BERR | Department for Business Enterprise & Regulatory Reform

THE EVALUATION OF DTI SUPPORT FOR BIOTECHNOLOGY

Annex B: UK performance in science related to biotechnology - An analysis of publications data

JUNE 2008

Since June 2007 the support analysed in the main evaluation report has been the responsibility of the Department for Business Enterprise and Regulatory Reform (BERR)

The Evaluation of DTI Support for Biotechnology

Annex B: UK Performance in Science related to Biotechnology: An Analysis of Publications data

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Executive Summary

One of the main distinguishing characteristics of biotechnology, compared to other technologies is that it depends crucially on developments in basic science. This study is a pioneering attempt at systematically analysing the UK science base related to biotechnology using data on scientific publications. The main objective is to present a set of reasonably robust findings or "stylised facts" for further discussion and debate. The report includes international comparisons of UK performance in 7 scientific fields and an analysis of the main institutional actors involved.

The main finding of the study are:

- The UK has maintained its position as the leading European country in terms of Biotechnology related scientific research throughout the 1980s and 1990s.

- Two areas in which UK science is relatively strong, both in terms of the volume of publishing and its impact, are *Experimental Biology* and *Molecular Biology & Genetics. Biotechnology & Applied Microbiology* is a field with a high and increasing level of impact. The main area of relative weakness for the UK is *Cell & Developmental Biology.* This is a potential cause for concern as it is an area of emerging applications.

- The US has maintained its position as the leading country in terms of Biotechnology related science base. Most European countries have been rapidly increasing their level of activity. This is especially the case for Germany and France. However they still lag behind the UK and US in terms of impact.

- Top ranked UK universities in terms of overall research performance are amongst the top publishers in biotechnology. At the same time a number of lower ranked universities and PSROs are also important players.

- While large Pharmaceutical firms are amongst the most prolific publishers, increasing numbers of smaller specialist biotechnology firms and consultancies are also becoming involved in publishing.

- For firms from all industries *Biotechnology and Applied Microbiology* is an important science field. For Pharmaceutical and dedicated Biotechnology firms, *Biochemistry and Biophysics* is also relatively important.

- There has been a rapid increase in the volume of collaborations (as measured by joint publications) between firms and universities and other public sector research organisations in the 1990s. This is especially the case in *Biotechnology & Applied Microbiology* and *Molecular Biology & Genetics*.

- More than half of all scientific output produced by industry is jointly with the public sector. In the early 1980s this proportion was 36%.

- The list of top co-publishing universities, in terms of volume, is dominated by those with the highest number of publications overall. On the whole these are also the top research universities in the UK. Their main industrial partners are large Pharmaceutical firms and some smaller specialist biotechnology firms.

- In general the universities with the highest intensity of collaboration are the 'new' universities or the ones that are more 'technology' based. At the same time a number of hospitals and public sector laboratories also collaborate intensively with industry.

Taken together these results suggest that the UK science system in relation to Biotechnology is strong. The volume and impact of scientific activity are high. There are a large number of top research active universities collaborating with some of the leading R&D intensive firms in the Pharmaceutical industry. At the same time a wide variety of other universities, public sector laboratories and hospitals are important actors in forging collaborative links with industry. This suggests that government policies and research funding are better aimed at encouraging a wide variety of scientific institutions rather than simply targeted towards the largest most research active universities.

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1. Introduction: Aim and Methodology

1.1 Aim

In contrast to many other technological fields, the main characteristic of the innovation process in biotechnology is that it depends crucially on developments in basic science. This means that advances in basic research are vitally important if countries are to succeed in creating new products and new processes. One way of measuring such advances is to analyse information on scientific publications. The first part of the report documents the results of comparing overall UK publishing and citation rates with those of other countries in seven different fields of biotechnology. The aim of the second part of the report is to identify the main institutions involved in conducting basic research related to biotechnology within the UK. The report also examines the key issue of the extent to which universities and other public sector research organizations publish jointly with industry.

The main questions addressed in the report are:

- *How does UK compare with its major competitors (G7 countries) in terms of publication shares, relative scientific advantage and relative impact?*
- *Who are the main institutions involved in UK publishing?*
- *What are the main changes in the distribution of publications by institutional category?*
- *Which public sector institutions are most closely involved in co-publishing with industry?*
- *Who are the main firms involved in co-publishing with public sector institutions?*

1.2 Methodology

Use of Bibliometric Data

Data on publications provide an indication of scientific output and those on citations provide an indication of scientific impact. Both of these sets of indicators have well known limitations but nevertheless provide the basis for systematic international comparisons. One such limitation is that the ISI database, which forms the basis of our analysis blow, probably provides a better coverage of scientific literature from English speaking countries than from non-English speaking countries. However in the scientific fields being analysed in this report this may not be an important issue as the databases used below cover most of the journals deemed to be most important in these fields.

Data Sources

This report is based on three data sources. The first is the Institute for Scientific Information's (ISI) *National Science Indicators* version 1.5, which is a database of summary publication and citation statistics for some 170 countries in 105 science fields for the period 1981 to 2000. This information forms the basis of the country level analysis reported in the first part of the report.

The data used for institution level analysis were obtained from two sources: the BESST database, and its subsequent update using information from ISI for all publications for 1995-2000 with at least one UK address. The current report is based on information from *articles, notes and reviews*, as these report substantial new research findings.

Definition of Biotechnology related Science Fields.

In terms of identifying Biotechnology related science fields, the idea behind this study is to use the classification list provided by ISI rather than construct a tailor-made scheme based on keyword searches of articles. Thus this report is based on 7 ISI science fields (out of a possible 105) which were judged to be of relevance to Biotechnology. These have been defined as follows by ISI[1]:

BIL: Biochemistry & Biophysics

Biochemistry & Biophysics focuses on the structure and chemistry of biomolecules and covers all aspects of basic biochemistry/biophysics, including molecular structure, enzyme kinetics and protein-protein interaction. This category also contains cross-disciplinary publications focused on a specific class of biological molecules, e.g., nucleic acids, steroids, magnesium, growth factors, free radicals, bio-membranes, and peptides.

BIO: Biology

The Biology category includes publications that cover a broad range of topics in the biological sciences. This category covers specific areas in biology, such as general microbiology, protozoology, parasitology, biometrics, biological education, heredity, and evolutionary biology.

BTC: Biotechnology & Applied Microbiology

[1] See Scope Notes for Science Citations Index and Current Contents/Life Sciences (http://www.isinet.com/isi/journals/index.html)

The Biotechnology & Applied Microbiology category includes a number of subjects that relate to the exploitation of living organisms or their components. The emphasis is on applied biology, including industrial microbiology. Applications include industrial chemicals and enzymes, biosensors, bioelectronics, pesticide development, food, flavour and fragrance industry applications, waste treatment, and pollution bioremediation.

CEL: Cell & Developmental Biology

Cell & Developmental Biology contains publications in biochemistry, molecular biology, biophysics, physiology, and pharmacology that have a specific emphasis on cellular function in eukaryotic systems. Topics of particular importance include receptor biology and signal transduction, regulation of gene expression at the cellular level, developmental genetics, developmental biology and morphogenesis, and cell-environment interactions.

EXP: Experimental Biology

Experimental Biology covers a wide array of topics concerned with research in general biology and biological systems, including evolution, ecology, radiation biology, anatomy, general biology, and resources containing diverse topics in basic biology research.

MBG: Molecular Biology & Genetics

Molecular Biology & Genetics considers all aspects of basic and applied genetics, including molecular genetics, prokaryotic and eukaryotic gene expression, mechanisms of mutagenesis, structure, function and regulation of genetic material. Also included are publications concerned with clinical genetics, patterns of inheritance, genetic cause, and screening and treatment of disease.

MCB: Microbiology

Microbiology covers the biology and biochemistry of microorganisms, bacterial, viral, and parasitic, as well as the medical implications and treatments of the subset of these organisms known to cause disease in humans and/or animals. Biotechnology applications of microorganisms for basic science or clinical use are also covered.

Given these definitions there is bound to be some overlap between these fields and this needs to be borne in mind when interpreting the results below. Thus the *Biology* field contains publications from some of the same journals as *Experimental Biology*,

Molecular Biology & Genetics and Microbiology. Further there is some overlap between *Biotechnology & Applied Microbiology* and *Microbiology*.

Finally there are a number of other science fields that are "somewhat" relevant to biotechnology but have not been included in this analysis:

AN	Animal & Plant Sciences
CVS	Cardiovascular & Hematology Research
CAR	Cardiovascular & Respiratory Systems
INF	Clinical Immunology & Infectious Disease
NUT	Endocrinology, Metabolism & Nutrition
END	Endocrinology, Nutrition & Metabolism
ENT	Entomology/pest Control
IMM	Immunology
DGX	Medical Research, Diagnosis & Treatment
MGN	Medical Research, General Topics
ONC	Oncology
OPH	Ophthalmology
PHM	Pharmacology & Toxicology
PMC	Pharmacology/Toxicology
PL	Plant Sciences
VET	Veterinary Medicine/Animal health

The main reason for omitting these fields is that without additional information it is difficult to assess their degree of relevance to biotechnology.

Unifying and Classifying Institutions

All publishing organisations with a UK address[2] were given 'clean, unified names' to eliminate spelling variations and to allocate departments and other sub-units to their parent institution[3].

Companies were unified on the basis of *Who Owns Whom (WOW)* for 1999, which gives ownership details for UK companies. This means that our data reflect company structures as of 1999.

This process yielded a list of clean organisation names, which were then allocated to one of the following institutional categories: industry, university, public sector or charity (including non-profit). The 'university' category includes old and new universities, and other educational institutions such as schools, independent research units and specialised training institutions as well as British Postgraduate Medical

[2] We have excluded all organisations with non-UK addresses from our analysis.

[3] For details on the precise process involved see Calvert and Patel (2002), *University- Industry Research Collaborations in the UK*, Report on Phase 1 of a project funded by EPSRC/ESRC http://www.sussex.ac.uk/spru/publications/reports/patel.pdf

Federation research institutes and university hospitals[4]. Under 'industry' we include all companies as well as veterinary surgeries, and industrial research associations. Finally the public sector category includes MRC, BBSRC and government laboratories.

The completed database for institutional level analysis has the following information:

- ISI allocated identifier code for each paper;
- Year the paper was published;
- Clean name(s) of the organisation(s) assigned;
- Institutional affiliation of the organisation;
- Scientific field of the publication;
- Companies only: industrial sector;
- Companies only: nationality.

[4] In such cases BESST data were adjusted to reflect this, as a number of these were classified under 'medical' in the BESST database.

2. International Comparisons

One of the main aims of this report is to compare UK publishing and citation rates with those of other countries in different fields of biotechnology. This will enable us to say something about the key areas of UK strengths and weaknesses in biotechnology related scientific research. Thus the question addressed in this section is the following:

- *How does UK compare with its major competitors (G7 countries) in terms of publication shares, relative scientific advantage and relative impact?*

Indicators Used

The analysis in this report is based on 'whole' counts of publications. Thus each internationally co-authored paper is allocated wholly to each country.

Comparisons below are based on the following set of indicators:

- *Number of publications over time.*

  This is an indicator of the volume of publishing over time.

- *% share of publications over time.*

  An indicator of the volume of publishing which takes into account the total number of publications in a specific field. However this indicator does not take into account the overall ('publishing') 'size' of the country, which may in turn be affected by the language bias in the journals included in ISI's *Current Contents*.

- *Relative Scientific Advantage index over time.*

  This is defined as the share of a country in a specific field divided by the aggregate share (i.e. across all fields combined) of world publications attributed to that country. It is an indicator of the relative position of a country in a specific field, taking into account the country bias mentioned above. Thus a value of greater than 1 indicates that the country has a relative advantage (or strength) in that field and a value less than 1 indicates relative disadvantage (or weakness).

- *Relative Impact index over time.*

  This is defined as the number of citations per paper for a given country in a specific field divided by the number of citations per paper for that field as a whole. It is a measure of the relative impact of a country's publications.

Countries

The comparisons below are between the G7 countries. However each table also includes information on 'Other EU' countries. These are the EU-15 less UK, France, Germany and Italy.

Year aggregations

In order to analyse the broad trends over the 20-year period, the analysis is based on four 5-year time periods: 1981-85, 1986-90, 1991-95 and 1996-2000.

2.1 Basic data on UK publications in Biotechnology related fields.

Table 1 presents basic data on UK publications in Biotechnology over the period 1981 to 2000. The main points to emerge from analysing this information are:

- The fastest increases have been in the more 'applied' fields: *Biotechnology & Applied Microbiology*, *Cell & Developmental Biology* and *Molecular Biology & Genetics*.
- At the same time the traditional 'basic' areas such as *Biology* and *Experimental Biology* have grown slowly or in the case of the latter, declined.
- The two largest categories in terms of the volume of publishing are *Biochemistry & Biophysics* and *Microbiology*, accounting for around half of all biotechnology related publications throughout the period.

Table 1. Total number of UK Publications in Biotechnology: 1981 to 2000

Scientific Field	*1981-85*	*1986-90*	*1991-95*	*1996-00*
Biochemistry & Biophysics	8219	8708	11133	11532
Biology	2374	2526	2623	3424
Biotechnology & Applied Microbiology	578	1224	1863	1886
Cell & Developmental Biology	1883	2434	3286	4340
Experimental Biology	4415	3500	3137	3428
Molecular Biology & Genetics	2764	3797	6097	7420
Microbiology	6119	7421	8508	8840
Total (All 7 Fields)	26352	29610	36647	40870

2.2 Evolution of Publication Shares

Table 2 presents an analysis of the evolution of publications shares in each of the 7 Biotechnology related science fields, with the first part of the table presenting data on all 7 fields combined. Before presenting the main findings, it is important to note that the sum of shares for each field is greater than 100 (row marked Total). This arises from the 'whole' counting of papers discussed above, and results in a certain amount of double counting.

The main points to arise from this analysis are:

- UK has maintained its position as the leading country for Biotechnology related science in Europe: both at the aggregate level, and in 5 of the 7 areas of Biotechnology, it has the highest share amongst the EU 15. The exceptions are *Biochemistry & Biophysics*, where Germany has caught up and moved ahead, and *Cell and Developmental Biology* where Germany has maintained its lead over the whole period.
- The largest increases in UK shares have been in *Experimental Biology* (from 11% to 17%) and in *Molecular Biology & Genetics*.
- The other main trend to note is that all EU countries have been catching up rapidly in most scientific areas of Biotechnology.
- The country at the forefront of all the scientific fields is the US.

Table 2. Percentage Share of Publications by Country: 1981-2000

		1981-85	*1986-90*	*1991-95*	*1996-00*
All 7 Fields	UK	9.7	9.6	10.2	10.3
	France	6.0	6.3	6.9	7.5
	Germany	7.4	7.5	8.0	9.1
	Italy	2.6	2.8	3.3	3.8
	Other EU	9.1	10.2	12.1	13.7
	Canada	4.6	5.1	5.2	4.9
	USA	39.7	40.2	41.5	40.7
	Japan	9.5	10.1	10.5	10.6
	Other	19.2	19.1	20.1	22.9
	Total	107.9	110.8	117.8	123.5
Biochemistry & Biophysics	*UK*	8.1	7.7	8.6	8.5
	France	6.0	6.5	6.5	7.0
	Germany	7.2	7.8	8.0	9.0
	Italy	2.7	3.1	3.6	4.1
	Other EU	8.8	9.8	11.1	12.2
	Canada	4.3	4.3	4.6	4.5
	USA	43.0	43.2	43.8	42.6
	Japan	11.9	13.0	13.5	13.6
	Other	15.5	15.7	17.1	20.4
	Total	107.7	111.0	116.7	121.7
Biology	*UK*	11.3	10.7	10.1	11.1
	France	3.7	4.1	5.5	6.7
	Germany	3.7	4.8	5.9	6.7
	Italy	1.4	1.5	2.1	2.8
	Other EU	5.6	7.8	11.5	14.2
	Canada	5.0	6.1	6.2	5.5
	USA	35.5	36.0	37.1	37.1
	Japan	3.6	3.6	4.6	4.9
	Other	36.7	33.8	32.9	33.8
	Total	106.5	108.5	115.9	122.9
Biotechnology & Applied Microbiology	*UK*	8.5	9.7	9.9	8.6
	France	3.9	6.7	6.4	6.6
	Germany	4.9	6.2	6.8	6.5
	Italy	1.5	1.5	3.0	2.7
	Other EU	8.8	10.9	14.4	16.8
	Canada	11.5	8.4	6.3	4.6
	USA	25.8	26.0	21.9	20.8
	Japan	12.6	11.4	12.3	12.1
	Other	27.3	24.9	29.1	36.4
	Total	104.9	105.6	110.2	115.0

Table 2 (Contd.) Percentage Share of Publications by Country: 1981-2000

		1981-85	*1986-90*	*1991-95*	*1996-00*
Cell & Developmental Biology	*UK*	9.0	9.2	8.6	9.1
	France	6.4	7.0	7.6	7.5
	Germany	9.5	9.7	8.7	10.1
	Italy	3.0	3.3	3.8	3.9
	Other EU	9.2	9.4	9.5	10.2
	Canada	4.0	6.5	5.7	5.7
	USA	46.8	45.0	51.2	50.9
	Japan	8.2	8.3	8.9	9.6
	Other	12.6	13.5	13.6	15.0
	Total	108.8	112.0	117.6	122.1
Experimental Biology	*UK*	11.4	11.2	13.1	16.9
	France	9.3	8.3	8.0	8.0
	Germany	7.9	6.1	6.8	8.6
	Italy	3.8	3.9	3.2	3.3
	Other EU	9.1	10.2	10.5	12.0
	Canada	4.0	4.7	5.4	5.9
	USA	31.1	33.2	37.6	41.1
	Japan	11.1	11.8	9.8	7.2
	Other	20.1	21.3	22.6	20.6
	Total	107.8	110.7	117.0	123.6
Molecular biology & Genetics	*UK*	10.1	10.1	12.0	12.4
	France	5.6	6.2	7.7	8.4
	Germany	7.8	7.9	8.7	9.7
	Italy	2.7	2.9	3.9	4.5
	Other EU	11.1	11.2	13.5	14.7
	Canada	4.6	5.4	5.9	5.7
	USA	40.4	44.0	45.5	44.9
	Japan	6.2	6.1	7.4	9.3
	Other	22.5	20.3	20.9	22.9
	Total	111.0	114.1	125.6	132.7
Microbiology	*UK*	11.1	11.3	11.6	11.2
	France	4.7	5.5	7.1	8.1
	Germany	8.0	7.6	8.4	9.8
	Italy	2.1	2.3	2.8	3.3
	Other EU	10.2	11.2	14.2	17.0
	Canada	4.9	5.0	4.9	4.2
	USA	40.0	38.6	37.6	34.8
	Japan	7.9	9.1	10.0	10.0
	Other	18.6	19.4	20.6	24.6
	Total	107.5	110.1	117.2	123.0

2.3 Evolution of Relative Scientific Advantage

As discussed above, the Relative Scientific Advantage index (RSA) indicates whether a country has a relatively high share of world publications in a particular science field compared to its average share of total world publications. This can be interpreted as an index of 'comparative advantage': with a value above unity indicating an area of strength and a value below unity an area of weakness. Table 3 presents a comparison of this index between the UK and other G7 countries over time. The main points to emerge from this analysis are:

- The UK is relatively strong in aggregate (i.e. all fields combined) and in 4 of the 7 individual science fields.
- The main area of concern for the UK is the relative weakness in the two of the more 'applied' fields: *Cell and Developmental Biology* and *Biotechnology & Applied Microbiology*. The former is an area of relative strength for the US, France and Germany.
- Two areas of greatest relative strength for the UK are *Experimental Biology* and *Molecular Biology & Genetics*. These are also the two areas that have seen the largest increase in the RSA index.
- UK has also managed to retain its relative strength in *Biology* and in *Molecular Biology and Genetics* throughout the 1980s and 90s.

Table 3. Relative Scientific Advantage by Country: 1981-2000

		1981-85	*1986-90*	*1991-95*	*1996-00*
All 7 Fields	*UK*	1.09	1.11	1.12	1.09
	France	1.18	1.19	1.18	1.18
	Germany	0.98	0.99	1.02	1.05
	Italy	1.13	1.03	0.98	0.94
	Other EU	1.15	1.12	1.12	1.08
	Canada	0.98	1.01	1.01	1.05
	USA	0.99	1.02	1.08	1.15
	Japan	1.49	1.37	1.25	1.16
	Other	0.83	0.82	0.81	0.79
Biochemistry & Biophysics	*UK*	0.91	0.89	0.95	0.90
	France	1.19	1.23	1.11	1.09
	Germany	0.95	1.04	1.02	1.04
	Italy	1.16	1.13	1.06	1.02
	Other EU	1.10	1.08	1.03	0.96
	Canada	0.91	0.84	0.89	0.95
	USA	1.07	1.10	1.14	1.21
	Japan	1.87	1.78	1.61	1.48
	Other	0.67	0.67	0.69	0.70
Biology	*UK*	1.26	1.25	1.12	1.17
	France	0.74	0.78	0.94	1.06
	Germany	0.49	0.65	0.76	0.77
	Italy	0.61	0.55	0.61	0.71
	Other EU	0.70	0.86	1.06	1.12
	Canada	1.05	1.20	1.21	1.18
	USA	0.88	0.92	0.96	1.05
	Japan	0.56	0.49	0.55	0.54
	Other	1.58	1.45	1.32	1.17
Biotechnology & Applied Microbiology	*UK*	0.95	1.13	1.10	0.91
	France	0.78	1.27	1.10	1.03
	Germany	0.65	0.82	0.87	0.75
	Italy	0.63	0.54	0.88	0.67
	Other EU	1.10	1.20	1.34	1.33
	Canada	2.43	1.65	1.21	0.99
	USA	0.64	0.66	0.57	0.59
	Japan	1.97	1.55	1.46	1.31
	Other	1.18	1.06	1.17	1.26

Table 3 (Contd.) Relative Scientific Advantage by Country: 1981-2000

		1981-85	*1986-90*	*1991-95*	*1996-00*
Cell & Developmental Biology	*UK*	1.01	1.07	0.95	0.96
	France	1.26	1.32	1.29	1.18
	Germany	1.26	1.29	1.12	1.17
	Italy	1.30	1.23	1.11	0.99
	Other EU	1.16	1.04	0.88	0.80
	Canada	0.85	1.28	1.11	1.22
	USA	1.17	1.14	1.33	1.44
	Japan	1.28	1.14	1.07	1.05
	Other	0.54	0.58	0.54	0.52
Experimental Biology	*UK*	1.28	1.30	1.45	1.78
	France	1.83	1.56	1.36	1.26
	Germany	1.04	0.81	0.87	0.99
	Italy	1.61	1.42	0.95	0.83
	Other EU	1.15	1.13	0.97	0.95
	Canada	0.85	0.94	1.04	1.27
	USA	0.78	0.85	0.97	1.16
	Japan	1.74	1.61	1.17	0.78
	Other	0.86	0.91	0.91	0.71
Molecular biology & Genetics	*UK*	1.13	1.17	1.32	1.31
	France	1.10	1.17	1.31	1.32
	Germany	1.03	1.05	1.12	1.12
	Italy	1.14	1.05	1.15	1.13
	Other EU	1.39	1.24	1.25	1.16
	Canada	0.98	1.07	1.14	1.23
	USA	1.01	1.12	1.18	1.27
	Japan	0.98	0.84	0.88	1.02
	Other	0.97	0.87	0.84	0.79
Microbiology	*UK*	1.25	1.32	1.29	1.19
	France	0.92	1.03	1.20	1.27
	Germany	1.05	1.02	1.08	1.13
	Italy	0.90	0.85	0.81	0.84
	Other EU	1.28	1.23	1.32	1.34
	Canada	1.02	1.00	0.95	0.90
	USA	1.00	0.98	0.97	0.98
	Japan	1.24	1.24	1.19	1.09
	Other	0.80	0.83	0.83	0.85

2.4 Analysis of Impact

This section analyses the relative impact of UK publications in Biotechnology related fields using information on citations. One caveat that needs to be borne in mind when examining citation rates is the possibility of English language bias in the citation process. This could account for a part of the lower rate of citation for papers from France, Germany and Japan.

This analysis is based on 1981 to 2000 as the 'citing year window', i.e., for each publishing year (or year aggregations such as 1981-85 etc.), we count the number of citations received in the period 1981-2000. This means that papers published in 1981 have a much greater chance of being cited than those published in the year 2000. This weakness is partly mitigated by the way in which the Relative Impact Index is constructed. As discussed above this is simply defined as the number of citations per paper for a given country in a specific field, divided by the number of citations per paper for that field as a whole. Thus although the absolute number of citations per paper will be much lower in the last period (1996-2000) this will be the same for all countries.

Table 4 contains information on the evolution of the Relative Impact index for the UK and its major rivals. The main points arising from this analysis are:

- UK science in all Biotechnology related areas has a relatively high level of impact. In terms of aggregate citation rates UK is second only to the US.
- The highest level of relative impact is in *Molecular Biology & Genetics* and *Biotechnology & Applied Microbiology*.
- In terms of trends, the relative impact of UK Biotechnology related science has been increasing, especially in *Biotechnology & Applied Microbiology*.
- The one area of concern is *Biology*, where the value of the Relative Impact index for the UK is below some of the EU countries and Canada.
- In general European science does not have a relatively high level of impact. However there are some exceptions: Germany at the aggregate level and in *Biotechnology & Applied Microbiology* and *Molecular Biology & Genetics*.
- The US has the highest value of the Relative Impact index in all fields, but especially in *Biotechnology & Applied Microbiology*.
- Japanese science has a relatively low level of impact in most areas.

Table 4. Relative Impact Index by Country: 1981-2000

		1981-85	*1986-90*	*1991-95*	*1996-00*
All 7 Fields	*UK*	1.07	1.04	1.09	1.12
	France	0.80	0.85	0.93	0.95
	Germany	0.97	1.03	1.07	1.08
	Italy	0.56	0.60	0.71	0.77
	Other EU	0.91	0.85	0.89	0.87
	Canada	0.89	0.87	0.98	1.08
	USA	1.45	1.47	1.42	1.44
	Japan	0.72	0.74	0.74	0.77
	Other	0.51	0.50	0.58	0.59
Biochemistry & Biophysics	*UK*	1.13	1.11	1.06	1.13
	France	0.81	0.82	0.91	0.92
	Germany	0.89	0.92	1.03	1.04
	Italy	0.59	0.63	0.66	0.71
	Other EU	0.96	0.87	0.90	0.86
	Canada	0.90	0.93	1.04	1.11
	USA	1.34	1.35	1.33	1.35
	Japan	0.72	0.77	0.77	0.78
	Other	0.56	0.56	0.62	0.62
Biology	*UK*	0.98	0.95	1.05	1.04
	France	0.65	0.87	0.96	1.06
	Germany	0.81	0.79	1.05	1.20
	Italy	0.59	0.58	0.73	0.81
	Other EU	1.09	1.17	1.16	1.13
	Canada	1.29	1.20	1.12	1.27
	USA	1.65	1.62	1.50	1.39
	Japan	1.24	1.02	0.91	0.96
	Other	0.42	0.40	0.50	0.60
Biotechnology & Applied Microbiology	*UK*	0.95	1.12	1.21	1.21
	France	1.24	0.76	0.80	0.82
	Germany	1.52	1.03	1.18	1.44
	Italy	0.87	0.74	0.86	0.93
	Other EU	1.27	1.18	1.24	1.09
	Canada	1.12	1.14	1.13	1.09
	USA	1.22	1.35	1.36	1.67
	Japan	0.77	0.85	0.80	0.75
	Other	0.71	0.65	0.68	0.64

Table 4 (Contd.). Relative Impact Index by Country: 1981-2000

		1981-85	*1986-90*	*1991-95*	*1996-00*
Cell & Developmental Biology	*UK*	0.95	1.09	1.18	1.09
	France	0.72	0.67	0.70	0.70
	Germany	0.89	0.96	0.92	0.96
	Italy	0.50	0.49	0.48	0.53
	Other EU	0.84	0.66	0.68	0.75
	Canada	0.69	0.54	0.71	0.88
	USA	1.40	1.49	1.39	1.39
	Japan	0.49	0.49	0.58	0.72
	Other	0.65	0.58	0.62	0.58
Experimental Biology	*UK*	1.21	1.08	1.17	1.15
	France	0.47	0.61	0.72	0.84
	Germany	0.82	0.79	1.02	1.10
	Italy	0.51	0.56	0.83	0.77
	Other EU	0.80	0.90	1.00	0.95
	Canada	1.15	1.19	1.13	1.14
	USA	1.74	1.73	1.45	1.25
	Japan	0.69	0.59	0.67	0.69
	Other	0.52	0.53	0.59	0.66
Molecular biology & Genetics	*UK*	1.25	1.09	1.20	1.24
	France	1.11	1.09	1.12	1.22
	Germany	1.25	1.29	1.20	1.09
	Italy	0.55	0.59	0.83	0.98
	Other EU	0.81	0.80	0.94	0.99
	Canada	0.78	0.89	1.12	1.17
	USA	1.39	1.36	1.30	1.29
	Japan	0.68	0.87	0.89	0.84
	Other	0.51	0.49	0.61	0.71
Microbiology	*UK*	1.03	0.99	1.05	1.11
	France	0.89	0.95	1.04	1.01
	Germany	0.93	0.95	1.04	1.06
	Italy	0.48	0.51	0.78	0.78
	Other EU	0.86	0.89	1.04	1.00
	Canada	0.92	0.87	0.98	1.02
	USA	1.39	1.45	1.33	1.44
	Japan	0.79	0.73	0.71	0.66
	Other	0.54	0.55	0.69	0.70

2.5 Summary: International Comparisons

The key result from the above analysis is that the UK has maintained its position as the leading European country in terms of Biotechnology related scientific publications and citations throughout the 1980s and 1990s. The main findings to emerge are:

- Two areas in which UK science is relatively strong, both in terms of the volume of publishing and its impact, are *Experimental Biology* and *Molecular Biology & Genetics. Biotechnology & Applied Microbiology* is a field with a high and increasing level of impact.
- The main area of relative weakness for the UK is *Cell & Developmental Biology.* This is a potential cause for concern as it is an area of emerging applications.
- The US has maintained its position as the leading country in terms of Biotechnology related science base.
- Most European countries have been rapidly increasing their level of activity. This is especially the case for Germany and France. However they still lag behind the UK and US in terms of impact.
- Japan has a relatively high volume of publications in a number of areas but the relative impact of these publications is low.

3. Analysis of Publishing Institutions

The aim of this section is to present an overview of institutions involved in knowledge production within the UK over the period 1981 to 2000. The following sets of questions are addressed:

- *What are the main trends in the contribution of the different institutional actors in UK scientific production in biotechnology? Do these vary across different scientific fields?*

- *Who are the top institutions involved in UK publishing*?

- *Firms from which industries publish in biotechnology related fields?*

3.1 Analysis by Institutional Affiliation

Table 5 contains information on the distribution of all publications according to the 4 institutional categories identified above: universities, industry, public sector and charities. As expected universities are dominant in scientific production in biotechnology related fields. In aggregate they participated in more than three-quarters (78%) of all publications in 1996-2000. Moreover their dominance has increased over time. At the same time the role of public sector institutions has diminished, with their share declining from 33% in the early 1980s to 27% in the late 1990s. In aggregate firms participated in around 5% to 6% of all biotechnology related publications, and this share has remained more or less constant throughout the period.

There are a number of differences in the importance of the various institutional categories by science field. For example universities are even more dominant in *Experimental Biology*, participating in 85% of all publications in 1996-2000. Firms are relatively more active in *Biotechnology and Applied Microbiology*, with a share of 14% in the last period. Two other areas in which firms participate more than average are *Microbiology* and *Biochemistry and Biophysics*.

3.2 Top Publishing Institutions

Table 6 lists the top 20 institutions involved in publishing in all fields of biotechnology in period 1996-2000, together with their ranking in the first half of the 1980s. Some of the most research active universities (as measured by their RAE rankings, for example) are included in this list: Cambridge, Oxford, University

Table 5: Trends in the Distribution of Publications by institutional category: 1981-2000

% shares	Year	All Biotech fields	BIL Biochemistry & Biophysics	BIO Biology	BTC Biotechnology & Applied Microbiology	CEL Cell & Developmental Biology	EXP Experimental Biology	MBG Molecular Biology & Genetics	MCB Microbiology
U	1981-85	67.8	72.6	50.4	70.9	67.5	74.9	67.4	61.3
	1986-90	67.2	71.6	49.5	70.3	68.5	75.9	66.2	61.5
	1991-95	70.7	74.4	60.3	67.8	73.0	80.1	67.8	65.0
	1996-00	77.8	81.3	68.6	79.3	77.8	85.1	76.1	72.1
I	1981-85	5.2	4.8	4.8	10.5	4.1	4.5	3.4	7.4
	1986-90	6.1	7.2	2.8	13.1	2.8	4.0	5.3	7.4
	1991-95	6.2	7.4	2.0	16.8	2.8	2.9	4.2	7.9
	1996-00	5.8	7.5	2.7	14.2	2.6	3.3	4.1	7.6
PS	1981-85	33.4	29.0	44.7	21.2	31.5	28.3	37.0	39.9
	1986-90	34.9	29.3	52.2	25.0	32.5	29.1	37.3	41.9
	1991-95	33.0	26.5	45.1	24.7	29.1	26.2	40.4	40.5
	1996-00	27.4	21.4	35.7	18.9	24.0	22.2	32.5	36.4
C	1981-85	3.0	2.9	5.1	2.3	5.3	1.2	5.0	1.7
	1986-90	3.6	4.2	2.5	2.1	7.5	0.9	6.3	1.2
	1991-95	4.8	5.2	2.3	2.7	8.7	2.3	8.4	1.3
	1996-00	4.3	3.3	6.6	1.7	7.6	3.5	6.7	1.4

U = University; I = Industry; PS = Public Sector; C = Charities
Note: the shares add up to more than 100% as a single paper can have authors from more than one institutional category.

Table 6: Top 20 Publishing Institutions in 1996-2000 in All Biotechnology

Rank		Name	Institutional Category	Average Number of papers per year	
1981-85	*1996-2000*			*1981-85*	*1996-2000*
1	1	UNIV CAMBRIDGE	U	195	536
2	2	UNIV OXFORD	U	155	536
4	3	UNIV LONDON,UNIV COLL	U	107	399
5	4	UNIV EDINBURGH	U	101	275
12	5	UNIV LONDON,IMPERIAL COLL	U	78	260
7	6	UNIV GLASGOW	U	94	209
10	7	UNIV MANCHESTER	U	87	204
13	8	IMPERIAL CANCER RES FUND	C	78	199
16	9	UNIV DUNDEE	U	69	198
3	10	UNIV BIRMINGHAM	U	108	181
11	11	UNIV BRISTOL	U	87	175
8	12	UNIV LONDON,KINGS COLL	U	88	147
15	13	UNIV LEEDS	U	70	143
17	14	GUYS & ST THOMAS HOSP	U	59	141
20	15	UNIV LEICESTER	U	55	139
9	16	MRC MOLEC BIOL LAB, CAMB.	PS	88	134
21	17	UNIV NEWCASTLE UPON TYNE	U	53	134
6	18	MRC NATL INST MEDICAL RES	PS	95	131
14	19	UNIV LIVERPOOL	U	74	127
26	20	UNIV NOTTINGHAM	U	44	123

College London, Imperial, Manchester and Bristol. However this list also includes Universities of Dundee, Leicester and Liverpool which are much lower in terms of their RAE rankings. Two MRC laboratories are also amongst the top publishers in the UK. The only remaining non-university to appear in this list is the Imperial Cancer Research Fund.

There has been very little change in the list of top publishing institutions in biotechnology as shown by the first two columns. The only new entrants are the Universities of Newcastle upon Tyne and Nottingham. There have been some changes in the rankings: Imperial going from 12th position in 1981-85 to 7th in 1996-2000 and both the MRC laboratories dropping down the rankings.

The last two columns of Table 6 show that in the period since the 1980s there has been a rapid increase in the volume of scientific production amongst these institutions. Three of the listed universities have increased the number of publications by more than 3-fold: Oxford, University College London and Imperial.

Table 7 shows that UK scientific production is highly concentrated. On average, across the 7 science fields, the top 20 institutions account for nearly two-thirds of all publications in the late 1990s. The level of concentration is much higher in two other

fields: *Cell & Developmental Biology* and *Molecular Biology & Genetics*. The degree of concentration has increased over time, with the share of top 20 institutions increasing from 59% to 68%.

Table 7. Concentration of publications in Biotechnology

Proportion of publications involving Top 20 Institutions	**1981-85**	**1996-00**
All Biotechnology	59.4	67.5
Biochemistry & Biophysics	52.6	67.2
Biology	62.4	66.7
Biotechnology & Applied Microbiology	67.3	57.2
Cell & Developmental Biology	64.7	79.5
Experimental Biology	52.4	66.8
Molecular Biology & Genetics	65.8	73.3
Microbiology	50.5	61.5

3.3 Analysis by Industry

Earlier SPRU studies[5] have highlighted the growing role of industry in knowledge production within the UK. They have shown that firms publish for a number of reasons, for example as a signal to the outside world that they possess scientific and technical capability in a certain field. This enables them to join scientific networks, which in turn allows them to gain knowledge about leading edge scientific research. This section analyses the role of industry in publishing activities within biotechnology.

Table 8 aggregates all firms publishing in biotechnology related scientific fields according to their principal activity. This information was obtained from a number of sources including *Who Own's Whom*, company reports and the Internet. Most categories are self-explanatory. The exceptions is Biotechnology, which consists of dedicated biotechnology firms. Chemical related category includes Petro-chemical firms such as Shell and BP.

[5] See for example, Hicks, D.M. and J.S. Katz (1997): *The Changing Shape of British Industrial Research*, STEEP Special Report No.6, Brighton, UK, SPRU

Table 8. Trends in the volume of Scientific Publications by Industry in Biotechnology: 1981-2000

Average Number of publications per year				
Industry	***1981-85***	***1986-90***	***1991-95***	***1996-00***
Biotechnology	6	19	48	59
Chemical and related	33	53	37	14
Consultancy services	6	9	12	17
Food, Drink and Tobacco	39	33	23	35
Pharmaceuticals	88	130	208	249
Other[*]	25	47	52	57
Total	197	291	380	431

* Includes Other manufacturing industries, Other Services, and Utilities

Well over half of all industry related publications in the UK are by Pharmaceutical firms. Two other industries with a significant volume are Biotechnology and Food, Drink and Tobacco. In terms of trends the fastest growth has been amongst the dedicated Biotechnology firms, increasing nearly 10-fold since 1981-85. This is faster than the growth of publications amongst the top universities listed in Table 6. The activity of Food related firms has changed very little over this period. Part of the decline in the Chemical related firms is due to the de-merger of Zeneca from ICI.

Table 9 names the top publishing firms in 1996-2000. As expected the large Pharmaceutical firms dominate the list. The exceptions are Unilever, Celltech, and TNO Bibra, a consultancy firm involved in contract research for the pharmaceutical and food industry and the government. The table also shows that there are a number of foreign firms publishing from the UK: Pfizer, Roche, Aventis and Merck. We look at the activity of foreign firms in more detail below.

Table 9. Top 10 Publishing Firms in 1996-2000 (all biotechnology fields)

Overall Rank		**Name**	**Average Number of publications per year**	
81-85	***96-00***		***81-85***	***96-00***
23	32	GLAXO WELLCOME PLC	49	72
63	50	SMITHKLINE BEECHAM PLC	17	53
	55	ASTRAZENECA	0	47
38	77	UNILEVER PLC	33	24
167	113	PFIZER INCORPORATED	4	14
153	127	CELLTECH GROUP PLC	4	12
182	144	ROCHE HOLDING AG	3	9
167	149	AVENTIS S.A.	4	9
458	190	MERCK & CO INC	0,3	7
220	195	TNO BIBRA INTERNATIONAL LTD	2	6

Despite the dominance of large firms in terms of volume of publication, Table 10 shows that small firms have a role to play in knowledge production in biotechnology. These are firms with less than 100 employees. The number of such firms grew 12-fold in the period since 1981-85. More than half the small firms are Biotechnology related.

Table 10. Trends in the Number of Small firms active in Publishing in Biotechnology: 1981-2000

Number of Firms	**1981-85**	**1986-90**	**1991-95**	**1996-00**
Industry				
Biotechnology	2	5	13	33
Chemical and related	0	0	0	2
Consultancy services	1	2	5	12
Food, Drink and Tobacco	0	0	0	4
Pharmaceuticals	2	2	4	3
Other[*]	0	2	6	9
Total	5	11	28	63

* Includes Other manufacturing industries and Other Services.

Table 11 shows that non-UK based firms make an important contribution to UK scientific production in biotechnology. In aggregate they represent more than one-fifth of the UK total for industry in 1996-2000. Foreign firms are especially important players in Chemical and related industries. In Pharmaceuticals they account for nearly a quarter of total publications.

Table 11. Importance of Foreign Firms in UK publishing: 1981-2000

Proportion of all publications accounted for by Foreign firms	**1981-85**	**1986-90**	**1991-95**	**1996-00**
Industry				
Biotechnology	0.0	2.1	4.5	10.6
Chemical and related	46.1	18.5	21.9	58.3
Consultancy services	0.0	4.7	0.0	2.3
Food, Drink and Tobacco	0.0	6.7	4.3	7.4
Pharmaceuticals	20.6	19.0	19.2	24.9
All Firms	19.1	15.5	15.5	21.7

Finally Table 12 addresses the question as to which fields are important in which industrial sectors. The analysis is based on an Index of Scientific Specialisation, which for a given industry and a given science field is simply the share of

publications of that industry in that scientific field, divided by the share of total publications (i.e., across all publishing institutions) in that scientific field. In other words it measures the extent to which the field is important for a sector relative to the importance of that field for all institutional actors (i.e. universities, PSROs and charities). A value of this index above unity signifies the relative importance of the field and vice versa.

Table 12 shows which science fields are important in a specific industry (using information by rows), and also the prevalence of science fields across industries (using information by columns). As an example, the last row shows that 3 fields are relatively more important for Pharmaceutical firms: *Biochemistry and Biophysics*, *Microbiology and Genetics* and *Biotechnology and Applied Microbiology*. Unsurprisingly *Biotechnology and Applied Microbiology* is relatively important for all 5 industries, and *Biochemistry and Biophysics* for 3 industries. On the other hand *Biology*, *Experimental Biology* and *Cell and Developmental Biology* are relatively unimportant for all 5 industries.

Table 12. Relative Importance of different Biotechnology related science fields for Industry: 1991-2000.

Index of Scientific Specialisation	BioChem & BioPhys BIL	Biology BIO	Biotech & App Microbio BTC	Cell & Dev. Bio CEL	Experim Biology EXP	Molecul Biology & Genetics MBG	Micro-Biology MCB
Industry							
Biotechnology	**1.3**	0.0	**4.3**	0.8	0.5	0.8	0.6
Chemical and related	**1.1**	0.3	**2.2**	0.5	0.6	**1.2**	1.0
Consultancy services	0.6	0.3	**4.3**	0.4	0.3	**1.8**	1.0
Food, Drink and Tobacco	0.6	0.3	**6.4**	0.2	0.5	0.5	**1.5**
Pharmaceuticals	**1.4**	0.1	**1.2**	0.6	0.5	0.8	**1.3**

3.4 Summary: Volume of publications by institutional affiliation

The main points to emerge from analysing the volume of publications by institutions are as follows:

- Top ranked universities in terms of overall research performance are amongst the top publishers in biotechnology related scientific fields. At the same time a number of lower ranked universities and PSROs are also important players.

- There have been large increases in the volume of publications in the late 1990s.
- There is a high level of concentration in the top 20 publishing institutions, and this has increased over time.
- While large Pharmaceutical firms are amongst the most prolific publishers, increasing numbers of smaller specialist biotechnology firms and consultancies are also becoming involved in publishing.
- For firms from all industries *Biotechnology and Applied Microbiology* is an important science field. For Pharmaceutical and dedicated Biotechnology firms, *Biochemistry and Biophysics* is also relatively important.

4. Analysis of Joint Publications with Industry

This section analyses joint publications between industrial firms and universities and other public sector research organisations (including laboratories belonging to MRC, BBSRC and the government laboratories, as well as charitable foundations). The underlying assumption is that co-publication data are a reasonably good, albeit partial indicator of research collaborations[6]. Such collaborations are a subject of considerable (and increasing) interest amongst both policy makers and academics. For example the period since the early 1990s has seen a large number of policy initiatives by successive UK governments (and related agencies) intended to further the development of networks of collaboration between university researchers and industrial firms. Many of these are specifically focussed on biotechnology.

The focus here is on analysing the following:

- *Overall trends in co-publications both as a proportion of all publications and as a proportion of all industry publications.*
- *The top universities involved in co-publishing.*
- *The top firms involved in co-publishing.*
- *Industries involved in co-publishing.*

4.1 Overview of the Co-publications data

Overall Trends

This analysis is based on 2954 joint papers published between 1981 and 2000 in biotechnology related science fields. As shown in Table 13 there has been a three-fold increase in such co-publications over the whole period: from 347 publications in the first half of the 1980s to 1121 in the second half of the 1990s. The same trend is reflected in 5 out of the 7 science fields. The rate of increase in some of the fields is much higher, ranging from a 26-fold increase in *Biotechnology and Applied Microbiology* (albeit from a low base) to over a 5-fold increase in *Molecular Biology and Genetics*. The slowest growth has been in *Cell & Developmental Biology* and *Experimental Biology*.

[6] There are a number of well-known limitations in using publications that list the name and address of a company and that of a public sector research institution as indicators of collaborations. See Calvert and Patel (2002) op.cit.

Table 13: Trends in number of Joint publications with Industry: 1981-2000

	Number of Publications			
Scientific Field	*1981-85*	*1986-90*	*1991-95*	*1996-00*
All Biotechnology fields	347	622	864	1121
Biochemistry & Biophysics	137	249	339	422
Biology	11	16	12	30
Biotechnology & Applied Microbiology	5	58	80	129
Cell & Developmental Biology	31	43	55	57
Experimental Biology	45	47	61	89
Molecular Biology & Genetics	26	59	111	139
Microbiology	92	150	206	255

As a Percentage of all Publications

In Table 14 we examine the percentage of all papers involving collaboration with industry (in other words the intensity of collaboration). In aggregate this proportion is small and has risen from around 1.6% in the early 1980s to around 2.4% in the late 1990s. The table also shows that the biggest increases were from the first half of the1980s to the second half. In the two time periods since then there has been very little change.

There are considerable variations across science fields according to this indicator. Thus in *Biotechnology and Applied Microbiology* around 7% of all papers are collaborative with industry in 1996-2000, while in *Cell & Developmental Biology* this proportion is 1%. There are two other scientific areas where collaborative papers account for more than 3% of all publications in the latest period: *Biochemistry & Biophysics* and *Microbiology*.

Table 14: Trends in Joint publications with Industry as a % of total publications: 1981-2000

	As a % of Total Publications			
Scientific Field	*1981-85*	*1986-90*	*1991-95*	*1996-00*
All Biotechnology fields	1.6	2.3	2.3	2.4
Biochemistry & Biophysics	1.9	2.9	3.1	3.2
Biology	0.7	0.9	0.8	1.5
Biotechnology & Applied Microbiology	1.3	4.9	4.6	6.9
Cell & Developmental Biology	1.4	1.5	1.3	1.0
Experimental Biology	1.4	1.6	1.6	1.7
Molecular Biology & Genetics	1.0	1.5	1.5	1.4
Microbiology	2.0	2.6	2.6	3.0

As a Percentage of all Industry Publications

The proportion of industry papers that are produced with a public sector partner rose from 36% in the early 1980s to 54% in 1996-2000 (see Table 15). Thus more than half of all industrial scientific output in recent years has been produced in collaboration with public sector research institutions. This proportion varies by scientific area: it is two-thirds or more in *Biology* and *Experimental Biology*, and less than a half in *Molecular Biology and Genetics* and *Cell & Developmental Biology.*

Table 15: Trends in Joint publications with Industry as a % of all Industry publications: 1981-2000

	As a % of Industry Publications			
Scientific Field	*1981-85*	*1986-90*	*1991-95*	*1996-00*
All Biotechnology fields	35.6	44.3	47.0	54.5
Biochemistry & Biophysics	45.2	49.1	52.3	56.5
Biology	16.7	34.8	44.4	71.4
Biotechnology & Applied Microbiology	12.2	43.0	31.7	58.6
Cell & Developmental Biology	38.8	62.3	57.9	48.3
Experimental Biology	37.8	44.3	66.3	66.9
Molecular Biology & Genetics	35.6	34.7	49.3	47.1
Microbiology	31.5	40.3	41.1	50.9

4.2 Co-Publishing Universities and Public Sector Research Organisations

In this section we identify the top universities and PSROs involved in joint publishing. Table 16 lists the top 20 institutions in terms of the volume of co-publications in the period 1996 to 2000 and makes a comparison with their record over 1981-85. On the whole these are the same universities that appear in the list of top 20 publishers in Table 6. There are 5 exceptions, three (Universities of Sheffield, Wales and Southampton) of which are ranked just below the top 20. The remaining two, University of Reading and Birkbeck college, are smaller players in terms of overall volume of papers, but with a relatively high number of joint publications.

The volume of co-publications has increased markedly since the early 1980s in most of the institutions listed in Table 16. The highest increases (more than 10-fold) have been for Birckbeck College, and Universities of Dundee, Sheffield, Newcastle, Southampton and University College, London.

Table 16: Top 20 Co-Publishing Universities and PSROs in 1996-2000.

Rank		Name	Institutional Category	Average Number of papers per year	
81-85	*96-00*			*81-85*	*96-00*
9	1	UNIV LONDON,UNIV COLL	U	1.6	17.2
5	2	UNIV OXFORD	U	2.4	16.4
1	3	UNIV CAMBRIDGE	U	3.4	15.4
17	4	UNIV LONDON,IMPERIAL COLL	U	1.2	8.2
7	5	UNIV MANCHESTER	U	2.0	7.8
7	5	UNIV LEEDS	U	2.0	7.8
24	7	UNIV GLASGOW	U	1.0	7.4
17	8	UNIV BIRMINGHAM	U	1.2	7.0
10	9	UNIV NOTTINGHAM	U	1.4	6.8
47	10	UNIV DUNDEE	U	0.4	5.4
3	10	UNIV WALES,CARDIFF	U	2.6	5.4
10	10	UNIV LEICESTER	U	1.4	5.4
47	13	UNIV SHEFFIELD	U	0.4	4.6
24	13	UNIV READING	U	1.0	4.6
0	15	UNIV LONDON,BIRKBECK COLL	U	0.0	4.4
2	15	UNIV LONDON,KINGS COLL	U	3.0	4.4
47	15	UNIV NEWCASTLE UPON TYNE	U	0.4	4.4
10	18	PUBLIC HLTH LAB SERV	PS	1.4	4.2
47	19	UNIV SOUTHAMPTON	U	0.4	4.0
10	19	UNIV LIVERPOOL	U	1.4	4.0
30	19	UNIV BRISTOL	U	0.8	4.0
17	19	UNIV EDINBURGH	U	1.2	4.0

Table 17 contains information on the collaborative activities of the top 6 co-publishing universities in the period 1996-2000. The list of the top 6 co-publishing industrial partners is dominated by large Pharmaceutical firms. However some smaller specialist biotechnology firms as well as large firms from different industries (such as food and instruments) are also collaborating with the top 6 universities. The table also shows that these universities are engaged with a wide variety of industrial partners, ranging from 37 in the case of Cambridge to 16 for Manchester. However the last row indicates that on the whole such activities are highly concentrated, with the top 5 firms accounting for between 74% and 48% of the total number of co-publications.

Table 16 and 17 concentrate on the universities with the highest volume of collaboration and hence list some of the largest institutions. In Table 18 we list the institutions that produce the highest proportion of their scientific output in collaboration with industry (i.e. according to the intensity of collaboration). Thus nearly 20% of all biotechnology related publications originating from Aston University are written in conjunction with an industrial partner. In general the

Table 17: Main Industrial Partners of the Top 6 Co-Publishing Institutions in 1996-2000.

UNIV LONDON, UNIV COLL Total No. of Partners: 24 Glaxo Wellcome plc Astrazeneca Smithkline Beecham plc Unilever plc Pfizer Incorporated Top 5 Partners as a % of total U-I Pubs of the Uni: 63.6	**UNIV OXFORD** Total No. of Partners: 27 Oxford Biomedica plc Glaxo Wellcome plc Smithkline Beecham plc British Biotech plc Astrazeneca Top 5 Partners as a % of total U-I Pubs of the Uni: 63.6	**UNIV CAMBRIDGE** Total No. of Partners: 37 Glaxo Wellcome plc Smithkline Beecham plc Astrazeneca Pfizer Incorporated Unilever plc Top 5 Partners as a % of total U-I Pubs of the Uni: 47.6
UNIV LONDON, IMPERIAL COLL Total No. of Partners: 18 Glaxo Wellcome plc Smithkline Beecham plc Thermo Electron Corporation Astrazeneca M-Scan ltd. W R C plc Top 5 Partners as a % of total U-I Pubs of the Uni: 66.7	**UNIV MANCHESTER** Total No. of Partners: 16 Astrazeneca Glaxo Wellcome plc Unilever plc Pfizer Incorporated British Biotech plc Top 5 Partners as a % of total U-I Pubs of the Uni: 73.8	**UNIV LEEDS** Total No. of Partners: 21 Smithkline Beecham plc Pfizer Incorporated British Biotech plc British Textile Technol Grp. Astrazeneca 3M INC Top 5 Partners as a % of total U-I Pubs of the Uni: 64.2

Table 18: Top 20 Institutions by Proportion of Joint Publications in 1996-2000[*].

Name	Institutional Category	Joint Publications as a % of total papers	
		81-85	96-00
ASTON UNIV	U	4.5	19.7
STRANGEWAY RES LABS	C	0.0	19.2
NOTTINGHAM TRENT UNIVERSITY	U	0.0	18.8
UK MOUSE GENOME CTR	PS	0.0	15.2
UNIVERSITY OF GLAMORGAN	U	0.0	15.0
ROYAL HALLAMSHIRE HOSP	PS	4.3	14.3
UNIV BRIGHTON	U	14.3	11.6
UNIV SALFORD	U	2.3	10.9
N MANCHESTER GEN HOSP	PS	0.0	10.8
UNIVERSITY OF WESTMINSTER	U	15.4	10.4
UNIV DURHAM	U	1.3	10.0
UNIVERSITY OF SUNDERLAND	U	0.0	10.0
MRC HUMAN GENET UNIT, EDINBURGH	PS	1.1	10.0
UNIV LONDON,BIRKBECK COLL	U	0.0	9.2
UNIV SURREY	U	3.4	8.7
KINGS COLL HOSP	U	0.0	8.5
MRC CTR PROT & ENGN, CAMBRIDGE	PS	0.0	7.7
UNIV LONDON,ROYAL HOLLOWAY & BEDFORD	U	6.5	7.5
UNIV LONDON,WYE COLL	U	5.6	7.4
UNIVERSITY OF WOLVERHAMPTON	U	0.0	7.4
UNIV LONDON,WYE COLL	U	4.5	7.4

[*] Only those institutions with >20 total papers in the time period 1996-2000 included.

universities with the highest intensity of collaboration are the 'new' universities or the ones that are more 'technology' based. In addition a number of hospitals and public sector laboratories also collaborate intensively with industry.

4.3 Top Co-Publishing Firms

We next examine the top firms involved in joint publishing (see Table 19). Six out of the ten firms listed are amongst the world leaders in Pharmaceutical R&D and three are dedicated biotechnology firms. The remaining firm with a relatively high number of co-publications is Unilever. The three leading firms (Glaxo Wellcome, Smithkline Beecham and Astrazeneca) have a higher number of joint publications than the universities listed in Table 16. For most firms listed here the volume of collaboration has increased rapidly in the late 1990s, and now represents more than half of all their scientific output. For the dedicated biotechnology firms this proportion is between 67% and 90%.

Table 19: Top 10 Collaborating Firms by Volume of Collaboration in 1996-2000

Rank		Name	Average No. of Collaborative papers per year		Joint Publications as a % of total papers	
81-85	96-00		81-85	96-00	81-85	96-00
1	1	GLAXO WELLCOME PLC	14.0	35.0	28.3	48.6
4	2	SMITHKLINE BEECHAM	5.6	28.2	32.2	53.4
0	3	ASTRAZENECA	0.0	25.4	0.0	53.8
2	4	UNILEVER PLC	10.2	14.4	30.9	61.0
10	5	PFIZER INCORPORATED	1.2	8.6	31.6	60.6
10	6	CELLTECH GROUP PLC	1.2	8.0	27.3	66.7
8	7	AVENTIS S.A.	1.6	4.8	42.1	52.2
0	8	OXFORD BIOMEDICA PLC	0.0	3.8	0.0	90.5
0	8	BRITISH BIOTECH PLC	0.0	3.8	0.0	70.4
9	10	NOVARTIS AG	1.4	2.7	35.0	54.2

These results are confirmed more generally in Table 20, which examines the joint-publications activities of firms according to their industry. The industries with highest volume of activity are Pharmaceuticals, Biotechnology and Food, Drink and Tobacco. Firms in these industries have also increased their collaborations greatly in the late 1990s. The downward trend in the Chemical related sector is a reflection of the de-merger between ICI and Zeneca.

Table 20: Co-publications by industry sector

Industry	Average number of publications per year		Joint Publications as a % of total papers	
	81-85	96-00	81-85	96-00
Biotechnology	2.0	33.2	35.7	56.7
Chemicals and related	16.8	9.0	50.3	62.5
Consulting Services	2.4	6.8	37.5	39.5
Food, Drink and Tobacco	11.4	20.8	30.3	59.4
Pharmaceuticals	26.0	129.0	30.0	51.8
Utilities	3.4	5.8	43.6	54.7

4.4 Summary: Joint Publications

The main points to emerge from analysing joint publications, between firms and universities and other public sector organizations, as indicators of research collaboration are:

- There has been a rapid increase in the volume of collaborations in the 1990s especially in *Biotechnology & Applied Microbiology* and *Molecular Biology & Genetics*.

- From the perspective of public sector research institutions the proportion of joint publications is small and has changed little in the 1990s.

- From the perspective of industry there has been an increase in collaborations so that in the late 1990s around 55% all industrial scientific output is produced jointly with the public sector. In the early 1980s this proportion was 36%.

- The list of top co-publishing universities, in terms of volume, is dominated by those with the highest number of publications overall. On the whole these are also the top research universities in the UK.

- Their main industrial partners are large Pharmaceutical firms and some smaller specialist biotechnology firms.

- In general the universities with the highest intensity of collaboration are the ‘new’ universities or the ones that are more ‘technology’ based. At the same time a number of hospitals and public sector laboratories also collaborate intensively with industry.

5. Conclusions

One of the main distinguishing characteristics of biotechnology, compared to other technologies is that it depends crucially on developments in basic science. This study is a pioneering attempt at systematically analysing the UK science base related to biotechnology using data on scientific publications. The main objective is to present a set of reasonably robust findings or "stylised facts" for further discussion and debate. The report includes international comparisons of UK performance in 7 scientific fields and an analysis of the main institutional actors involved.

The main finding of the study are:

- The UK has maintained its position as the leading European country in terms of Biotechnology related scientific research throughout the 1980s and 1990s.

- Two areas in which UK science is relatively strong, both in terms of the volume of publishing and its impact, are *Experimental Biology* and *Molecular Biology & Genetics. Biotechnology & Applied Microbiology* is a field with a high and increasing level of impact. The main area of relative weakness for the UK is *Cell & Developmental Biology.* This is a potential cause for concern as it is an area of emerging applications.

- The US has maintained its position as the leading country in terms of Biotechnology related science base. Most European countries have been rapidly increasing their level of activity. This is especially the case for Germany and France. However they still lag behind the UK and US in terms of impact.

- Top ranked UK universities in terms of overall research performance are amongst the top publishers in biotechnology. At the same time a number of lower ranked universities and PSROs are also important players.

- While large Pharmaceutical firms are amongst the most prolific publishers, increasing numbers of smaller specialist biotechnology firms and consultancies are also becoming involved in publishing.

- For firms from all industries *Biotechnology and Applied Microbiology* is an important science field. For Pharmaceutical and dedicated Biotechnology firms, *Biochemistry and Biophysics* is also relatively important.

- There has been a rapid increase in the volume of collaborations (as measured by joint publications) between firms and universities and other public sector

research organisations in the 1990s. This is especially the case in *Biotechnology & Applied Microbiology* and *Molecular Biology & Genetics*.

- More than half of all scientific output produced by industry is jointly with the public sector. In the early 1980s this proportion was 36%.

- The list of top co-publishing universities, in terms of volume, is dominated by those with the highest number of publications overall. On the whole these are also the top research universities in the UK. Their main industrial partners are large Pharmaceutical firms and some smaller specialist biotechnology firms.

- In general the universities with the highest intensity of collaboration are the 'new' universities or the ones that are more 'technology' based. At the same time a number of hospitals and public sector laboratories also collaborate intensively with industry.

Taken together these results suggest that the UK science system in relation to Biotechnology is strong. The volume and impact of scientific activity are high. There are a large number of top research active universities collaborating with some of the leading R&D intensive firms in the Pharmaceutical industry. At the same time a wide variety of other universities, public sector laboratories and hospitals are important actors in forging collaborative links with industry. This suggests that government policies and research funding are better aimed at encouraging a wide variety of scientific institutions rather than simply targeted towards the largest most research active universities.

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