

**THE EVALUATION OF DTI
SUPPORT FOR BIOTECHNOLOGY**

Annex A: UK performance
in biotechnology-related
innovation – An analysis of
patent 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 A: UK Performance in Biotechnology-related Innovation: An Analysis of Patent data

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Executive Summary

Many analysts and policy makers regard biotechnology as a major contributor to future economic development and structural change in a variety of industries, namely pharmaceuticals, food, textiles, agriculture, energy and chemicals. It is also perceived to have important implications for the quality of life of human beings in terms of their health, environment and nutrition. Despite this widespread policy interest there is a lack of systematic (internationally comparable) data on many aspects of biotechnology and its effects on the economy and society. This study assembles a set of indicators related to one aspect, namely innovative activities related to biotechnology. It uses the wealth of information contained in US patent documents to compare the UK with G7 countries in 10 fields of biotechnology over the period 1986 to 2000.

The main findings of the analysis are as follows:

- The UK is one of the few countries to have substantially increased its share of US patenting in Biotechnology related fields in the second half of the 1990s. This has resulted in a substantial narrowing of the gap with Germany, the leading EU country.
- There are two important areas where UK technology is particularly strong. The first is Biological Materials for therapeutic applications where UK is the leading European country. The second is Biosensors where it has a high volume of patenting, and where these patents are amongst the most highly cited.
- The main areas of weakness are Tissue culture and Plant related biotechnology.
- Three UK-based large Pharmaceutical firms are amongst the world leaders in a number of fields of biotechnology, whether measured by volume or by impact of patenting: SmithKline Beecham, AstraZeneca and Glaxo Wellcome. They are particularly strong in Biological Materials for therapeutic applications.
- Within the UK, Universities and other public sector research organisations as well as small specialised biotechnology firms have become increasingly important players in the late 1990s. They account for more than half of all UK invented patents, especially in the two areas of strength identified above.
- Foreign firms, especially those based in the US and Switzerland, make an important contribution to UK biotechnology. As both these countries are at the forefront of biotechnology innovation this represents a good opportunity for UK firms to learn from the world best practice technology located within national boundaries.
- UK firms, especially the large Chemical and Pharmaceutical firms, are amongst the most internationalised in the world. Their favoured location is the US, where they conduct more than two-thirds of all their biotechnology related activities.

These results suggest that the UK is strong in biotechnology, especially in technologies with applications to the Pharmaceutical industry, which is one of the most successful industries in the UK. Moreover it is well placed in another important set of technologies with applications in many different fields, namely Biosensors. There is some indication that this strength is partly due to public policies encouraging innovative activities amongst PSROs and small specialised firms.

An important source of strength is the large UK-based Pharmaceutical firms who are at the forefront of world technology. They are also well placed to absorb new knowledge from leading edge foreign sources of innovation, an essential component of innovative activity in a fast moving area such as biotechnology. Whether this will result in continuing improvement in the innovation performance of the UK as a whole depends on the extent to which these firms are able to transfer this new knowledge back to the UK, and the extent of their domestic linkages with smaller firms and other institutions.

Taken as a whole the above analysis implies that, compared to their major counterparts, UK firms are in a strong position to introduce new biotechnology related products and processes in the future. Whether this potential is realised or not will depend on a number of factors, including the availability of venture capital and the continuing supply of well trained scientists and engineers from the UK science system, both of which have the potential to be greatly influenced by government policies.

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1. Introduction

1.1 *Aims and Background*

Many analysts and policy makers regard biotechnology as a major contributor to future economic development and structural change in a variety of industries, namely pharmaceuticals, food, textiles, agriculture, energy and chemicals. It is also perceived to have important implications for the quality of life of human beings in terms of their health, environment and nutrition. Despite this widespread policy interest there is a general perception that we lack systematic (internationally comparable) data on many aspects of biotechnology and its effects on the economy and society. The aim of this study is to assemble a set of indicators related to one aspect, namely innovative activities related to biotechnology. It uses information on patenting activity to address the following sets of questions:

- *How does UK compare to its major competitors in terms of biotechnology patenting?*
- *What have been the changes over time?*
- *Who are the major UK based institutions (firms, universities, public sector research institutions) involved in patenting?*

1.2 *Use of Patent Data*

There are a number of advantages in using patent data to track innovative activities. Firstly by the very nature of the patenting process, they reflect the capacity of a firm (or of any other institution being granted a patent) to generate change and improvement over an existing body of knowledge in a particular area of technology. Secondly patent records are available at a detailed level of technology, over long periods of time, and are comprehensive in the sense of covering small as well as large firms. Finally patent statistics can also be analysed according to geographic location of where the invention occurred.

In general there are at least two drawbacks of patent statistics that need to be borne in mind, when interpreting the results below. *First*, there are major inter-sectoral differences in the relative importance of patenting in achieving its prime objective, namely, acting as a barrier to imitation. However this is unlikely to be a problem in the current study as we are only concerned with one area, namely, biotechnology. Moreover this is an area where it is generally agreed that patents are important in protecting technological leads. Of course it could be argued that there are differing propensities to patent amongst the different sub-areas of biotechnology. However

some of the indicators used below have been constructed precisely to take account of such a bias.

Second, there are major differences amongst countries in procedures and criteria for granting patents. For this reason, comparisons are most reliable when using international patenting, or patenting in one country. Hence in this study we have chosen to use US patenting statistics which are a particularly rich source of information, given the rigour and fairness of criteria and procedures for granting patents. Moreover as the US is the world's leading country in terms of the commercial development of biotechnology, there are strong incentives for firms and other institutions to obtain patent protection there.

There is a further criticism of patenting as an indicator of technological activities, which we think is not justified. We are not convinced that it is a drawback that patents differ greatly in their economic value¹. The same is true of R & D projects² and for the same reasons. Technological activities involve cumulative learning under uncertainty. There are therefore bound to be failures, major successes and follow-up improvements, all of which are interdependent. We would therefore expect similar and large variations in the distribution of the value of both R & D and patenting across all firms and countries.

The main problem in using US patent data for international comparisons is that the results exaggerate the importance of the US, as in general there is a higher propensity to patent amongst domestic inventors compared to those residing in other countries. As we shall see below this is particularly a problem in the present study as US inventors account for a large share of biotechnology related inventions.

1.3 Plan of the report

The next section discusses the methodology employed in the current study. In particular it focuses on the construction of the database, classification of biotechnology into sub-areas and the types of indicators used. Section 3 presents the main results of international comparisons at the country level. In section 4 we address the question of who are the main patenting institutions worldwide and how many of them are UK-based? Section 5 contains the results of analysing UK invented patents, and section 6 focuses on the increasing internationalisation of technology amongst large UK firms. Conclusions are presented in the final section.

¹ See M. Schankerman, and A. Pakes (1986), "Estimates of the Value of Patent Rights in European Countries during the Post-1950 Period", *Economic Journal*, 96, 1052-1076

² See C. Freeman, (1982), *The Economics of Industrial Innovation*, Pinter, London

2. Methodology

The study is based on the following information for each patent granted in the US, obtained from the US Patent and Trademark Office (USPTO):

- Name of the assignee
- Country of the inventor
- US Patent Class (Area of technology)
- Citations to other US patents

There are two main difficulties in using these data for the purposes of this study. Firstly biotechnology related patents can be found in a number of different USPC classes. These need to be identified and grouped into different areas of biotechnology. The second problem is that many patents are granted under the names of subsidiaries and divisions that are different from those of the parent companies, and are therefore listed separately. In addition the names of companies and other institutions are not unified, in the sense that the same company (or institution) may appear several times in the data, with a slightly different name in each case. The rest of this section discusses our approach to solving these problems.

2.1 *Defining and Classifying Biotechnology related Patenting.*

There are two ways in which one can arrive at a classification of patents related to biotechnology. The first is to construct an a priori list of biotechnology related fields of interest and associate a number of technical keywords to each field. The task then is to identify patents to be included within field class by searching through their titles and abstracts using these keywords. The second method is to use the information from the US patent classification system and group the USPC classes into biotechnology related categories. This study is based on the second approach.

The USPC has one major class related to biotechnology, class 435, *Chemistry: molecular biology and microbiology*, which is obviously relevant to the study. However there are a number of other classes, which also contain some patents related to biotechnology. For example, 514 *Drug, bio-affecting and body treating compositions*, and 530 *Chemistry: natural resins or derivatives; peptides or proteins; lignins or reaction products thereof*.

The classification process began with a careful examination of the subclasses delineated under class 435 and the titles of the patents included therein. This process yielded information on biotechnology related patents within specific subclasses of

other major classes (such as 514 and 530). Definitions of all these subclasses were used to create a preliminary classification system contained in Table 1³.

Table 1. SPRU Biotech Classification: Preliminary version

SPRU Class	Definition
ANIMAL	Preparation of, production of, and use of ANIMALS (and their related applications e.g. for assay, protein production, disease models)
PLANT	Preparation of, production of, and use of PLANTS (and their related applications e.g. for assay, or food production)
MICROORGANISM	MICROORGANISMS, including Viruses, Bacteria, and Microscopic eukaryotes such as Fungi, Compositions thereof; Process of propagating, maintaining, or preserving, or Compositions thereof; Process of preparing or isolating a Composition containing such organisms ; Culture Media thereof.
BIOLOGICAL MATERIALS FOR THERAPEUTIC APPLICATION	Preparation of, compositions of or production of BIOLOGICAL MATERIALS for therapeutic use (e.g. peptides and proteins and their related applications e.g. as drugs)
BIOLOGICAL MATERIALS WITH GENERIC APPLICATIONS	Preparation of, compositions of, or production of BIOLOGICAL MATERIALS for industrial applications (eg. Peptides or proteins or whole bacteria)
TISSUE CULTURE	Preparation of or production of cell and organs eg. Cell culture, for transplantation, or for in vitro assay.
GENETIC ENGINEERING	GENETIC ENGINEERING - including materials (eg DNA, RNA and recombinant DNA, RNA), processes for isolating such materials, and composition of such materials; methods for modification and manipulation of such materials and products of such manipulation
BIOSYNTHESIS	Use of higher living organism, Microorganisms, or single cells or part thereof for BIOSYNTHESIS (e.g., in fermentation)
BIOSENSORS	BIOSENSORS: Processes for the control of biological materials or modified biological materials or for their use for methods of analysis, diagnosis, detection and sensing
METHODS OF ANALYSIS (NON-BIOLOGICAL)	Methods for detecting the presence of biological materials, or analysing compositions or properties thereof, where the method of analysis is not derived from a biological process
APPARATUS	APPARATUS including instrumentation, vessels, etc. for use in production, analysis or storage of biological materials (including organisms) or control of processes utilising such materials
BIO-SEPARATION AND CLEANING	BIO- SEPARATION or cleaning through use of enzymes, microorganisms etc. for processes such as liquid purification, Waste treatment.
FERTILIZERS & PESTICIDES	Use of microorganisms, enzymes or peptides, as, or for production of, FERTILIZERS or PESTICIDES
BIOINFORMATICS	BIOINFORMATICS: methods for the storage, retrieval or analysis of biological data (inc. DNA sequences, and protein structures)

In common with any patent classification system, the USPC has very detailed and useful information on technologies/processes/apparatus. However there is very little information on the application of these to specific products mainly because patent

³ See Appendix for more details.

documents do not routinely contain such information. Nonetheless, Table 1 contains some classes that are based on application: Animal, Plant, Biological materials for therapeutic application, and Fertilizers & pesticides.

There are some similarities between this classification and that advocated by the OECD⁴. For example our Biological Materials classes are equivalent to the OECD category, Proteins and Molecules, and our class Genetic Engineering, is equivalent to the OECD category entitled DNA. The SPRU classification contains a number of process related areas not covered by the OECD classification.

The next step in this process was to count the number of patents according to this classification in order to see whether there were enough patents in each category for the proposed types of analysis (see Table 2).

Table 2. US patenting by SPRU Biotechnology classes (Preliminary Classification).

SPRU Preliminary Class	Number of patents: 1991-2000	Included in Subsequent Analysis
Animal	297	No
Plant	2290	Yes
Microorganism	2403	Yes
Biological Materials for therapeutic application	8852	Yes
Biological Materials with generic applications	7062	Yes
Tissue culture	2249	Yes
Genetic engineering	6074	Yes
Biosynthesis	3363	Yes
Biosensors	10900	Yes
Methods of analysis (non-biological)	410	No
Apparatus	2180	Yes
Bio-separation and cleaning	1261	Yes
Fertilizers & Pesticides	186	No
Bioinformatics	116	No

On the basis of this information 4 classes were deemed to have too few patents for meaningful analysis by country and by named institutions: Animal, Non-Biological methods of analysis, Fertilizers & Pesticides and Bioinformatics. The problem with classes with very few patents is that small changes in the number of patents from one time period to the next could show up as large changes in some of the indicators used below. Nevertheless, the last of these classes, bioinformatics, is a rapidly growing

⁴ See "A statistical framework for biotechnology statistics", prepared for the Working party of National Experts on Science and Technology Indicators, Directorate for Science, Technology and Industry, OECD (April 2002).

class and if this study were to be repeated with more recent data, then it would certainly be included in the analysis.

2.2 *Consolidating and cleaning institutional names*

As mentioned above one of the main difficulties in using the primary information supplied by the USPTO is that patents are often granted under the names of subsidiaries and divisions. Moreover the name of the same institution may appear many times in different forms. Thus for the purposes of analysing the data by named institutions, companies need to be consolidated and institutional names unified. In this report we have consolidated companies on the basis of the 1999 edition of *Who Owns Whom*, which contains information on company structures as they existed at the end of 1998.

There is one caveat that needs to be borne in mind when interpreting the results of the analysis below. As our firms are consolidated for one year only: 1998, the time-trend analyses of patenting by firms, say from 1986 to 2000, reflects the firm as constituted in that year. However this does not include any of the changes resulting from either the purchases or sales of subsidiaries or divisions since then, or divestments undertaken over the period since 1986. Thus measured changes over time are composed of changes in those parts of the firm retained up to 1998, together with those resulting from acquisitions made up to 1998: in other words, what the firm kept and what it bought, up to 1998.

Time Trends

USPTO data by named institution are available over the period 1969 to 2000. In this report the analysis is confined to the period from 1986 to 2000, as the type and scale of patenting activities prior to 1986 were very different. In any case many analysts would claim that biotechnology in the 1990s comprises of very different set of activities compared to the 1970s and 1980s.

We have also aggregated the data into three 5-year time periods (1986-90, 1991-95 and 1996-2000) in order to overcome random fluctuations in patent numbers and the problem of small numbers.

3. Country Trends in Patenting

3.1 Structure of UK Patenting

The volume of US patenting by UK inventors in all biotechnology related areas has been increasing rapidly. In aggregate the number of patents in 1996-2000 were higher by a factor of more than 3, compared to the period 1991-95. There are big differences in the rate of growth amongst different fields: ranging from very high growth in genetic engineering (more than 500%) to slower growth in apparatus (around 60%). The other point to emerge from this table and the subsequent analysis is that very little changed between the second half of the 1980s and the first half of 1990s. The big period of take-off was the period since 1996.

Table 3. Total number of UK Patents granted in the US in Biotechnology: 1986 to 2000

No. Class	1986-90	1991-95	1996-00
1 Plant	5	15	51
2 Microorganism	14	18	63
3 Biological materials for therapeutic applications	70	82	268
4 Biological materials with generic applications	40	53	126
5 Tissue culture	6	8	30
6 Genetic engineering	9	31	158
7 Biosynthesis	49	47	76
8 Biosensors	76	81	296
9 Apparatus	22	25	40
10 Bio-separation and cleaning	7	9	30
11 Other	15	4	26
All Biotechnology	313	373	1164

Two fields are dominant in terms of UK technology: Biosensors and Biological materials for therapeutic application, accounting for nearly half all biotechnology related patents in the UK. On the other hand Tissue culture, Bio-separation and cleaning, and Apparatus have a much smaller level of activity, with less than 5% of all patents.

3.2 *Patent Shares Analysis*

This section addresses the question of how the UK performs compared to its major competitors, as measured by its share of all US patenting in the different fields of technology. The data in Table 4 show that in 1996-2000 the UK is in 4th position in terms of the volume of US patenting in biotechnology as a whole, behind the US, Japan and Germany. The biases due to differing propensities to patent are evident in this table, with US inventors accounting for around two-thirds of all patenting in the latest period, and Japanese inventors with for more than twice the number of patents granted to the leading European countries.

Over the 15-year period since the mid-1980s, there has been a decline in the share of all biotechnology patenting for most countries, the two exceptions being Canada and the US. However a comparison of the two sub-periods in the 1990s, shows that the only other country to increase its overall share is the UK. On the other hand Germany and Japan have seen a substantial decline in their share over the same period.

There are two fields in which the UK share of patenting has increased throughout the period since 1986: Genetic Engineering and Bio-separation and cleaning. In the same period UK patenting in Plant biotechnology has declined. In three other fields there have been big increases in the UK share in the period since 1991-95: Microorganism, Biosensors and Biological Materials for therapeutic applications.

Although the German share has been declining in 8 out of the 10 fields, in the second half of the 1990s Germany still remains the leading European country in most fields. The only exceptions are Biological Materials for therapeutic applications, where the UK is the leader, and Microorganism, where France is the leading EU country, closely followed by the UK. The two areas in which UK lags behind both France and Germany are: Tissue Culture and Biosynthesis. Finally the analysis in Table 4 shows that the UK is catching up fast with Germany in most areas of biotechnology, with the exception of Apparatus and Plant biotechnology, where the German lead has increased.

Table 4. Trends in Patent Shares of US Patenting By Country of Origin of Inventor: 1986-2000

		All Biotechnology	Plant	Microorganism	Biological Materials for therapeutic applications	Biological Materials with generic applications	Tissue culture	Genetic engineering	Biosynthesis	Biosensors	Apparatus	Bio- separation and cleaning
UK	1986-90	3.8	3.7	3.3	4.2	2.8	2.6	2.2	4.9	3.9	4.2	3.0
	1991-95	2.7	4.4	2.3	3.2	2.1	1.3	2.7	3.4	2.7	2.9	1.8
	1996-00	3.5	2.6	3.9	4.3	2.8	1.8	3.2	3.8	3.7	3.1	4.0
Germany	1986-90	6.4		2.9	5.7	6.3	5.6	4.7	7.8	7.5	6.5	12.1
	1991-95	5.1	1.7	3.5	5.1	5.6	2.1	3.7	6.9	6.1	4.8	6.1
	1996-00	3.9	3.1	2.5	3.7	3.8	2.7	3.6	5.4	3.9	7.1	6.0
France	1986-90	3.0	2.9	3.1	4.3	3.1	0.9	2.0	3.1	2.1	3.8	1.7
	1991-95	2.9	2.0	2.3	3.5	3.5	2.1	1.8	3.5	2.5	3.2	3.3
	1996-00	2.9	1.7	4.0	3.2	2.4	2.2	3.0	4.1	2.9	2.7	1.9
Switzerland	1986-90	1.3	1.5	1.0	2.1	0.6	3.5	0.5	1.7	1.0	1.5	1.3
	1991-95	1.4	0.3	1.9	1.8	0.8	1.0	1.7	2.9	0.5	2.0	2.9
	1996-00	1.0	0.5	1.5	1.0	1.4	0.5	0.8	1.3	0.6	2.6	0.8
Italy	1986-90	1.4		0.7	2.5	1.9	0.4	1.0	1.1	0.7	0.8	3.0
	1991-95	1.3		1.3	2.2	1.6	1.0	0.9	1.6	0.7	0.7	1.4
	1996-00	0.8	0.2	1.3	1.3	0.9	0.5	0.7	1.6	0.4	1.2	0.5
Sweden	1986-90	0.9	1.5	0.7	0.8	1.1	0.4		0.5	1.4	1.1	0.9
	1991-95	0.8		1.0	0.9	1.2	0.7	0.4	0.4	0.8	1.0	0.8
	1996-00	0.9	0.1	0.6	1.5	0.9	0.4	0.6	0.9	0.9	1.8	0.4
Japan	1986-90	14.6	5.9	16.9	11.7	16.7	10.8	12.0	26.3	11.0	13.8	13.4
	1991-95	13.9	7.6	12.3	11.5	17.9	8.2	11.2	28.0	10.6	9.9	12.4
	1996-00	7.8	3.2	8.8	6.3	10.2	5.1	6.2	21.1	6.4	8.0	11.6
Canada	1986-90	2.1	5.1	1.9	2.5	1.8	2.2	1.5	2.4	1.4	4.2	2.2
	1991-95	2.3	4.7	2.6	3.0	2.4	1.8	1.9	1.1	2.1	2.4	2.5
	1996-00	3.0	2.8	3.1	3.8	2.5	2.6	3.5	1.5	2.8	1.7	3.7
USA	1986-90	60.1	67.6	62.1	58.7	59.6	68.8	70.6	44.1	66.5	58.6	50.9
	1991-95	62.5	72.6	63.8	59.9	57.5	75.8	68.9	45.2	68.8	66.2	61.2
	1996-00	67.6	77.1	64.9	64.2	65.6	78.5	71.1	48.8	71.8	62.3	57.7

3.3 Patterns of Revealed Technological Advantage.

One of the problems with an analysis based on patent shares is that there are differing propensities to patent in the US amongst inventors from different countries. As shown above in Table 4, this is most evident in the case of the US, where we are comparing US based inventors patenting in their home market versus inventors from other countries patenting in a foreign market. The position of Japanese inventors may also be exaggerated in such an analysis, as in all areas of biotechnology Japan leads Germany, UK, and France.

An indicator that corrects for this bias is the Revealed Technological Advantage (RTA) Index, which simply shows whether a country has a relatively high share of US patents in a particular technical field compared to its average share of all US patents (i.e. across all technical fields). This can be interpreted as an index of ‘comparative advantage’: with a value above unity indicating an area of relative strength (compared to other areas of technology) and a value below unity an area of relative weakness. Table 5 reports the value of this index for the UK and its major competitors over the period 1986-2000. This analysis shows that UK is relatively strong in almost all areas of biotechnology, and that this relative strength has increased over time. Only two other countries share a similar profile: Canada and the USA. According to this analysis German biotechnology is relatively weak in almost all areas. France occupies a position somewhere in between Germany and UK, with relative strength in 6 out of the 10 areas in 1996-2000.

The two technical fields in which UK has maintained a consistently high degree of relative strength throughout the period 1986 to 2000 are Biological Materials for therapeutic applications and Biosynthesis. In the latest period upto the year 2000 other areas with the highest value of the RTA index are Bio-separation and cleaning, Microorganism, and Biosensors. One area of relative weakness for the UK is Tissue culture. Perhaps the biggest change over the period since 1986 has been in Genetic engineering, which has gone from being an area of relative weakness to one of relative strength.

Table 5. Trends in Revealed Technological Advantage¹: 1986-2000

		All Biotechnology	Plant	Microorganism	Biological Materials for therapeutic applications	Biological Materials with generic applications	Tissue culture	Genetic engineering	Biosynthesis	Biosensors	Apparatus	Bio-separation and cleaning
UK	1986-90	1.17	1.13	1.02	1.29	0.87	0.79	0.69	1.49	1.19	1.29	0.92
	1991-95	1.08	1.77	0.94	1.30	0.86	0.53	1.09	1.37	1.09	1.16	0.71
	1996-00	1.49	1.12	1.66	1.83	1.19	0.79	1.38	1.65	1.61	1.31	1.72
Germany	1986-90	0.70		0.31	0.63	0.69	0.62	0.52	0.86	0.82	0.71	1.32
	1991-95	0.72	0.25	0.49	0.71	0.79	0.30	0.52	0.98	0.86	0.68	0.85
	1996-00	0.62	0.49	0.40	0.60	0.61	0.43	0.58	0.86	0.63	1.14	0.96
France	1986-90	0.89	0.88	0.93	1.30	0.94	0.26	0.60	0.92	0.62	1.15	0.52
	1991-95	0.98	0.69	0.79	1.19	1.18	0.72	0.62	1.18	0.85	1.09	1.13
	1996-00	1.14	0.70	1.59	1.26	0.94	0.88	1.21	1.63	1.14	1.06	0.74
Switzerland	1986-90	0.86	0.95	0.61	1.35	0.41	2.23	0.32	1.09	0.63	0.99	0.83
	1991-95	1.16	0.25	1.63	1.49	0.64	0.83	1.46	2.43	0.42	1.64	2.48
	1996-00	1.06	0.52	1.65	1.13	1.54	0.55	0.89	1.47	0.62	2.90	0.89
Italy	1986-90	0.98		0.51	1.77	1.38	0.31	0.72	0.78	0.48	0.55	2.17
	1991-95	1.04		1.06	1.76	1.28	0.80	0.71	1.30	0.54	0.56	1.12
	1996-00	0.76	0.14	1.21	1.27	0.82	0.46	0.69	1.47	0.33	1.15	0.50
Sweden	1986-90	0.93	1.46	0.71	0.77	1.06	0.43		0.49	1.43	1.14	0.85
	1991-95	1.14		1.47	1.28	1.76	0.93	0.61	0.51	1.14	1.47	1.11
	1996-00	1.03	0.06	0.63	1.73	1.03	0.42	0.72	0.99	1.02	2.01	0.46
Japan	1986-90	0.71	0.29	0.82	0.57	0.82	0.53	0.58	1.28	0.54	0.67	0.65
	1991-95	0.63	0.34	0.56	0.52	0.81	0.37	0.51	1.27	0.48	0.45	0.56
	1996-00	0.38	0.16	0.43	0.30	0.50	0.25	0.30	1.03	0.31	0.39	0.56
Canada	1986-90	1.08	2.62	0.97	1.28	0.90	1.10	0.76	1.21	0.70	2.14	1.10
	1991-95	1.15	2.30	1.27	1.49	1.16	0.89	0.94	0.53	1.02	1.19	1.26
	1996-00	1.44	1.33	1.47	1.81	1.21	1.23	1.67	0.72	1.33	0.80	1.78
USA	1986-90	1.14	1.29	1.18	1.12	1.13	1.31	1.34	0.84	1.26	1.11	0.97
	1991-95	1.15	1.34	1.18	1.11	1.06	1.40	1.27	0.83	1.27	1.22	1.13
	1996-00	1.24	1.41	1.19	1.17	1.20	1.43	1.30	0.89	1.31	1.14	1.05

¹See text for a definition of Revealed Technological Advantage

3.4 *Patent Citation Analysis.*

In this section we analyse how frequently patents granted to inventors from a particular country are cited in subsequent patents. The basic assumption is that the frequency of citation is a reasonably good proxy for both the technological and economic value of a patent. The underlying rationale is that a patent disclosing information about a major advance in technology generates a stream of new inventions which all cite that patent⁵. Moreover a recent study conducted by Harhoff et al.⁶ indicates that the higher the estimated value of an invention, the higher the citation frequency of the patent underlying the invention.

There are two possible sources of bias that need to be considered when constructing an indicator based on citations. The first is that the longer the time period that a patent has been in force the higher the probability of it being cited. Thus in terms of the year aggregations used in this report, patents granted in 1986-90 will have a higher rate of citation than those granted in 1996-2000. The second source of bias is the possibility of differing rate of citation amongst different technical fields. The citation index used here corrects for both of these. This index is simply the number of citations per patent for inventors from a given country in a given class divided by the average number of citations per patent in that class. A value of greater than unity indicates that a particular country's patents are more highly cited than average and vice versa for a value less than unity.

Table 6 shows that patents granted to US inventors are amongst the most highly cited, both at the aggregate level and within each of the 10 technical fields. For biotechnology as a whole, the other two countries with a high rate of citation are Switzerland (period since 1991) and Sweden (period since 1996). UK invented patents are cited slightly below average at the aggregate level, with the citation index just below 0.9. However in 4 technical fields, UK patents have a higher than average rate of citation: Biosensors, Plant, Microorganism and Apparatus. The two areas with the lowest value of the citation index for the UK are Tissue culture and Genetic engineering.

⁵ This is precisely the underlying rationale behind the Current Impact Index used by F. Narin and his colleagues at CHI Research.

⁶ Harhoff D., Narin F., Scherer F.M., Vopel K., 1997, "Citation Frequency and the Value of Patented Innovation", Social Science Research Center Berlin, Discussion Paper n°97-26.

Table 6. Trends in the Patent Citation Index¹: 1986-2000

		All Biotechnology	Plant	Microorganism	Biological Materials for therapeutic applications	Biological Materials with generic applications	Tissue culture	Genetic engineering	Biosynthesis	Biosensors	Apparatus	Bio-separation and cleaning
UK	1986-90	0.88	0.13	0.63	0.86	0.86	0.50	1.57	0.73	1.10	1.00	0.62
	1991-95	0.86	0.85	1.07	0.67	0.95	0.67	0.82	0.63	1.09	0.95	0.49
	1996-00	0.89	1.14	1.08	0.68	0.85	0.34	0.49	0.94	1.15	1.06	0.79
Germany	1986-90	0.68		0.59	0.66	0.65	0.62	0.44	0.63	0.53	1.35	0.75
	1991-95	0.68	1.04	0.78	0.69	0.55	0.57	0.86	0.75	0.53	1.08	0.91
	1996-00	0.58	1.01	0.38	0.69	0.69	1.20	0.52	0.44	0.51	0.27	0.73
France	1986-90	0.63	0.27	0.62	0.60	0.64	1.30	0.70	0.42	0.80	0.54	1.30
	1991-95	0.61	0.43	0.75	0.57	0.59	0.89	0.96	0.70	0.58	0.52	0.68
	1996-00	0.53	1.03	0.30	0.52	1.19	0.38	0.61	0.51	0.37	0.50	0.21
Switzerland	1986-90	0.96	0.07	1.28	0.74	0.61	2.08	0.66	0.69	1.16	0.77	0.64
	1991-95	1.23	1.16	0.60	1.97	0.91	0.67	0.35	0.75	0.39	2.88	0.72
	1996-00	2.11	1.04	0.55	1.69	0.87	0.21	0.78	0.71	1.19	3.93	1.73
Italy	1986-90	0.36		0.00	0.34	0.52	0.27	0.37	0.48	0.33	0.26	0.44
	1991-95	0.41		0.42	0.59	0.53	0.28	0.11	0.33	0.44	0.33	0.14
	1996-00	0.52	0.00	0.52	0.88	0.60	0.21	0.56	0.89	0.15	0.10	1.11
Sweden	1986-90	0.82	0.07	0.85	1.09	1.01	2.39		1.68	0.54	0.65	1.27
	1991-95	0.82		0.86	1.00	1.07	0.25	0.59	2.25	0.50	0.77	0.58
	1996-00	1.27	0.00	1.47	1.76	0.85	1.42	0.20	0.95	1.81	0.38	0.00
Japan	1986-90	0.56	0.31	0.62	0.88	0.54	0.42	0.36	0.63	0.54	0.59	0.65
	1991-95	0.51	0.34	0.48	0.63	0.59	0.41	0.36	0.53	0.54	0.64	0.59
	1996-00	0.54	0.59	0.55	0.62	0.66	0.72	0.53	0.54	0.43	0.49	0.48
Canada	1986-90	1.19	2.67	1.10	1.18	1.54	2.63	0.75	0.66	0.96	0.64	0.87
	1991-95	1.09	1.06	0.59	0.95	1.59	0.60	1.32	3.17	0.68	0.96	1.23
	1996-00	0.80	0.35	0.53	1.07	1.09	0.85	0.77	0.62	0.73	0.27	1.11
USA	1986-90	1.21	1.16	1.12	1.17	1.22	1.06	1.19	1.42	1.15	1.18	1.20
	1991-95	1.19	1.09	1.23	1.18	1.21	1.13	1.18	1.35	1.16	1.05	1.15
	1996-00	1.12	1.02	1.22	1.08	1.10	1.09	1.17	1.44	1.12	1.03	1.25

¹See text for a definition of the Patent Citation Index.

3.5 *Summary: Analysing Country Trends.*

The main points to emerge from the above country comparisons are:

- The UK is one of the few countries to have substantially increased its share of US patenting in Biotechnology related fields in the 1990s. The only other countries with similar trends are Canada and the USA.
- In 8 out of the 10 fields UK share has increased substantially in the second half of the 1990s. Amongst the fields with the largest increases are Biosensors and Biological Materials for therapeutic applications. In the latter the UK is the leading EU country.
- UK is relatively strong in 9 out of the 10 biotechnology related fields, and this relative strength has increased over time.
- The two main areas of relative weakness are Tissue culture and Plant biotechnology.
- On average UK biotechnology related patents have a lower level of impact as measured by the frequency of citation. However in 4 areas the rate of citation is higher than average: Biosensors, Plant, Microorganism and Apparatus.

Together these results imply that UK is strong in biotechnology. It is rapidly catching up with Germany to become the leading country in the EU. In one key set of technologies, those related to applications in Pharmaceuticals, UK is ahead of Germany. In another set of general purpose technologies with applications in many different fields, Biosensors, UK has a high (and rapidly increasing) volume of patenting and a high level of impact.

4. Top Patenting Institutions in the World

4.1 *Top 20 Institutions World-wide*

Thus far we have analysed performance at the country level. In this section the focus is on the main institutions, namely firms, universities, and public sector research institutions, involved in patenting in the US. As discussed above (Section 2), firms have been consolidated for the year 1998. This means that some of the most recent mergers and acquisitions have been ignored in this analysis. Thus for example Smithkline Beecham and Glaxo Wellcome appear as separate firms rather than as Glaxo-Smithkline.

Each institution has also been allocated a ‘home’ country and a product group. In the case of a firm, the former refers to the country in which the firm has its headquarters. Bi-national firms have been assigned to a single country, for example, for Smithkline Beecham and Unilever, UK is the home country, but for Shell it is the Netherlands. Firms have been assigned product groups on the basis of their principal activity. We make a distinction between Pharmaceutical and Biopharmaceutical firms. The latter category contains firms commonly referred to as dedicated biotechnology firms (DBFs). Another important product group containing DBFs is Instruments/Devices/ and Reagents. The Chemical & related product group includes Petrochemical firms such as Shell and BP.

Table 7 lists the top 20 institutions patenting in the US ranked according to their volume of patenting in 1996-2000. These institutions can be regarded as the leading players in the world in biotechnology. As may be expected the list is dominated by American institutions, numbering 13 out of the 20. However the top patenting firm in the US in biotechnology is Roche, and it has held that spot throughout the period since 1986. Amongst the 7 European companies to appear in this list is Novo Nordisk, the Danish pharmaceuticals firm. The two large German chemical companies, Hoechst and Bayer, are also amongst the leading patentees, as is Rhone Poulenc from France and Novartis, based in Switzerland.

The only UK firm to appear in the world top 20 is Smithkline Beecham, at number 7. It is also one of the companies in this list that has rapidly increased its level of patenting in the 1990s (by more than four fold since 1991-95). Other UK based companies that could be included if we extended this list to the top 50 are AstraZeneca (at number 25), Nycomed Amersham (42) and Glaxo Wellcome (48).

Table 7. Top 20 Institutions in Biotechnology related US patenting: 1996-2000

Rank (96-00)	Parent Name	Ctry	Product Group	1986-90	1991-95	1996-00
1	Roche Holding	CH	Pharmaceuticals	296	492	790
2	University of California	US	PSRO	96	141	669
3	Monsanto	US	Chemicals & Related	79	171	535
4	Incyte Pharmaceuticals, Inc.	US	Biopharmaceutical		15	526
5	Novo Nordisk	DK	Pharmaceuticals	50	117	523
6	United States of America, Health & Human Services	US	PSRO	73	205	465
7	SmithKline Beecham Plc	UK	Pharmaceuticals	89	98	442
8	Hoechst Ag	DE	Chemicals & Related	145	240	416
9	Pioneer Hi-Bred International	US	Food & Drink	8	60	381
10	Novartis	CH	Pharmaceuticals	53	121	355
11	Chiron Corp.	US	Pharmaceuticals	124	109	342
12	Rhone-Poulenc	FR	Chemicals & Related	74	86	298
13	American Home Products Corp.	US	Pharmaceuticals	76	141	284
14	Abbott Laboratories	US	Pharmaceuticals	45	158	260
15	Isis Pharmaceuticals, Inc.	US	Biopharmaceutical		6	249
16	Merck & Company Inc.	US	Pharmaceuticals	108	230	237
17	Eli Lilly and Company	US	Pharmaceuticals	103	92	227
18	Becton, Dickinson and Company	US	Medical Equipment/Suppliers	90	96	222
19	Johns Hopkins University	US	PSRO	12	54	214
20	Bayer Ag	DE	Chemicals & Related	203	135	211

Table 7 also points to the importance of US public sector research organisations in biotechnology related patenting, with the presence of UCLA, US Department of Health and John Hopkins University amongst the top 20. It also shows the rapid rise of US Biopharmaceutical firms such as Incyte and ISIS in the 1990s.

4.2 Top Patenting UK based Firms.

Table 8 lists the top UK based firms patenting in the US in 10 areas of biotechnology. Thus UK firms are well represented at the world technological frontier in biotechnology related Apparatus, with 3 out of the top 20, including Nycomed Amersham at number 1. In two other technical fields there are two UK firms in the world top 20: Biological Materials for therapeutic applications and Bio-separation and cleaning. However in Microorganism, Tissue culture, and Biosynthesis there are no UK representatives amongst the top 20.

Table 8. UK-based firms Patenting in the US: 1996-00

Technology Class	Company and Ranking
Plant	AstraZeneca (5)
Microorganism	Unilever (25)
Biological Materials for therapeutic application	SmithKline Beecham (18), AstraZeneca (19), Glaxo Wellcome (25)
Biological Materials with generic applications	SmithKline Beecham (3)
Tissue culture	
Genetic engineering	SmithKline Beecham (2)
Biosynthesis	AstraZeneca (21), ICI (24)
Biosensors	SmithKline Beecham (18)
Apparatus	Nycomed Amersham (1), SmithKline Beecham (14), Glaxo Wellcome (20)
Bio-separation and cleaning	AstraZeneca (10), Unilever (11)

Table 8 also shows that SmithKline Beecham is amongst the world leaders in 5 out of the 10 technical fields, with a particularly strong performance in Genetic engineering (2nd) and Biological materials with generic applications (3rd). AstraZeneca is also at the forefront of world technology in 4 technical fields, amongst which is Plant biotechnology, where it is ranked 5th in the world.

4.3 UK-Based Institutions with highly cited patents.

This section addresses the question of who are the main UK institutions involved in inventing highly cited UK patents. For this analysis we ranked all patents in each of the technology class by the number of times they were cited and then identified the top 10% of such patents. Table 9 lists the UK institutions with the number of highly cited patent in each of the 10 classes in the period 1996 to 2000. The first column indicates the total number of highly cited patents.

A comparison of Tables 8 and 9 shows that although SmithKline Beecham is amongst the world leaders in terms of volume of patenting in a number of areas, it only holds important patents (as measured by citation counts) in two of these. On the other hand Glaxo Wellcome appears in the world top 10 in only one technical field, but has highly cited patents in 3 areas, namely Biosensors, Genetic Engineering and Biological

Materials for generic applications. Further Nycomed Amersham is not only the world's leading firm in biotechnology related apparatus, it also holds the highest number of the most important patents in the field.

Table 9: UK-Based Firms and Institutions with highly cited US patents: 1996-00

Technology Class	Company and Number of Patents
Plant [26 Total]	
Microorganism [40 Total]	ICI (1), MAFF (1)
Biological Materials for therapeutic application [133 Total]	AstraZeneca (2), SmithKline Beecham (2) Unilever Plc (2), ICI(1)
Biological Materials with generic applications [106 Total]	Celltech (1), Glaxo Wellcome (1), SmithKline Beecham (1)
Tissue culture [36 Total]	
Genetic engineering [93 Total]	Glaxo Wellcome (5)
Biosynthesis [42 Total]	AstraZeneca (1), Babraham Institute (1), Unilever (1)
Biosensors [224 Total]	Glaxo Wellcome (12), Unilever (3), British Technology Group (1), Generics Group Plc (1), ISIS Innovation (1)
Apparatus [46 Total]	Nycomed Amersham (8)
Bio-separation and cleaning [22 Total]	Allied Colloids (1)

This list of holders of the most highly cited patents also includes a number of smaller firms, Generics Group and ISIS Innovation (a spin-off from Oxford University) as well as public sector research organisations such as British Technology Group, Babraham Institute and MAFF.

4.4 Summary of the Top Patenting Institutions Worldwide

The main points to emerge from this analysis are:

- Three UK-based large Pharmaceutical firms are amongst the world leaders in a number of fields of biotechnology, whether measured by volume or by impact of patenting: SmithKline Beecham, AstraZeneca and Glaxo Wellcome. They are particularly strong in Biological Materials for therapeutic applications.
- In terms of volume, SmithKline Beecham is amongst the world leaders in 5 out of the 10 fields of biotechnology. On the other hand Glaxo Wellcome has a high number of the most highly cited patents in Genetic engineering and Biosensors.
- Apart from the big 3, two other UK based firms are amongst the top patentees in the world, namely Nycomed Amersham and Unilever. The former is number one in terms of the volume of patenting in biotechnology related Apparatus, and also has a large number of highly cited patents. Indeed this area of technology has two other UK firms in the top 20.
- A number of UK small firms and public sector research organisations are holders of high impact patents.

5. UK Invented Patents: Analysis by Institutions

Section 4 was based on all patenting by named institutions, regardless of the geographic location of where the invention related to a patent occurred. This section focuses on patents that have inventor addresses within the UK. Thus the main questions being addressed are:

- Who are the main actors in biotechnology related patenting within the UK?
- What are the main differences according to nationality and product group of the assignees with UK invented patents?

5.1 Top Patenting Institutions in the UK

Table 10 lists the top 20 institutions patenting in the US with inventor addresses in the UK in the period 1996-2000. As expected the list contains some of the large R&D

Table 10. Top 20 Institutions with UK-invented US patents in 1996-2000.

Rank	Company Name	Par Ctry	1986-90	1991-95	1996-00
1	AstraZeneca	UK	5	12	74
2	Medical Research Council	UK		5	46
3	Smithkline Beecham Plc	UK	17	13	44
4	Unilever Plc	UK	11	15	42
5	Celltech Group Plc	UK	8	9	31
6	British Technology Group	UK	20	27	26
7	Glaxo Wellcome	UK	17	14	25
8	Nycomed Amersham	UK	7	3	24
9	Ludwig Institute for Cancer Research	US		1	22
10	Bristol-Myers Squibb Company	US	3	2	21
11	British Biotech Pharmaceuticals Ltd.	UK	1	3	20
12	Cancer Research Campaign	UK		4	16
13	Novartis	CH	1	3	16
14	Hoechst Ag	DE	1	3	15
15	Imperial College	UK			15
16	Akzo Nobel N.V.	NL	1	5	14
17	Rhone-Poulenc Sa	FR		3	14
18	Chiroscience Limited	UK		1	14
19	Lynx Therapeutics, Inc.	US			13
20	Medeva Plc	UK		1	13

performing companies in the UK already identified as world leaders in section 4, such as AstraZeneca, SmithKline Beecham and Unilever. However the institution with the second highest number of patents within the UK is MRC. It also shows a very high rate of growth of patenting in the 1990s. The table also points to the importance of non-profit making institutions (PSROs and Charities) in innovative activities within biotechnology in the UK, with 4 out of the 20 institutions falling in this category.

Another important point to emerge from Table 10 is that foreign firms and institutions are important players in the UK: 6 out of the top 20 are based outside the UK. Three out of the 6 institutions are US-based, with the rest from Switzerland, Germany and France. We return to this issue below (section 5.3).

5.2 Analysis by Industry/Institutional Affiliation

Table 11 shows the distribution of all UK invented patents according to product group (in the case of firms) or institutional affiliation (in the case of other institutions). This analysis is limited to the UK as it was extremely difficult to obtain such information for other countries. In the case of the UK we managed to identify nearly all assignees for the period 1996 to 2000: for only 1.3% of all patents we could not obtain information on the product group or nationality of the firm. All firms have been assigned to one of 10 product groups, and the 2 remaining categories are Public Sector Research Organizations (such as universities, research council and other government laboratories) and Private Non Profit organizations or Charities.

Table 11 highlights the changing locus of biotechnology related patenting in the UK since the mid-1990s. For example in the period upto 1995, (mainly) large Chemical and Pharmaceutical firms accounted for around 40% of all patenting. However in the period since then their share has dropped to less than 27%. In 1996-2000 nearly 25% of all UK invented patents in the US were assigned to PSROs, this proportion having increased from 15% in the second half of the 1980s. At the same time, Table 12 shows that the number of PSROs active in biotechnology has increased from 20 to 84. A large number of these are Universities who began to patent extensively in the late 1990s. More detailed data show that PSROs are especially important in Biosensors (accounting for 32% of all UK patents in 1996-2000) and Biological Materials for therapeutic applications (28% of all UK patents in 1996-2000)

The other main trend to note from Tables 11 and 12 is the rising contribution of the mainly small specialist biotechnology firms (or DBFs). Thus Biopharmaceutical firms have increased their share from 6% to 19%. And if we include firms involved in

Table 11. Distribution of Patenting by Product Group/Institutional Affiliation in the UK: 1986-2000

	1986-90	1991-95	1996-00
PSRO	14.7	17.2	24.9
Pharmaceuticals	21.7	21.7	21.7
Biopharmaceuticals	5.8	12.1	18.9
Instruments/Devices/Reagents	6.4	4.0	6.6
Chemicals & Related	19.8	16.9	6.0
Food & Drink	5.4	5.6	5.0
Private Non Profit/Charities	1.3	3.2	4.6
Other Manufacturing	5.4	4.0	2.7
Agricultural Biotechnology	1.3	3.2	1.5
Misc. Biotechnology	1.6	1.3	1.3
Electrical/Electronics	0.0	1.3	0.7
Medical Equipment/Suppliers	0.3	0.3	0.4
Unassigned patents	11.2	7.2	4.5
Unknown	5.1	1.9	1.3
Total	100	100	100

Table 12. Number of Active Firms and Institutions by Product Group in the UK: 1986-2000

	1986-90	1991-95	1996-00
PSRO	20	25	84
Biopharmaceutical	9	20	64
Instruments/Devices/Reagents	12	10	30
Pharmaceuticals	15	19	28
Chemicals & Related	11	14	19
Other Manufacturing	9	9	14
Food & Drink	0	5	10
Misc. Biotechnology	5	4	9
Private Non Profit/Charities	4	5	8
Agricultural Biotechnology	2	3	5
Electrical/Electronics	4	4	5
Medical Equipment/Suppliers	1	1	3
Total	92	119	279

Instruments/Devices/Reagents, Agricultural and other biotechnology, then together they account for around 28% of all UK invented patents. Moreover the number of such firms has increased from 28 in the second half of the 1980s to 108 in 1996-2000. More detailed data show that Biopharmaceutical firms are especially important in Biological Materials for therapeutic applications, accounting for around 30% of all UK patents in 1996-2000.

5.3 Importance of Foreign firms in the UK

Table 13 shows that foreign firms make a relatively high contribution to UK activity in biotechnology: nearly 30% of all UK patenting is accounted for by non-UK firms and this proportion has remained constant throughout the period since 1986. This is similar to the share of foreign firms in the Germany and Italy, but very different to that in France, US and Japan, where it is around 10%.

Table 13. Percentage share of US Patents granted to Foreign firms by Inventor Country: 1986-2000

	1986-90	1991-95	1996-00
UK	29.4	29.8	28.8
Germany	26.1	32.1	28.5
France	7.0	12.3	10.9
Italy	23.2	17.9	31.1
Japan	2.6	3.7	3.7
Canada	29.3	26.3	23.4
USA	12.9	10.9	10.5

Detailed data show that the importance of foreign firms in the UK varies little across the 10 fields of biotechnology, ranging from around 18% in Plant to 37% in Tissue culture in 1996-2000.

In terms of nationalities of the firms active in the UK, American firms account for more than half of the total foreign share in 1996-2000 (17% compared to a total of nearly 29%). The next largest category is Swiss firms (Novartis and Roche), accounting for around 3.5% of all UK patenting.

5.4 Summary of UK invented Patents

The following results emerge from this analysis of institutions involved in patenting from the UK:

- While large Pharmaceutical firms have remained important players in UK biotechnology throughout the period since 1986, Universities and other public sector research organisations as well as small specialised biotechnology firms have become increasingly important in the late 1990s. Indeed the increasing share of UK patenting identified in Section 3 could be attributed to the activities of PSROs and DBFs, especially in the two main areas of strength: Biological Materials for therapeutic applications and Biosensors. As many government policies are directed at encouraging innovative activities in these two sets of institutions, this result can be interpreted as a sign of success of such policies.
- Foreign firms, especially those based in the US and Switzerland, make an important contribution to UK biotechnology. As both these countries are at the forefront of biotechnology innovation this represents a good opportunity for UK firms to learn from the world best practice technology located within national boundaries.

6 Foreign Activities of UK Based firms

In section 5 we analysed firms and other institutions that locate their biotechnology related research activities within the UK. The purpose of this section is to examine the extent to UK based firms are internationalising their technology. In other words we are analysing patents granted to UK firms where the inventor address is not the UK. This information is used to address the following sets of questions:

- What proportion of UK firms' patenting activities are conducted outside the UK? And how has this changed over time?
- What are the main differences according to areas of technology and product group of the firm?
- How important is the US as a location in different areas of technology?

6.1 Home versus Foreign technological activities

In Table 14, we aggregate all firms according to their nationality and examine the proportion of their US patenting with inventor addresses outside the UK. As discussed above one of the main difficulties with such analysis is that some bi-national companies have been assigned an arbitrary nationality. Thus AstraZenca, SmithKline Beecham, Nycomed Amersham, and Unilever are all classed as UK firms in the analysis below. This means that extent of internationalisation of technology of UK firms may be exaggerated.

Table 14. Proportion of US patenting outside the Home Country: 1996-2000

<i>Nationality</i>	<i>% Outside Home Ctry</i>	<i>% in USA</i>	<i>% in Other Ctrys</i>
UK	52.5	37.6	14.9
Germany	45.1	25.5	19.6
France	30.2	16.4	13.8
Italy	47.4	9.6	37.7
Japan	9.6	8.5	1.1
Canada	6.9	5.6	1.3
USA	6.5		6.5

Table 14 shows that there are major differences in the level of internationalisation of technology amongst firms of different nationalities. UK based firms are amongst the most internationalised, with more than half their patenting activity located outside the UK in 1996 to 2000. On the other hand firms based in the US, Canada and Japan locate more than 90% of their biotechnology related patenting within the home country. An important difference between UK-based firms and their EU counterparts is that UK firms locate a large share of their foreign activity in the US.

Table 15. Changes in the Proportion of US patenting outside the Home Country: from 1986-1990 to 1996-2000

	Changes since 1986-90		
	<i>% Outside Home Ctry</i>	<i>% in USA</i>	<i>% in Other Ctrys</i>
UK	7.8	3.0	4.8
Germany	-1.2	-10.6	9.4
France	4.3	-1.8	6.1
Italy	27.9	-0.1	28.0
Japan	7.8	7.0	0.8
Canada	3.4	3.9	-0.4
USA	0.5		0.5

Table 15 shows that for firms from most countries there have been steady changes in the degree of internationalisation in the period since 1986. Thus UK firms increased their foreign share by around 8% in the period upto 2000. In comparison German firms have decreased their overall activity outside Germany. At the same time US has become relatively less important as a location and other countries, mainly in the EU, have become more important.

6.2 Differences by Product Group and Technical field.

As shown in Table 16, large UK Pharmaceutical and Chemical firms are highly internationalised: with more than three-quarters of their biotechnology-related patents being invented outside the UK. Their most favoured location is the US, accounting for more than two-thirds of all their patents. Although the Instruments/Devices/Reagents

product group shows a high level of internationalisation, this is the effect of including Nycomed Amersham as a UK based firm, when a large part of its patenting is based in Norway and Sweden. The final point to note from Table 16 is that small Biopharmaceutical firms tend to locate their innovative activities in the UK.

Table 16. Proportion of US patenting outside the Home Country by Product Group: 1996-2000

	<i>1996-2000</i>	
	<i>% Abroad</i>	<i>In US</i>
Biopharmaceuticals	11.0	2.8
Chemicals & Related	75.6	69.2
Food & Drink	48.4	13.2
Instruments/Devices/Reagents	64.4	14.4
Pharmaceuticals	80.4	67.0

Table 17. Proportion of US patenting outside the Home Country by Technical Field: 1996-2000

	<i>1996-2000</i>	
	<i>% Abroad</i>	<i>In US</i>
Apparatus	75.2	18.8
Genetic engineering	69.5	58.8
Biological Materials with generic applications	65.8	56.8
Plant	46.1	26.3
Biosensors	43.9	38.5
Tissue culture	42.9	35.7
Biological Materials for therapeutic application	42.3	21.8
Bio-separation and cleaning	38.7	16.1
Biosynthesis	37.6	22.4
Microorganism	13.7	5.9
All Classes Combined	52.5	37.6

The next question we address concerns the areas of technology in which UK firms locate their activities outside the UK. Table 17 shows that foreign activities are especially

important in 3 technical fields, namely Apparatus⁷, Genetic Engineering and Biological Materials with generic applications. In these fields around two-thirds or more of all patents assigned to UK firms have inventor addresses outside the UK, and more than half are in the US. The Table also shows that the US is an important location for UK firms in Biosensors and Tissue culture.

6.3 Summary Foreign Activities of UK Based firms

The main results emerging from analysing the foreign activities of UK based firms are:

- UK firms are amongst the most internationalised in the world, undertaking more than half of all their biotechnology related innovative activities outside the UK. This proportion rises to 75% for the (mainly) large Pharmaceutical and Chemical firms.
- The preferred location for these large Pharmaceutical and Chemical firms is the US, accounting for more than two-thirds of their total activity.
- Foreign sources are especially important in a number of 'platform' (or generic) technologies such as Apparatus, Genetic Engineering and Biological Materials with generic applications.

Together these results imply that UK firms are well placed to absorb new knowledge from leading edge foreign sources of innovation, an essential component of innovative activity in a fast moving area such as biotechnology. Whether this will result in continual improvement in the innovation performance of the UK as a whole depends on the extent to which these firms are able to transfer this new knowledge back to the UK, and the extent of their domestic linkages with smaller firms and other institutions.

⁷ Again the case of Apparatus can be explained by the decision to classify Nycomed Amersham as a UK firm, as most of the foreign activity in this field is based in Norway or Sweden.

7. Conclusions

Despite the increasing level of policy interest very few studies have systematically (i.e. across country and across different fields) analysed innovative activities in biotechnology. This report uses data on US patenting to map such activities for the UK over a period of 15 years, from 1986 to 2000. The validity of this measure has been discussed a great deal in a number of different studies. Suffice to say that for our purposes, as the above analysis has shown, patent data contain a wealth of information that can be used to analyse different aspects of the innovation process.

The main findings of the analysis are as follows:

- The UK is one of the few countries to have substantially increased its share of US patenting in Biotechnology related fields in the second half of the 1990s. This has resulted in a substantial narrowing of the gap with Germany, the leading EU country.
- There are two important areas where UK technology is particularly strong. The first is Biological Materials for therapeutic applications where UK is the leading European country. The second is Biosensors where it has a high volume of patenting, and where these patents are amongst the most highly cited.
- The main areas of weakness are Tissue culture and Plant related biotechnology.
- Three UK-based large Pharmaceutical firms are amongst the world leaders in a number of fields of biotechnology, whether measured by volume or by impact of patenting: SmithKline Beecham, AstraZeneca and Glaxo Wellcome. They are particularly strong in Biological Materials for therapeutic applications.
- Within the UK, Universities and other public sector research organisations as well as small specialised biotechnology firms have become increasingly important players in the late 1990s. They account for more than half of all UK invented patents, especially in the two areas of strength identified above.
- Foreign firms, especially those based in the US and Switzerland, make an important contribution to UK biotechnology. As both these countries are at the forefront of biotechnology innovation this represents a good opportunity for UK firms to learn from the world best practice technology located within national boundaries.

- UK firms, especially the large Chemical and Pharmaceutical firms, are amongst the most internationalised in the world. Their favoured location is the US, where they conduct more than two-thirds of all their biotechnology related activities.

These results suggest that the UK is strong in biotechnology, especially in technologies with applications to the Pharmaceutical industry, which is one of the most successful industries in the UK. Moreover it is well placed in another important set of technologies with applications in many different fields, namely Biosensors. There is some indication that this strength is partly due to public policies encouraging innovative activities amongst PSROs and small specialised firms.

An important source of strength is the large UK-based Pharmaceutical firms who are at the forefront of world technology. They are also well placed to absorb new knowledge from leading edge foreign sources of innovation, an essential component of innovative activity in a fast moving area such as biotechnology. Whether this will result in continuing improvement in the innovation performance of the UK as a whole depends on the extent to which these firms are able to transfer this new knowledge back to the UK, and the extent of their domestic linkages with smaller firms and other institutions.

One of the main weaknesses of the above analysis is that it is based on data upto the year 2000. This means that we are not able to capture some of the new and fast growing areas of biotechnology such as Bioinformatics. Neither are we able to judge whether the UK position has continued to improve in the last few years.

Taken as a whole the above analysis implies that, compared to their major counterparts, UK firms are in a strong position to introduce new biotechnology related products and processes in the future. Whether this potential is realised or not will depend on a number of factors, including the availability of venture capital and the continuing supply of well trained scientists and engineers from the UK science system, both of which have the potential to be greatly influenced by government policies.

Appendix. USPC Classes associated with each Biotechnology field

Class	Label	Related Class in USPTO
1	ANIMAL	800/21-25, 800/3; 800/8-20
2	PLANT	47/57.6; 435/410-431 800/260-275; 800/276; 800/277; 800/278-294; 800/295-323.3
3	MICROORGANISM	435/235-239; 435/242; 435/243-261 424/93.1-93.73
4	BIOLOGICAL MATERIALS FOR THERAPEUTIC APPLICATION	424/85.1-85.7; 424/94.1-94.67; 424/130.1-283.1; 424/520-583 435/68.1 514/2-22
5	BIOLOGICAL MATERIALS WITH GENERIC APPLICATIONS	435/174-182 435/183-234 530/300-345; 530/350-427; 530/800-868; 930
6	TISSUE CULTURE	435/1.1-1.3; 435/2; 435/325-408; 600/36
7	GENETIC ENGINEERING	536/22.1-25.2; 514/44; 536/25.1-25.2 435/69.1-69.9; 435/320; 435/440-490
8	BIOSYNTHESIS	435/41-67; 435/68.1; 435/70.1-70.5; 435/71.1-71.3; 435/72-105; 435/106-116; 435/117-168; 435/169-171 502/007 800/4-7
9	BIOSENSORS	435/3; 435/4-40.52; 436/500-548; 436/800-829; 536/25.3
10	METHODS OF ANALYSIS (NON-BIOLOGICAL)	205/777.5; 356/39-40; 382/133-134; 436/63-67
11	APPARATUS	204/403; 424/9.1-9.81 435/283.1; 435/284.1; 435/285.1-285.3; 435/286.1-286.7; 435/287.1-288.7; 435/289.1-305.4; 435/306.1; 435/307.1; 435/308.1-309.4
12	BIO-SEPARATION AND CLEANING	210/600-602; 210/606; 210/610-611; 210/615; 210/632; 210/645; 435/262-282 210/922; 510/114; 510/226; 510/300; 510/305; 510/306; 510/374; 510/394; 510/530; 510/FOR102; 510/FOR228
13	FERTILIZERS & PESTICIDES	71/6-10; 71/15-24 504/117
14	BIOINFORMATICS	702/19; 702/21; 703/11-12, 702/20, 382/129

