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Collaboration

Hospitals: the hidden research system

Diana Hicks and J Sylvan Katz

Using co-authored scientific papers as indicators of research collaboration the pattern of research linkages in the UK during the 1980s is analysed. All sectors collaborate with each other at a rate proportional to publishing size to a first approximation. However, there are deviations from this pattern. Analysing these deviations, two groups of sectors are found that collaborate with each other more than expected: the GIPU group composed of government, industry, polytechnics and universities, and the HSNR group composed of hospitals, special health authorities (SHAs), non-profit organisations and research councils. This suggests that a biomedical innovation system coexists with the more commonly recognised, industry-oriented system. Better knowledge of the biomedical system would augment our understanding of innovation processes and facilitate deeper insight into the contributions of a previously neglected component of the UK science base.

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THE UK SCIENCE BASE comprises the institutions producing public scientific and technical research. Research produced by the science base is seen by policy-makers to have the potential to enhance UK economic performance and quality of life. To realise this potential, the government would like to strengthen interaction between industry and both universities and research councils, and between government laboratories and users of their research.[1]

Bringing researchers and innovators together helps to make those working in the science base more aware of the issues confronting industry and, *vice versa*, industry more aware of the skills and knowledge the science base can offer in solving complex problems. It also produces research of direct commercial importance and aids recruitment — providing trained people is one of the main contributions the science base makes to industry.[2]

While the importance of these interactions is understood, the patterns of interaction and their evolution are less clear because the phenomenon is complex, and data are limited. For example, in the OECD (Organisation for Economic Co-operation and Development) science and technology statistics, a science system is composed of four sectors: industry, higher education, government and non-profit. The statistics indicate that, in the UK, industry spends 65% of R&D expenditure, universities 17%, government laboratories 14%, and non-profits 4%.

These statistics provide a good overview, enabling comparisons to be made between nations over time. However, they are less useful for examining the science base *per se* for three reasons. First, they cover development as well as research and so incorporate non-public elements outside the science base. Second, they do not separately identify hospitals, which publish one quarter of UK scientific output and so are

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crucial to the science base.[3] Third, they are uninformative about a key issue of current policy concern — research linkages. They do not track the links between the sectors, or between institutions within each sector, or the evolution of number and type of linkages over time.

We have developed a bibliometric database that complements available information by addressing some of these gaps. Our database offers one method of tracking research linkages in the science base. We use co-authored scientific papers as indicators of research collaboration to analyse the pattern of research linkages in the UK during the 1980s. We have previously examined the strong growth of research collaboration in the UK and considered the policy implications.[4] This paper examines the patterns of inter-institutional collaboration at the sectoral level and how these might be changing.

We ask: with whom does each sector collaborate? Almost all sectors collaborate most often with universities, as we might expect, since universities are the largest single source of potential collaborative partners. Indeed, more generally, the frequency of collaboration is related to size of sector with which one is collaborating.

In mathematical terms, the number of papers a sector produces in collaboration with each other sector correlates well with the number of papers produced by each sector. Nevertheless, there are deviations from this rule, and in analysing these deviations we identify two clusters of institutions in the system — one linked to companies, the other to hospitals. Theoretical considerations suggest these might be two separate sources of technical opportunity and sites of application. One is relatively well understood, the other less so.

Methodological background

The bibliometric evidence used here is drawn from the project on the Bibliometric Evaluation of Sectoral Scientific Trends (BESST) at the Science Policy Research Unit (SPRU) at the University of Sussex. This project analysed 11 years of UK scientific output as indexed in the *Science Citation Index* (SCI) at the sectoral level, adhering to *de facto* standards in the bibliometric community.[5]

Information on all papers indexed in the SCI and listing a UK address from 1981 to 1991 was purchased from the Institute of Scientific Information on tape, and three document types were extracted — articles, notes and reviews — as these tend to report original, substantive research results. UK addresses on the 376,226 papers we processed were assigned to one of approximately 5,000 unified institutional names.

Thus, for every paper produced in the UK during the 1980s and indexed in the SCI, we know with which institutions its authors were affiliated. Because the database is completely unified, we can identify every collaborative paper produced.

Table 1. List of sectors and notes on their definition

Sector name	Notes on definitions
University	'Old' universities, polytechnics were a separate sector in the 1980s, see below.
Hospital	Hospitals were counted separately from universities.
Research council	Intra-mural laboratories, excluding 'groups' at universities, but including 'units' at universities.
Industry	Including all laboratories privatised during the decade.
SHA & BPG	Special Health Authority and British Postgraduate medical research Institutes.
Government	Departmental laboratories and local government.
Non-profit	Does not include research funded by grants from charities, in universities for example.
Polytechnics	Sector became universities in the 1990s.
Other	Comprising other educational, other medical and unknown, each of which produces less than 2% of UK output.

Research collaboration occurs when more than one person contributes to a piece of research. Contributors tend to become authors, but not always, and thus collaboration is indicated by multiply authored papers.[6] Sometimes authors from two or more institutions work together; we refer to this as 'institutional collaboration' and assume it results in papers that list two or more addresses.

Sometimes authors in one organisation collaborate to produce a paper listing several addresses, for example, 'Department of Physics, Manchester University' and 'Department of Chemistry, Manchester University'. Such a paper would not be counted as an institutional collaboration in our database because both these addresses are unified to the same clean name 'Manchester University'. However, the paper would be counted as institutionally collaborative if another institution's address were listed, for example, 'Imperial College, University of London'.

Each institution was assigned to one of nine institutional sectors (see Table 1). It is worth mentioning that, in general, medical schools are either departments of universities or of hospitals. Because we did not unify to the departmental level, medical schools' papers are assigned to the hospital or university of which they are a part. In this paper, institutional collaboration is analysed at the sectoral level.

Analysing collaboration

Our approach to analysing collaborative patterns stresses the importance of asymmetry in collaborative relationships. In this it differs from commonly used methodologies. Previous analyses have examined patterns of collaboration between countries, and have sought to measure not just the extent of collaboration (the number of collaborative papers for example) but whether it is more or less than expected given the publishing 'size' of the countries. This requires an 'expected rate of collaboration' to be calculated based on size and propensity to collaborate.

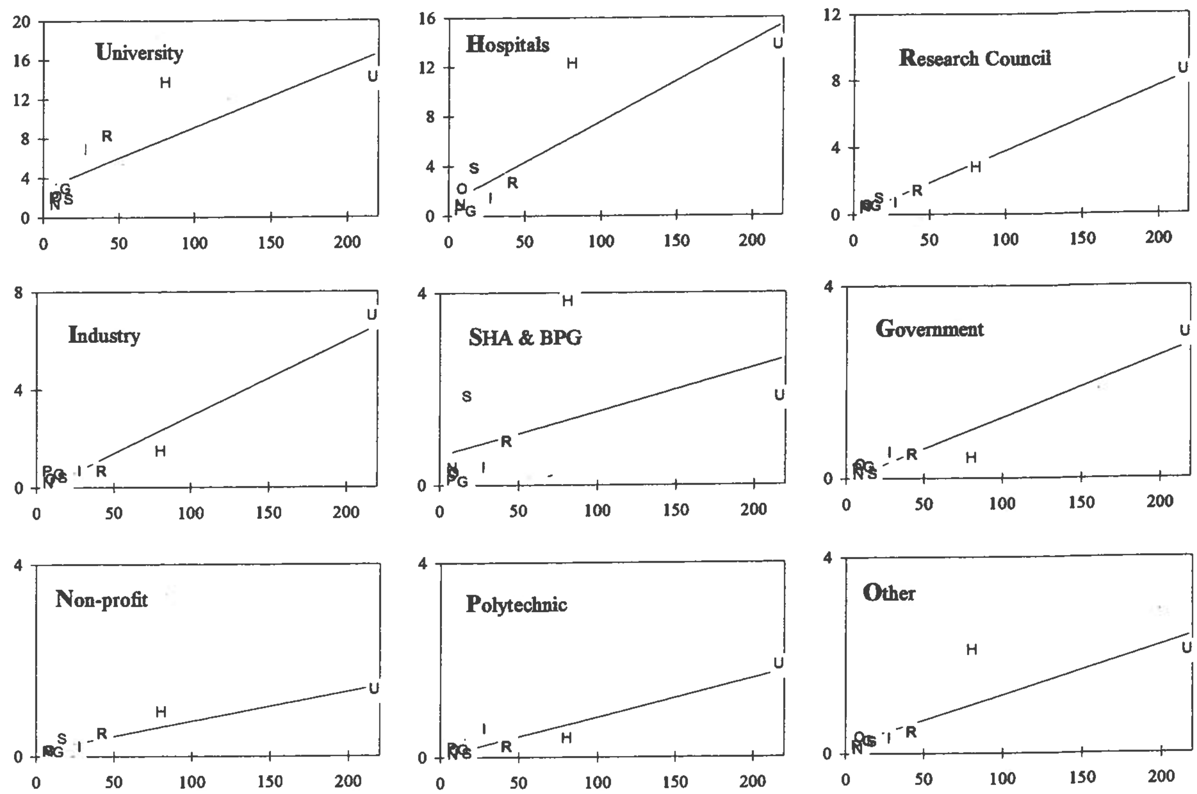


Figure 1. Inter-sector collaborations versus publications for each sector

Note: y-axis = collaborations in thousands
x-axis = total papers in thousands

The problem is that countries publish very different numbers of papers and have different propensities to collaborate. For example, the expected rate at which the United States and Israel might collaborate is difficult to calculate since the USA produces 35% of world scientific output and Israel only 1%. In traditional bibliometric work, various mathematical techniques have been devised to remove the asymmetry and calculate one statistic summarising the relationship.

By contrast, we suggest the story of collaboration is in the asymmetry. We use it; we do not suppress it. Thus, when we examine collaborative patterns, it is always from the perspective of a given sector. For example, how important are university–industry collaborations to the production of public knowledge? We would say there is no single answer to this question. From the perspective of publishing by industry, the answer is that they are quite important; one in four papers published by industry is produced in collaboration with a university. From the perspective of universities, they are less important; only one in 30 papers is produced in collaboration with industry. However, from the perspective of industrial R&D, such links are again less important since published output reports a small part of a company's whole R&D effort. In the analysis below, university–industry collaboration is placed in two contexts: as part of university collaborations and as part of industry collaborations.

Collaboration and size of sector

The graphs in Figure 1 illustrate this approach. There is a graph for each sector which displays the distribution of its collaborative papers across all sectors and how this relates to the number of papers published by each sector. The number of collaborative papers is plotted along the y-axis (and listed in the table in Figure 2 below) and the total number of papers published by the sectors is plotted along the x-axis.[7] Numbers on both axes are in thousands.[8] The identity of each data point is indicated with an abbreviation, U for university and so on, and the abbreviations are listed in Table 2.

Thus from the first graph, which illustrates the university perspective, we see that industrial partners are the fourth most frequent collaborators with university researchers. The same data point appears on the industry graph — this time at the top — and we see that university researchers are by far the most frequent collaborative partner listed on industry papers.

Table 2. Linear regression of frequency of collaboration and sector publishing size

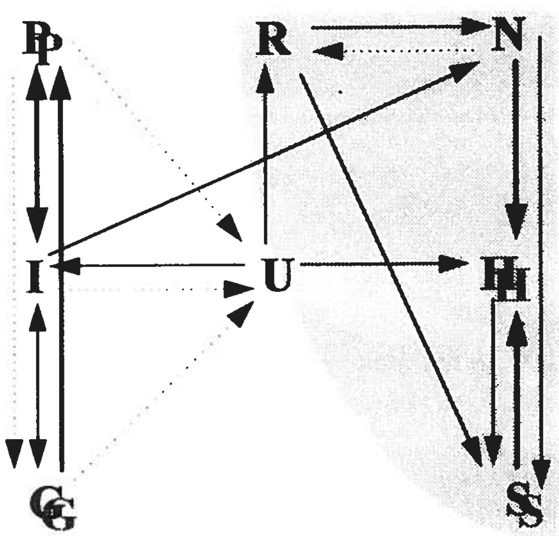
Sector	Abbreviation	Slope	r^2
University	U	.062 ± 016	0.69
Hospital	H	.066 ± 014	0.77
Research council	R	.038 ± 001	0.99
Industry	I	.031 ± 002	0.96
SHA & BPG	S	.009 ± 006	0.25
Government	G	.013 ± 001	0.92
Non-profit	N	.006 ± 001	0.89
Polytechnic	P	.008 ± 001	0.91
Other	O	.010 ± 002	0.73

The graphs reveal that every sector collaborates with every other sector. Because the collaborating sectors are arranged along the x-axis according to the number of papers they publish, the overall pattern suggests that the number of collaborative papers is related to the publishing size of the collaborating sectors. If this were so, mathematically there would be a significant, possibly linear, relationship between the number of joint papers a sector produces in collaboration and the number of papers produced by the collaborating sectors.

Table 2 displays the slopes, standard errors and r^2 (correlation coefficient) values obtained from regressing one sector's distribution of collaborative papers across the sectors against the distribution of papers published by each sector. The regression lines are plotted on the graphs. The linear relationship between the frequencies of collaboration and the publishing size of the sectors is very strong except in the case of SHA & BPG (Special Health Authority and British Postgraduate Federation institutes, see below).[9] This sector collaborates surprisingly little with universities, as will be discussed below.

The linear relationship between frequencies of collaboration and sector publishing size is strong except for Special Health Authorities and British Postgraduate Federation institutes: this sector collaborates surprisingly little with universities

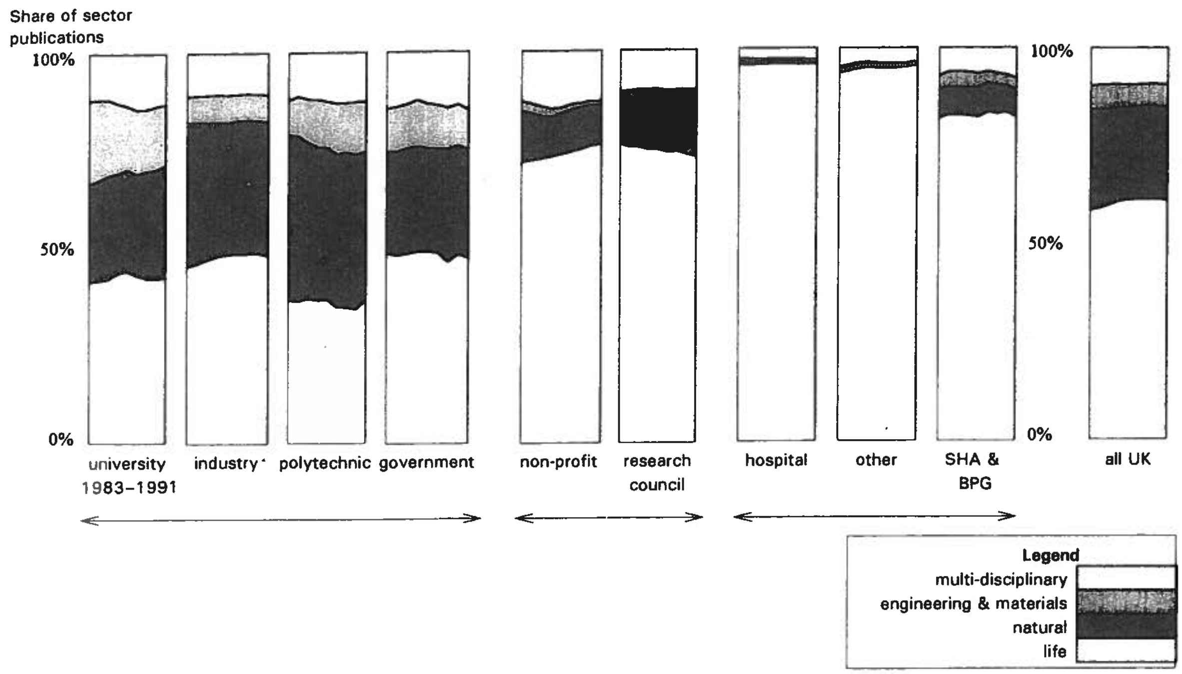
The slopes in Table 2 are a measure of sectors' *propensities to collaborate*. For example, the slope of the linear regression of universities' distribution of



Number of intra- and inter-sectoral collaborations, 1981–1991

Sector	With sector U	H	R	I	S	G	N	P	O
University	*13935*	13603	8416	6919	1791	2958	1347	1851	2049
Hospitals	13603	*12187*	2766	1439	3812	413	915	385	2095
Research council	8416	2766	*1493*	715	931	528	508	253	468
Industry	6919	1439	715	*682*	378	546	204	600	315
SHA & BPG	1791	3812	931	378	*1831*	77	359	71	236
Government	2958	413	528	546	77	*244*	95	169	267
Non-profit	1347	915	508	204	359	95	*111*	67	104
Polytechnic	1851	385	253	600	71	169	67	*152*	131
Other	2049	2095	468	315	236	267	104	131	*319*

Figure 2. Pattern of stronger than expected collaboration between sectors



collaborations across the sectors on the number of papers published by each sector is .062. This means that 6.2% of hospitals' papers would be expected to be with a university partner, and similarly for research councils, industry, and so on. The relationship holds for collaborations between universities as well; 6.2% of universities' papers would be expected to be produced in collaboration with other universities. Universities therefore have the propensity to collaborate on 6.2% of each sectors' papers.[10]

The regression lines on the graphs can be thought of as the *expected* number of collaborative papers, given the hypothesis that collaboration is linearly related to the publication size of a sector (Table 2). However, many *actual* values are above or below the line. In the next section we look for patterns in these deviations of actual from expected values.

Two-part science base

We looked for patterns in sectoral collaborative publishing by calculating the ratio of actual to expected numbers of collaborative papers. We then inspected the patterns of higher than expected collaborative ratios. Figure 2 displays the results. The letters representing the sector names are connected by lines whose thickness varies according to the strength of the relationship. The thickest line represents an actual to expected ratio of two or more; the thin line a ratio of 1.5 to 2; the dotted line a ratio of 1.1 to 1.5. Higher than expected rates of intra-sectoral collaboration are represented by a shadow on the letter; this is not coded by strength.

The lines between sectors have arrow heads indicating the perspective from which the relationship is stronger than expected. An arrow pointing from universities to industry means that, from the perspective of the universities, their collaborations with industry are higher than expected. The arrows are two-way when the size of the relationship is the same in both directions; otherwise two separate lines are drawn.

The table below the diagram lists the number of collaborative papers between pairs of sectors; it is a symmetrical table, so numbers appear twice except on the diagonal. The diagonal contains the number of intra-sectoral collaborations (that is, collaborations within a sector).

The figure indicates that the British research system divides itself into two groups of collaborating sectors. One group comprises government, industry, polytechnics and universities (GIPU group). The other, shaded in Figure 2, comprises: hospitals, SHA & BPG institutes, non-profits and research councils (HSNR group). Every sector in the GIPU group is connected to every other, and the connections between industry, polytechnics and government laboratories are particularly strong.

The HSNR group is slightly less well connected as research councils and hospitals are not linked. The strong link between hospitals and SHA & BPG units is not surprising, since hospitals collaborate among themselves quite considerably (hence the shadow on the H) and SHAs are hospitals — in general, they are national referral centres. They differ from hospitals in that they have funding earmarked for, and a strong history of, research, combined with a specific focus on a disease or patient group (except for Hammersmith Hospital whose research strengths are broader).

We might hypothesise that research collaborators require complementary skills and techniques — broadly similar knowledge and interests combined

Table 3. Fastest and slowest growing collaborative sector pairings: annual growth in percentage share of sector's publications

Sector	With sector	Collaborative papers	% change per year in share of sector's papers	r^2
Fastest growing				
Industry	University	6919	1.52 ± 0.13	0.93
Government	University	2958	1.28 ± 0.11	0.94
Research council	University	8416	1.09 ± 0.09	0.94
Polytechnics	University	1851	0.65 ± 0.13	0.73
Polytechnics	Industry	600	0.61 ± 0.11	0.78
Non-profit	Hospital	915	0.54 ± 0.09	0.81
Non-profit	University	1347	0.52 ± 0.12	0.66
SHA & BPG	Hospital	3812	0.46 ± 0.10	0.69
SHA & BPG	University	1791	0.37 ± 0.11	0.56
Hospital	University	13603	0.34 ± 0.04	0.90
Stable or decreasing				
SHA & BPG	Research council	931	0.00 ± 0.05	0.00
Non-profit	Industry	204	0.00 ± 0.04	0.00
Non-profit	Polytechnics	67	0.00 ± 0.04	0.00
Hospital	Government	413	-0.01 ± 0.01	0.04
SHA & BPG	SHA & BPG	1831	-0.02 ± 0.10	0.00
Polytechnics	Government	169	-0.02 ± 0.06	0.01
Hospital	Industry	1439	-0.03 ± 0.01	0.49
Industry	Government	546	-0.03 ± 0.03	0.10
Industry	Hospital	1439	-0.03 ± 0.03	0.11
Hospital	Research council	2766	-0.05 ± 0.02	0.50

with differences at a more detailed level. We can then look at sectors' publishing across fields to explain the groupings. In this light, the non-profit placement is not surprising. Although there are over 100 non-profit publishers with a range of interests, the sector is quite concentrated. Imperial Cancer Research Fund units[11] publish almost one-third of non-profit papers. Biomedical research is not all that is published by non-profits, but it is a substantial percentage of the output. Therefore, the link to hospitals is a natural one.

In contrast, the placement of universities in the GIPU group is somewhat surprising. Since universities perform research across the spectrum of scientific fields, we might expect them to bridge the groups. They almost do; the reason they seem more closely associated with the GIPU group is that, relatively speaking, the rate at which non-profit and SHA institutions collaborate with universities is slightly low.

More systematically, the collaborative groups roughly correspond to groups formed by clustering sectors according to the similarity of their publishing profiles across 17 scientific fields. An SPSS clustering technique was used to group the sectors by field profile.[12] Universities, industry, polytechnics and government form one group; hospitals, SHA & BPG and 'other' another group;[13] and research councils and non-profits a third group.

Figure 3 confirms these similarities at the disciplinary level. Each bar displays the distribution of a sector's papers among four disciplines — life, natural, engineering and materials, and multi-disciplinary.[14] The bars also show how the distribution changed over time (three-year moving averages from 1983 to 1991 are plotted across each bar).

The GIPU group has the most even distribution of papers among fields. The group consisting of hospital, other and SHA publishes little except life sciences papers, and these are mostly medical. The research council and non-profits group publishes multi-disciplinary and some natural papers, but almost no engineering and materials research. The virtual absence of publishing in 'engineering and materials' by the HSNR group is quite striking.

That the groups found in the data on distribution of papers across fields are similar to those found in the collaboration data seems to confirm the hypothesis that people with similar research interests (at a broad level) collaborate more.

Are these two groups strengthening or weakening? To analyse trends over time we examined the change in share of each sector's papers performed in collaboration with the other sectors. To obtain a measure of yearly change, we performed a linear regression and used the resultant slope to indicate the average yearly change in the percentage share of a sector's papers performed in collaboration with another sector. This analysis yields figures for over 64 sector pairings of which Table 3 lists the ten fastest growing and ten slowest growing.

About 40 of the 64 sector pairings were strengthening, two were weakening and the rest were stable. The fastest growing pairings are with universities, accounting for seven of the ten in this group, and including every other sector. The remaining three of the ten fastest growing pairings are within group. The slowest growing pairings are both within and between groups. The pairings: hospital–industry and hospitals –research councils have significant negative slopes. These are the only two pairings whose frequency has been decreasing over time. Given the strong trend towards increasing collaboration generally, these two trends must be considered somewhat unusual.

Interpretation

To summarise, all sectors collaborate with each other at a rate proportional to publishing size to a first

Industrial and clinical publishing is considered to be of low quality; but high temperature superconductors were discovered in an IBM laboratory and a clinician discovered the role played by Helicobacter Pylori in digestive ailments

approximation. However, there are deviations from this pattern. Analysing these deviations, we find two groups of sectors that collaborate with each other more than expected: the GIPU group composed of government, industry, polytechnics and universities, and the HSNR group composed of hospitals, SHAs, non-profits and research councils.

The split is not perfect: industry collaborates more than expected with non-profits and universities more than expected with research councils and hospitals. Nevertheless, in general the pattern holds, and the notion of the two groups makes sense of the data. Examining patterns of publishing across fields confirms this grouping. During the 1980s there was no clear trend to either strengthen or weaken within-group linkages as opposed to across-group linkages.

The pattern contrasts with current understanding of the UK science system, however. Universities, polytechnics (now universities), and government laboratories are exhorted to develop stronger links to industry. In this scheme, industry is the user of research produced by the science base (that is, universities, polytechnics and government).

Our scheme can be interpreted as augmenting this understanding. We see the user or site of application — companies — connected to sources of technical opportunity — polytechnics, universities and government laboratories. However, we also see a second site of application for research — hospitals — connected to sources of biomedical technical opportunity — non-profits, SHAs and through them research councils and indeed universities. Hospitals then are the site at which much UK research is ultimately applied — biomedical research to be exact. In this light, we should pause to reflect on the apparent decreasing trend in collaboration between hospitals and industry, the two user sectors.

The similarity between industry and hospitals extends to the way in which their publications are viewed. The general attitude seems to be that individuals in companies or hospitals publish for their own reasons, and the quality of the publications is low. Hicks has analysed the reasons why companies publish and provided evidence that some company publications are of high quality.[15] This analysis has yet to be carried out for hospitals. However, just as the discovery of high temperature superconductors in an IBM laboratory should lead us to question common assumptions about industrial publishing, so the discovery by a clinician of the role played by Helicobacter Pylori in digestive ailments should lead us to query assumptions about clinical publishing.

This analysis depends on separating hospitals from universities. Many hospitals are attached to universities not least because doctors cannot be trained from textbooks and blackboards alone; patient contact is needed. Thus, hospitals and universities are commonly not separated in analyses of research systems. However, hospitals' close association with universities does not mean that they are universities. Their separate identity makes sense from the perspective of users and sources of technical opportunity. Hospitals use research results to improve treatment; universities rarely apply research internally.[16]

An analogy might be made with engineering: sometimes university engineering training is said to be inadequate; engineers are not prepared to solve real-world problems. Perhaps engineering training would be improved if engineering departments were similarly intermingled with companies. However, if this were to happen, companies would not thereby become universities.

The analysis also separated hospitals and SHAs. As discussed above, SHAs are similar to hospitals in that they have patient beds. The differences lie in the specialisation, research intensity and the regional or national remit of the SHAs. They are specialised, sophisticated, research-intensive hospitals.[17]

In distinguishing between users and sources of technical opportunity, we must carefully consider the position of government laboratories. Their mission is to support the work of departments; they are therefore analogous to industrial laboratories in being users as well as producers of research. However, given their position in the public sector and the longer-term perspective that this presumably entails, they also function as sources of technical opportunity.

Analysis of one such laboratory, the Plant Breeding Institute (PBI), suggested that this ambiguous positioning enabled the laboratory to combine basic and applied approaches to research in a unique and fruitful way. This combination was compromised when the applied part of PBI was privatised, and the basic and applied researchers were separated.[18]

The position of research councils — sources of technical opportunity — is also worth considering. Research council collaborations are distributed among sectors in almost exact proportion to the publishing size of each sector (Figure 1). They form the sector whose behaviour most exactly fits the model. This may partly explain why they do not have stronger than expected links with the user sectors — industry and hospitals.

More worrying is that hospitals links with them may be decreasing, which is unusual, as collaboration as a whole is increasing. This trend cannot be explained by the irrelevance of research council work to hospitals since research councils publish medical research. Stronger links would presumably enhance clinicians' access to biomedical advances produced by the research councils and increase the chances of biomedical advances finding swift application.

Summary

Hospitals and SHA/BPG institutes contribute to approximately 25% of British scientific output. Although this is hardly a surprising result, it does lead us to question current understanding which pays scant attention to these institutions. The 1993 White Paper does not mention them.[19] NHS (National Health Service) reorganisation seemed to address research almost as an afterthought and possibly in isolation from science policy. Yet hospitals and SHA/BPG institutes are integral to biomedical research, and in the biomedical area the UK has a comparative advantage.[20]

This analysis strongly suggests that a biomedical innovation system coexists with the more commonly recognised, industry-oriented system. However, the biomedical system is not named as such, is not the focus of policy attention and is not as well understood by academic analysts as is the industry-oriented system.

Most analyses of interactions between users and sources of technical opportunity only examine industrial collaborations. This is unfortunate because the biomedical system is quite different: hospitals are more substantial contributors to the science base than are companies, and, for biomedical research, access to patients is needed. Better knowledge of the biomedical system would augment our understanding of innovation processes and facilitate deeper insight into the contributions of a previously neglected component of the UK science base.

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7. Hence the x-axis and the position of the data points along it is identical in each graph.
8. So for example, 100 means 100,000.
9. It is almost as if researchers chose partners at random from the different sectors. If that were so, a sector's distribution of collaborative papers across other sectors would mirror the distribution of papers produced by these different sectors. Of course, researchers choose collaborative partners for very specific reasons; they look for complementary capabilities and interests in the same problem. However, with so many researchers making choices and with capabilities and interests in problems so widely dispersed, the random model explains quite a large part of how collaborations are distributed at the national level.
10. The propensity to collaborate has an upper bound determined by the sector size.
11. Unified to one institutional name.
12. SPSS for Windows version 6.1 hierarchical clustering using between-groups linkage and the cosine-similarity measure was used to cluster the sectors based on their publication profiles across the 17 fields.
13. The other category was not included in the collaboration analysis because those institutions collaborate in a different pattern. This residual sector is composed of small medical organisations, with strong links to hospitals and small educational units, with a more diverse range of links.
14. We have classified papers into 17 scientific fields based on the journal in which they appeared. These fields were aggregated into the disciplinary groups. Life science fields are: medicine, biology, agriculture and inter-field life (containing journals that span two of the other life fields). Natural sciences fields are: chemistry, physics, earth and space sciences, mathematics and inter-field natural. Engineering and materials sciences are: engineering, materials, information and communication and inter-field engineering and materials. Inter-disciplinary categories are multidisciplinary (containing environmental sciences as well as *Nature*, *Science*, *Proceedings of the National Academy*, and so on), and three fields containing journals that span two disciplines. J S Katz and D Hicks, "A classification of interdisciplinary journals: a new approach", *Proceedings of 5th International Conference on Scientometrics and Informetrics* (1995).
15. D M Hicks, "Published papers, tacit competencies and corporate management of the public/private character of knowledge", *Industrial and Corporate Change*, 4, 1995, pages 401–424.
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