional names and the design of software to use the thesaurus to produce a unified data set. An overview of the methodology and unification rules used in the BESST project are given in Appendix I.

The choice of domestic R&D sectors for bibliometric analysis of a national innovation system is primarily determined by the R&D structure of the nation. In the original UK study we used six sectors (education, medical, industry, research councils, government and non-profit). However, in order to reduce the complexity and amount of data for international comparisons fewer sectors maybe required. Our preference of domestic sectors for international comparison are education, health, industry and other defined as follows:

- ➨ education - higher education institutions such as universities (including university-based medical schools), colleges and technical schools;
- ➨ health - hospitals (including hospital-based medical schools) and medical centres;
- ➨ industry - private sector firms;
- ➨ other - research council (*e.g.* Engineering and Physical Science Research Council), government and non-profit labs (*e.g.* Imperial Cancer Research Fund) that often provide a supporting R&D infrastructure for education, health and industry sectors. The composition of this heterogeneous sector will vary from nation to nation.

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[2] Essentially, a thesaurus is a translation or look-up table that links all variations of an institutional name to a standardised name.

The recent US NSF Science and Engineering Indicators report (1996) gives publication and citation statistics for only three US sectors: education, industry and other. Frequently, hospitals and medical centres are included in the education sector. Medical innovation tends to occur around a patient base which is not usually part of the education sector and in countries like the UK it is not part of the industry sector (Hicks and Katz, 1996). Thus, we feel that the health sector should be disaggregated from the other sectors since in most OECD countries a significant percentage of GDP is spent on health and associated medical research.

Difficulties of regularly producing systemic bibliometric indicators

The difficulty of unifying name variants has several implications for any attempt to regularly publish institutional level indicators for several countries. First, it is expensive. The cost of data combined with the labour and capital expenditure for equipment can be large. Second, ongoing unification is needed, a process requiring three to four weeks for the UK (excluding data analysis time). And third, quality control procedures are required to ensure the integrity of the indicators.

We anticipate that the development of Europe-wide systemic indicators would take about three years. Software and unification procedures would need to be developed, a group responsible for unifying addresses in each EU country would have to be trained and a quality assurance system would have to be developed. The complexity and high manual component means that all work must be checked for consistency to ensure compliance with agreed unification conventions and to eliminate inevitable errors. Quality control is essential if data are to be consistent across countries and over time - *i.e.* if the data are to be usable. This suggests that international co-ordination is essential.

Another class of difficulties is conceptual. First, the relationship between addresses and institutions is not entirely straightforward. The technique assumes that addresses indicate the institutional affiliation of authors. This may not be true. For example, in France the address of a researcher may be a university but the institutional affiliation may be CNRS. In the UK the address "Cavendish Laboratory" is often given meaning "Cambridge University, Physics Department". Alternatively, independent institutes may be located on university campuses, for example the consulting company "Institute for Employment Studies" is in the same building as SPRU, which is a department of the University of Sussex.

Second, institutions change, but time series data assume they remain the same. Some universities in the UK have had three names in the last 10 years. Government laboratories have been privatised and consolidated. Companies merge, split and acquire.

Third, an institution may not always be clearly assigned to one sector. Fortunately, this is an infrequent problem. Indicators developed at the sectoral level assume that institutions can be assigned to one of the following UK sectors: medical, educational, research council, industry, non-profit or government. In the UK, new institutions seem to be appearing that get funding from several sources - governmental, industrial and charity for example. These institutions transcend the sectoral boundaries as traditionally defined. Fortunately, few exist at the moment.

The most pervasive problem in institutional and sectoral assignment is determining which institutions belong to the health sector. Clinical researchers often have dual university-hospital affiliations; there are two streams of funding and medical schools (in the UK at least) can be departments of universities or hospitals. Separating the two is not just a problem of bibliometric method, clinicians are not clear about which stream of money paid for what themselves. In the US, this has never proved a problem. Research hospitals are components of universities. In the UK however, calling National Health Service (NHS) hospitals "universities" is inaccurate and discounts the large (if hitherto invisible) contribution made to the UK science base by NHS research funding. We resolved the dilemma with the following rules which are based on the principle that we do not second guess the author of the paper:

1. As we unified to the institutional not the departmental level, medical schools as departments were unified to their institution - hospital or university.

2. If an author lists hospital and university addresses on one line as one address, which occurs infrequently the paper was assigned to the first affiliation.
3. If an author lists hospital and university affiliations as two separate addresses on two lines, the paper is counted as collaborative between the hospital and university.

The conceptual difficulties of unification, namely complex and changing institutional structures and multiple sector affiliations, have several consequences for multi-national indicator development. First, the process will only be possible in countries where addresses reflect institutional affiliation to a reasonable degree. Second, national experts must oversee unification. Only local knowledge brought to bear on institutional complexity will produce sound data. Third, no single sector classification will suit all countries. At this point the best solution would seem to be two levels of sector classification: a more detailed level designed to meet national policy interest and an internationally negotiated higher level aggregation designed for international indicator use.

Assigning publications to science areas

Frequently policy analysts want information about the size or impact of R&D activity in scientific disciplines, fields or subfields. This raises the questions of how to assign papers to scientific areas. There are two general approaches. The first and most time consuming approach is to assign individual papers to one or more science areas. In other words by examining the content of each paper, the keywords in the title or exploring citations to the paper by other papers one determines which science area(s) the paper addresses. This approach is costly in terms of time and computational resources. For example, between 1981 and 1994 the UK published approximately 500,000 refereed papers. For a data set of this size it isn't practical to manually examine each publication's content and it is computationally too expensive to use techniques such as co-word analysis of title words (Cunningham, 1997) or citation clustering.

The second approach classifies papers based on the journal in which they appear. This approach is less precise but has proven to be acceptable and is affordable. It is used in national indicators such as the NSF science indicators which are given for each of eight science fields based on a fixed journal set developed at CHI Research, Inc.

ISI classifies SCI papers into 154 subfields of science (see Appendix I). Each journal in the SCI is assigned to one or more subfields by using a mixture of techniques: keyword analysis, journal to journal citation analysis and user feedback. The assignment of journals to subfields is an on-going process and journal assignments can change with time as the research focus of the journal changes. Although it is not a perfect classification scheme it has the advantage of being standardised over a long period of time and inexpensive. Furthermore, since journals are assigned to one or more subfields, one can develop at least a minimal set of indicators to explore the R&D activity in interdisciplinary and multidisciplinary science areas.

For policy analyses, we have aggregated the 154 ISI subfields into 17 science fields which are in turn aggregated into four scientific disciplines: natural, life, engineering and materials and multidisciplinary sciences (Katz and Hicks, 1995). This classification scheme provides enough flexibility to develop indicators at three levels of detail. In this paper we will use both journal classification schemes.

SYSTEMIC BIBLIOMETRIC INDICATORS

Introduction

In this second part of the paper we go on to demonstrate what we mean by systemic bibliometric indicators. We define a *systemic bibliometric indicator* to be a times series indicator derived from peer reviewed scientific and technical publications that describe the size, impact and diversity of research in a national system of innovation and depict the interactions between various domestic participants and foreign systems. A systemic indicator is *not a single value* but rather *it is a table of values* that *collectively* describe a characteristic of an innovation system.

In general, we derive the size indicator from the number of publications, the impact indicator from the number of citations, the diversity indicator from rankings of size and impact and the interaction indicator from institutional co-authorship information. Since we only have detailed data for the UK, we will explore the use of systemic indicators to portray the UK research system. The indicators will be presented in three sections. The first section will define and provide examples of systemic bibliometric indicators of the size, impact and diversity of the British innovation system within a global context. In the next section, we will give examples of each of the same indicators and as well, we will explore the interaction (collaboration) within the British innovation system using sectoral data from the BESST database. Finally, we will explore indicators of size, diversity and interaction derived from publications involving UK industry.

In general, we will compare an indicator for the UK and other members of the international community to the world indicator. For example, in this paper our international community is composed of six countries and one region: UK, EU, USA, France, Germany, Canada and Australia. The world or global system of innovation against which we shall make comparisons is composed of all nations that participate in the global innovation system by publishing at least one refereed paper indexed in the SCI.

All international comparisons will be made with respect to the global system. For example, we will create relative indicators (*e.g.* relative impact) for each member country by normalising the national data to the global data for the indicator. When we examine the British innovation system we will compare an indicator for each UK sector (education, health, industry and other) to the indicator for the UK national system. In other words, UK sectoral data will be normalised to the data for the UK system as a whole.

In general, size, impact and interaction indicators will be given in the form of a table composed of the following elements:

- a time series
- the total or average over the time interval
- the value and error of the slope for the linear time regression trend
- the coefficient of determination (r-squared) for the linear regression.

These data indicate the magnitude of the property being measured, the linear trend in the rate of change of the magnitude and the reliability of interpreting the rate of change as a true linear trend. As we mentioned previously, sometimes the time series will be expressed as a relative series (*e.g.* relative to the global or British system).

Usually, a diversity indicator will be a table composed of rows ranked in descending order by values contained in one of the columns. For example, a measure of average impact diversity would be a table containing the impact values in a number of scientific fields for the world and various countries. The scientific fields are listed in decreasing order of impact for the global system and for each country the rank of each field within the country and a relative impact value (national impact/global impact) are given. This allows one to easily see how the rank and magnitude of the national impact of a scientific area compares with the global impact.

The UK System of Innovation: a Global Perspective

In this section we define, with examples, size, impact and diversity indicators and explore how the UK is situated within the global innovation system compared to five other national systems and one regional system (USA, France, Germany, Canada, Australia and the EU).

Size

The size of an innovation system can be measured in a number of ways (*e.g.* total expenditure on R&D, number of scientists and engineers, etc.). A traditional bibliometric measure of size is the number of published papers. It has been shown that in general there is a direct correlation between the size of a country as measured by its GDP and the number of papers it produces and there is a correlation between the number of researchers in an institution and the number of papers published (Narin, 1976).

Table 1: International size indicator (publications)

Country	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*Total*	*Slope*	*R^2*
World	331,678	340,155	343,467	346,184	369,475	378,642	379,908	400,683	417,854	432,172	438,837	459,872	455,168	458,604	5,552,699	11128±516	0.97
US	126,972	131,605	130,474	132,310	139,840	143,016	143,399	152,001	157,736	163,511	168,794	174,148	173,364	171,393	2,108,563	4080±236	0.96
EU	98,501	101,167	103,503	104,529	113,263	116,074	117,856	122,871	130,070	136,176	141,673	152,404	154,491	160,647	1,753,225	4959±234	0.97
UK	31,167	31,746	32,425	32,142	34,875	34,355	34,227	34,581	35,677	37,165	37,866	40,503	41,001	43,050	500,780	846±73	0.92
Germany	24,312	24,948	24,621	24,494	27,043	27,160	27,865	28,497	30,275	31,723	33,122	35,140	35,249	36,650	411,099	1016±65	0.95
France	15,703	15,778	15,632	16,218	17,444	18,646	19,726	21,178	22,347	23,532	24,971	27,176	27,668	28,600	294,619	1113±58	0.97
Canada	14,738	15,414	15,741	16,456	18,008	18,518	19,157	20,158	20,823	21,672	22,541	24,233	24,002	23,982	275,443	791±29	0.98
Australia	8,423	8,320	8,518	8,554	9,156	9,580	9,461	9,574	10,207	10,359	10,850	11,438	12,040	12,389	138,869	314±21	0.95

Table 2: International size indicator (percent participation in World publications)

Country	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*Ave.*	*Slope*	*R^2*
US	38.3	38.7	38.0	38.2	37.8	37.8	37.7	37.9	37.7	37.8	38.5	37.9	38.1	37.4	38.0	-0.04±0.02	0.21
EU	29.7	29.7	30.1	30.2	30.7	30.7	31.0	30.7	31.1	31.5	32.3	33.1	33.9	35.0	31.6	0.36±0.04	0.86
UK	9.4	9.3	9.4	9.3	9.4	9.1	9.0	8.6	8.5	8.6	8.6	8.8	9.0	9.4	9.0	-0.04±0.02	0.27
Germany	7.3	7.3	7.2	7.1	7.3	7.2	7.3	7.1	7.2	7.3	7.5	7.6	7.7	8.0	7.4	0.04±0.01	0.51
France	4.7	4.6	4.6	4.7	4.7	4.9	5.2	5.3	5.3	5.4	5.7	5.9	6.1	6.2	5.3	0.13±0.01	0.94
Canada	4.4	4.5	4.6	4.8	4.9	4.9	5.0	5.0	5.0	5.0	5.1	5.3	5.3	5.2	5.0	0.06±0.01	0.9
Australia	2.5	2.4	2.5	2.5	2.5	2.5	2.5	2.4	2.4	2.4	2.5	2.5	2.6	2.7	2.5	0.01±0.01	0.19

Table 1 and Table 2 are size indicators, listing the number of papers in the SCI that each system of innovation *participated in*. Table 1 gives the annual number of refereed publications for each system and Table 2 gives the relative size of each national system expressed as a percentage of the total published output from the global system. These are standard indicators regularly published in, for example, the US, Japanese and European indicator series.

Note the use of the word *participated*. We use this term for two reasons. First, we 'whole' count papers; that is, if a paper lists institutional addresses in two or more countries we attribute the full paper to each participating country. There is no fair way to determine how much effort, expertise, equipment, etc. each country contributed to the research that produced a paper and we think it inappropriate to make unjustifiable assumptions by arbitrarily dividing the paper up between the participating countries. Instead we make a simple assumption. We assume that researchers in each country *participated* in the paper. Second, collaboration is now the rule not the exception (Katz and Hicks, 1995). Currently, more than 25% (see Section 4.4) of the British papers involve a researcher from a foreign institution. This is typical for most countries; it is even higher in smaller countries (Luukkonen, 1992). In such an interconnected R&D system it makes little sense to think of a country's contribution to the global system but rather we must think of the amount of participation a country has in the world R&D system.

The first thing to observe is that the global innovation system published about 5.5 million papers over the time period and almost 460,000 refereed scientific and technical publications in 1994. The annual rate of increase was about 11,000 publications per year which equates to approximately 3-4 additional publications per journal. In absolute terms the size of each innovation system has increased. In relative terms, the UK has participated in approximately 9% of the world output and exhibited a decline in output between 1986 and 1993. Over the decade and a half the US had the largest relative participation (38%) and it exhibited a slight decline in participation between 1985 and 1990. The largest relative growth came from the EU[3] whose participation grew from 29.7% to 35%. Germany, France, Canada and Australia also had an increase with France exhibiting the second largest rate of growth among these seven innovation systems.

In summary, on average, the British innovation system participates in 9% of the publications produced by the global innovation system and 28.5% of those publications involving an EU institution. Its participation is approximately 20% greater than the German innovation system and 70% greater than the French system.

Impact

Citations are used to measure impact. The premise underlying this indicator is that a research finding frequently referenced by other researchers has had greater *impact* on the research community than an infrequently cited paper. Impact is not the same as quality. However, in many instances impact and quality may be congruent. On the other hand, a contentious research finding, for example the claim of the discovery of cold fusion, may be highly cited not because the work was of high quality but because it stimulated a vibrant debate about a research claim. In other words, it impacted the research community. We must never forget that negative impact can spawn new research ideas.

The simplest measure of impact is citations per paper. This is calculated by counting the number of citations to papers in a science field over a fixed time period called the *citation window*. The number of citations divided by the number of papers receiving those citations yields the average number of citations received per paper.

For example, one might count the number of papers published in a given year and then count the number of citations to those papers in the publication year and the subsequent two, three or four years. The choice of the citation window width is somewhat arbitrary. Typically, within five years most papers will receive about 40-50% of their citations. Narin (1976) has shown that the citation peak usually occurs

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[3] The European Union data is derived from publications in which at least one author resided at an institution from one of the 15 core member countries.

in the second or third year after publication although this can vary across science fields. We use a three year citation window (*i.e.* publication year plus two subsequent years). The result is that 1994 impact information is based on 1992 publications. This narrower citation window provides a measure of the impact of faster moving, perhaps leading edge, research. However, one must keep in mind that the citation culture can vary from field to field and in some areas of research the rate of diffusion of new research findings can be much slower than in others.

Another factor to consider is the effect of self-citation (*i.e.* an author citing previously published work in a current paper) on the impact measure. Removing the effect of self-citation in a large corpus of publications is computationally difficult and expensive so the effect of self-citations is rarely considered. However, it has been demonstrated that for a large cohort of papers, such as those for a nation or institution, the percentage of self-citations remains fairly constant (Martin and Irvine, 1983) thus affecting the impact indicator in a similar and comparable manner across most institutions and nations. On the other hand one could argue that only excessive self-citations should be removed as it is common practice for researchers to build on their previous work since knowledge production is cumulative and by necessity cite it.

Table 3 and Table 4 are examples of an indicator of impact that is published in some national indicators. Table 3 gives the annual impact (citations per paper), the average citations per paper over the time period, the growth rate (slope) and the r-squared value of the trend line. Table 4 gives the relative impact expressed by dividing the citations per paper for a given innovation system by the global citations per paper.

From the table we can see that papers involving a US researcher had the greatest impact. UK publications had the second largest impact and on average they were cited 1.15 times more than the world average which is higher than France, Germany and the European innovation systems. Of the five national systems, Canada and Australia had the lowest impact and their relative impact was below the global average. It is interesting to see that, in general, the relative impact values remained quite constant with time as indicated by the slope values.

Table 3: International impact indicator

Country	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*Ave.*	*Slope*	*R2*
US	4.7	4.5	4.8	5.0	5.0	5.1	5.4	5.5	5.4	5.6	5.7	5.9	5.2	0.12±0.01	0.95
UK	3.8	3.9	4.0	4.2	4.0	4.1	4.2	4.3	4.4	4.7	4.6	4.9	4.3	0.09±0.01	0.89
France	3.4	3.5	3.8	3.9	3.8	3.9	3.9	4.0	3.8	4.1	4.3	4.4	3.9	0.07±0.01	0.82
Germany	3.4	3.4	3.6	3.7	3.6	3.7	3.9	3.9	3.9	4.2	4.2	4.5	3.8	0.09±0.01	0.95
EU	3.5	3.5	3.6	3.7	3.6	3.6	3.7	3.8	3.8	4.0	4.1	4.2	3.7	0.06±0.01	0.88
World	3.4	3.3	3.5	3.6	3.5	3.6	3.8	3.8	3.8	3.9	4.0	4.1	3.7	0.07±0.01	0.95
Canada	3.4	3.3	3.4	3.6	3.6	3.4	3.5	3.7	3.7	3.9	4.0	4.3	4	0.07±0.01	0.83
Australia	3.1	3.1	3.3	3.3	3.4	3.4	3.4	3.7	3.5	3.4	3.5	3.7	3.4	0.04±0.01	0.78

Table 4: International impact indicator (compared to the world)

Country	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*Ave.*	*Slope*	R^2
US	1.38	1.36	1.39	1.39	1.41	1.42	1.45	1.44	1.44	1.43	1.42	1.42	1.42	0.01±0.00	0.56
UK	1.13	1.16	1.15	1.18	1.13	1.15	1.12	1.12	1.16	1.20	1.15	1.19	1.15	0.00±0.00	0.13
France	1.00	1.06	1.09	1.09	1.07	1.08	1.04	1.02	1.02	1.04	1.06	1.06	1.05	0.00±0.00	0.01
Germany	1.00	1.03	1.03	1.03	1.01	1.03	1.03	1.03	1.05	1.08	1.04	1.08	1.04	0.01±0.00	0.61
EU	1.02	1.04	1.03	1.03	1.01	1.01	0.99	0.99	1.01	1.02	1.01	1.03	1.02	0.00±0.00	0.11
World	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00±0.00	1.00
Canada	0.99	1.00	0.97	0.99	1.01	0.96	0.94	0.96	0.98	1.01	1.00	1.03	0.99	0.00±0.00	0.06
Australia	0.91	0.95	0.95	0.93	0.96	0.95	0.90	0.96	0.92	0.88	0.87	0.90	0.92	0.00±0.00	0.32

In summary, UK innovation system papers have slightly less impact on the global innovation system than US innovation system papers but more impact than any of the other innovation systems we have examined. The growth in impact of UK research on the global world-wide research system is the same as the Germany system, less than the US system and greater than the remaining innovation systems.

Diversity

A systemic indicator of diversity portrays the similarity and differences within and between innovation systems. There are many measures of diversity and we will only provide three. The three diversity indicators we will focus on are size, impact rank and impact growth. Each indicator is described in detail in the following subsections. We will see that the various diversity indicators do not converge to tell a uniform story but rather each indicator portrays diversity from a different perspective. For example we will see that in the global system *biochemistry & molecular biology*, *chemistry* and *pharmacology & pharmacy* are ranked one to three, respectively, in size while *multidisciplinary sciences*, *cytology & histology* and *biochemistry & molecular biology* are ranked one to three, respectively, in impact, and *developmental biology*, *cytology & histology* and *biochemistry & molecular biology* are ranked one to three, respectively, in the rate of growth of impact. Furthermore, the rankings for each of these scientific subfields varies remarkably within each system of innovation demonstrating that the global system of innovation is composed of diverse national systems of innovation.

Size diversity

A systemic indicator of size diversity illustrates the diversity in the size distribution of the scientific subfields within each innovation system compared to the global innovation system. Size is measured by counting the total number of papers published in each of the 154 SCI subfields across the 1981-1994 time interval.

Table 5: International size diversity

	Percent		UK		EU		US		France		Germany		Canada		Australia	
Rank	Total	ISI category	*Rank*	*RCA*	*Rank*	*RCA*	*Rank*	*RCA*	*Rank*	*RCA*	*Rank*	*RCA*	*Rank*	*RCA*	*Rank*	*RCA*
1	7.17	Biochemistry & Molecular Biology	1	0.93	1	1.04	1	1.14	1	1.33	1	1.02	1	1.01	1	0.74
2	4.47	Chemistry	9	0.50	3	0.85	6	0.56	9	0.68	2	1.60	5	0.74	5	0.71
3	4.21	Pharmacology & Pharmacy	3	1.01	2	1.10	3	0.87	3	0.99	5	0.94	4	0.88	7	0.75
4	3.37	Neurosciences	4	1.01	4	1.04	2	1.22	7	1.02	8	0.93	2	1.30	8	0.89
5	3.15	Physics	10	0.70	6	1.03	10	0.71	2	1.38	3	1.33	9	0.74	23	0.53
6	2.95	Multidisciplinary Sciences	8	0.76	17	0.65	4	1.09	5	1.20	29	0.52	28	0.51	20	0.60
7	2.89	Medicine, General & Internal	2	1.79	5	1.14	8	0.81	18	0.73	12	0.80	18	0.62	2	1.53
8	2.69	Chemistry, Organic	5	0.98	7	1.17	22	0.63	4	1.48	7	1.24	24	0.61	27	0.51
9	2.54	Physics, Applied	30	0.55	23	0.69	12	0.85	11	1.03	16	0.81	42	0.49	42	0.43
10	2.43	Physics, Condensed Matter	26	0.62	10	1.05	24	0.68	6	1.45	4	1.68	30	0.60	62	0.31
11	2.41	Immunology	7	0.99	9	1.07	5	1.18	10	1.23	20	0.79	10	0.96	9	1.23
12	2.36	Chemistry, Physical	12	0.89	8	1.13	26	0.66	8	1.40	9	1.28	20	0.72	26	0.64
13	2.32	Plant Sciences	6	1.06	11	1.08	15	0.86	19	0.90	10	1.19	3	1.64	3	1.84
14	2.13	Oncology	15	0.92	13	1.07	7	1.18	14	1.02	21	0.83	22	0.78	28	0.65
15	1.92	Engineering, Electrical & Electronic	13	1.03	29	0.74	13	1.10	34	0.61	37	0.59	13	1.02	36	0.64
16	1.86	Chemistry, Analytical	39	0.59	22	0.96	32	0.72	25	0.97	26	0.86	38	0.70	32	0.69
17	1.83	Microbiology	11	1.17	14	1.15	23	0.92	22	1.05	14	1.14	16	1.03	22	0.94
18	1.83	Surgery	14	1.08	24	0.95	9	1.26	50	0.44	32	0.72	19	0.96	16	1.19
19	1.80	Physiology	29	0.82	26	0.88	11	1.20	28	0.83	34	0.72	6	1.71	14	1.30
20	1.75	Cardiovascular System	24	0.91	16	1.09	16	1.12	16	1.22	23	0.98	34	0.77	40	0.65
		Spearman Rank Correlation Coeff.	*0.96*		*0.98*		*0.97*		*0.93*		*0.95*		*0.93*		*0.89*	

Notes:

Percent Total - percent of World papers in subfield

RCA - Revealed comparative advantage (percent national papers/percent world papers)

Table 5 is a systemic international size indicator. In order to keep the list of subfields to a reasonable length but still illustrate the value of the indicator only the largest 20 subfields are given. The subfields are listed in decreasing order of world size. Also the percentage of the total number of papers contributed by each subfield is provided for the world and the Revealed Comparative Advantage (percent national papers/percent world papers) is given for the countries and regions. Finally, the Spearman rank correlation coefficient using all 154 subfields is given. It is important to remember that journals can be assigned to more than one subfield and thus the sum of the percentages will be greater than 100 percent. The excess represents the amount of journal overlap between subfields.

Notice that the traditional Spearman rank correlation coefficient suggest that, in general, the UK and the other systems of innovation have a similar rank distribution of their 154 scientific subfields when compared to the World distribution. All countries and regions have a correlation coefficient greater than or equal to 0.93 except Australia which is 0.89. However, a closer inspection of the top 20 scientific subfields in the world paints a picture of differences. First, we see that the UK is similar to the other systems of innovations because it contributes the largest percentage of its published output in *biochemistry & molecular biology*. However, next we see a difference. In the UK *chemistry*, the second highest ranked subfield in the world, is ranked 9th while *general & internal medicine* is ranked 2nd. The differences become even more apparent when we examine *applied physics* and *condensed matter physics*. These subfields are ranked 10th and 11th in size, respectively, in the global innovation system but are ranked 30th and 26th in the British system. They are ranked even lower in Canadian and Australian systems. In contrast, the French and German systems rank *condensed matter physics* higher than the World rank at 6th and 4th, respectively. It is apparent that there is a diversity in the distribution of subfield sizes within national systems when compared to the World system.

Unlike traditional statistical measures such as the Spearman rank correlation coefficient which suggests similarity in the size distribution across national systems of innovation, the size diversity indicator suggests that even within the twenty largest subfields world-wide each national system displays a different subfield size rank distribution. This is not surprising given that each national system’s scientific priorities are determined by many factors including economics, politics and skill base, to mention a few. One must remember that there is an English language bias in the SCI. Some subfields deal with more local scientific problems and the research results are better suited for publication in a local journal not SCI journals. The language bias will affect the size distribution more in non-English speaking countries.

In summary, in the British innovation system, the distribution of the top twenty scientific subfields world-wide is quite different from the distribution in the global system and other innovation systems. Five of the world's top twenty subfields (*applied physics, condensed matter physics, analytical chemistry, physiology* and *cardiovascular systems*) are not ranked in the top twenty UK subfields. The size distribution of scientific subfields suggests that the British innovation system has its own unique characteristics.

Impact rank diversity

The impact rank diversity indicator demonstrates the diversity of the impact distribution across subfields within innovation systems compared to the World system. It is constructed in the following manner. First, for each country we calculate the annual impact (citations per paper) for each of the 154 ISI subfields (see Appendix I). However, we restrict ourselves to subfields with a size greater than or equal to 0.05% of the total number of papers that each country participated in. A cut-off of 0.05% was used to reduce spurious results produced by subfields with very few papers (say one or two) that were highly cited. Second, we rank the subfields for each country by the average impact. And finally, we compare the national impact ranks to the world impact ranks. Table 6 lists the top 20 impact ranked ISI science subfields world-wide and for each country the impact rank and average relative impact. Note, the Spearman rank correlation coefficient is not given because the number of subfields that have more 0.05% of the total differs from system to system and the subfields that are ignored are different for each country. In order to calculate the Spearman rank correlation coefficient there has to be the same number of subfields in each country.

Before we examine the impact rank diversity indicator let us explore the similarity between the systems using a unique measure. This measure will also explain why we will only examine the 20 largest impact subfields in each country. Recall that at the completion of the second step of the procedure outlined above we will have produced average impact values and the rank for each subfield for the World and various innovation systems. As we will see the rank impact order of these subfields differs from country to country according to the amount of impact a country's research has on the World system. However, let us ask "is there a correlation between a decrease in the magnitude of impact and an increase in rank order?" and if there is, "is there the same degree of correlation between these variables across innovation systems?"

We know the impact decreases as rank increases, we ordered the subfields this way. However, we don't know if there is a relationship between each unit increase in rank and the amount that the impact decreases.

Figure 1: Global impact distribution

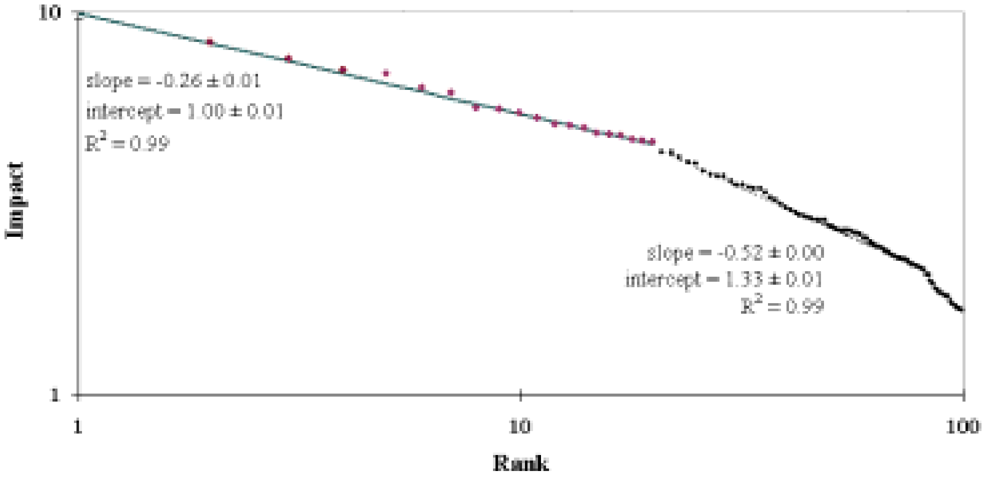

Figure 1 is a log-log plot of the average impact of refereed papers published in the global system between 1981 and 1992 in 135 of the 154 SCI subfields versus the rank of the subfield. We see three distinct regions: a linear top region, a linear middle region and a lower region. In the top and middle regions there is a linear correlation between log(impact) and log(rank) indicating that impact and rank are related by a power law relationship (*i.e.* impact = c rank^n where n is the slope of the regression line and c is the intercept). The top region is composed of 20 subfields and the impact decreases with increasing rank with a slope = -0.26. The middle region is composed of sixty-two subfields and the impact decreases more rapidly with increasing rank than it does in the top region with a slope = -0.52. In the lower region impact drops even more rapidly as rank increases. Now, we will focus our attention on the twenty subfields in the top region.

Figure 2: Impact distribution of 20 highest impact sub-fields

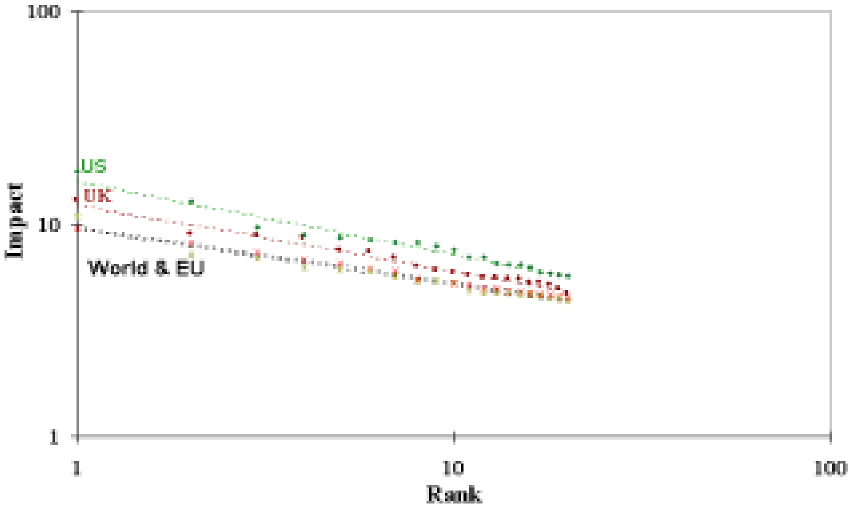

Figure 2 is a log-log plot of impact versus rank for the 20 highest impact science subfields in the UK, EU, US and World. Table 7 gives the regression slope, intercept and r-squared values for the countries in the figure as well as for Germany, France, Canada and Australia. The intercept is simply the impact of the highest ranked subfield in each country. Notice that in each instance log(impact) changes linearly with log(rank) and the slopes of the regression lines for each country are quite similar; they range from -0.23 to -0.34. Nevertheless, if we look closely we find that the rank of a specific subfield can vary from system to system. For example, the circular points on the graph indicate the rank of the *haematology* subfield in each system of innovation (World - rank 7, UK - rank 14, US - rank 9, and EU - rank 13). In other words, although the impact decreases with increasing rank by a similar amount, the rank of a given subfield in one innovation system may be different from that in another and the top twenty impact subfields in one system can be different than in another. This difference is the impact rank diversity and we use the 20 highest impact subfields in the World system as a point of reference against which to find the diversity.

Table 6: International impact rank diversity

World			UK		EU		US		Germany		France		Canada		Australia	
Rank	Impact	**ISI category**	*Rank*	*RI*	*Rank*	*RI*	*Rank*	*RI*	*Rank*	*RI*	*Rank*	*RCR*	*Rank*	*RI*	*Rank*	*RI*
1	9.61	Multidisciplinary Sciences	1	1.34	1	1.14	1	1.85	1	1.41	1	0.85	1	1.29	1	1.00
2	8.27	Cytology & Histology	2	1.10	3	0.84	2	1.58	3	1.03	3	0.81	5	0.76	8	0.70
3	7.51	Biochemistry & Molecular Biology	4	1.19	2	0.96	3	1.31	2	1.14	5	0.86	4	0.85	5	0.84
4	7.00	Developmental Biology	3	1.29	4	0.91	4	1.30	4	1.09	16	0.66	7	0.85	20	0.61
5	6.83	Immunology	6	1.10	5	0.93	5	1.30	5	0.97	8	0.90	9	0.85	4	0.96
6	6.28	Virology	5	1.21	6	0.98	7	1.34	13	0.85	9	0.87	8	0.93	7	0.96
7	6.11	Hematology	14	0.90	13	0.80	9	1.32	9	0.91	13	0.80	2	1.09	3	1.14
8	5.55	Infectious Diseases	22	0.87	11	0.89	17	1.14	21	0.81	2	1.34	6	1.12	2	1.31
9	5.51	Genetics & Heredity	8	1.20	8	1.03	11	1.35	6	1.16	6	1.14	11	1.02	13	0.93
10	5.42	Biophysics	7	1.27	7	1.05	18	1.10	8	1.14	12	0.91	12	1.02	9	1.04
11	5.22	Medicine Research & Experimental	9	1.15	16	0.90	6	1.66	12	1.03	11	0.96	3	1.22	10	1.02
12	5.04	Endocrinology & Metabolism	16	1.05	19	0.88	15	1.29	28	0.79	22	0.80	10	1.14	6	1.20
13	5.00	Physics, Atomic Molecular & Chemical	21	0.98	14	0.96	14	1.31	11	1.08	18	0.88	20	0.94	16	0.97
14	4.94	Neurosciences	10	1.19	12	1.00	22	1.16	19	0.92	10	1.03	16	1.01	18	0.92
15	4.78	Physics, Nuclear	13	1.15	9	1.12	12	1.45	14	1.08	7	1.31	27	0.91	31	0.75
16	4.77	Clinical Neurology	24	0.94	24	0.82	19	1.24	15	1.02	39	0.68	18	1.00	14	1.07
17	4.71	Oncology	11	1.24	15	1.00	24	1.21	23	0.92	14	1.04	14	1.17	12	1.12
18	4.61	Astronomy & Astrophysics	12	1.21	17	1.00	16	1.39	17	1.01	17	0.99	15	1.18	11	1.15
19	4.59	Physiology	17	1.15	18	0.98	20	1.27	10	1.20	21	0.91	29	0.94	26	0.83
20	4.55	Physics	15	1.20	10	1.17	8	1.85	7	1.37	4	1.44	23	1.00	40	0.74

Notes:
Impact - citations per paper (i.e. total 1981-1992 citations/total 1981-1992 papers)
RI - relative impact (i.e. national impact/world impact)
RCA - Revealed comparative advantage (percent national papers/percent world papers)

Table 6 lists the 20 highest impact world-ranked ISI subfields arranged in descending order of impact. For each subfield we give the national rank and relative impact (national impact/World impact). First, we see that in each innovation system *multidisciplinary sciences* has the highest impact rank. This ISI subfield is represented by papers published in the most widely read prestigious international multidisciplinary journals (*Science*, *Nature*, *Proceedings of the National Academy of Sciences*, etc.). Impact rank diversity in the UK shows up in the third and fourth highest impact subfields, *biochemistry & molecular biology* and *developmental* *biology* where the rank in the British system is inverted compared to the global rank. The impact rank diversity is even more apparent if we look at a subfield like *infectious diseases*, ranked 8th world-wide in impact but it does not appear in the top 20 ranked subfields in the UK and Germany. Also, it has a higher impact rank in France, Canada and Australia, lower in the EU, near the bottom of the top 20 in the US. Although we see many similarities we can also see impact diversity across systems of innovation.

Table 7: Impact versus rank: log-log regression statistics

Country	*Slope*	*Intercept*	R^2
World	-0.26 ± 0.00	0.99 ± 0.01	1.00
UK	-0.31 ± 0.01	1.09 ± 0.01	0.98
US	-0.34 ± 0.01	1.20 ± 0.01	0.97
EU	-0.27 ± 0.01	0.98 ± 0.01	0.96
France	-0.24 ± 0.02	0.96 ± 0.01	0.93
Germany	-0.34 ± 0.01	1.08 ± 0.01	0.97
Canada	-0.23 ± 0.02	0.96 ± 0.01	0.81
Australia	-0.26 ± 0.02	0.98 ± 0.02	0.94

In summary, the British system has many similarities to the global and other national system in the distribution of its research impact in the top twenty scientific subfields world-wide. The top four impact subfields world-wide have a similar rank in the UK system as well as in the US, EU and German systems. France, Canada and Australia have notable exceptions. However, there are substantial differences. The impact in *infectious diseases, atomic molecular & chemical physics* and *clinical neurology* are not even in the UK's top twenty high impact subfields.

Impact growth diversity

Finally, let us now look at impact diversity from another perspective - the growth rate of impact. This indicator will help us see how national systems are increasing or losing their impact on the global innovation system in the 20 highest impact subfields world-wide. We construct this indicator by determining the growth trend of impact in each subfield over time using the slope of the times series linear regression. The subfields in each system of innovation are ranked in decreasing order by the growth rate (slope). However, in this instance we only rank the 20 subfields given in the previous table because the significance of the regression trend lines decrease quickly with decreasing rank. Table 8 lists the 20 highest impact rank subfields given in Table 6 but this time they are arranged in decreasing order of global impact growth rate. The national impact growth rank and the relative impact growth rate (RIG = national impact growth/world impact growth) are given for each country. The impact growth trends with a reasonable statistical significance ($p < 0.05$) are indicated by the italicised slope values for the World and RIG values for the other systems. We also give the Spearman rank correlation coefficient as a measure of similarity between the rank in each system and the global system.

The Spearman rank correlation coefficient suggests the ranking of impact growth in the US and global systems are similar. This is to be expected given that the US has the largest citing community in the World system. The UK, EU and Germany are fairly similar to the global ranks, Canada is close but France and Australia have quite different rankings.

Using the diversity impact rank indicator we see that *developmental biology* has the highest impact growth world-wide. This ISI subfield is covered by journals such as *Advances in Anatomy*, *Embryology and Cell Biology*, *Developmental Biology* and *Genes and Development*. Although this subfield has the highest impact growth in the UK, US and the EU, it is 2nd in Germany and France, 3rd in Canada and 7th in Australia. Already we can see diversity in the ranking of impact growth among the national systems compared to the global system. In the UK *multidisciplinary sciences* is ranked 4th behind *cytology and histology* and *genetics and heredity* while world-wide it has the second largest growth rate.

In summary, the impact growth of UK research compared to the impact growth in the global system of the top twenty impact subfields world-wide is similar in many respects but different in others. Notable differences are found in *hematology*, *neurosciences* and *immunology*.

Table 8: International impact growth diversity

World			UK		EU		US		France		Germany		Canada		Australia	
Rank	Slope	**ISI category**	*Rank*	*RIG*	*Rank*	*RIG*	*Rank*	*RIG*	*Rank*	*RIG*	*Rank*	*RIG*	*Rank*	*RIG*	*Rank*	*RIG*
1	*0.57*	Developmental Biology	1	*1.45*	1	*0.76*	1	*1.47*	2	*0.61*	2	*1.33*	3	*0.65*	7	*0.27*
2	*0.43*	Multidisciplinary Sciences	4	*0.95*	9	*0.29*	3	*1.26*	20	*-1.06*	1	*4.70*	1	*1.96*	2	*0.86*
3	*0.35*	Cytology & Histology	2	*1.46*	2	*0.84*	2	*1.89*	1	*1.05*	3	*2.93*	2	*1.21*	8	0.30
4	*0.31*	Genetics & Heredity	3	*1.36*	3	*0.85*	4	*1.53*	5	*0.98*	10	*1.83*	4	*1.09*	4	*0.70*
5	*0.21*	Biochemistry & Molecular Biology	5	*1.33*	6	*0.84*	5	*1.68*	8	*0.94*	5	*6.21*	7	*1.02*	6	*0.76*
6	*0.19*	Virology	6	*1.10*	5	*0.93*	6	*1.18*	6	*1.44*	11	*3.51*	12	*0.56*	18	-0.60
7	*0.15*	Hematology	14	*0.37*	7	*0.97*	7	*1.33*	7	*1.44*	7	*9.47*	5	*1.65*	3	1.72
8	*0.12*	Neurosciences	11	*0.71*	13	*0.66*	8	*1.46*	13	0.19	9	*12.2*	10	*0.99*	12	0.27
9	*0.11*	Oncology	9	*1.39*	10	*0.92*	10	*1.63*	10	*1.14*	13	*5.63*	14	*0.58*	11	0.33
10	*0.10*	Medicine Research & Experimental	8	*1.67*	4	*1.85*	9	*1.83*	3	*3.53*	4	*32.3*	6	*2.43*	1	*4.84*
11	*0.09*	Clinical Neurology	12	*0.72*	11	*1.10*	11	*1.52*	14	0.21	6	*27.3*	13	*1.11*	9	1.06
12	*0.08*	Infectious Diseases	10	*1.50*	8	*1.62*	13	*1.37*	4	*3.90*	8	*28.1*	15	*0.11*	19	-1.82
13	*0.05*	Endocrinology & Metabolism	16	0.45	14	0.58	14	*1.89*	11	*1.00*	15	12.9	18	-0.50	5	*3.53*
14	*0.05*	Immunology	7	*3.51*	12	*1.87*	16	0.89	9	*3.01*	14	19.1	9	*3.66*	17	-1.70
15	*0.04*	Biophysics	13	1.65	16	-0.03	15	*2.09*	15	0.08	12	*56.0*	20	-3.35	16	-1.58
16	0.03	Physics	20	-1.32	15	0.01	18	-0.09	18	-0.21	16	24.9	8	*6.86*	10	1.50
17	*0.02*	Physiology	18	*0.56*	17	-0.57	17	2.07	16	*0.09*	17	-47.4	16	-0.90	14	-1.91
18	0.00	Physics, Atomic Molecular & Chemical	19	-6.01	19	-7.79	12	*42.8*	12	14.3	19	*8504*	17	-9.06	20	*-78.9*
19	*-0.07*	Astronomy & Astrophysics	15	-0.46	18	0.27	20	*1.51*	17	0.07	20	*-12.2*	11	*-1.52*	15	0.63
20	-0.10	Physics, Nuclear	17	-0.16	20	*0.86*	19	1.03	19	0.82	18	-2.50	19	0.73	13	-0.07
		Spearman rank correlation coefficient	*0.87*		*0.89*		*0.96*		*0.58*		*0.87*		*0.76*		*0.58*	

Notes:

RIG - relative impact growth (i.e. national impact growth rate/world impact growth rate)

Summary of the UK System in a Global Context

We have been exploring systemic bibliometric indicators of size, impact and diversity to determine where the British innovation system is situated in the global innovation system. We have seen the following:

➨ Britain's innovation system is second largest in size in comparison to the other countries examined (needless to say it is smaller than the EU);

➨ Britain's innovation system has the second largest impact on the global innovation system followed by France and Germany;

➨ size and impact growth diversity indicators suggest that in the top twenty subfields world-wide there are some similarities to the global innovation system but like other systems there are major differences. The impact diversity indicator suggests that most innovation systems have a similar profile to the World system with a few notable exceptions;

➨ the British innovation system contributes most to the global innovation system in *biochemistry & molecular biology*, *general and internal medicine* and *pharmacy and pharmacology*. It has the highest impact in *multidisciplinary sciences*, *cytology and histology* and *developmental biology* and it has the largest impact growth in *developmental biology, cytology and histology* and *genetics and heredity*;

➨ using systemic bibliometric indicators we see the UK system of innovation contributes most, has the greatest impact and impact growth in the life sciences.

Let us now we explore the UK innovation system in more detail.

The UK System of Innovation: a Sectoral Perspective

In this section we will explore the British innovation system in greater detail. Again we will use systemic indicators of size, impact and diversity and we shall introduce an interaction indicator to explore collaboration between institutional sectors. We will also introduce the notion of a composite indicator which we believe may give a better measure of impact. The four sectors we will examine are education, health, industry and 'other'. The definitions and rationale for choosing these sectors was explained earlier.

Table 9: UK sector size indicator (publications by UK sector)

Sector	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*Total*	*Slope*	*R^2*
Education	18,473	18,935	19,143	19,089	20,596	20,147	20,670	20,583	21,181	22,130	23,014	24,914	25,672	27,663	*302,210*	623±68	0.88
Health	7,576	7,771	8,006	8,277	9,290	9,212	9,344	9,686	10,242	10,737	10,688	11,412	11,417	11,634	*135,292*	332±14	0.98
Industry	2,546	2,582	2,710	2,606	2,771	2,682	2,660	2,936	3,001	3,159	3,177	3,412	3,350	3,378	*40,970*	72±7	0.90
Other	5,465	5,510	5,842	5,597	6,005	6,254	5,860	5,729	5,837	6,262	6,333	6,789	6,841	6,990	*85,314*	106±16	0.78

Table 10: UK sector size indicator (relative size; percent participation in UK publications)

Sector	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*Ave.*	*Slope*	*R^2*
Education	59.3	59.6	59.0	59.4	59.1	58.6	60.4	59.5	59.4	59.5	60.8	61.5	62.6	64.3	*60.2*	0.29±0.07	0.59
Health	24.3	24.5	24.7	25.8	26.6	26.8	27.3	28.0	28.7	28.9	28.2	28.2	27.8	27.0	*26.9*	0.30±0.06	0.66
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	7.8	*8.2*	0.01±0.02	0.01
Other	17.5	17.4	18.0	17.4	17.2	18.2	17.1	16.6	16.4	16.8	16.7	16.8	16.7	16.2	*17.1*	-0.11±0.03	0.58

Size

Table 9 and Table 10 present a systemic bibliometric indicator of the size of four UK sectors. Table 9 gives the annual number of refereed publications in which at least one institution in a given sector *participated*. Table 10 expresses the size of each sector's participation as a percentage of the total UK output.

As we saw in Table 1 and Table 2, Britain's participation in the global innovation system has been increasing at a rate of about 850 publications per year. Using the averages from Table 10 we can see that of this increase, on average, education participated in about 600 (60%) of these publications, health in 310 (27%), industry in 65 (8%) and the other in 100 (11%)[4]. Education is by far the largest sector, followed by health, 'other' and industry. Industry's participation has been quite constant even faced with some harsh economic challenges over the time period. On the other hand we see a relative decline in the 'other' sector's participation, no doubt mostly due to the down-sizing of government labs.

In summary, education is the largest participant in the UK science system followed by the health, 'other' and industry sectors. Even with industry's need focus on profits it makes a significant and sustained contribution to the science base in the British innovation system.

Impact

Table 11 and Table 12 present a systemic bibliometric indicator of the impact for UK sector participants in the British innovation system. Table 11 gives the annual impact, the average impact over the time period, the impact growth (slope) and the r-squared value for the trend line. Table 12 gives the relative impact as calculated by dividing the impact for a given sector by the overall impact of the UK's participation in the global system.

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[4] Recall that we use a whole counting technique. Thus the sum of the number of papers that each sector participated in (600+310+65+100 = 1075) is greater than the actual increase of 850 UK papers per year. This simply indicates that there was collaboration between these sectors.

Table 11: UK sector impact indicator

Sector	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*Ave.*	*Slope*	R^2
Education	3.7	3.7	3.9	4.0	4.0	4.0	4.0	4.0	4.1	4.5	4.4	4.7	4.1	0.1±0.0	0.81
Health	4.0	4.1	4.1	4.3	4.0	4.0	4.2	4.2	4.4	4.7	4.8	5.0	4.3	0.1±0.0	0.71
Industry	3.1	3.4	3.0	3.2	3.2	3.5	4.2	4.2	4.6	4.5	4.6	4.5	3.8	0.2±0.0	0.85
Other	4.8	5.0	5.1	6.0	5.4	5.5	5.9	6.1	6.3	6.8	6.3	7.1	5.9	0.2±0.0	0.85

Table 12: UK sector impact indicator (relative impact; compared to the UK as a whole)

Sector	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*Ave.*	*Slope*	R^2
Education	0.97	0.97	0.99	0.96	0.99	0.98	0.95	0.94	0.93	0.96	0.96	0.96	0.96	0.00±0.00	0.30
Health	1.05	1.06	1.04	1.01	1.01	0.98	1.00	0.99	1.00	1.00	1.03	1.02	1.02	0.00±0.00	0.25
Industry	0.81	0.87	0.76	0.75	0.81	0.85	1.00	0.98	1.05	0.96	0.98	0.93	0.91	0.02±0.01	0.53
Other	1.26	1.28	1.29	1.43	1.35	1.34	1.41	1.44	1.44	1.45	1.35	1.45	1.38	0.01±0.00	0.56

The largest UK impact on the global system comes from British researchers in ’other’ sector institutions. Recall, this sector contains research council, government and non-profit labs. Many of these laboratories have a focused research agenda with world class personnel, leading edge instrumentation and state-of-the-art computing facilities. They frequently concentrate their efforts on fundamental problems, both basic and applied. One might expect them to have a large impact. Researchers in education and health sector institutions are the largest participants in terms of size and thus could be expected to generate the UK’s average impact. Industry although a sizeable participant has the lowest impact, at least as measured by publications. Again notice how constant the relative impact from each of the sectors remained with time.

Notice we speak of the impact that a UK sector has on the global system of innovation. Recall impact is measured in citations per paper. The citations to a UK sector’s paper are found in papers published throughout the global system, some in the UK and some abroad. Thus, this indicator is a measure of the impact a UK sector has on the global system not just its impact on the British system.

Table 13: Composite systemic impact indicator

Sector	*Indicator*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*Ave.*	*Slope*	*R^2*
Education	size	59.3	59.6	59	59.4	59.1	58.6	60.4	59.5	59.4	59.5	60.8	61.5	59.7	0.29±0.07	0.59
	impact	3.7	3.7	3.9	4.0	4.0	4.0	4.0	4.0	4.1	4.5	4.4	4.7	4.1	0.1±0.0	0.81
	median	2.6	2.7	2.7	2.7	2.7	2.7	2.6	2.7	2.7	2.8	2.8	2.9	2.7	0.0±0.0	0.54
	elite	30	31	33	35	34	33	34	37	38	45	42	46	36	1±0	0.84
	max. citations	182	271	332	234	586	272	234	336	407	489	425	444	351	19±9	0.32
	% uncited	23	24	24	23	24	23	23	24	25	24	24	23	24	0.00±0.1	0.04
Health	size	24.3	24.5	24.7	25.8	26.6	26.8	27.3	28	28.7	28.9	28.2	28.2	26.8	0.30±0.06	0.66
	impact	4.0	4.1	4.1	4.3	4.0	4.0	4.2	4.2	4.4	4.7	4.8	5.0	4.3	0.1±0.0	0.71
	median	2.8	2.7	2.7	2.8	2.7	2.7	2.7	2.7	2.8	2.8	2.8	2.9	2.8	0.0±0.0	0.43
	elite	38	41	39	36	41	38	42	41	41	48	50	53	42	1±0	0.67
	max citations	101	157	140	155	186	206	340	362	472	240	425	298	257	26±7	0.62
	% uncited	26	26	25	24	27	25	25	26	27	26	26	25	26	0.0±0.1	0.01
Industry	size	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	0.01±0.02	0.01
	impact	3.1	3.4	3	3.2	3.2	3.5	4.2	4.2	4.6	4.5	4.6	4.5	3.9	0.2±0.0	0.85
	median	2.4	2.5	2.4	2.5	2.5	2.4	2.6	2.6	2.7	2.7	2.8	2.9	2.6	0.0±0.0	0.82
	elite	37	41	35	34	30	42	51	48	61	55	45	53	44	2±1	0.53
	max citations	72	152	72	119	171	126	439	253	284	172	959	147	247	35±18	0.27
	% uncited	35	33	36	35	33	30	29	32	30	28	30	30	32	-0.6±0.1	0.64
Other	size	17.5	17.4	18	17.4	17.2	18.2	17.1	16.6	16.4	16.8	16.7	16.8	17.2	-0.11±0.03	0.58
	impact	4.8	5.0	5.1	6.0	5.4	5.5	6.0	6.1	6.3	6.8	6.3	7.1	5.9	0.2±0.0	0.85
	median	2.9	2.9	2.9	3.4	3.4	2.9	3.4	3.5	3.5	3.7	3.6	3.8	3.3	0.1±0.0	0.76
	elite	46	49	48	64	59	61	62	69	65	74	64	70	61	2±0	0.75
	max citations	277	157	410	867	206	288	725	326	813	337	284	392	424	9±21	0.02

Now, let us introduce the notion of a composite systemic impact indicator. This indicator is a collection of indicators which when taken together represent impact by imparting a broader meaning than the systemic impact indicator. However, it can only be constructed when all of the publication data is available for analysis. We could not produce it for the various national innovation systems because we don't have access to the complete SCI data.

Table 13 is an illustration of a composite systemic impact indicator for UK sectors. It is composed of size, impact, median, elite, maximum citations, percent uncited values, as well as growth rates and r-squared values. The size and impact values were previously given in Table 3 and Table 6. The remaining values are defined as follows:

➨ The median value is the maximum number of citations received by 50% of the cited papers.

- ➨ The elite value is the maximum number of citations received by 99% of the cited papers. In other words, a paper receiving more than this number is in the top 1% of the cited papers. These papers belong to an elite impact fraternity.
- ➨ The maximum citation values are the maximum number of citations received by a single paper in that year.
- ➨ Percent uncited is the percentage of papers that did not receive a single citation in the citation window.

Collectively these values indicate the *skewedness* of the impact that research in the UK sectors is having on the global system. Let us explain this notion in more detail. Notice that for each sector a large percentage (25% - 30%) of refereed publications in the mostly highly cited international journals are never cited once. One might expect that many papers are poorly cited and few papers are highly cited. Indeed, we can see this is the case by examining the median, elite and maximum citation indicators. For example, using the 1992 values we see that educational institutions participated in about 60% of UK publications and they had an impact of 4.1 citations per paper. The median impact, that is the impact from the lowest 50% of cited papers was 2.9 citations per paper. In other words 50% of the papers Britain participated in received, on average, 2.9 or fewer citations. In the same year an elite paper (top 1%) was cited more than 46 times. The most highly cited education paper received 444 citations.

What does the composite indicator tell us about the impact that UK sector research has on the global innovation system? First, we see that the ’other’ sector has the lowest percentage of uncited papers. Industry had the most. However, in both sectors the percentage uncited papers is slowly declining. Second, we notice that the ’other’ sector has the highest median impact (3.3 citations on average) while education, health and industry have similar median impacts (2.6-2.8 citations). Furthermore, the ’other’ sector is the only sector which is demonstrating a slight increase in the median impact over time. Third, we see that on average, the top 1% of papers in the ’other’ sector receive the most citations (> 61) followed by industry (> 44) and health (> 42) while education’s elite researchers receive the lowest average number of citations (> 36). Finally, we observe that on average the highest impact papers come from the ’other’ sector (392) followed by education (351), while health (257) and industry

(247) received the lowest number of average maximum citations. It is interesting to note that the most highly cited paper in the time interval came from an industry lab[5] and the second most highly cited from an 'other' sector lab[6].

The composite systemic impact indicator tells us that while there is a slow trend to increase the number of citations per paper (see Table 6, slope column) it is a not due to an increasing number of citations to papers at or below the median but rather it is due to an increasing number of citations to the top 50% of British research. It also tells us that about 25-30% of all research publications go unnoticed in the SCI indexed journals. However, they may be cited by articles published in one of the other 100,000 scientific journals.

In summary, even though education has the largest size, 'other' sector research is having the greatest impact on the global innovation system. Education and health research is setting the average for the UK as a whole. Although industry has a lower impact in general it produced the most highly cited paper in the time interval. Approximately 25-30% of all UK research is uncited by other papers published in the SCI.

Diversity

Size Diversity

Table 14 is a systemic indicator of UK sector size diversity. Again we only provide data for the largest 20 scientific subfields in the UK listed in decreasing order of size in the British national system. Also the percentage of the total number of papers contributed by each subfield is provided for the UK as a whole while the Revealed Comparative Advantage (percent sector papers/percent UK papers) is given for each sector. The Spearman rank correlation coefficient is not given because in some subfields a sector may not publish anything.

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[5] 959 cites in 1991

[6] 813 cites in 1989

Table 14: UK sector size diversity

Rank	Percent total	**ISI category**	Education		Health		Industry		Other	
			Rank	*RCA*	*Rank*	*RCA*	*Rank*	*RCA*	*Rank*	*RCA*
1	6.60	Biochemistry & Molecular Biology	1	1.05	5	0.68	3	0.79	1	1.48
2	5.35	Medicine, General & Internal	12	0.47	1	2.86	23	0.33	16	0.43
3	4.31	Pharmacology & Pharmacy	2	0.93	3	1.16	1	2.58	21	0.44
4	3.37	Neurosciences	6	0.95	4	1.44	29	0.46	8	0.93
5	2.63	Chemistry, Organic	3	1.52	69	0.03	4	1.88	64	0.20
6	2.53	Plant Sciences	9	1.13	82	0.01	36	0.50	2	2.14
7	2.33	Immunology	22	0.68	10	1.70	20	0.82	7	1.41
8	2.33	Multidisciplinary Sciences	11	1.13	36	0.40	21	0.82	5	1.49
9	2.26	Chemistry	5	1.45	51	0.12	5	1.60	49	0.33
10	2.18	Physics	4	1.51	80	0.01	30	0.68	24	0.73
11	2.16	Microbiology	15	1.00	21	0.93	17	0.95	12	1.20
12	2.02	Chemistry, Physical	8	1.50	70	0.03	7	1.61	54	0.35
13	1.99	Surgery	51	0.42	2	3.01	110	0.07	84	0.16
14	1.96	Chemistry, Inorganic & Nuclear	7	1.61	79	0.02	42	0.50	66	0.25
15	1.96	Engineering, Electrical & Electronic	14	1.16	77	0.03	2	3.92	47	0.39
16	1.88	Oncology	35	0.63	7	2.21	46	0.45	14	1.27
17	1.85	Veterinary Science	25	0.83	49	0.17	11	1.44	3	2.82
18	1.83	Genetics & Heredity	26	0.82	23	1.05	26	0.94	6	1.83
19	1.75	Endocrinology & Metabolism	29	0.79	13	1.77	54	0.42	20	1.16
20	1.74	Pathology	36	0.66	9	2.30	60	0.32	27	0.81

Notes:
Percent Total - percent of sector papers in subfield
RCA - Revealed comparative advantage (percent sector papers/percent UK papers)

Notice that the five largest subfields in the UK are composed of a mixture of life and chemical sciences. The largest subfield, *biochemistry & molecular biology*, has most of it contribution from activities in the education and ’other’ sectors and ranks 3rd and 5th, respectively, in the health and industry sectors. The 2nd rank size subfield in the UK is *general & internal medicine* and this appears to be mainly due to the research activities in the health sector with small contributions from the other sectors. *Pharmacy & pharmacology* is dominated by industry with a significant contribution from education and health. *Chemistry* contributions come mainly from education and industry but has a low priority in health and the ’other’ sector. And finally notice, as expected, *surgery* is completely dominated by the health sector.

The top five subfields by size for each sector are:

➨ education: *biochemistry & molecular biology, pharmacology & pharmacy, organic chemistry, physics* and *chemistry*

➨ health: *general & internal medicine, surgery, pharmacy & pharmacology, neurosciences* and *biochemistry & molecular biology*

➨ industry: *pharmacy & pharmacology, electrical & electronic engineering, biochemistry & molecular biology, organic chemistry* and *chemistry*

➨ other: *biochemistry & molecular biology, plant sciences, veterinary sciences, agriculture* and *multidisciplinary sciences*

In summary, all sectors have a sizeable portion of their publications in *biochemistry & molecular biology*. Similarly, all sectors but the ’other’ sector contribute a large portion of their publications in *pharmacy & pharmacology.* Sectoral size diversity can be seen by the fact that the second largest field for industry is *electrical & electrical engineering,* for health it is *surgery* and in the ’other’ sector it is *plant sciences* suggesting that each sector has a distinctive character to its research focus.

Impact Rank Diversity

Now we will explore impact rank diversity for the UK sectors. Instead of using the 20 highest world-ranked impact subfields we will use the top twenty impact ranks within the British system. Table 15 gives the top 20 subfields in the UK as well as the rank and relative impact (*i.e.* impact of sector papers/impact of all UK papers) for each sector. As in the global system *multidisciplinary sciences* is the highest impact subfield across all sectors. *Cytology & histology* is the second highest impact subfield for the ’other’ sector, just as in the global system, however, it is ranked 4th in education and industry, and 5th in health. Researchers from ’other’ sector institutions making the UK second highest impact on the global system as seen by the fact that impact is 1.68 times the national average of 9.13 citations per paper.

Table 15: UK sector impact rank diversity

World			Education		Health		Industry		Other	
Rank	Ave	**ISI category**	*Rank*	*RI*	*Rank*	*RI*	*Rank*	*RI*	*Rank*	*RI*
1	12.92	Multidisciplinary Sciences	1	0.77	1	1.66	1	1.03	1	1.68
2	9.13	Cytology & Histology	4	0.86	5	0.78	4	1.00	2	1.66
3	9.03	Developmental Biology	2	0.88	6	0.77	9	0.87	4	1.37
4	8.94	Biochemistry & Molecular Biology	3	0.89	3	0.85	3	1.06	3	1.43
5	7.57	Virology	5	0.98	2	1.01	10	0.98	11	1.06
6	7.52	Immunology	6	0.94	4	0.99	13	0.91	7	1.24
7	6.87	Biophysics	7	0.98	9	0.80	5	1.31	10	1.19
8	6.61	Genetics & Heredity	11	0.90	7	1.02	19	0.84	9	1.28
9	6.01	Medicine Research & Experimental	9	1.00	10	0.92	30	0.73	6	1.65
10	5.89	Neurosciences	12	1.01	14	0.91	8	1.34	12	1.33
11	5.84	Oncology	14	0.97	8	0.98	15	1.10	13	1.33
12	5.57	Astronomy & Astrophysics	13	1.02	n.a.	n.a.	65	0.47	24	1.05
13	5.50	Physics, Nuclear	18	0.98	n.a.	n.a.	33	0.76	15	1.26
14	5.50	Hematology	16	0.99	11	0.99	17	1.06	14	1.31
15	5.45	Physics	15	1.01	n.a.	n.a.	32	0.77	5	1.94
16	5.28	Endocrinology & Metabolism	22	0.93	13	1.01	26	0.93	20	1.15
17	5.27	Physiology	19	0.98	12	1.02	2	1.90	32	0.95
18	5.13	Gastroenterology & Hepatology	17	1.06	15	0.99	6	1.60	18	1.29
19	5.10	Medicine, General & Internal	8	1.25	16	0.97	12	1.35	8	1.76
20	4.92	Physics, Particles & Fields	23	1.00	n.a.	n.a.	80	0.41	16	1.40

Notes:
Impact - citations per paper (i.e. total 1981-1992 citations/total 1981-1992 papers)
RI - relative impact (i.e. national impact/world impact)

The top five highest impact subfields in each sector are:

➨ education: *multidisciplinary sciences, developmental biology, biochemistry & molecular biology, cytology & histology* and *virology*

➨ health: *multidisciplinary sciences, virology, biochemistry & molecular biology, immunology* and *cytology & histology*

➨ industry: *multidisciplinary sciences, physiology, biochemistry & molecular biology, cytology & histology* and *biophysics*

➨ ’other’: *multidisciplinary sciences, cytology & histology, biochemistry & molecular biology, developmental biology* and *physics*

In summary, the impact subfield profiles are similar across sectors with the notable exception of industry's impact in *biophysics* and the 'other' sector's impact in *physics*. The impact diversity does not become apparent until we look at the bottom half of the top 20 high impact subfields. As we might expect, the health sector has no impact and industry little impact in physics (*astronomy & astrophysics, physics, nuclear physics and particle & field physics*). The greatest impact on the global systems from these subfields comes from education and the 'other' sector.

Impact Growth Diversity

Table 16 lists the 20 highest impact rank subfields in the UK as given in Table 15 but this time they are arranged in decreasing order of impact growth rate. The impact growth rank and the relative impact growth rate (sector impact growth/UK impact growth) is given for each sector. As we did previously, the slope or relative impact growth values will be italicised when the trend statistics are significant ($p < 0.05$).

As in the global system, *developmental biology* has the highest impact growth in the education sector. Its growth ranks 2nd in health and the 'other' sector, however, it seems to be of little importance to industry at the moment. Impact growth is highest for health and industry in *biochemistry and molecular biology*.

All sectors have their largest impact growth in the life and medical sciences with the exception of strong growth for industry in physics. There appears to be much more diversity in the subfield growth impact subfield profiles than we saw in the impact profiles. The highest impact growth in the UK system is in *developmental biology* and we see industry is not having a growing impact in this subfield. Industry's highest impact growth is occurring in the *multidisciplinary sciences* and it is experiencing growing impact on the global system in physics (*biophysics, nuclear physics* and *physics).*

Table 16: UK sector impact growth diversity

UK			Education		Health		Industry		Other	
Rank	Slope	**ISI category**	*Rank*	*RIG*	*Rank*	*RIG*	*Rank*	*RIG*	*Rank*	*RIG*
1	0.82	Developmental Biology	1	*0.92*	2	*0.80*	n.a.	n.a.	2	*1.33*
2	0.51	Cytology & Histology	2	1.03	5	*0.67*	18	-0.70	1	*2.25*
3	0.42	Genetics & Heredity	3	*0.94*	3	*1.31*	16	-0.12	5	*1.20*
4	0.41	Multidisciplinary Sciences	4	*0.75*	1	*2.45*	1	*2.36*	3	*1.36*
5	0.27	Biochemistry & Molecular Biology	6	*0.93*	4	*1.28*	8	*0.93*	8	*0.99*
6	0.24	Physics, Particles & Fields	8	*1.00*	n.a.	n.a.	n.a.	n.a.	9	*0.99*
7	0.21	Virology	5	*1.28*	6	*1.40*	3	*2.57*	11	0.60
8	0.17	Immunology	10	*0.94*	8	*0.95*	7	*1.52*	10	*1.33*
9	0.16	Medicine Research & Experimental	11	0.60	7	*1.70*	17	-0.48	6	*1.95*
10	0.15	Oncology	7	*1.66*	9	*0.68*	9	*1.30*	7	*2.07*
11	0.09	Neurosciences	12	*1.08*	10	*1.06*	11	1.31	17	0.07
12	0.06	Biophysics	18	0.26	13	0.04	2	*9.87*	14	1.00
13	0.05	Hematology	9	*3.60*	11	0.65	14	1.34	16	0.31
14	0.04	Medicine, General & Internal	14	1.63	12	0.75	12	2.36	4	*11.51*
15	0.03	Astronomy & Astrophysics	16	1.35	n.a.	n.a.	10	3.82	19	-1.75
16	0.02	Endocrinology & Metabolism	13	*3.18*	15	-1.07	15	0.80	12	*4.53*
17	0.02	Physics, Nuclear	17	2.16	n.a.	n.a.	13	5.21	18	-0.45
18	0.01	Physiology	19	-3.54	14	-0.99	4	52.50	13	12.10
19	-0.04	Gastroenterology & Hepatology	15	-1.45	16	1.47	6	-9.35	15	-0.68
20	-0.04	Physics	20	1.14	n.a.	n.a.	5	-9.94	20	9.19

Notes:
RIG - relative impact growth (i.e. sector impact growth rate/UK impact growth rate)

The impact growth in physical sciences is different for each sector. For example, p*article & field physics* is ranked 8th in impact growth nationally. As we might expect, health and industry are not having a growing impact this subfield. The growth is strictly due to the research efforts of education and the ’other’ sector (probably from research council labs).

The top five growth impact subfields for each sector are:

➨ education: *developmental biology, cytology & histology, genetics & heredity, multidisciplinary sciences* and *virology*

- ➨ health: *multidisciplinary sciences*, *developmental biology*, *genetics & heredity*, *biochemistry & molecular biology* and *cytology & histology*
- ➨ industry: *multidisciplinary sciences*, *biophysics*, *virology*, *nuclear physics* and *physics*
- ➨ 'other': *cytology & histology*, *developmental biology*, *multidisciplinary sciences*, *general & internal medicine* and *genetics & heredity*

In summary, the UK's growth in impact on the global system of innovation varies from sector to sector but is concentrated mostly in the life and medical sciences followed by some physical sciences. Industry and health are increasing their impact in *multidisciplinary sciences* the most, education in *developmental biology* and the 'other' sector in *cytology & histology*.

Interaction

Here we shall introduce a new indicator, the systemic interaction indicator. This indicator is constructed from the co-authorship information on publications and is used to reveal collaborative activities (Katz and Martin, 1997). Recall that each paper indexed in the SCI contains a complete list of authors and the institutional address for each author. Unfortunately, ISI does not link authors to institutions so it is not possible to tell which author resides at which institution. However, using the institutional addresses we can determine if the paper involved an institutional collaboration. Although collaboration actually occurs between individuals we restrict our study to counting collaborations between the institutions. Institutional collaborations come in many forms and can range from two authors from two different institutions working together to two institutions sharing an individual (*e.g.* joint appointment).

We can distinguish two main types of institutional collaboration: domestic and foreign. Also, we can distinguish three subtypes of domestic collaboration: intra-institutional (collaboration between researchers in the same institution), intra-sectoral (collaboration between researchers in different institutions in the same sector) and inter-sectoral (collaboration between researchers in different institutions in different sectors). We will not provide data for intra-institutional collaboration activity.

A great deal of bibliometric work has been focused on the growth of international collaboration (Luukkonen, 1992; Narin and Whitlow, 1990; Schubert and Braun, 1990) but very little has explored sectoral or institutional collaboration. Since the BESST database only contains publications involving a UK author we don't have comparable international data. However, we refer you to Appendix, Table 5-35 in the Science & Engineering Indicators 1996 published by the NSF which provides 1981-87 and 1988-93 aggregate summary collaborative statistics for many countries and regions.

Needless to say we can construct systemic interaction indicators of size, impact and diversity. The size indicator is based on the number of collaborative papers that we co-authored with other domestic and/or foreign institutions. If we gave the average impact of these papers we would have the systemic interaction impact indicator. And finally if we had enough papers in our database to construct a reliable indicator, which we don't, we could produce a variety of systemic interaction diversity indicators. We shall provide examples of the size and impact indicators.

Table 17: UK interaction size indicator

Collaboration Type	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*Ave.*	*Slope*	*R^2*
All collaboration	27.8	28.6	29.4	31.3	31.5	33.1	35.2	36.3	37.6	39.6	41.4	44.2	44.9	46.0	36.8	1.5±0.1	0.99
No collaboration	72.2	71.4	70.6	68.7	68.5	66.9	64.8	63.7	62.4	60.4	58.6	55.8	55.1	54.0	63.2	-1.5±0.1	0.99
Intra-sectoral	8.2	8.4	8.8	9.1	9.6	10.0	10.6	11.1	11.2	11.7	11.7	13.0	13.1	13.3	10.8	0.4±0.0	0.99
Inter-sectoral	9.0	9.3	9.8	10.3	10.5	11.0	12.0	12.1	12.3	13.2	13.5	14.1	14.5	14.6	12.0	0.5±0.0	0.99
Domestic	15.7	16.2	16.9	17.7	18.0	18.9	20.3	20.6	21.2	22.2	22.4	23.9	24.2	24.2	20.5	0.7±0.0	0.99
World	13.7	14.1	14.3	15.7	15.6	16.5	17.6	18.5	19.5	20.7	22.6	24.6	25.3	26.5	19.3	1.0±0.1	0.96
Europe	4.6	4.7	4.9	5.4	5.4	5.7	6.2	6.6	7.0	7.9	8.3	9.9	10.0	10.8	7.1	0.5±0.0	0.94
USA	4.5	4.6	4.7	5.6	5.4	5.6	5.9	6.1	6.4	6.6	7.1	7.9	7.9	8.3	6.3	0.3±0.0	0.97
France	1.1	1.2	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.9	1.8	2.4	2.5	2.7	1.7	0.1±0.0	0.89
Germany	1.3	1.4	1.4	1.6	1.6	1.7	1.9	1.9	2.0	2.3	2.1	2.8	2.6	3.1	2.0	0.1±0.0	0.92
Canada	1.0	1.1	0.9	1.1	1.0	1.1	1.2	1.1	1.3	1.4	1.4	1.5	1.6	1.5	1.3	0.0±0.0	0.86
Australia	0.8	0.9	0.9	0.9	0.8	0.9	0.9	1.0	1.0	1.1	1.3	1.2	1.4	1.4	1.1	0.0±0.0	0.84

Table 17 is a systemic interaction size indicator. It lists the percentage of UK papers that involve institutional collaborations of various types. It is an aggregate level indicator that shows us how the UK is interacting with the global systems, some individual national systems and how its sectors are interacting with each other.

First, note that every type of institutional collaboration is growing and the number of non-collaborative papers is declining. In 1994, almost 50% of UK papers involved an institutional collaboration of some type. As we said earlier institutional collaboration is becoming the rule not the exception. The strongest growth occurred in foreign collaborations (World) followed by domestic collaboration of which the inter-sectoral subtype grew most but it was closely followed by intra-sectoral collaborations.

Second, we see that UK researchers collaborate frequently with researchers from EU institutions. In the early 1980s the UK was participating in collaborative research more frequently with an EU institution than with a US institution. However, we have shown previously (Katz *et al*, 1995) that the growth rate of EU collaborations has been greater than the growth rate for collaboration with the US for almost twenty-five years. The longevity of this trend suggests it pre-dates European Commission funding.

Table 18: UK interaction impact indicator

Collaboration Type	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*Ave.*	*Slope*	R^2
All types	4.7	5.0	5.1	5.6	5.2	5.2	5.3	5.4	5.4	5.8	5.6	6.1	5.4	0.1±0.0	0.75
No collaboration	3.5	3.4	3.5	3.6	3.4	3.5	3.6	3.6	3.7	3.9	3.9	4.0	3.6	0.0±0.0	0.84
Intra-sectoral	4.5	4.6	5.1	5.5	4.9	5.0	4.9	4.9	5.1	5.3	5.3	5.5	5.1	0.1±0.0	0.42
Inter-sectoral	4.7	5.2	5.3	5.5	5.4	5.3	5.5	5.3	5.5	6.1	5.7	6.4	5.6	0.1±0.0	0.71
Domestic	4.6	4.7	4.9	5.4	5.0	5.0	5.0	5.0	5.2	5.5	5.4	5.8	5.2	0.1±0.0	0.68
World	5.1	5.6	6.0	6.2	5.9	5.9	6.0	6.2	6.2	6.8	6.4	6.9	6.2	0.1±0.0	0.74
Europe	5.2	6.4	6.4	6.3	6.2	6.2	6.1	6.6	6.2	7.3	6.8	7.5	6.6	0.1±0.0	0.61
USA	6.7	7.0	8.2	9.1	8.3	7.9	8.5	8.7	8.7	9.5	8.8	9.6	8.6	0.2±0.0	0.65
France	5.4	6.5	8.2	8.1	6.8	7.1	7.9	8.6	8.1	9.6	8.8	9.0	8.1	0.3±0.1	0.65
Germany	6.3	7.8	8.0	8.0	7.7	8.2	7.8	8.6	7.3	10.2	8.3	10.0	8.4	0.2±0.1	0.48
Canada	4.5	5.2	5.0	4.3	5.1	5.7	5.3	6.5	6.7	8.9	5.6	6.7	6.0	0.3±0.1	0.51
Australia	4.1	5.2	4.8	5.2	5.3	5.2	5.1	*6.9*	6.1	6.2	6.0	6.0	5.6	0.2±0.0	0.62

Table 18 is a systemic interaction impact indicator. It lists for each collaboration type and subtype the annual impact for each type of institutional collaboration, the slope, the standard error and r-squared values. The most important observation is that collaborative papers have the highest impact and non-collaborative papers the lowest. On average, the highest impact publications involved a foreign partner, followed by inter-sectoral collaborations and then intra-sectoral collaborations. In other words, the British innovation system gets its greatest impact from research activities involving other members of the global innovation system.

Table 19: UK sector interaction size indicator

Sector	with	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*Total*	*Slope*	*R^2*
Education	Education	1,074	1,093	1,155	1,145	1,404	1,438	1,567	1,654	1,698	1,854	1,975	2,504	2,547	2,861	23,969	133±11	0.92
	Health	1,085	1,115	1,157	1,230	1,432	1,502	1,569	1,639	1,726	1,846	1,922	2,199	2,395	2,493	23,310	109±6	0.96
	Industry	453	548	594	547	624	638	772	833	897	1,031	1,122	1,184	1,241	1,312	11,796	68±4	0.96
	Other	774	835	903	1,015	1,103	1,152	1,302	1,230	1,263	1,516	1,553	1,847	1,917	2,054	18,464	95±6	0.95
Health	Education	1,085	1,115	1,157	1,230	1,432	1,502	1,569	1,639	1,726	1,846	1,922	2,199	2,395	2,493	23,310	109±6	0.96
	Health	1,255	1,327	1,378	1,483	1,669	1,664	1,776	1,854	1,996	2,118	2,119	2,376	2,407	2,467	25,889	98±3	0.99
	Industry	147	147	159	169	191	173	175	178	201	192	213	249	211	230	2,635	7±1	0.83
	Other	426	408	461	445	454	487	539	521	543	583	608	646	622	700	7,443	21±2	0.95
Industry	Education	453	548	594	547	624	638	772	833	897	1,031	1,122	1,184	1,241	1,312	11,796	68±4	0.96
	Health	147	147	159	169	191	173	175	178	201	192	213	249	211	230	2,635	7±1	0.83
	Industry	63	44	*73*	68	73	64	68	98	90	84	104	113	140	125	1,207	6±1	0.81
	Other	102	105	100	130	126	147	145	141	*142*	169	181	204	221	180	2,093	8±1	0.86
Other	Education	774	835	*903*	1,015	1,103	1,152	1,302	1,230	*1,263*	1,516	1,553	1,847	1,917	2,054	18,464	95±6	0.95
	Health	426	408	461	445	454	487	539	521	543	583	608	646	622	700	7,443	21±2	0.95
	Industry	102	105	100	130	126	147	145	141	142	169	181	204	221	180	2,093	8±1	0.86
	Other	176	224	261	252	234	296	254	280	273	334	292	354	371	396	3,997	13±2	0.84

Let us explore domestic collaboration in more detail. Table 19 and Table 20 bring a UK sector interaction size indicator. Table 19 gives the number of papers that each sector co-authored with at least one institution from another sector and from its own sector. Table 20 gives the same information expressed as a percentage of a sector’s total number of publications.

Table 20: UK sector interaction size indicator (relative size; percentage of sector's papers)

Sector	with	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*Ave.*	*Slope*	*R^2*
Education	Education	5.8	5.8	6.0	6.0	6.8	7.1	7.6	8.0	8.0	8.4	8.6	10.1	9.9	10.3	7.9	0.4±0.0	0.96
	Health	5.9	5.9	6.0	6.4	7.0	7.5	7.6	8.0	8.1	8.3	8.4	8.8	9.3	9.0	7.7	0.3±0.0	0.97
	Industry	2.5	2.9	3.1	2.9	3.0	3.2	3.7	4.0	4.2	4.7	4.9	4.8	4.8	4.7	3.9	0.2±0.0	0.92
	Other	4.2	4.4	4.7	5.3	5.4	5.7	6.3	6.0	6.0	6.9	6.7	7.4	7.5	7.4	6.1	0.3±0.0	0.96
Health	Education	14.3	14.3	14.5	14.9	15.4	16.3	16.8	16.9	16.9	17.2	18.0	19.3	21.0	21.4	17.2	0.5±0.1	0.91
	Health	16.6	17.1	17.2	17.9	18.0	18.1	19.0	19.1	19.5	19.7	19.8	20.8	21.1	21.2	19.1	0.4±0.0	0.98
	Industry	1.9	1.9	2.0	2.0	2.1	1.9	1.9	1.8	2.0	1.8	2.0	2.2	1.8	2.0	1.9	0.0±0.0	0.00
	Other	5.6	5.3	5.8	5.4	4.9	5.3	5.8	5.4	5.3	5.4	5.7	5.7	5.4	6.0	5.5	0.0±0.0	0.13
Industry	Education	17.8	21.2	*21.9*	21.0	22.5	23.8	29.0	28.4	29.9	32.6	35.3	34.7	37.0	38.8	28.8	2.0±0.1	0.97
	Health	5.8	5.7	5.9	6.5	6.9	6.5	6.6	6.1	*6.7*	6.1	6.7	7.3	6.3	6.8	6.4	0.1±0.0	0.36
	Industry	2.5	1.7	*2.7*	2.6	2.6	2.4	2.6	3.3	*3.0*	2.7	3.3	3.3	4.2	3.7	2.9	0.1±0.0	0.69
	Other	4.0	4.1	3.7	5.0	4.5	5.5	5.5	4.8	4.7	5.3	5.7	6.0	6.6	5.3	5.1	0.2±0.0	0.66
Other	Education	14.2	15.2	15.5	18.1	18.4	18.4	22.2	21.5	21.6	24.2	24.5	27.2	28.0	29.4	21.6	1.2±0.1	0.97
	Health	7.8	7.4	7.9	8.0	7.6	7.8	9.2	9.1	9.3	9.3	9.6	9.5	9.1	10.0	8.7	0.2±0.0	0.80
	Industry	1.9	1.9	1.7	2.3	2.1	2.4	2.5	2.5	2.4	2.7	2.9	3.0	3.2	2.6	2.5	0.1±0.0	0.79
	Other	3.2	4.1	4.5	4.5	3.9	4.7	4.3	4.9	4.7	5.3	4.6	5.2	5.4	5.7	4.7	0.1±0.0	0.75

In a previous study (Katz *et al*, 1995) we showed that, in general, the number of collaborations that a sector has with another sector is proportional to their relative size. For example, the education sector is the largest UK sector and as expected industry and 'other' sector institutions collaborate most with education.

We see that on average the health sector produced about 17% of its papers with education but preferred to collaborate with other health sector institutions (19%). Since education is the largest UK sector, we might expect health institutions to collaborate more with universities but they prefer to collaborate with institutions in their own sector. This suggests that health research maybe a separate sub-innovation system in the UK national system (Hicks and Katz, 1995).

On the other side of the coin, we see that a relatively small percentage of industry collaborations are with other industrial partners. This suggests that competition and proprietary knowledge concerns may be an over-riding determining factor for industry. Also, it is interesting to note that the percentage of industry papers produced in collaboration with the health sector and the percentage of health sector papers produced in collaboration with industry display the lowest growth rate of all inter-sectoral collaborations. This is a curious finding given the amount and growth of medical research in the UK.

Table 21: UK sector interaction impact

Sector	with	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*Ave.*	*Slope*	*R^2*
Education	Education	4.4	4.4	5.0	5.1	5.0	4.9	4.9	4.8	5.1	5.5	5.3	5.5	5.1	0.1±0.0	0.62
	Health	4.3	4.9	4.5	5.0	5.3	4.8	4.9	4.8	4.8	5.5	5.8	6.2	5.2	0.1±0.0	0.61
	Industry	3.2	3.2	3.3	3.3	3.7	4.5	3.9	4.0	4.5	4.5	4.0	4.1	4.0	0.1±0.0	0.64
	Other	5.7	6.2	7.2	6.7	6.7	6.5	6.6	6.6	6.1	7.1	5.9	7.5	6.6	0.0±0.0	0.11
Health	Education	4.3	4.9	4.5	5.0	5.3	4.8	4.9	4.8	4.8	5.5	5.8	6.2	5.2	0.1±0.0	0.61
	Health	4.5	4.4	4.9	5.0	4.7	4.4	4.7	4.5	4.5	4.8	5.0	5.2	4.7	0.0±0.0	0.20
	Industry	6.7	8.9	4.8	5.3	5.5	4.2	5.4	5.2	5.9	7.0	5.4	7.4	6.0	0.0±0.1	0.00
	Other	5.7	7.4	6.3	7.2	6.8	7.1	8.6	6.9	8.9	11.7	10.3	9.9	8.3	0.4±0.1	0.70
Industry	Education	3.2	3.2	3.3	3.3	3.7	4.5	3.9	4.0	4.5	4.5	4.0	4.1	4.0	0.1±0.0	0.64
	Health	6.7	8.9	4.8	5.3	5.5	4.2	5.4	5.2	5.9	7.0	5.4	7.4	6.0	0.0±0.1	0.00
	Industry	2.0	1.9	2.2	2.3	2.0	2.7	2.2	3.1	2.8	3.0	3.0	2.7	2.6	0.1±0.0	0.65
	Other	4.1	5.0	4.1	6.0	7.3	5.6	4.9	5.2	6.3	5.5	7.1	6.3	5.8	0.2±0.1	0.34
Other	Education	5.7	6.2	7.2	6.7	6.7	6.5	6.6	6.6	6.1	7.1	5.9	7.5	6.6	0.0±0.0	0.11
	Health	5.7	7.4	6.3	7.2	6.8	7.1	8.6	6.9	8.9	11.7	10.3	9.9	8.3	0.4±0.1	0.70
	Industry	4.1	5.0	4.1	6.0	7.3	5.6	4.9	5.2	6.3	5.5	7.1	6.3	5.8	0.2±0.1	0.34
	Other	6.4	8.4	7.1	11.7	7.0	8.6	8.2	8.6	11.6	9.2	8.4	9.1	8.8	0.2±0.1	0.14

Table 21 and Table 22 present a UK sector interaction impact indicator. Table 21 gives the average impact of the co-authored papers given in Table 19 and Table 20. Table 22 expresses the impact relative to a sector’s overall impact. Thus the impact of education sector collaborations are divided by the overall impact of education sector papers. We will focus on the relative impacts.

First we will explore partnerships with RCIs below 1.0 which indicates that the impact of these partnerships are below the impact of all papers from the sector. For example, education-industry papers have an RCI of 0.96 suggesting that these papers have slightly less impact than education papers in general. The same is true for ’other’-industry sector papers. The lowest RCI comes from industry-industry papers indicating that industrial partnerships produce papers with a much lower impact that the average industrial paper. The highest RCI (1.90) is for health-’other’ papers suggesting that, in general, these collaborations have nearly twice the impact of health papers. Similarly, ’other’-health sector papers have an RCI of nearly 1.5 indicating that the impact of ’other’ sector papers is greater when they collaborate with health sector institutions.

Table 22: UK sector interaction impact (relative to sector’s overall impact)

Sector	with	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*Ave.*	*Slope*	*R^2*
Education	Education	1.2	1.2	1.3	1.3	1.3	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	0.00±0.00	0.05
	Health	1.2	1.3	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3	0.00±0.01	0.07
	Industry	0.9	0.9	0.9	0.8	0.9	1.1	1.0	1.0	1.1	1.0	0.9	0.9	1.0	0.01±0.01	0.18
	Other	1.5	1.7	1.8	1.7	1.7	1.6	1.6	1.6	1.5	1.6	1.3	1.6	1.6	-0.02±0.01	0.27
Health	Education	1.1	1.2	1.1	1.2	1.3	1.2	1.2	1.2	1.1	1.2	1.2	1.2	1.2	0.01±0.01	0.08
	Health	1.1	1.1	1.2	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.1	1.0	1.1	-0.01±0.00	0.46
	Industry	1.7	2.2	1.2	1.3	1.4	1.0	1.3	1.2	1.4	1.5	1.1	1.5	1.4	-0.03±0.02	0.14
	Other	1.4	1.8	1.5	1.7	1.7	1.8	2.1	1.7	2.1	2.5	2.2	2.0	1.9	0.06±0.02	0.56
Industry	Education	1.0	1.0	1.1	1.1	1.1	1.3	0.9	1.0	1.0	1.0	0.9	0.9	1.0	-0.01±0.01	0.19
	Health	2.2	2.7	1.6	1.7	1.7	1.2	1.3	1.2	1.3	1.6	1.2	1.6	1.5	-0.08±0.03	0.43
	Industry	0.7	0.6	0.7	0.7	0.6	0.8	0.5	0.7	0.6	0.7	0.7	0.6	0.7	0.00±0.01	0.01
	Other	1.3	1.5	1.4	1.9	2.3	1.6	1.2	1.3	1.4	1.2	1.6	1.4	1.5	-0.02±0.03	0.05
Other	Education	1.2	1.3	1.4	1.1	1.2	1.2	1.1	1.1	1.0	1.1	1.0	1.1	1.1	-0.03±0.01	0.60
	Health	1.2	1.5	1.2	1.2	1.3	1.3	1.5	1.1	1.4	1.7	1.6	1.4	1.4	0.03±0.01	0.29
	Industry	0.8	1.0	0.8	1.0	1.4	1.0	0.8	0.9	1.0	0.8	1.1	0.9	1.0	0.00±0.01	0.00
	Other	1.3	1.7	1.4	1.9	1.3	1.6	1.4	1.4	1.8	1.4	1.3	1.3	1.5	-0.02±0.02	0.06

In summary, the interaction indicators suggest many things. First, institutional collaboration is becoming the rule not the exception in the British innovation system. The portion of papers with an institutional collaboration is increasing while the portion of non-collaborative papers is decreasing. Second, Britain has its greatest impact on the global system when it collaborates with other countries. Its second highest amount of impact comes from papers that involve an inter-sectoral institutional collaboration within the national system. On average, education-’other’ papers have 60% more impact than education papers as a whole; health-’other’ sector papers have about 90% more impact than health papers as a whole; industry-health and industry-’other’ papers have about 50% more impact than industry papers as a whole; and ’other’-health and ’other’-’other’ papers have about 50% more impact ’other’ sector papers as a whole.

Summary of the UK Innovation System from a Sectoral Perspective

Systemic bibliometric indicators have shown us that with the UK national system of innovation

- ➨ education is the largest participant in the UK science system followed by the health, ’other’ and industry sectors;
- ➨ on average, publications from the ’other’ sector (*i.e.* research council, non-profit and government laboratories) produce Britain’s greatest impact on the global innovation system;
- ➨ Britain’s most highly cited paper over the time period came from an industry laboratory;
- ➨ 25-30% of UK research indexed in the SCI is uncited by other papers indexed in the SCI;
- ➨ all UK sectors publish a sizeable portion of their papers in *biochemistry & molecular biology* but there is diversity in the size distribution of the subfields for each sector. This suggests that each of the four institutional sectors in the UK innovation system has a unique and distinctive character to their research focus;
- ➨ the impact of the twenty highest impact subfields in the UK is similar across sectors with some notable exceptions;
- ➨ growth in impact in the twenty highest impact subfields is diverse across sectors but is concentrated mostly in the life and medical sciences;
- ➨ institutional collaboration is becoming the rule not the exception in the British innovation system;
- ➨ Britain has its greatest impact on the global system when it collaborates with other member countries and its second highest impact when the published research involves collaboration between two or more institutional sectors.

The UK System of Innovation: a Sector's Perspective

Up to this point we have used systemic bibliometric indicators to explore (1) how the UK's system of innovation fits in the context of the global innovation system and (2) how this fit is constructed from the unique blend of sectoral activity and their dynamic interaction. Now we will explore one sector in more detail. We choose the industry sector because it links commercial activity and scientific research. As we mentioned earlier, the fact that industry publishes at all is interesting and as we have seen, firms participate in about 8% of the research publication indexed in the SCI involving a UK institution. For a more detailed description of UK industrial publishing activity we point you to our recent report *The Changing Shape of British Industrial Research* (Hicks and Katz, 1997).

UK firms participated in approximately 41,000 publications between 1981 and 1994 which gives us about an order of magnitude fewer papers on which to build indicators than we had for the UK as a whole. In order to maintain the accuracy we must do two things: (1) we will use a different journal classification scheme and (2) we will group UK firms into industrial sectors. Thus for the following discussion we will adopt a more traditional and less systemic bibliometric indicators methodology by not providing a time series but rather using aggregate publication counts for the time period. First we shall outline the journal classification scheme and industrial sectors.

SPRU Journal Classification

The ISI journal classification scheme used previously assigned a journal to one or more of 154 scientific subfields. The SPRU scheme aggregates the 154 subfields into 17 scientific fields which in turn are aggregated into 4 disciplinary groups: life sciences, natural sciences, engineering & material sciences and inter-disciplinary sciences (Katz and Hicks, 1995). This classification is unique in how it handles journals that are not easily classified into one field. Some schemes fractionate such journals across two or more fields; others force journals into one primary field. This scheme places journals not classified into a single field into categories containing other journals that spanned field boundaries.

Table 23: Structure of fields

Discipline	**Field**
Life Sciences	Agricultural Sciences (Agr)
	Biological Sciences (Bio)
	Medical Sciences (Med)
	Inter-field Life (Ifl)
Natural Sciences	Chemical Sciences (Chm)
	Earth Sciences (Eth)
	Mathematical Sciences (Mth)
	Physical Sciences (Phy)
	Inter-field Natural (Ifn)
Engineering & Material Sciences	Engineering (Eng)
	Information, Computers & Communications Technologies (Ict)
	Materials Science (Mat)
Inter-disciplinary	Inter-disciplinary Life-Natural (Dln)
	Inter-disciplinary Life-Engineering & Materials (Dle)
	Inter-disciplinary Natural-Engineering & Materials (Dne)
	Multidisciplinary (Mul)

The field abbreviations in parentheses will be used instead of the full field name in the indicator tables we will present later.

The fields are listed in Table 23 where they are grouped by discipline[7]. Life science fields are agriculture, biology, medicine and inter-field life (containing journals that span two or more of the other fields). Natural sciences fields are: *chemistry*, *earth sciences*, *physics*, *mathematics* and *inter-field natural*. Engineering & materials science fields are: *information & communication*, *materials* and *inter-field engineering*. The inter-disciplinary category consists of three fields containing journals that span two disciplines (*inter-disciplinary life-natural*, *inter-disciplinary life-engineering* and *inter-disciplinary natural-engineering*) and a multi-disciplinary field containing *environmental sciences* as well as journals such as *Nature*, *Science*, *Proceedings of the National Academy of Sciences* and other high prestige journals that publish papers from a range of disciplines.

*Industrial Sectors*Recall that the BESST database unifies variant institutional names found in the SCI to a set of standard names. We consolidated the standardised firm names into parent companies as listed in 1992 edition of UK *Who Owns Whom*. Parent companies are those that own *more* than 50 percent of another company. Finally, this list of consolidated names was used to assign a company and its subsidiaries to an industrial sector based on the Times 1000 list of Britain’s largest firms (Times Book, 1994). If a firm could be identified on this list it was assigned to

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[7] Figure 1 in Appendix B, *The Changing Shape of British Science*, STEEP Special Report No 3, SPRU 1995 illustrates the relationship between fields, disciplines and 'inter-' categories.

one of the following categories: Research and Technology Organisations, Farms, Veterinary Surgery, Research Associations, Unclassified Foreign and SMEs (see Hicks and Katz, 1997 for more details).

Industrial Sector Size

Table 24 is an industrial sector size indicator. It lists the Times 1000 industrial sectors in decreasing order of total publications produced in the 1981-1994 time period. Only sectors with 50 or more publications are listed. For each industrial sector we provide the number of papers published in each of the 17 SPRU science fields. Also, we have provided counts of the number of papers that were published in journals for which a classification could not be identified (Unk), most of which are no longer indexed in the SCI.

First, we see that Health & Household (*i.e.* pharmaceuticals) is the largest publishing industrial sector in the British innovation system, participating in about one-quarter of industry's papers. The next largest publisher, chemicals, is about two-thirds the publishing size of pharmaceuticals. In total, thirty-one industrial sectors published 50 or more papers during the time period in one of the world's 3,200 leading scientific journals. Imperial Chemical Industries (ICI) published as much as some of the UK's medium-sized universities (Hicks and Katz, 1997).

Table 24: UK industry Times 1000 sector size indicator

			Life sciences				Natural sciences				Engineering & materials science				Inter-disciplinary sciences				
Sector	*All*	*Agr*	*Bio*	*Med*	*Ifl*	*Chm*	*Eth*	*Mth*	*Phy*	*Ifn*	*Eng*	*Ict*	*Mat*	*Ife*	*Die*	*Dln*	*Dne*	*Mul*	*Unk*
Health & Household	10111	299	830	4983	1028	1854	5	4	40	44	11	2	11	9	5	614	31	320	21
Chemicals	6437	226	440	1992	534	2093	4	8	155	60	103	11	134	34	5	193	218	216	11
SME	4609	275	331	846	287	543	163	46	207	46	527	51	179	176	15	95	466	342	14
Engineering - General	3187	20	13	101	14	306	86	22	799	51	183	8	385	368	15	46	443	314	13
Electronics	2833	2	1	124	6	284	7	17	897	17	614	131	80	231	5	2	341	64	10
Oil, Gas & Nuclear Fuels	2335	79	132	131	117	723	216	13	108	36	86	5	71	167	2	46	262	140	1
Communications	2322	2	2	9	2	99	1	10	433	3	976	57	26	520	0	1	166	14	1
Food Manufacturing	1987	269	490	263	261	364	1	7	49	27	31	0	5	9	1	110	16	81	3
RIO	1468	273	46	199	284	146	4	4	33	4	77	7	93	20	2	37	59	171	9
Electricity	1218	8	63	23	9	121	12	6	162	6	175	3	203	175	4	6	88	152	2
Unclassified Foreign	873	93	44	225	62	161	9	7	49	20	36	8	31	13	1	29	42	39	4
Aerospace	455	3	1	12	2	37	6	8	73	1	117	14	75	39	0	1	56	10	0
Metal & Metal Forming	423	0	1	29	6	52	0	3	12	4	17	0	228	16	0	1	36	16	2
Research Association	411	58	13	70	18	108	0	1	9	1	44	2	24	24	1	6	22	9	1
Water	406	3	34	16	40	33	9	2	0	2	23	0	2	2	1	2	28	209	0
Engineering - Instrument	351	6	2	8	2	76	26	1	48	11	52	52	4	5	0	3	37	18	0
Business Services	318	18	6	102	71	23	0	5	15	0	5	2	0	5	0	47	6	13	0
Other Industrial Materials & Products	253	6	7	22	15	68	1	1	22	0	12	1	67	2	0	3	20	6	0
Contracting, Construction	249	1	1	2	3	17	10	1	8	0	72	1	19	18	0	2	67	27	0
Veterinary Surgery	240	211	0	16	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stores	204	0	16	146	12	8	0	0	0	0	3	0	1	0	0	12	2	3	1
Mines	189	0	1	18	3	30	10	4	2	0	14	2	14	58	0	0	16	17	0
Farm	151	93	24	10	11	1	1	0	2	0	1	0	0	0	2	1	1	4	0
Brewers & Distillers	130	85	7	2	23	9	0	0	0	0	0	0	1	0	0	1	0	1	1
Transport Services	130	0	0	17	0	13	0	6	18	0	64	0	3	3	0	1	4	1	0
Media	128	6	3	15	2	5	0	0	4	0	25	5	2	22	0	0	22	17	0
Building Materials & Services	86	1	0	3	2	30	1	0	1	4	6	0	24	5	0	0	4	5	0
Transport - Manufacture & Distribution	83	0	0	4	0	3	1	13	21	0	10	4	4	3	0	1	13	6	0
Electricals	65	0	0	4	0	0	0	0	28	0	11	1	2	is	0	0	3	1	0
Property	54	0	0	2	3	4	0	0	1	0	17	0	13	7	0	0	5	1	1

Publishing more than 1,000 papers are: pharmaceuticals, chemicals, electronics, oil gas and nuclear, Research and Technology Organisations (RTOs), engineering general, food and electricity. Except for RTOs, these industries contain large companies and have been found to be relatively heavy users of science in previous studies (Nelson and Levin, 1986; Narin and Olivastro, 1992; Arundel, 1995). Communications (BT, etc.) is unusual exhibiting a high 'papers per company' ratio. Between 100 and 1,000 papers we find the mid-range of publishers, sectors such as aerospace, metal and metal forming, water, instruments, business services, other industrial materials, construction, stores, mines, transport, brewers and media. In previous studies some of these industries have also been found to be rather intensive users of science. Others were excluded from previous studies because they are not manufacturing sectors. Between 10 and 100 papers we find industries whose presence on a list of publishers is a bit of a surprise: building materials, transport, property and conglomerates, food retailers, even banks, building societies and insurance.

The size indicator also gives us a sense of the scientific fields where each sector is concentrating its publishing activity. Health & Household is concentrated in the medical sciences with more than 10% of its activity also in the chemical and inter-field life sciences. The Chemical sector naturally concentrates in chemistry, and as expected more than 10% of its activity is in the medical sciences. On the other hand, the Food Manufacturing sector appears to be more diverse in its scientific publishing. Most of its publications are concentrated in the biological sciences but more than 10% of its activity is in four other scientific fields: agriculture, medicine, inter-field life and chemistry. Then there are sectors like General Engineering and Electronics. They concentrated mostly in physics but have significant research output in one of the engineering & materials science subfields or interdisciplinary sciences subfield.

In general UK industrial sectors fall into two broad classes. Those sectors whose research activities are concentrated in the life and/or natural sciences and those concentrated in the natural and/or applied sciences. Few industrial sectors span the life and/or engineering sciences or the life and/or natural and/or engineering sciences. Having said this we must recognise that many sectors publish in inter-disciplinary journals but usually only one of the inter-disciplinary science fields.

Industrial Sector Impact

Table 25 is an industrial sector impact indicator. It lists the Times 1000 industrial sectors in decreasing order of total publications as in Table 24 but the values in the table are impact values (average citations per paper using a three year citation window). Again, only sectors with 50 or more publications are listed. For each industrial sector we provide the impact of the papers published in each of the 17 SPRU science fields.

Although impact values are affected by the variation in the sizes of the citing community and rates of diffusion of knowledge in different science fields, we will use this indicator to get a sense of the fields in which UK industrial sectors are having the greatest impact on the global innovation system. We will only explore the impact of those science fields in which the sector has 10% or more of its research publications.

The top three publishing sectors in size (Health & Households, Chemicals and SME) are having their greatest impact in the medical sciences. This is followed by the Engineering-General and Electronics sectors whose impact is felt most in the physical sciences. Notice that almost no one is having their greatest impact in Engineering & Materials. This is partly due to the fact that more applied research papers such as those in Engineering & Materials are, in general, poorly cited. Again, the two sectors with the greatest impact in this discipline are Communications and Engineering-Instruments. Interestingly, the two highest impact sectors in the inter-disciplinary sciences are Transportation-Manufacturing & Distribution and Electricity. In general, we see that the UK industrial sectors are having their greatest impact on the global innovation system in the medical and physical sciences and relatively low impact in the inter-disciplinary sciences.

Table 25: UK industry Times 1000 sector impact indicator

		Life sciences						Natural sciences			Engineering & materials science				Inter-disciplinary sciences				
Sector	*All*	*Agr*	*Bio*	*Med*	*Ill*	*Chm*	*Eth*	*Mth*	*Phy*	*Ifn*	*Eng*	*Ict*	*Mat*	*Ife*	*Dla*	*Din*	*Dne*	*Mul*	*Unk*
Health & Household	6.6	1.9	9.9	7 3	5.3	3.3	4.0	0.3	2.9	3.9	0.9	0.5	0.4	2.0	1.5	6.6	1.6	19.1	1.2
Chemicals	4.4	1.5	8.6	4.9	5.2	3.2	2.7	0.4	3.4	3.6	1.9	1.9	1.9	0.8	1.0	3.6	2.1	11.7	1.4
SME	2.7	1.3	7.5	4.0	3.5	2.4	1.6	0.7	3.3	1.6	0.7	0.5	0.6	0.8	0.8	4.9	1.5	3.3	0.9
Engineering - General	2.6	0,4	1.9	3.0	2.1	3.1	2.9	2.8	L 9	2.6	0.7	3.4	2.1	1.4	1.4	1.6	1.9	3.0	0.2
Electronics	3.6	0.5	2.0	15.0	4.5	2.4	1.0	1.3	£7	2.3	1.9	1.1	1.2	0.7	5.4	0.0	2.3	3.8	0.0
Oil, Gas & Nuclear Fuels	2.5	1.7	3.6	2.7	3.4	2.7	2.6	1.2	3.1	4.1	1.0	0.4	1.7	1.1	7.5	2.3	1.5	3.4	0.0
Communications	3.2	1.0	9.5	0.6	0.0	2.1	0.0	0.9	5.0	4.5	3.8	0.5	1.4	0.8	0.0	1.0	3.6	1.2	0.0
Food Manufacturing	4.4	2.1	7.3	4.1	3.4	3.0	1.0	0.4	3.5	3.3	2.1	0.0	0.8	2.0	0.0	3.9	2.2	7.9	0.7
RTO	2.0	1.8	2.7	4.5	2.4	1.2	2.0	2.7	1.5	3.3	0.9	0.4	0.4	0.6	0.0	1,8	0.8	1.9	0.1
Electricity	2.0	5.6	3.6	2.5	1.8	2.3	3.0	0.2	3.8	2.7	0.5	0.0	1.6	0.7	4.0	1.7	1.6	2.8	0.0
Unclassified Foreign	2.8	1.2	4.0	3.5	2.3	3.9	2.0	2.5	3.9	4.9	0.3	0.8	0.5	2.0	0.0	2.7	1.1	3.0	1.0
Aerospace	0.8	0.0	0.0	1.1	1.0	0.5	2.4	1.7	1.0	2.0	0.8	0.2	0.9	0.7	0.0	0.0	1.0	0.3	0.0
Metal & Metal Forming	1.4	0.0	6.0	5.3	1.0	2.4	0.0	1.0	1.0	1.0	0.4	0.0	0.9	1.4	0.0	0.0	1.4	2.5	0.0
Research Association	1.1	1.2	0.7	1.6	2.1	1.0	0.0	0.0	1.3	1.0	0.7	3.0	0.9	0.8	1.0	0.8	1.4	0.7	0.0
Water	1.6	0.0	1.6	5.8	L 8	2.4	1.3	1.5	0.0	0.0	0.5	0.0	2.0	1.0	3.0	1.5	1.6	1.2	0.0
Engineering - Instrument	2.3	2.4	1.5	4.9	0.0	2.3	2.1	0.0	3.5	2.3	2.5	0.9	0.0	0.7	0.0	0.0	1.2	3.6	0.0
Business Services	1.3	0.5	3.5	1.6	1.2	2.5	0.0	1.8	2.1	0.0	1.0	0.0	0.0	0.3	0.0	0.3	1,0	1.1	0.0
Other Industrial Materials & Products	2.1	0.4	3.1	3.4	3.9	L 6	0.0	0.0	1.9	0.0	7.5	3.0	0.8	2.0	0.0	0.3	2.6	0.8	0.0
Contracting, Construction	0.8	0.0	0.0	8.5	1.3	0.5	2.3	0.0	0.6	0.0	0.6	0.0	0.3	0.4	0.0	1.0	0.5	2.3	0.0
Veterinary Surgery	1.1	1.1	0.0	1.3	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stores	2.4	0.0	2.1	2 7	3.5	0.4	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	1.3	0.0	1.3	0.0
Mines	1.9	0.0	1.0	1.6	0.0	2.6	1.0	0.8	0.5	0.0	0.4	0.0	0.5	26	0.0	0.0	1.8	2.5	0.0
Farm	1.9	L 9	1.1	5.8	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.8	0.0
Brewers & Distillers	1.7	1.2	2.8	6.0	2.6	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	1.0	0.0
Transport Services	0.6	0.0	0.0	L 9	0.0	0.4	0.0	1.2	0.1	0.0	0.5	0,0	0.0	0.7	0.0	1.0	0.7	1.0	0.0
Media	0.4	0.0	L3	1.0	1.0	0.2	0.0	0.0	1.0	0.0	0.2	0.0	0.0	0.4	0.0	0.0	0.2	0.6	0.0
Building Materials & Services	1.1	0.0	0.0	1.0	4.0	L 1	2.0	0.0	0.0	4.0	0.3	0.0	0.8	1.0	0.0	0.0	1.5	0.8	0.0
Transport - Manufacture & Distribution	1.3	0.0	0.0	0.3	0.0	1.0	0.0	0.8	1.7	0.0	0.3	0.3	1.0	1.0	0.0	0.0	2.9	1.0	0.0
Electricals	1.6	0.0	0.0	4.3	0.0	0.0	0.0	0.0	3.7	0.0	0.5	2.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Property	0.6	0.0	0.0	0.0	3.3	1.5	0.0	0.0	0.0	0.0	0.5	0.0	0.4	0.2	0.0	0.0	0.0	0.0	0.0

Industrial Sector Interaction

Table 26 is an industrial sector interaction indicator. This indicator shows how industry's domestic collaborations are distributed among various UK institutional sectors: educational, medical, research council, non-profit and government. It displays for each sector the number of times its firms collaborated with each type of institution. Sectors are ordered descending by the education share of collaborations. These figures are transformed into percentages in the second half of the table. The first row reports the percentage share of UK publishing accounted for each public sector. In the table, percentages exceeding those in the first row are highlighted in bold.

As we mentioned before we expect sectors to collaborate in proportion to their relative sizes. For example, assuming the number of papers is roughly proportional to the number of researchers available as partners for publishable collaborative research, an industrial researcher looking for a collaborator should have a 10 per cent chance of finding one in a sector accounting for 10 per cent of the output and a 60 per cent chance of finding one in a sector publishing 60 per cent of the output. However, Table 26 indicates this is not happening. Overwhelmingly, industry finds partners in universities.

Industrial sectors most dependent on universities seem to be those with a physical or engineering flavour to their technology: communications; aerospace; oil, gas & nuclear fuel; electricity and engineering. The least dependent sectors are farms and veterinary surgeries. Although not shown here we have found that industry-industry collaborations are very low and, in general, account for only a few percent of the total number of collaborations (Hicks and Katz, 1997).

Table 26: UK Industry Times 1000 sector interaction size indicator

		Number of collaborations							% Share of collaborations					
Papers	**Sector**	*Edu*	*Med*	*Res*	*Npr*	*Gov*	*Unk*	*Total*	*Edu*	*Med*	*Res*	*Npr*	*Gov*	*Unk*
	Share of UK publishing, normalized								58	26	11	2	4	0
2325	Communications	455	1	3	3	25	0	487	**93**	0	1	1	**5**	0
455	Aerospace	172	5	1	2	14	0	194	**89**	3	1	1	**7**	0
2335	Oil, Gas & Nuclear Fuels	939	26	64	8	39	2	1078	**87**	2	6	1	4	0
249	Contracting, Construction	77	1	6	0	6	0	90	**86**	1	7	0	**7**	0
1218	Electricity	222	11	12	0	15	0	260	**85**	4	5	0	**6**	0
3188	Engineering - General	801	27	60	16	85	3	992	**81**	3	6	2	**9**	0
351	Engineering - Instrument	121	8	18	2	2	0	151	**80**	5	**12**	1	1	0
130	Brewers & Distillers	38	3	6	1	0	0	48	**79**	6	**13**	2	0	0
253	Other Industrial Mat. & Prod.s	90	14	5	2	4	0	115	**78**	12	4	2	3	0
6437	Chemicals	2569	507	170	41	59	5	3351	**77**	15	5	1	2	0
189	Mines	59	7	3	6	2	0	77	**77**	9	4	**8**	3	0
2833	Electronics	814	137	20	2	90	0	1063	**77**	13	2	0	**8**	0
423	Metal & Metal Forming	126	22	4	1	13	1	167	**75**	13	2	1	**8**	1
413	Water	97	11	15	2	12	1	138	**70**	8	11	1	**9**	1
1987	Food Manufacturing	596	76	131	21	36	1	861	**69**	9	**15**	2	4	0
873	Unclassified Foreign	281	73	30	13	11	3	411	**68**	18	7	3	3	1
130	Transport Services	19	5	0	0	3	1	28	**68**	18	0	0	**11**	4
4610	SME	1439	392	170	77	151	7	2236	**64**	18	8	3	**7**	0
204	Stores	66	29	7	2	0	0	104	**63**	**28**	7	2	0	0
10111	Health & Household	2595	1222	253	75	64	8	4217	**62**	**29**	6	2	2	0
1467	RTO	202	42	55	7	42	1	349	58	12	**16**	2	**12**	0
411	Research Association	55	8	15	7	14	0	99	56	8	**15**	**7**	**14**	0
318	Business Services	33	18	4	2	8	1	66	50	**27**	6	3	**12**	2
128	Media	8	6	0	2	2	0	18	44	**33**	0	**11**	**11**	0
240	Veterinary Surgery	63	22	12	14	36	0	147	43	15	8	**10**	**24**	0
151	Farm	38	17	19	14	7	0	95	40	18	**20**	**15**	**7**	0
	All sectors	12118	2704	1092	321	760	35	17030	**71**	16	6	2	4	0

Note:

Bold indicates shares higher than expected

Sector Key: Edu - education; Med - medical; Res - research council; Npr - non-profit; Gov - government; Unk - unknown

CONCLUSIONS

The purpose of this paper was to examine the potential for a systemic analysis of publishing activity to produce bibliometric indicators of size, impact and diversity of a knowledge-based economy and to portray interactions between sectors by exploring the British system. We have done this by developing systemic indicators to:

1. reveal the size and diversity of the UK innovation system compared to the World innovation system and five other national/regional systems; and explore the impact the British system has on the global innovation system;
2. reveal the size, diversity and amount of interaction that occurs between four UK institutional sectors and other members of the global system; and explore how these institutional sectors impact the global system; and
3. reveal the size of UK industrial sectors within the industry institutional sector; examine how they interact with various UK public sectors; and explore how UK industrial sectors impact the global innovation system.

We will now summarise the findings.

In a global context, throughout the 1980s and part of the 1990s Britain’s innovation system participated in about 9% of the research publications published in approximately 3,200 of the World’s leading science and technology journals indexed by the SCI. The UK is the second largest participant out of a group of national systems of innovation composed of the US, UK, France, Germany, Canada and Australia. The US is the largest. The British innovation system has the second greatest impact of the group on the global system. The US has the most impact. In the UK, the size, impact and impact growth distributions of the twenty largest scientific subfields world-wide are somewhat similar to those of the global and other national systems, however, the British system has its own unique distribution shaped by the economics, politics, culture, history and skills of the UK research community.

At a domestic level, education is the largest institutional participant in the UK science system followed by the health, ’other’ and industry sectors. On average, publications from the ’other’ sector (*i.e.* research council, non-profit and government laboratories) produce Britain’s greatest impact on the global system, however, the UK’s most highly cited paper came from an industry laboratory. There is great diversity in size, impact and impact growth between the four sectors. Each has its unique speciality but all publish a sizeable portion of their papers and impact in the medical and life sciences. Institutional collaboration is not only becoming the rule but it has greater impact than non-collaborative research. And most importantly, British research institutions have their greatest impact on the global system when they collaborate with researchers from institutions in other countries.

At the industrial sector level we find that the sectors fall into two broad classes: sectors that concentrate in the life and/or natural sciences and sectors that concentrate in the natural and/or applied sciences. In general, British industrial sectors have their greatest impact on the global innovation system in the medical and physical sciences but relatively low impact in the inter-disciplinary sciences. All industrial sectors seem to rely heavily on public sector educational institutions for knowledge exchange as indicated by the large percentage of industry-education co-authored papers.

There is nothing particularly surprising about this portrait of the British innovation system. What is surprising is that a simple empirical tool - systemic bibliometric indicators - helps us confirm some of our intuitive understanding of the British innovation system. We can see the shape and diversity of its structure and get some insight into its dynamic personality. There is no doubt in these authors' minds that comparable, verifiable and standardised systemic bibliometric indicators from other national systems of innovation could help build a better model of the global innovation system. With this tool and our help, policy makers could visualise their national system of innovation, see its growth and distinctive character evolve, explore how it interacts and impacts other systems to form the complex and self-organising meta-system - the global innovation system.

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APPENDIX - ISI SUBJECT CATEGORIES

Acoustics
Aerospace Engineering & Technology
Agriculture
Agriculture Economics & Policy
Agriculture, Dairy & Animal Science
Agriculture, Soil Science
Allergy
Anatomy & Morphology
Andrology
Anesthesiology
Astronomy & Astrophysics
Behavioral Sciences
Biochemistry & Molecular Biology
Biology
Biology, Miscellaneous
Biomethods
Biophysics
Biotechnology & Applied Microbiology
Cardiovascular System
Chemistry
Chemistry, Analytical
Chemistry, Applied
Chemistry, Clinical & Medicinal
Chemistry, Inorganic & Nuclear
Chemistry, Organic
Chemistry, Physical
Clinical Neurology
Computer Applications & Cybernetics
Computer Science, Artificial Intelligences
Computer Science, Cybernetics
Computer Science, Hardware & Architecture
Computer Science, Information Systems
Computer Science, Interdisciplinary Application
Computer Science, Software, Graphics, Program
Computer Science, Theory & Methods
Construction & Building Technology
Critical Care
Crystallography
Cytology & Histology
Dentistry & Odontology
Dermatology & Venereal Diseases
Developmental Biology
Ecology
Education, Scientific Disciplines
Electrochemistry
Embryology
Endocrinology & Metabolism
Energy & Fuels
Engineering
Engineering, Biomedical
Engineering, Chemical
Engineering, Civil
Engineering, Electrical & Electronic
Engineering, Industrial
Engineering, Manufacturing
Engineering, Mechanical
Engineering, Petroleum
Entomology
Environmental Sciences
Ergonomics
Fisheries
Food Science & Technology
Forestry
Gastroenterology & Hepatology
Genetics & Heredity
Geography
Geology
Geosciences
Geriatrics & Gerontology
Hematology
History & Philosophy of Science
Horticulture
Immunology
Infectious Diseases
Instruments & Instrumentation
Limnology
Marine & Freshwater Biology
Materials Science
Materials Science, Biomaterials
Materials Science, Ceramics
Materials Science, Characterization & Testing
Materials Science, Coatings & Films
Materials Science, Composites
Materials Science, Paper & Wood
Materials Science, Textiles
Mathematics
Mathematics, Applied
Mathematics, Miscellaneous
Mechanics
Medical Laboratory Technology
Medicine Legal
Medicine Miscellaneous
Medicine Research & Experimental
Medicine, General & Internal
Metallurgy & Mining
Meteorology & Atmospheric Sciences
Microbiology
Microscopy
Mineralogy
Multidisciplinary Sciences
Mycology
Neurosciences
Nuclear Science & Technology
Nutrition & Dietetics
Obstetrics & Gynecology
Oceanography
Oncology
Operations Research & Management
Ophthalmology
Optics
Ornithology
Orthopedics
Otorhinolaryngology
Paleontology
Parasitology
Pathology
Pediatrics
Pharmacology & Pharmacy
Photographic Technology
Physics
Physics, Applied
Physics, Atomic Molecular & Chemical
Physics, Condensed Matter
Physics, Fluids & Plasma
Physics, Mathematical
Physics, Nuclear
Physics, Particles & Fields
Physiology
Plant Sciences
Polymer Science
Psychiatry
Public Health
Radiology & Nuclear Medicine
Rehabilitation
Remote Sensing
Reproductive Systems
Respiratory Systems
Rheumatology
Robotics & Automatic control
Spectroscopy
Sport Sciences
Statistics & Probability
Substance Abuse
Surgery
Telecommunications
Thermodynamics
Toxicology
Tropical Medicine
Urology & Nephrology
Veterinary Science
Virology
Water Resources
Zoology