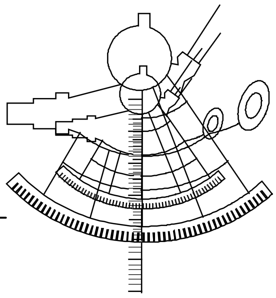
European Trend Chart on Innovation



2002 European Innovation Scoreboard
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1. Preface

The European Trend Chart on Innovation

Innovation is a priority of all Member States and of the European Commission. Throughout Europe, hundreds of national policy measures and support schemes aimed at innovation have been implemented or are under preparation. The diversity of these measures and schemes reflects the diversity of the framework conditions, cultural preferences and political priorities in the Member States.

The European Trend Chart on Innovation serves the "open policy co-ordination approach" laid down by the Lisbon Council in March 2000. It delivers summarised and concise information and statistics on innovation policies, performances and trends in the European Union. It is also a European forum for benchmarking and the exchange of good practices in the area of innovation policy.

The Innovation Scoreboard and other Trend Chart products

The European Innovation Scoreboard (EIS) is one of the products of the Trend Chart. Initially developed at the request of the Lisbon European Council in 2000, it is now being published on a yearly basis[1]. The scoreboard focuses on high-tech innovation and provides indicators for tracking the EU's progress towards the Lisbon goal of becoming the most competitive and dynamic knowledge-based economy.

The European Innovation Scoreboard is complemented by thematic scoreboards such as the present "Biotechnology Innovation Scoreboard".

The scoreboards and all other Trend Chart products (annual country reports; a database of innovation policy measures; annual trend reports; etc) are all available from the Trend Chart website (www.cordis.lu/trendchart).

This study has been produced by Lionel Nesta (SPRU), Pari Patel (SPRU) and Anthony Arundel (MERIT) under a service contract with the European Commission. The views in this study are those of the authors and do not necessarily reflect the policies of the European Commission. Copyright of the document belongs to the European Commission. Neither the European Commission, nor any person acting on its behalf, may be held responsible for the use to which information contained in this document may be put, or for any errors which, despite careful preparation and checking, may appear.

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[1] COM(2000) 567; SEC(2001) 1414; SEC(2002) 1349

2. Executive Summary

1. The Biotechnology Innovation Scoreboard (BIS) is a benchmarking exercise highlighting strengths and weaknesses of the EU Member States in biotechnology innovation. It also includes data on the US, Japan, Switzerland, Norway and Canada. The BIS is has been produced under the *"European Trend Chart on Innovation"*. As a theme-specific exercise it complements the Trend Chart and the *"European Innovation Scoreboard"*, which both cover the entire range of innovation policies.

2. The BIS is a first attempt to measure the main drivers of innovation in the area of biotechnology. One of the main difficulties in constructing this scoreboard is the lack of (publicly available) comparable data, as biotechnology does not yet appear in any official statistical classification scheme. Little is known about the level of R&D, employment, output associated with biotechnology and no information is available on one of the key aspects of innovative activity in this area: collaboration between public and private organisations. As a result of the scarcity of data, only 11 out of 19 potential indicators have been retained and no trend analysis can be offered.

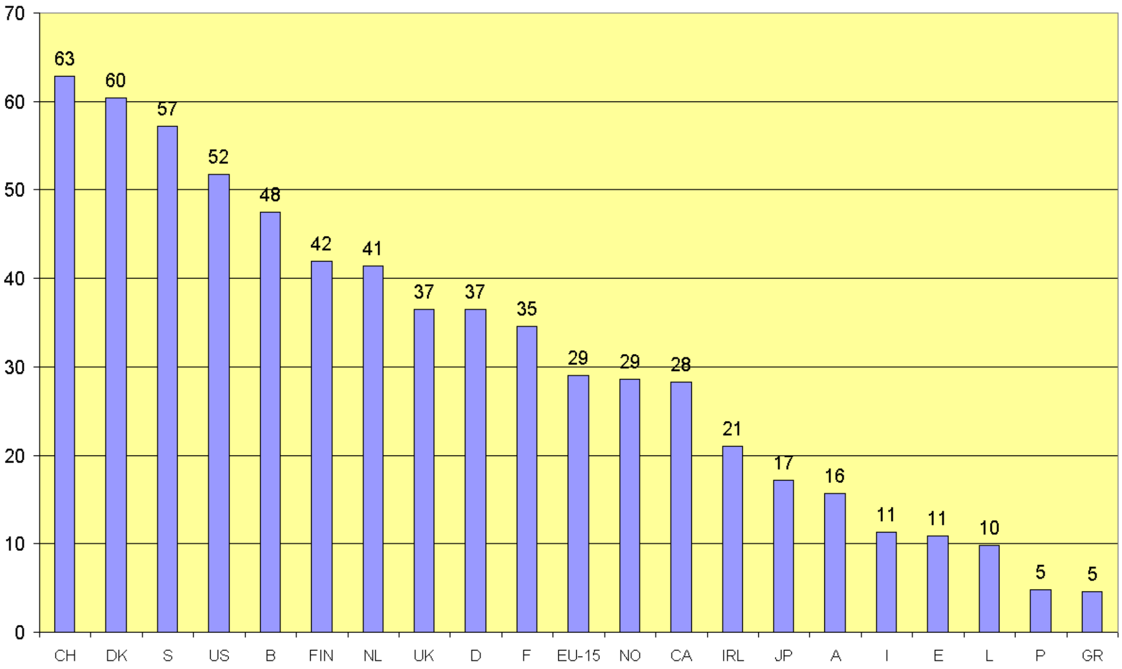
3. In addition to these overall limitations in statistical data, the number of available indicators per country varies greatly across countries, with a median of 10 indicators per country. Therefore, the findings of the BIS should be treated with care and no direct link should be made between BIS performance and the efficiency of national policies. The database of innovation policies under the Trend Chart and the findings of the more specialised EPOHITE project in assessing the effectiveness of national biotechnology policies are very useful in this respect.

4. The BIS data suggest that the Nordic countries (Denmark, Sweden and Finland) are the leading EU performers in biotechnology. Sweden is in a leading position in biotechnology publications, the number of dedicated biotechnology firms and the public knowledge about biotechnology. Denmark is the top performing country in terms of USPTO patents and drug approvals. Other small EU countries are also amongst the leaders. For example Belgium is in a leading position in terms of government R&D spending venture capital, and field trials of GMO crops. Switzerland has also a high level of innovation in biotechnology.

5. The larger countries, Germany, the United Kingdom and France are in the second tier, achieving very similar level of performance. They are relatively strong in eight out of the 11 indicators. The UK is relatively strong in public spending in biotechnology, biotechnology publications and in the number of DBFs. Germany is relatively strong in the number of citations per paper, in biotechnology patent applications at the EPO and in venture capital. France is relative strong in the number of PhD graduates and in field trials in GMO crops.

6. The composite Best Performance Index (BPI) was constructed in order to give an "at a glance" overview of countries according to their general performance in biotechnology. For a given indicator, each country's score is first converted into a standardized value (z score). Each score is then re-scaled to vary within an identical range (0 to 1). The BPI is then the average of the re-scaled z-values and reveals the average relative performance for all the eleven indicators for which data are available.

Best Performance Index in the Biotechnology Innovation Scoreboard



(All BPI means have been multiplied by 100)

7. While the European Union as a whole lags significantly behind the USA, the top performing EU countries have a comparable level of performance. However this result needs to be treated with care as two key indicators for the USA are missing in the above analysis: government spending in biotechnology and venture capital. The inclusion of these may substantially improve the US position.

8. There are some interesting correlations amongst the different indicators of *BIS*. For example government spending in biotechnology is linked positively to the number of citation per paper, USPTO patents, venture capital and the public knowledge about biotechnology. This suggests that countries with a relatively high level of public spending on biotechnology are relatively more successful in terms of knowledge creation and also attract a higher level of venture capital. Additionally public knowledge about biotechnology is linked to seven BIS indicators covering almost all aspects of biotechnology. This is consistent with the view that the public awareness of biotechnology goes hand in hand with the development of biotechnology.

9. Importantly, the BIS offers hints how the EU Member States might mobilise their various strengths jointly in order to increase the overall critical mass of the European Union in biotechnology innovation. This could encourage the development of biotechnology in Europe on a scale comparable to the US.

3. Introduction

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, 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. As the recent communication from the European Commission to the European Parliament, the Council and the Economic and Social Committee, and the Committee of the Regions states:

"*Life Sciences and biotechnology are widely recognised to be, after information technology, the next wave of the knowledge-based economy, creating new opportunities for our societies and economies*" (Life Sciences and Biotechnology – A Strategy for Europe, EC (2002), p. 7).

That communication also outlines a strategy for Europe to develop sustainable and responsible policies to benefit from the positive potential of biotechnology. At the same time Member States have also undertaken a broad range of policies to achieve similar aims.

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 purpose of the ***Biotechnology Innovation Scoreboard*** (***BIS***) is to see the extent to which we can assemble a set of indicators related to one aspect, namely the innovation process in biotechnology. The idea is to gather readily available data from a number of disparate sources to make systematic comparisons of innovative activities of EU countries, and where possible compare them to the US and Japan. A number of recent studies (e.g. Chapter 5 in the EC Competitiveness Report (2001), and OECD (2002a, 2002b) have addressed similar issues at length, and information from these will be utilised here. Hence this report is mainly about assembling and interpreting available data in a readily accessible form similar to the *European Innovation Scoreboard (EIS)*. However given the experimental nature of such thematic scoreboards, the information and analysis is not as systematic and comprehensive as in the *EIS*.

The main contribution of *BIS* is to provide readily available data and indicators on which informed policy debates could be based. It will allow policy makers to relate their existing set of S&T policies to a set of indicators charting innovative activities in biotechnology. It is worth noting that another EU funded project aims at assessing the effectiveness of biotechnology policies in all EU countries (the EPOHITE project)[2]. This project utilises two methods in order to link biotechnology policies to country performance. First, at a macro level the aim is to link gross national indicators (similar to those included in *BIS*) to some policy profiles. Of course the main difficulty is that only a very small number of policies are specifically aimed at a specific area of

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[2] More details on EPOHITE can be found at: http://www.epohite.fhg.de/index.html.

technology, such as biotechnology. Secondly, this project involves a set of interviews with firms and public sector research organisations that are the likely beneficiaries of government policies in the various EU countries. Preliminary EPOHITE results suggest that there are a number of difficulties in relating specific policies to a set of macro indicators. Thus it will be difficult to use *BIS* to assess policy effectiveness. Rather it should be seen as a first step towards a more rigorous assessment of the impact of given policies within the realm of biotechnology.

Section 2 outlines the main characteristics of biotechnology and how these are related to the innovation process. Section 3 discusses the main elements of the scoreboard and the indicators, and section 4 presents the main results.

4. Characteristics of Innovation in Biotechnology

The first step in characterising innovation in biotechnology is a discussion of what the technology entails. Biotechnology can be defined in many ways. For example we could begin by listing the main areas of technology. This would produce a list of various scientific and technical disciplines such as genetic engineering (gene manipulation), cell culture (preparation of given tissues), fermentation techniques, bioinformatics (storage, retrieval and analysis of DNA sequences), etc. Alternatively one could list the various areas of application, such as the preparation of biological material for therapeutic solutions (pharmaceuticals), manipulation of animal (e.g. protein production), plants (e.g. food production) and microorganisms (mainly viruses and bacteria). Such an approach would then result in mapping the national knowledge base and market specialisation of a given set of countries. This is the approach adopted in EC Competitiveness Report (2001) and is suitable for detailed surveys of firms and other institutions involved in the innovation process.

However *BIS* is concerned with providing a set of macro-level indicators that could describe innovative activities within Europe in a summary fashion. Thus the definition of biotechnology used in this report is the one suggested by the OECD working party of National Experts on Science and Technology Indicators (NESTI):

“Biotechnology is the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services.*”(A Statistical Framework for Biotechnology Statistics (OECD, 2002a), p. 4)*

Importance of Public Sector Research

This definition makes it clear that although much has been written about the death of the linear model of innovation, in biotechnology the linear model lives on. Unlike many other technological fields, the main characteristic of the innovation process in biotechnology is that it depends crucially on developments in basic science. One of the implications of this is that publicly funded basic research is vitally important if countries are to succeed in creating new products and new processes. Such research produces specific scientific discoveries leading directly to new products and processes and new instrumentation, as well as trained graduates and researchers.

Collaborations between PSROs and firms

One of the ways in which the scientific knowledge developed by public sector research organisations (universities, government laboratories, etc.) gets translated into new biotechnology related products and services is by means of collaborative activity between such institutions (PSROs) and industrial firms. Most EU countries have a range of policies aimed at encouraging such collaboration, from subsidies for firms to contract out research to PSROs, to providing incentives for supplying consultancy and technical services to industry, to funding for collaborative programmes of research.

Importance of Commercialisation

Ultimately biotechnology is about applying knowledge about living organisms to developing new products and processes. Thus the expected end result is the launching of new medicines (pharmaceuticals), or new productive processes (e.g. fermentation techniques in the food industry), or new crops (seed industry). This may arise from staff of PSROs getting directly involved in commercialisation by launching spin-off firms. Alternatively it may be the result of licensing arrangements between firms and PSROs. Policies to encourage such activities are widespread among EU countries.

Role of large and small firms

Although public research has been widely recognised to be a major factor towards the development of biotechnology, one should not downplay the critical role played by private actors. Because biotechnology is at the forefront of scientific research, researchers have a natural advantage in foreseeing potential applications. A substantial number of dedicated biotechnology firms (DBFs) have been created, many founded by former university scientists. DBFs are deemed to have 3 roles: (i) they play the role of knowledge explorers in an enormously complex space of innovative opportunities; (ii) they transform scientific knowledge into technological and commercial applications; and (iii) they are crucial agents in the division of innovative labour (Saviotti, *et al*., 1996; EC Competitiveness Report, 2001). Initially aiming at replacing incumbents in a particular market, DBFs have met great difficulties in reaching the market and thus in becoming profitable. Hence they have had to re-position themselves as collaborators with larger firms, who have the necessary financial and marketing expertise to commercialise new products. Large firms themselves have invested heavily in the acquisition, integration and exploitation of biotechnology knowledge. In the long run successful developments in biotechnology require a strong partnership between small and large firms.

Contributions to the quality of life

The belief that biotechnology will become the next major wave of economic transformation and development is based on the pervasive character of biotechnology. Biotechnology offers new technological solutions for a variety of industries, i.e. pharmaceuticals, food, agriculture, energy and chemicals. Yet estimations on the extent to which productive activities are affected by biotechnology challenge this view. For example, the Ernst & Young report on the economic contribution of the biotechnology industry to the US Economy estimates that in 1999, the direct and indirect impact of biotechnology amounts to 0.22%, and 0.5% of GDP[3], respectively (Ernst & Young, May 2000). However such estimations miss out what may well turn out to be the most important impacts of biotechnology, i.e. those on the quality of life (nutrition, health and environment). The main challenge is how to measure and assess these.

Role of public perceptions in shaping biotechnology

Biotechnology is the subject of vigorous public debates in a number of different areas: GMO crops, manipulation of human cells and embryos for pharmaceuticals research, human and animal cloning. The rate and direction of research and innovation in these fields is likely to be shaped by public attitudes to these issues. The Eurobarometer report 52.1 “The Europeans and Biotechnology” published by the European Commission (DG Research) in 2000 shows that there exists a positive relationship between knowledge about biotechnology and optimism concerning the benefits that one might expect for future developments in this domain.

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[3] In nominal values, the direct and indirect impacts amount to US$20.2 billion and $46.5 billion.

5. The Biotechnology Innovation Scoreboard (BIS)

BIS adopts the framework used in the *European Innovation Scoreboard (EIS)* in organising the relevant indicators, with some modification. One modification is a new category that includes both Human Resources and Creation of New Biotechnology Knowledge. The other two categories remain the same: Transmission and Application of Biotechnology Knowledge, and Innovation Finance, Output and Markets in Biotechnology. The 19 potential indicators chosen for BIS are identified and briefly discussed in the next three subsections. Annex A presents them in greater detail.

5.1. Human Resources and Creation of New Knowledge

Biotechnology is one of the most “science-intensive” areas of technology. This means that the generation of new knowledge is one of the most crucial aspects of the innovation process. Such new knowledge is firstly incorporated in scientists trained within universities and other public sector institutions. Thus indicator 1.1 (PhD. Graduates in Life Sciences) reflects the capacity of countries to produce a pool of such highly skilled labour.

One way of gauging the priority given by governments to the creation of new knowledge in biotechnology is by examining the amount of government expenditure on research (indicator 1.2). The 1990s have witnessed a substantial increase in the intervention of public authorities in such research. Public programmes are aimed notably at strengthening the national knowledge base and tightening the links between public research bodies and research undertaken in private organisations.

Creation of new knowledge can also be measured using counts of scientific publications. Thus indicator 1.3 captures very well the scientific capacity of a country. A measure of the “quality” of a scientific publication is the number of times it is subsequently cited by other publications (1.4). The other two indicators of knowledge creation are based on patenting at the EPO and at the USPTO (indicator 1.5 and 1.6 respectively).

New knowledge can also be created by private firms engaged in biotechnology related research and BIS includes 3 indicators to capture this process. The first is simply the private investments in biotechnology R&D (indicator 1.7).

5.2. Transmission and Application of New Knowledge in Biotechnology

The Inventory report (1999) has shown that many EU countries have extensive public programmes in biotechnology aimed at supporting knowledge transfer from public research institutes to private organisations, be they large companies or DBFs. This is crucial as successful innovative activities in biotechnology require a network of relationships between heterogeneous actors, ranging from those engaged in upstream research to those involved in downstream development activities (Kenney, 1986; Orsenigo, 1999; Orsenigo, *et al.*, 1998). Thus it is not surprising that a key objective for policy markers in most countries is to encourage research collaborations between publicly funded basic research organisations and private firms. A commonly used incentive relies on allowing scientists to devote a substantive part of their allocated time to private research and consultancy.

In order to capture evidence of such inter-institutional flows of knowledge and expertise, one source of information is the number of collaborative agreements between public research organisations and companies (indicator 2.1). An alternative, more indirect way of capturing such linkages is to count the number of joint publications and joint patents, between public sector scientists and those engaged in R&D and other activities in industry (indicators 2.3 and 2.4).

Another way of transferring knowledge is by encouraging scientists to create firms to exploit research conducted within universities and other public research organisations. As well as providing financial incentives to create new firms, many EU member states have modified the legal status of public researchers to enable this process. Thus the number of university spin-offs is a potential indicator for inclusion in BIS (2.2).

5.3. Innovation finance, outputs and markets

Innovative activities in biotechnology can lead to the introduction of a new product to the market, improvement in some process technologies, or to the introduction of new instrumentation. This section of the scoreboard is concerned with measuring some aspects of this process of commercialisation. In biotechnology creation of new firms (DBFs) remains one of the most effective means of bringing scientific knowledge to the market. The creation of such new firms has also been a policy priority in most European countries, as revealed in the Inventory report (1999). Indicator 3.1 thus counts the number of DBF by country. The availability of venture capital is an essential ingredient for creating new firms. The underlying rationale is that bringing successful products to market in biotechnology is a long term and risky process, requiring substantial funds. The availability of such funds is also perceived to be one of the major reasons for the US lead in the commercialisation of biotechnology. Indicator 3.1 measures the amount of venture capital by country.

One measure of the success of biotechnology is the amount of employment generated. As shown in successive Ernst & Young reports, the creation of new firms in EU has not led to a corresponding growth of employment in DBFs. European DBFs are found significantly smaller to those of the USA. Thus indicator 3.2 compares employment levels associated with biotechnology. Another related measure of economic success is the amount of revenue generated (indicator 3.5). Data availability is problematic for both these indicators as biotechnology related activities are undertaken not only by DBFs (as identified in indicator 3.1) but also by large firms involved in a number of industries such as Pharmaceuticals and Food.

One of the key ways in which biotechnology products may reach the market successfully is through a partnership between DBFs and large firms. Many DBFs initially aimed at replacing incumbent large firms, but they often lacked the necessary financial/managerial/marketing resources to bring major products to market. Large firms typically possess such skills but often do not have in house knowledge capabilities possessed by the DBFs. This situation has led to the latter specialising in niches of knowledge exploration (Pyka and Saviotti, 2002) and setting up collaborations with the former to commercialise innovations. Indicator 3.4 is a measure of this process.

Indicators 3.6 and 3.7 focus on biotechnology outputs in two major applications of biotechnology: pharmaceuticals and GMO crops. Indicator 3.6 focuses on the number of biotechnology drug approvals. Such drug approvals are a rare occurrence, but lead to major pay-offs for the company introducing them. Indicator 3.7 counts the number of field trials of GMO crops being undertaken in each country. National field trial counts for GM organisms provides an indication of national capabilities in GM crop research. Here we use the number of field trials summed over the period 1996-2001. The annual data show that, in Europe, the number of field trials (trial-trait combinations) declined after 1998, possibly due to the effect of the de facto moratorium on the commercialisation of GM crops in July 1998. For example, the total number of EU field trials in 1999-2000 inclusive declined by 33.6% in comparison with the two year period of 1996-1997 before 1998. In comparison, the number of field trials in the US increased by 38.4% over the equivalent time period.

The last indicator (3.8) provides information on public awareness of biotechnology, i.e., it measures the extent to which people have knowledge about biotechnology. Other indicators could have served a similar purpose, for example by focusing on public attitude (expected benefits, acceptation and risk) to the development of biotechnology. Here, it is assumed that greater knowledge leads to greater acceptance of biotechnology.

6. Main Findings

6.1. Availability of Indicators

The complete results for the Biotechnology Innovation Scoreboard are given in Annex C. Table C1 defines each indicator, gives the reference year and provides the data sources. Table C2 provides the actual results in relative terms, for the 15 European countries and for Norway, Switzerland, the USA, Canada and Japan. An important consideration in the construction of BIS is the unavailability of data and Annex B discusses further the way missing values and zero values have been handled in BIS[4].

Table 1. Number of countries per indicator

No	Indicator	Number of Countries	EU countries	Non EU countries
1.1	PhD. Grads in Life Sciences	13	10	3
1.2	Gov. Biotech. R&D	16	14	2
1.3	Biotech Publications	20	15	5
1.4	Citations per publication in Biotech	20	15	5
1.5	Biotech EPO patents	20	15	5
1.6	Biotech USPTO patent applications	20	15	5
1.7	Business Biotech R&D	0	0	0
2.1	Coll. Res. Agreements PSRO-Industry	6	2	4
2.2	University Spin-offs	0	0	0
2.3	Joint Pub. PSROs and Industry	0	0	0
2.4	Joint EPO patents PSROs and Industry	0	0	0
3.1	Dedicated Biotech Firms	17	12	5
3.2	Biotech Employment	0	0	0
3.3	Biotech Venture Capital	16	14	2
3.4	Alliances large firms and DBFs	0	0	0
3.5	Biotech Revenues	0	0	0
3.6	Drug Approvals	10	7	3
3.7	Field Trials in GMO crops	15	14	1
3.8	Average Score Knowledge About Biotech	15	15	0

Table 1 displays the number of observations per indicator (Column 3) and the regional origin (Columns 4 and 5). Information for only 12 of the 19 indicators has been found, reflecting the general scarcity of systematic data in emerging fields such as biotechnology. Moreover data availability is unevenly distributed across the three parts of BIS. In part 1, *Human Resources and Creation of New Knowledge,* we have information on 6 of the 7 indicators. However very little information is available for indicators in part 2, *Transmissions and Application of New Knowledge*. This is surprising given the importance of research collaborations between public and private institutions in the development of biotechnology. The only indicator for which any information was found was the number of collaboration agreements between PSROs and firms (indicator 2.1). Even in this case the data only exist for two EU countries.

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[4] This has important implications for the way in which the EU mean has been calculated as well as BPI.

Thus, indicator (2.1) is not used in the analysis below. In the case of *Innovation finance, outputs and markets* (part 3) data exist for 5 out of the proposed 8 indicators.

The data collection exercise involved a widespread search of empirical literature[5]. This resulted in the identification of a number of indicators that were available at the national level for some countries. Examples are indicators 1.7 (*Business Biotech R&D*), 2.2 (*University Spin-offs*), 3.2 (*Biotech Employment*) and 3.5 (*Biotech Revenues*). These firm-level data are contained in national reports, journal articles or privately held databases. They are often based on differing definitions of what constitutes a biotechnology firm and its subparts, and therefore are not comparable. The result is that very few firm-level indicators are included in BIS. Data for most of the 11 indicators that are included in BIS are either gathered by some government or public body or are available from publicly available databases (e.g. on patents and publications).

Table 2 displays the number of indicators found per country (Column 5) and their related themes (Columns 2 to 4). The median number of available indicators per country is 10, but ranges from 5 (Luxembourg) to 12 (Germany and the UK). There is very little difference in the mean number of indicators found between the EU (with mean 9.9) and non-EU countries (with mean 8.0).

Table 2. Number of indicators per country

	BIS-PART 1	BIS-PART 2	BIS-PART 3	BIS-ALL
Austria	6	0	4	10
Belgium	6	0	5	11
Germany	6	1	5	12
Denmark	6	0	5	11
Spain	6	0	4	10
Finland	6	0	4	10
France	6	0	5	11
Greece	5	0	3	8
Ireland	6	0	5	11
Italy	5	0	4	9
Luxembourg	4	0	1	5
The Netherlands	5	0	5	10
Portugal	5	0	3	8
Sweden	6	0	4	10
United Kingdom	6	1	5	12
Norway	5	0	2	7
Switzerland	6	1	3	10
US	5	1	3	9
Canada	5	1	2	8
Japan	4	1	1	6

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[5] We are most grateful to M. Bernhard Zechendorf and Waldemar Kütt (Scientific Officers at the European Commission – DG Research) who provided us with a substantial support in our search for data.

One of the main difficulties in collecting data and organising *BIS* is that biotechnology does not yet appear in any official statistical classification scheme. This means that we cannot make use of the usual data sources such as CIS and R&D surveys. It also means that a number of important datasets have been collected privately, for example by Ernst & Young or by academic researchers at the University of Sienna (the so-called *BID* database (*Biotechnology Information Databank*)). It is very difficult to check the validity of these databases, as there is very little information on how the data were collected. Additionally although some data for constructing some of the proposed indicators may exist, for example in the *BID* database, they were not available for the construction of BIS.

6.2. Results for European Countries

Table 3 summarizes the main findings of BIS. For each indicator, table 3 provides the EU mean, the first two leading countries in Europe and the coefficient of variation (CV), multiplied by a hundred. The latter informs us on the degree of dispersion throughout EU countries around the mean.

Table 3. Main Findings in the Biotechnology Innovation Scoreboards

No	Indicator	EU mean	EU leaders		CV
1.1	PhD. Grads in Life Sciences pmC	23.8	34.5 F	28.0 IRL	29.3
1.2	Gov. Biotech. R&D % GDP	0.028	0.052 B	0.050 UK	74.7
1.3	Biotech Publications pmC	94.8	195.8 S	192.7 DK	54.1
1.4	Citations per publication in Biotech	7.1	9.5 UK	9.2 D	26.5
1.5	Biotech EPO patent applications pmC	4.5	19.2 NL	17.0 DK	102.0
1.6	Biotech USPTO patents pmC	1.8	12.0 DK	5.0 FIN	129.1
3.1	Dedicated Biotech Firms pmC	5.4	26.5 S	10.3 IRL	92.0
3.3	Biotech Venture Capital % GDP	0.0094	0.0257 B	0.0240 D	122.7
3.6	Drug Approvals pmC	0.114	1.124 DK	0.528 IRL	130.3
3.7	Field Trials in GMO crops per 10^9. GDP in Agr	6.8	19.9 B	12.0 S	128.5
3.8	Average Score Knowledge About Biotech	41.7	58.1 S	57.4 NL	19.2

The Scandinavian countries (Denmark, Sweden and Finland) dominate the EU leadership in biotechnology, as they are among the top two EU leading countries in 5 of the 12 indicators. Sweden is in a leading position in biotechnology publications (1.3), the number of dedicated biotechnology firms (3.1) and the public knowledge about biotechnology (3.8). Denmark is the top performing country in terms of USPTO patents (1.6) and drug approvals (3.6). Other small EU countries are also amongst the leaders. For example Belgium is in a leading position in terms of government R&D spending (1.2) venture capital (3.3), and field trials of GMO crops (3.7).

As for the large EU countries, France has a lead in PhDs in life sciences. Germany is amongst the leaders (citations per publication) and venture capital provision. The UK takes the lead in the quality of its science base and is in second position for government biotechnology funding.

The coefficient of variation (CV) provides a measure of the variation of each indicator across the member states for which data are available. Indicator (3.6) has the largest value for CV, showing a highly skewed distribution of drug approvals across countries. This partly reflects the fact that a large part of research in biotechnology does not necessarily lead to new drugs. Rather, innovation in the bio-pharmaceutical industry follows a Poisson distribution, where a few successes result from a very large number of trials.

Likewise, the higher CV value for indicator (1.6) as compared to that of indicator (1.5) indicates that differences amongst EU countries tend to increase when patenting in the USA. This must be interpreted with care, as it is likely to reflect two different effects. First, it may be the result of the fact that it is harder for EU inventors to patent in the USA (compared to patenting at the EPO), and that this process may be harder for some EU countries than others. The second effect might be due to differences in the nature of the two indicators: indicator (1.5) counts patent *applications* (at the EPO) while indicator (1.6) counts patent *granted* (at the USPTO).

Results are more uniform for knowledge about biotechnology (3.8) and citations per publication in biotechnology (1.4). Comparing CV values between the number of publication per country (indicator 1.3) and the number of citations received (indicator 1.4) shows that differences amongst countries in the volume of scientific activity are greater than those in the quality of that output.

6.3. The BIS Composite Performance Index

A composite Best Performance Index (BPI) was constructed along the lines suggested in the EIS Methodology Report (2002) for TrendChart. Briefly for a given indicator, each country's score is first converted into a standardized value (z score). Each score is then re-scaled to vary within an identical range (0 to 1). The BPI is then the average of the re-scaled z-values and reveals the average relative performance for all the eleven indicators for which data are available. This measure was preferred to the Summary Innovation Index (SII) as proposed in the methodological report of the 2002 scoreboard[6] because the SII measure is very sensitive to cross country differences in the availability of data[7].

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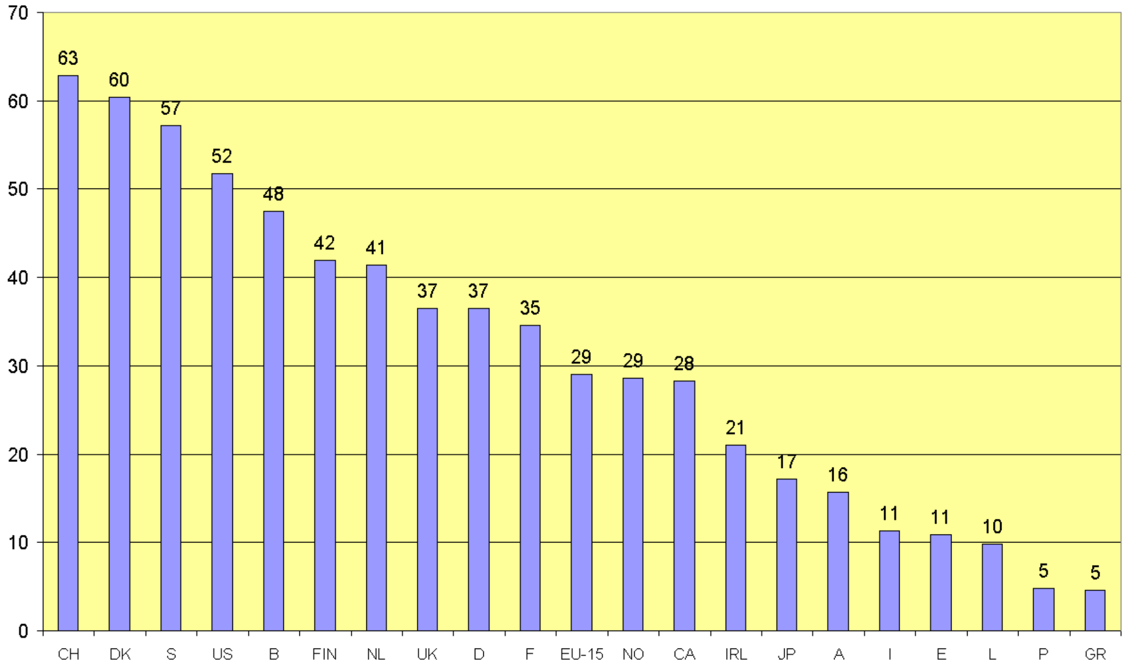
[6] Downloadable from http://trendchart.cordis.lu/Scoreboard2002/html/download_area/download_area.html

[7] The SII is equal to the number of indicators that are 20% above average minus the number of indicators that are 20% below average. While this technique could prove suitable when we have the same number of indicators across countries, its relevance declines sharply when observations are unevenly distributed across countries, as is the case here.

Although the BPI is less sensitive to the uneven distribution of indicators across countries than the SII, the results should still be interpreted with care. The number of indicators per country ranges from 5 (Luxembourg) to 11 (Germany and the UK). Thus for the latter countries the BPI is a fairly good reflection of performance in a wide range of innovative activities within biotechnology. However the same cannot be said for Luxembourg. Interestingly, the correlation coefficient between the number of indicators per country and the BPI is 0.67 (p-value = 0.009) for the European countries[8].

Graph 1. Best Performance Index in the Biotechnology Innovation Scoreboard



(All BPI means have been multiplied by 100)

Graph 1 shows that Denmark, Sweden and Belgium are leaders in innovation in biotechnology within the EU. The larger EU countries such as Germany, the UK and France are a part of the second group of countries around the median (• 30). These results reflect two different patterns of biotechnology development in the EU. The first group could be labelled specialised biotechnology countries, where innovative activities are of a smaller scale, and in niche areas but which enables these countries to be world leaders. The second group of countries has a high volume of activity spread across a range of biotechnology areas. This is quite important insofar as the development of biotechnology is increasingly reliant on the availability of heavy equipment and on large-scale research programs, be they public (as is the case for most countries in Europe), or private (as in the case in large firms). The remaining countries

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[8] This suggests that better performing countries may monitor their biotechnology related activities more than others.

reflect heterogeneous country performances. The Netherlands and Finland perform well, while there is substantial gap that separates Southern European countries from the better performing groups.

Graph 1 displays the BPI of other non-EU countries. It illustrates the significant lead of the USA over the European Union. The position of the USA is not surprising, as it is widely acknowledged to be the leader in biotechnology innovation, with considerable first-mover advantages. Moreover the BPI of the USA is likely to be underestimated due to the unavailability of two key indicators, namely government biotechnology R&D spending (1.2) and biotechnology venture capital (3.3). The inclusion of these indicators would positively affect the overall position of the US.

Graph 1 also shows that Switzerland has a higher BPI than all European countries. The case of Switzerland is interesting, as it is a country where the development of biotechnology is tightly linked to the translation of biotechnology knowledge into new products, mainly in the pharmaceutical industry. The performance of Canada and Norway conforms to that of the EU-15, while that of Japan appears to lag significantly behind.

6.4. National Strengths and Weaknesses

Table 5 identifies the countries' main strengths and weaknesses across the 11 indicators. These are limited to the first three indicators that are 25% above or below the EU mean. The countries are ranked according to their BPI.

The table shows that only the USA and Sweden do not have any major relative weaknesses while Austria, Italy, Spain, Portugal and Greece do not have any major relative strength. All other countries exhibit both heterogeneous strengths and weaknesses, though their number varies consistently with their rank in the BPI.

Not surprisingly, most countries with major relative strengths have few major weaknesses and conversely, most countries with major relative weaknesses have few major strengths. This is quite consistent with the idea that the development of biotechnology requires investment in many different areas, ranging from human resources and the creation of new knowledge to the creation of new firms and markets. Moreover, the fact that countries cannot bypass the general path from mere knowledge to markets may prove difficult for countries that lag behind. It is quite likely that these countries have not only to cope with low resources in biotechnology in some given areas, but are also facing more general shortcomings in public and private infrastructures.

Table 5. Strengths and Weaknesses in the Biotechnology Innovation Scoreboard

Country	Major Relative Strengths	Major Relative Weaknesses
Switzerland	1.3 Biotech Publications; 1.5 Biotech EPO patents Appl.; 3.6 Drug Approvals	1.2 Gov. Biotech. R&D; 3.3 Biotech VC
Denmark	1.5 Biotech EPO patents Appl.; 1.6 Biotech USPTO patents; 3.6 Drug Approvals	1.2 Gov. Biotech. R&D
Sweden	1.3 Biotech Publications; 1.6 Biotech USPTO patents; 3.1 DBFs	None
US	1.6 Biotech USPTO patents; 3.6 Drug Approvals; 3.7 Field Trials in GMO crops	None
Belgium	1.5 Biotech EPO patents Appl.; 3.3 Biotech VC; 3.7 Field Trials in GMO crops	1.1 PhD. Grads in LF
Finland	1.2 Gov. Biotech. R&D; 1.6 Biotech USPTO patents; 3.1 DBFs	1.5 Biotech EPO patents Appl.; 3.3 Biotech VC; 3.7 Field Trials in GMO crops
The Netherlands	1.3 Biotech Publications; 1.5 Biotech EPO patents Appl.; 1.6 Biotech USPTO patents	1.2 Gov. Biotech. R&D; 3.3 Biotech VC; 3.7 Field Trials in GMO crops
United Kingdom	1.2 Gov. Biotech. R&D; 1.3 Biotech Publications; 3.1 DBFs	3.3 Biotech VC
Germany	1.4 Citations per publication; 1.5 Biotech EPO patents Appl.; 3.3 Biotech VC	3.6 Drug Approvals; 3.7 Field Trials in GMO crops
France	1.1 PhD. Grads in LF; 3.7 Field Trials in GMO crops	3.3 Biotech VC
Norway	3.1 DBFs	1.5 Biotech EPO patents Appl.; 3.3 Biotech VC
Canada	1.4 Citations per publication; 1.6 Biotech USPTO patents; 3.1 DBFs	1.1 PhD. Grads in LF; 3.6 Drug Approvals
Ireland	3.1 DBFs; 3.6 Drug Approvals	1.6 Biotech USPTO patents; 3.3 Biotech VC; 3.7 Field Trials in GMO crops
Japan	1.6 Biotech USPTO patents	1.3 Biotech Publications; 1.5 Biotech EPO patents Appl.; 3.1 DBFs
Austria	None	1.2 Gov. Biotech. R&D; 3.1 DBFs; 3.7 Field Trials in GMO crops
Italy	None	1.2 Gov. Biotech. R&D; 1.5 Biotech EPO patents Appl.; 3.3 Biotech VC
Spain	None	1.2 Gov. Biotech. R&D; 1.5 Biotech EPO patents Appl.; 3.3 Biotech VC
Luxemburg	None	1.3 Biotech Publications; 1.5 Biotech EPO patents Appl.; 1.6 Biotech USPTO patents
Portugal	None	1.5 Biotech EPO patents Appl.; 1.6 Biotech USPTO patents; 3.3 Biotech VC
Greece	None	1.5 Biotech EPO patents Appl.; 1.6 Biotech USPTO patents; 3.3 Biotech VC

Table 5 also shows that government policies can have a major role in alleviating some of the major weaknesses of the leading EU countries. In Denmark and Netherlands these relate to government funding of biotechnology related R&D, and in Belgium and Finland the number of PhDs is a major concern.

Turning to the 3 larger countries we see that together they are relatively strong in 8 out of the 11 indicators. The UK is relatively strong in public spending in biotechnology (indicator 1.2), biotechnology publications (indicator 1.3) and in the number of DBFs (indicator 3.1). Germany is relatively strong in the number of citations per paper (indicator 1.4), in biotechnology patent applications at the EPO (indicator 1.5) and in venture capital (indicator 3.3). France is relative strong in the number of PhD graduates (1.1) and in field trials in GMO crops (indicator 3.7). Importantly, the joint mobilisation of these strengths may provide a minimal critical mass in Europe that could encourage the development of biotechnology on a scale comparable to the US.

6.5. Correlations

We conducted an analysis of the 11 indicators of the biotechnology innovation scoreboard for which data are available in order to detect correlations amongst indicators and with BPI. The aim of this analysis is to provide a picture of the links within the BIS, and at the same time to look at some of the relationships amongst different aspects of the innovation process within biotechnology. Table 6 displays the Spearman correlation coefficients[9], their associated p-values and the number of observations. All correlations that are significant at 5% level are highlighted.

An examination of the correlations amongst the 11 indictors shows that 25 out of 55 correlation coefficients are significant. Most indicators in part 1 (*Human Resources and Creation of New Knowledge*), with the exception of 1.1, are highly correlated amongst each other. This suggests that countries that perform well in terms of the volume and quality of the science base are also likely to perform well in terms patenting. This shows that both these set of activities are linked to some common underlying structure, which is likely to be related to public sector research activities. This result implies that public programmes aimed at improving knowledge creation in various different forms may follow common or complementarity channels. Conversely, indicators in part 3 (*Innovation finance, outputs and markets*), with the exception of 3.8, have very few significant correlations amongst each other. There is a positive correlation between the venture capital (3.3) and the number of field trials (3.7), though the exact nature of the relationship between these two indicators is not clear. This result suggests that each indicator in this part is capturing a different aspect of innovative activity.

From a policy perspective it is interesting to note that indicator 1.2 on government spending in biotechnology is linked positively to citations (indicators 1.4), USPTO patents (indicator 1.6), venture capital (indicator 3.3) and the public knowledge about biotechnology (3.8). These results suggest that the countries with a relatively high level of the public spending on biotechnology are relatively more successful in terms of knowledge creation and also attract a higher level of venture capital. However it is difficult to argue on the basis of these correlations that government policies are highly effective in stimulating innovative activities in biotechnology.

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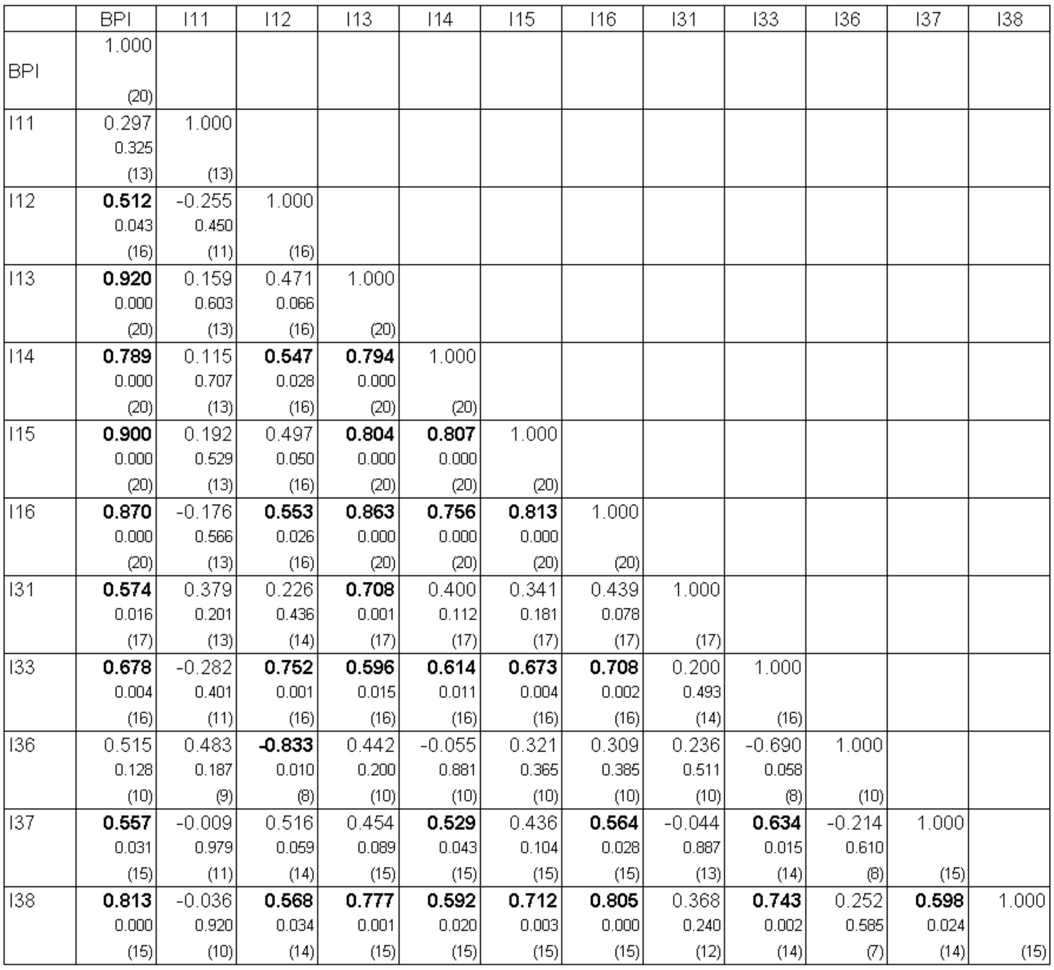
[9] The Spearman rank correlation is a non-parametric measure of correlation between two ordinal variables. The values of each of the variables are ranked from smallest to largest, i.e. all countries are ranked, and a Pearson correlation coefficient is computed on the ranks. The advantage in using the Spearman calculation is that it does not assume normality in the distribution of the variables, an assumption that is likely to be violated here when considering the number of observations at hand.

Table 6. Correlations amongst BIS indicators (*p-values in Italics*)



	BPI	I11	I12	I13	I14	I15	I16	I31	I33	I36	I37	I38
BPI	1.000 (20)											
I11	0.297 0.325 (13)	1.000 (13)										
I12	**0.512** 0.043 (16)	-0.255 0.450 (11)	1.000 (16)									
I13	**0.920** 0.000 (20)	0.159 0.603 (13)	0.471 0.066 (16)	1.000 (20)								
I14	**0.789** 0.000 (20)	0.115 0.707 (13)	**0.547** 0.028 (16)	**0.794** 0.000 (20)	1.000 (20)							
I15	**0.900** 0.000 (20)	0.192 0.529 (13)	0.497 0.050 (16)	**0.804** 0.000 (20)	**0.807** 0.000 (20)	1.000 (20)						
I16	**0.870** 0.000 (20)	-0.176 0.566 (13)	**0.553** 0.026 (16)	**0.863** 0.000 (20)	**0.756** 0.000 (20)	**0.813** 0.000 (20)	1.000 (20)					
I31	**0.574** 0.016 (17)	0.379 0.201 (13)	0.226 0.436 (14)	**0.708** 0.001 (17)	0.400 0.112 (17)	0.341 0.181 (17)	0.439 0.078 (17)	1.000 (17)				
I33	**0.678** 0.004 (16)	-0.282 0.401 (11)	**0.752** 0.001 (16)	**0.596** 0.015 (16)	**0.614** 0.011 (16)	**0.673** 0.004 (16)	**0.708** 0.002 (16)	0.200 0.493 (14)	1.000 (16)			
I36	0.515 0.128 (10)	0.483 0.187 (9)	**-0.833** 0.010 (8)	0.442 0.200 (10)	-0.055 0.881 (10)	0.321 0.365 (10)	0.309 0.385 (10)	0.236 0.511 (10)	-0.690 0.058 (8)	1.000 (10)		
I37	**0.557** 0.031 (15)	-0.009 0.979 (11)	0.516 0.059 (14)	0.454 0.089 (15)	**0.529** 0.043 (15)	0.436 0.104 (15)	**0.564** 0.028 (15)	-0.044 0.887 (13)	**0.634** 0.015 (14)	-0.214 0.610 (8)	1.000 (15)	
I38	**0.813** 0.000 (15)	-0.036 0.920 (10)	**0.568** 0.034 (14)	**0.777** 0.001 (15)	**0.592** 0.020 (15)	**0.712** 0.003 (15)	**0.805** 0.000 (15)	0.368 0.240 (12)	**0.743** 0.002 (14)	0.252 0.585 (7)	**0.598** 0.024 (14)	1.000 (15)

There are a number of reasons for this. Firstly, such an argument ignores the inherent time lag between the actual implementation of biotechnology policies and their end results. Innovation in biotechnology is a time consuming process with a high probability of failure. Secondly government programmes have a variety of aims. For example many programmes are aimed at promoting collaborations between biotechnology actors (PSROs, DBFs, large firms), but, as discussed in section 4.1, indicators related to such collaborative activities are not available. Others programmes have been directed towards the creation of DBFs, but Table 6 shows that there is no correlation between relatively high levels of government spending (1.2) and the number of DBFs (3.1).

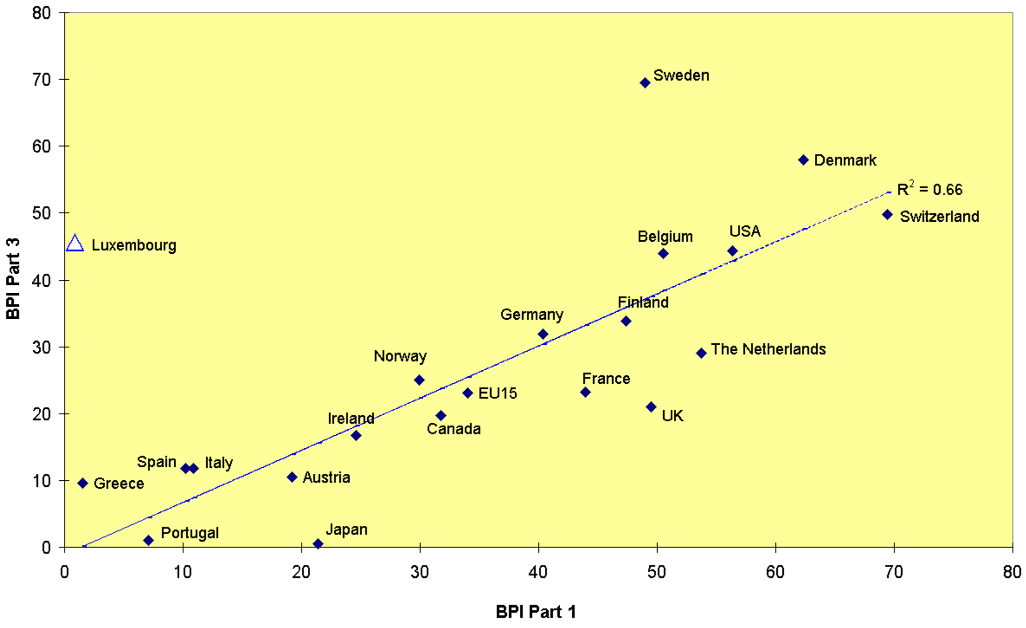
There is a puzzle regarding the lack of relationship between the number of PhD graduate students (1.1) and other indicators. This suggests that a country’s performance in many aspects of innovative activities in biotechnology is not correlated with its success in producing a relatively high volume of qualified scientists. This supports some analysts who have repeatedly warned that the production of high skilled labour in

Life Sciences may prove dramatic for cohorts of young researchers who face little job opportunities that correspond to their educational background[10] (Dany and Mangematin, 2001; Robin, 2003).

Meanwhile, indicator 3.8 on public knowledge about biotechnology is linked to seven BIS indicators, ranging throughout almost all aspect of biotechnology. This is consistent with the view that the public awareness of biotechnology goes hand in hand with the development of biotechnology. However, considering the statistical independence (r = -0.036) between indicators 1.1 and 3.8, it appears that such general knowledge is not channelled through the educational system in Life Sciences. It is quite likely that it follows other routes.

Indicator 3.3 on venture capital is significantly correlated with seven other indicators, ranging across all aspects of BIS-part 1 (except indicator 1.1) and only some aspects of BIS-part 3. This suggests that private venture capital investment in biotechnology is relatively more attracted to EU member states with a strong overall knowledge base and where public funding is rather high. However there is an absence of correlation between venture capital and the number of firms (indicator 3.1). This is surprising as the (lack of) availability of venture capital has often been cited as seriously hampering firm creation in Europe. The result of our analysis suggests that countries with a high level of firm creation are not necessarily those with readily available venture capital. One explanation could be that venture capital investments are directed more at sustaining the growth rate of existing firms than at investing in new companies.

Graph 2. The relationship between BPI for Part 1 and BPI for Part 3 indicators



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[10] In other words more does not imply better. More PhDs in life Sciences may well lead to an increase in unemployment related to this discipline.

Nine of the 11 indicators are significantly linked to the overall BPI. Indicators on the number of PhD graduates (1.1) and on drug approvals (3.6) do not contribute significantly to the overall performance of a country. Additionally, the relationship between BIS-Part 1 and BIS Part-3 is illustrated in graph 2. Graph 2 plots each country according to its BPIs calculated for part 1 and part 3 respectively. The R^2 between part 1 and part 3 is 0.66 when excluding Luxembourg, dropping to 0.41 when including it. This result is consistent with the above discussion that country performance in knowledge creation is related to the performance in innovation finance, output and markets.

7. Conclusions

Biotechnology is often referred to as the prime mover in the next major wave of technological change, with profound effects on economic growth and structural change. It is seen as a major opportunity to improve the quality of life by developing new products in the pharmaceutical and agro-food industries, while bringing new technical solutions for problems related to the environment. The *Biotechnology Innovation Scoreboard* (BIS) assembles 11 indicators to examine the performance of EU countries in this technology.

The analysis shows that the smaller European countries, i.e. Denmark, Sweden, and Belgium, and to a lesser extent Finland and the Netherlands, are the leaders within the EU. The Nordic countries are also leaders in terms of overall innovation performance within Europe, as shown in the *Trend Chart European Innovation Scoreboard (EIS)*. At the same time Switzerland has a high level of innovation in biotechnology. The larger countries, Germany, the United Kingdom and France are in the second tier, achieving very similar level of performance. There is a substantial gap between these and the remaining EU countries.

Further while the European Union as a whole lags significantly behind the USA, the top performing EU countries have a comparable level of performance. However this result needs to be treated with care as two key indicators for the USA are missing in the above analysis: government spending in biotechnology and venture capital. The inclusion of these may substantially improve the US position.

These problems highlight the main difficulty in constructing this Scoreboard, namely the lack of publicly available systematic data. Thus we know little about the level of R&D, employment and output associated with biotechnology. Moreover there is no information on one of the key aspects of innovative activity in this area: collaboration between public and private organisations. Finally for many of the indicators in BIS there are great difficulties in obtaining data over time, making trend analysis impossible.

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Annex A. Indicator definitions

1.1 PhD. Graduates in Life Sciences Per Million Capita

Biotechnology is a science-based activity with a strong reliance on highly skilled labour. This indictor reflects the capacity of a country to produce a pool of such highly skilled labour. Of course not all PhD's will be eventually be employed in biotechnology related activities, and some may end up working outside the country in which they trained. Alternative indicators could be based on first degrees or Masters in Life Sciences. However the proportion of graduates ending up doing biotechnology related work would be even less than above. The data will be those of Education online database (EOL- OECD). The database is constructed from data as delivered by OECD countries. However the definition of what constitutes Life Sciences is not standardised, which in turn may yield artificial differences amongst countries (e.g. see Italy).

1.2 Government Biotechnology R&D Expenditures As Percentage of GDP

This indicator is the share of Government R&D expenditures that are devoted to biotechnology, as percentage of GDP. This provides an overall picture of the priority given by governments to the creation if new knowledge in biotechnology. Data collected for the EC funded project, *Inventory of Public Biotechnology Programmes in Europe (INV)* are used. The aim of the project was to collect detailed information on government funding of biotechnology related research across EU countries. The Inventory project was a unique attempt at quantifying public R&D expenditures in biotechnology. However some of the inter-country differences might reflect differences in the degree of difficulty in gathering the information. The data are only available for the period 1994-1998 as a whole (i.e. there are no annual data). The denominator thus sums the country's GDP for the same years.

1.3 Biotechnology Publications Per Million Capita

This indicator counts the number of biotechnology publication per million capita. Country level data are based on the institutional address of one of the authors of the publication. The indicator provides an overall picture of scientific output of a country. Institute for Scientific Information's (ISI) *National Science Indicators Database.* This contains information by scientific field, country and over time (1981-2000). There are a number of scientific fields that are relevant to biotechnology, namely Biochemistry & Biophysics, Biology, Biotechnology & Applied Microbiology, Cell & Developmental Biology, Experimental Biology, Molecular Biology & Genetics, Microbiology.

1.4 Citations Per Publication in Biotechnology

The mean number of citation per publication, i.e., the ratio of total citations received, over the sum of biotechnology publications for a given year (or a set of years) aims at grasping the quality of biotechnology research for a given country. Thus, citations are used as a measure of the impact of scientific output. The data source is identical to those of indicator (1.3). The measure developed here takes into account the time truncation inherent in citation data. Because the number of citations received by a publication increases over time, it is important not to focus simply on the last year for which the data is available, i.e. 2000. Here we use the average number of citations per publications produced between 1996 and 2000.

1.5 Biotechnology EPO Patents Applications Per Million Capita

The indicator is the number of patent applications at the EPO in biotechnology per million of population. The data are aggregated according to the country address of the inventor. This is an indicator of inventive activity within a country. Biotechnology is an area with a high propensity to protect innovations by means of patenting. The European Patent Office provides the data. The following IPC codes are included in the analysis. C12M (apparatus for enzymology or microbiology); C12N (micro-organisms or enzymes; compositions thereof), C12P (fermentation or enzyme-using processes to synthesise a desired chemical compound or composition or to separate optical isomers from a racemic mixture), C12Q (measuring or testing processes involving enzymes or micro-organisms), C12S (processes using enzymes or micro-organisms to liberate, separate or purify a pre-existing compound or composition).

1.6 Biotechnology USPTO Patents Per Million Capita

The indicator is the number of patents granted by USPTO in biotechnology per million of population. The data are aggregated according to the country address of the inventor. As the US is perceived to be the leader in biotechnology related research, there are strong incentives to protect innovations in that market. The data are provided by USPTO. The analysis is based on class 435 of the USPTO classification system: Molecular biology and microbiology, in 2000. SPRU database.

1.7 Biotechnology Business R&D Expenditures As Percentage of GDP

This indicator is the amount of R&D funded and performed by business firms, as percentage of GDP. It provides an overall picture of biotechnology effort by the private businesses. *Data Source:* At present these data are not available. However they may be available in the future through the surveys of biotechnology companies currently being undertaken, co-ordinated by the OECD. As such, it is not in a usable or reliable format for BIS.

2.1 Collaborative Research Agreements Between PSROs and Industry per Million Capita.

Count of the number of technology related agreements involving at least one Public Sector Research Organisation (PSRO) and one firm, divided by million of population. The indicator provides information on extent of linkages between public research organisations and private firms. Such linkages are crucial to the commercialisation of biotechnology. The information used here is contained in an OECD publication, *Economic Aspects of Biotechnologies Related to Human Health* (part II, 1998, p. 103). However, the OECD document refers to information from two independent publications: The New scientist (2 March, 1996) and Nature Biotechnology, 14 April 1996). These figures refer to year 1994. A substantial effort in building more accurate data is needed, given the persistence of collaborations agreements between public and private actors. Latest information maybe available in the *BID* database (Biotechnology Industry Database) located at the University of Siena. See the recent DG Enterprise report on *Innovation and Competitiveness in European Biotechnology (Enterprise Paper no. 7)*, but the data are not publicly available.

2.2 University Spin-offs, per million capita.

This indicator counts the number of university spin-offs in biotechnology per capita. The indicator directly measures the commercialisation of university knowledge. It is often argued that the success of US in biotechnology is the result of a large number of spin-offs coming out of research conducted in US Universities. Such data are not available at present.

2.3 Joint Scientific Publications Between PSROs and Industry Per Million Capita.

This indicator counts the number biotechnology publication involving at least one PSRO and one firm, divided by millions of population. This is a measure of research collaboration between PSROs and industry. Such data are not available at present.

2.4 Joint EPO Patents Applications Between PSROs and Industry Per Million Capita

This indicator counts the number of EPO patent applications assigned to at least one PSRO and one firm, divided by millions of population. This is one of the results from research collaboration between PSROs and industry. Such data are not available at present.

3.1 Dedicated Biotechnology Firms (DBFs), Per Million Capita

This indicator counts the number of dedicated biotechnology firms, per capita. DBFs are deemed to have 3 roles: (i) they play the role of knowledge explorers in an enormously complex space of innovative opportunities; (ii) they transform scientific knowledge into technological and commercial applications; and (iii) they are crucial agents in the division of innovative labour. There are two main sources of systematic data: Ernst & Young and the *BID* database (University of Siena). BIS uses the *BID* as published in the Competitiveness Report. The main problem with both these databases is that very little is known about how the data are collected and hence their reliability.

3.2 Biotechnology Employment Per Million Capita

This indicator counts the number of employees in DBFs per million capita. It is not enough just to count the number of DBFs, we need some indication of their economic importance. An alternative could be the mean size of DBFs by country, with the underlying assumption that bigger DBFs have a higher chance of survival and growth and are a sign of vigorous biotechnology industry. Such data are not available on a systematic basis.

3.3 Biotechnology Venture Capital As Percentage of GDP

The amount of venture capital raised in biotechnology is expressed as a proportion of GDP. The availability of venture capital is widely recognised as an essential ingredient of entrepreneurship in biotechnology. The underlying rationale is that bringing successful products to market in biotechnology is a long term and risky process, requiring substantial funds. The availability of such funds is also perceived to be one of the major reasons for the US lead in the commercialisation of biotechnology. The European Venture Capital Association (EVCA) provides such data with a breakdown into several industries or areas. Biotechnology is defined as: Agricultural and animal biotechnology (e.g. plant diagnostics); Industrial biotechnology (e.g. derived chemicals); Biotechnology related research and production equipment. EVCA distinguish medical and health care venture capital to biotechnology venture capital, though the definition of the health related venture capital could well comprise some pharmaceutical research using some biotechnology (see EVCA, pp. 305-306).

3.4 Alliances Between Large Firms and DBFs Per Million Capita

This indicator counts the number of biotechnology related strategic alliances between DBFs and large firms divided by millions population. One of the key ways in which biotechnology products may reach the market successfully is through a partnership between DBFs and large firms. The former often lack the necessary financial/managerial/marketing resources, which can be provided by large firms. Data are not available but they possibly exist in the *BID* database from the University of Siena.

3.5 Biotechnology Revenues As Percentage of GDP

Revenues derived from commercial activities involving biotechnology (as percentage of GDP) provide an overall picture of biotechnology activities other than pure knowledge creation. As such, it is much closer to market that other indicators traditionally concentrating on R&D. Data are not available.

3.6 Drug Approvals PmC

This indicator counts the number of biotech drugs approved between 1980 and September 2002 divided by population. The indicator provides an overall picture of biotechnology innovation by the private businesses. The data are provided by MERIT.

Biotechnology drugs are difficult to define, since they can include small chemical drugs that have been in production for years but for which there is a recent stereoisomer form produced using GM microorganisms. We exclude vaccines, rattlesnake anti-venom, topical drugs, and diagnostics. Stereoisomers are included when the drug is a large molecule, but not if it is a stereoisomer of a small chemical drug. For example, we do not include Fluoxetine (Prozac) because first, there are alternative methods of manufacturing stereoisomers that are increasingly used and that may replace biotechnology and secondly, the development of the drug did not depend on biotechnology. Importantly, these numbers include double counts, for instance, if a drug has been jointly developed by a US and a French firm the drug is assigned both to the United States and to France. In total, 18 out of 124 drugs have been developed jointly by two countries. Alternatively, Ernst & Young figures can be found in the global biotechnology report 2002. Yet we remain sceptical about their data as they may include drugs, which are not biotech drugs. Moreover their data only includes drugs from public companies.

3.7 Field Trials of GMO Crops Per Billion GDP in Agriculture

This indicator is based on the number of field trials of GMO crops being undertaken in each country between January 1 1996 and December 31 2001. National field trial counts for GM organisms provides an indication of national capabilities in GM crop research. It is normalised using GDP in Agriculture, thus taking account of differences in natural endowments: not all countries in Europe can grow most crops - Norway, Sweden and Finland are severely disadvantaged, Denmark moderately so, in comparison with France, Spain and Italy.

The indicator is not perfect because some trials are conducted by national subsidiaries of multinational seed firms. Very little expertise in GM is needed for a Spanish subsidiary to conduct a field trial of tomatoes. It would be possible to limit the indicator to GM trials counted by domestic firms, but this would create the opposite error, by excluding subsidiaries that do have the capabilities to conduct GM research. GM field trial data are available for both the US and Europe from 1990 onwards. In order to limit the data to a more recent period, the count includes only field trial applications that were granted between January 1 1996 and April 2001 for Europe, and for US trials between January 1, 1996 and December 31, 2001. European data for the whole of 2001 were not available, but very few trials were conducted in Europe at this time due to the moratorium. The data are provided by MERIT, with the following sources: For EU data: JRC (Joint Research Council), Summary Notification Information Format (SNIF) database, European Commission; For the US: Animal and Plant Health Inspection Service (APHIS) of the USDA.

3.8 Public Understanding of Biotechnology

The average score on biotechnology knowledge as assessed in EUROBAROMETER 5.2 (2000) is expressed in percentage of correct answers. The indicator is based on the study undertaken on behalf of the DG Research in November and December 1999. It follows similar studies in 1993 and 1996 and looks at the knowledge of Europeans to various and general problems connected with biotechnology. Importantly, 16,082 people were asked to answer true and false to 12 statements related to biology, genetics and biotechnology. Out of these 12 questions, we selected 6 questions that we view as concerning the core of biotechnology knowledge, usage, processes or products. These are:

1. Ordinary tomatoes do not contain genes while genetically modified tomatoes do.
2. The cloning of living things produces exactly identical offspring.
3. By eating a genetically modified fruit, a person’s genes could also become modified.
4. Genetically modified animals are always bigger than ordinary ones.
5. More than half of the human genes are identical to those of the chimpanzees.
6. It is impossible to transfer animal genes into plants.

The set of questions that were withdrawn from the original questionnaire is:

7. There are bacteria, which live from wastewater.
8. It is the father’s genes that determine whether a child is a girl.
9. Yeast for brewing beer consists of living organisms.
10. It is possible to find out in the first few months of pregnancy whether a child will have Down’s syndrome.
11. Criminal tendencies are mainly genetically inherited.
12. Musical abilities are mainly learned.

The sample was designed to be representative of the population of 15 years of age or more. The average response provides us with a picture of the diffusion of general biotechnology knowledge to the public. The underlying hypothesis is that the greater the amount of general knowledge the easier it is for biotechnology related products to succeed on the market. The EU weighted average has been calculated by using the share of each country in the total EU population. The data are provided by the European Commission, DG Research.

Annex B. The Difference between Missing and Zero Values

An important question that has arisen in the building of BIS is the treatment of missing and zero values. Missing values are those for which no information was found in some EU countries[11]. Zero values are those values for which the information has been found to be 0 for a given indicator and for a given country. For example, count data such as publications (indicator 1.3), citations (1.4), patent applications (indicator 1.5) or patent granted (indicator 1.6) per country is likely to be zero in some countries, while for some others it is significantly different than zero. This latter case provides substantial information on the performance of a given country, and thus zero values are treated as such.

Table B1. The treatment of zero values

No	Indicator	Zero Treatment
1.1	Ph.D. Grads in Life Sciences	Excluded
1.2	Gov. Biotech. R&D	Excluded
1.3	Biotech Publications	Included
1.4	Citations per publication in Biotech	Included
1.5	Biotech EPO patents	Included
1.6	Biotech USPTO patent applications	Included
1.7	Business Biotech R&D	Excluded
2.1	Coll. Res. Agreements PSRO-Industry	Excluded
2.2	University Spin-offs	-
2.3	Joint Pub. PSROs and Industry	-
2.4	Joint EPO patents PSROs and Industry	-
3.1	Dedicated Biotech Firms	Excluded
3.2	Biotech Employment	-
3.3	Biotech Venture Capital	Included
3.4	Alliances large firms and DBFs	-
3.5	Biotech Revenues	-
3.6	Drug Approvals	Excluded
3.7	Field Trials in GMO crops	Excluded
3.8	Average Score Knowledge About Biotech	Does not apply

In some cases, it is not clear whether the missing information indicates missing values or zero outcomes. For example, it has been found that some countries do not have dedicated biotechnology firms. However, the basis on which the count has been made remains quite uncertain. Thus the general position adopted in the building of BIS is the following: in cases such as publication and patent data, the quality of the assessment by regulatory offices or public association (e.g. EVCA) allows the inclusion of zero values. In other cases, it has been chosen to treat zero values as missing data. This choice has consequences in the calculation of the country performance and the EU average. Table 3 displays detailed information on the treatment of zero values.

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[11] When no information is found for all countries, the indicator is *de facto* screened out of BIS, as shown in table 1.

Annex C. Biotechnology Innovation Scoreboard. Data definitions, sources and results

In table C1, details on data sources and definition is provided. Table C2 provides the Biotechnology Innovation Scoreboard. Graphs C1 to C3.8 display the results for each indicator, by ranking the countries according to their performance. When the EU mean has been calculated on only a part of European countries, it is referred to as the EU. When it has been computed on all 15 member-states, the EU is referred to as the EU-15. The graphs are numbered accordingly to their BIS number.

Table C1. Data definition and Sources

No	Indicator	Year	Observations
PART 1. Human Resources and Creation of New Knowledge			
1.1	PhD. Grads in Life Sciences pmC	1999	OECD: Education On Line Database. Belgium: Flemish Community only. Italy: PhD graduates students included in other categories.
1.2	Gov. Biotech. R&D % GDP	1994-98	European Commission (1999). Inventory of public Biotechnology R&D programmes in Europe.
1.3	Biotech Publications pmC	2000	SPRU
1.4	Citations per publication in Biotech	1996-00	SPRU. Sums of Citations 1996-2000 over sums of publications 1996-2000.
1.5	Biotech EPO patents applications pmC	2001	European Patent Office.
1.6	Biotech USPTO patent pmC	2000	SPRU
1.7	Business Biotech R&D % GDP	NA	Existing figures not Reliable.
PART 2. Transmissions and Application of New Knowledge in Biotechnology			
2.1	Coll. Res. Agreements PSRO-Industry pmC	1994	OECD: Economic Aspects of Biotechnologies Related to Human Health, part II, 1998, p. 103
2.2	University Spin-offs pmC	NA	NA
2.3	Joint Pub. PSROs and Industry pmC	NA	NA
2.4	Joint EPO patents PSROs and Industry pmC	NA	NA
PART 3. Innovation finance, outputs and markets			
3.1	Dedicated Biotech Firms pmC	2000	BID (Biotechnology Information Databank). University of Siena. For other countries: E&Y (USA), JBA (Japan) and Statistics Canada (Canada).
3.2	Biotech Employment pmC	NA	Existing figures not Reliable.
3.3	Biotech Venture Capital % GDP	2001	EVCA
3.4	Alliances between large firms and DBFs pmC	NA	NA
3.5	Biotech Revenues % GDP	NA	Existing figures not Reliable.
3.6	Drug Approvals pmC	1980-02	Excludes vaccines, rattlesnake anti-venom, biotech skin, diagnostics, etc. Possible double count for drugs developed by two firms of different nationalities.
3.7	Field Trials in GMO crops per 10^9 GDP in Agriculture	1996-01	For the US: Animal and Plant Health Inspection Service (APHIS) of the USDA. For EU data: JRC (Joint Research Council), Summary Notification Information Format (SNIF) database, European Commission.
3.8	Average Score Knowledge About Biotech	2000	EUROBAROMETER 52.1

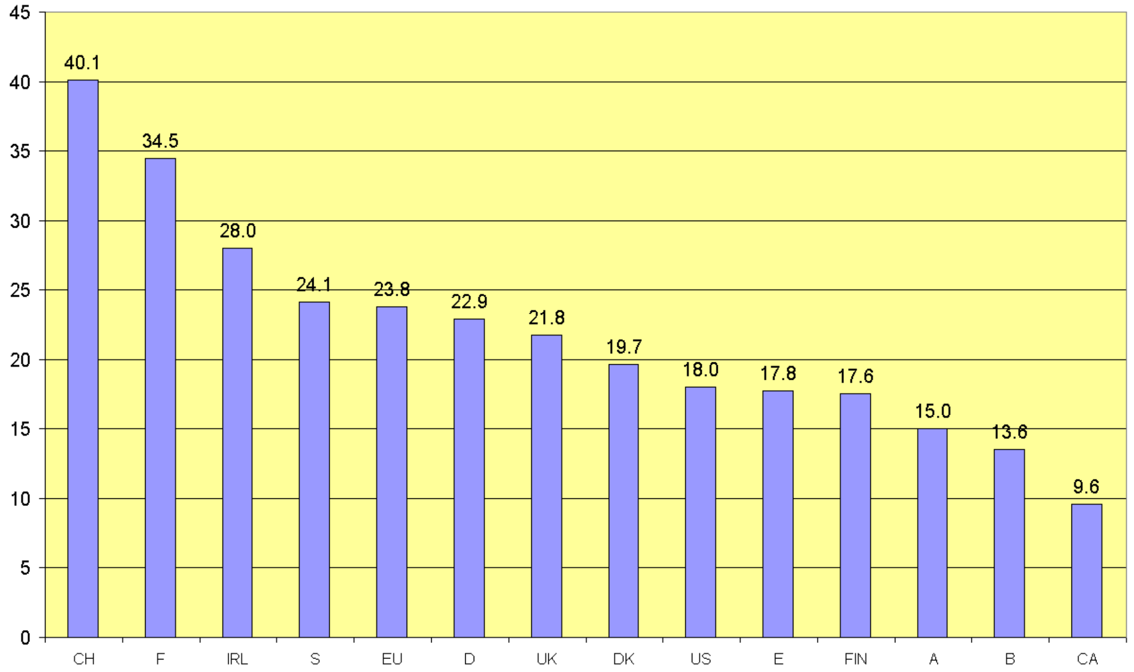
Table C2. Biotechnology Innovation Scoreboard

No	Indicators	EU	A	B	D	DK	E	FIN	F	GR	IRL	I	L	NL	P	S	UK	NO	CH	US	CA	JP
PART 1. Human Resources and Creation of New Knowledge																						
1.1	PhD. Grads in Life Sciences pmC[1]	23.8	15.0	13.6	22.9	19.7	17.8	17.6	34.5	--	28.0	--	--	--	--	24.1	21.8	--	40.1	18.0	9.6	--
1.2	Gov. Biotech. R&D % GDP	0.028	0.005	0.052	0.032	0.019	0.002	0.049	0.035	0.004	0.015	0.004	--	0.019	0.017	0.027	0.050	0.032	0.004	--	--	--
1.3	Biotech Publications pmC	94.8	88.5	114.2	87.6	192.7	61.5	152.3	99.6	29.0	80.5	54.6	31.9	138.4	39.9	195.8	140.0	106.2	242.8	116.1	122.1	68.8
1.4	Citations per publication in Biotech	7.1	8.0	8.4	9.2	7.5	5.4	8.3	8.1	4.3	6.0	6.6	4.2	8.8	4.1	8.5	9.5	6.6	12.4	12.2	9.2	6.6
1.5	Biotech EPO patents applications pmC	4.5	1.5	13.5	6.3	17.0	0.3	2.7	3.6	0.0	1.8	0.6	0.0	19.2	0.2	5.9	4.7	1.6	15.2	6.4	3.8	2.9
1.6	Biotech USPTO patent pmC	1.8	0.9	3.4	1.9	12.0	0.2	5.0	2.0	0.1	0.5	0.5	0.0	3.1	0.0	4.1	2.2	1.8	3.9	9.9	4.1	2.6
PART 2. Transmissions and Application of New Knowledge in Biotechnology																						
2.1	CRA[2] PSRO-Industry pmC	0.127	--	--	0.085	--	--	--	--	--	--	--	--	--	--	--	0.184	--	1.392	0.287	0.130	0.150
PART 3. Innovation finance, outputs and markets																						
3.1	Dedicated Biotech Firms pmC	5.4	1.4	5.4	6.1	9.6	0.8	10.2	5.8	--	10.3	1.1	--	5.0	--	26.5	7.5	8.2	12.9	4.6	10.4	0.9
3.3	Biotech Venture Capital % GDP	0.0094	0.0028	0.0257	0.0240	0.0229	0.0001	0.0049	0.0051	0	0	0.0005		0.0048	0	0.0135	0.0051	0.0054	0.0005	--	--	--
3.6	Drug Approvals pmC	0.114	--	0.098	0.036	1.124	--	--	0.119	--	0.528	--	--	0.126	--	--	0.100	--	1.531	0.305	0.065	--
3.7	Field Trials in GMO crops 10^9 GDP in Agriculture	6.8	0.6	19.9	4.0	5.6	7.7	4.9	9.3	2.4	0.8	7.2	--	3.6	2.1	12.0	8.4	--	--	45.9	--	--
3.8	Average Knowledge About Biotech	41.7	38.1	45.5	40.5	53.3	38.8	49.7	44.7	36.9	33.8	38.3	42.7	57.4	30.0	58.1	40.5	--	--	--	--	--

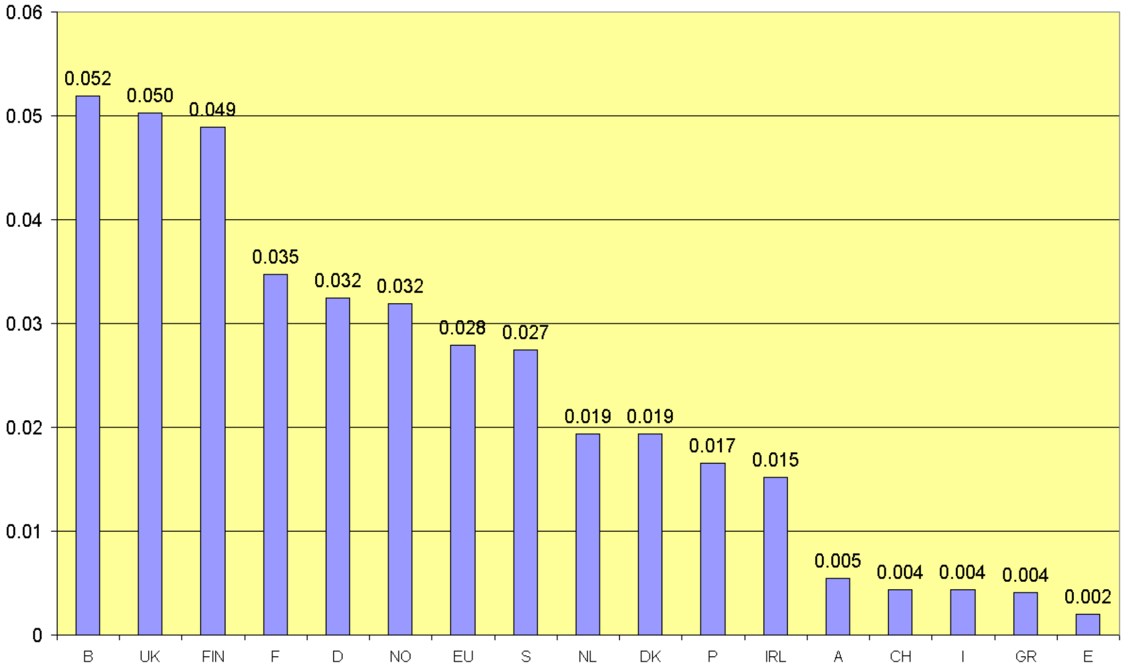
Indicators are highlighted in blue when 25% above the EU mean and in red when 25% below the EU mean.

1. pmC: per million capita.
2. CRA: Collaborative Research Agreements.

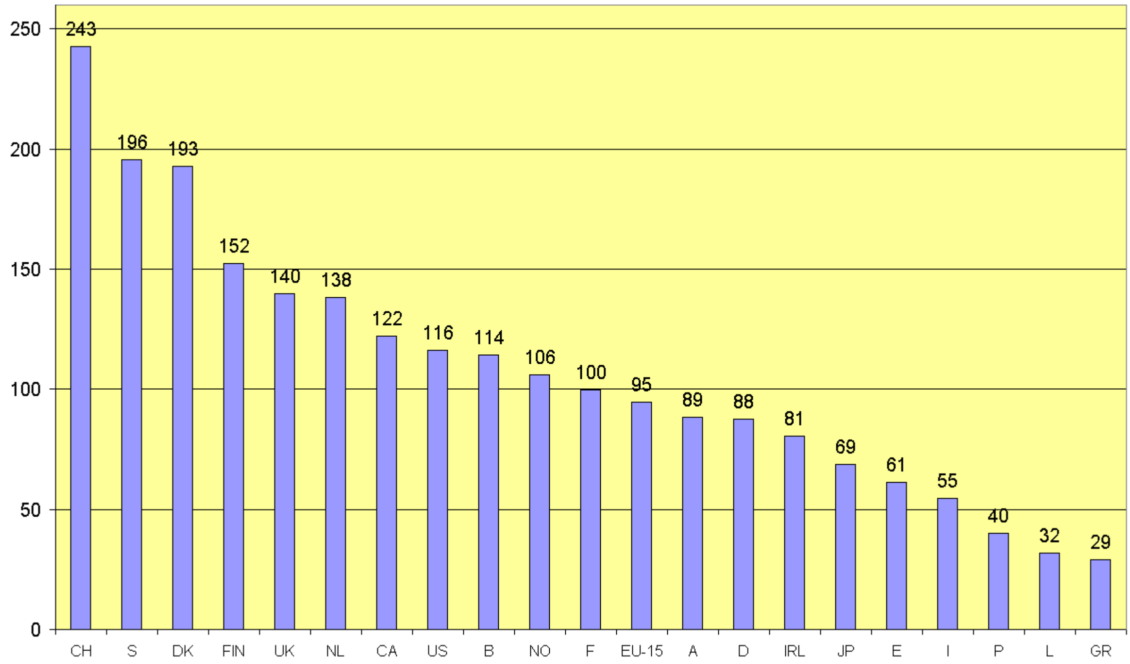
Graph C11. PhD. Graduates in Life Sciences pmC (1999)



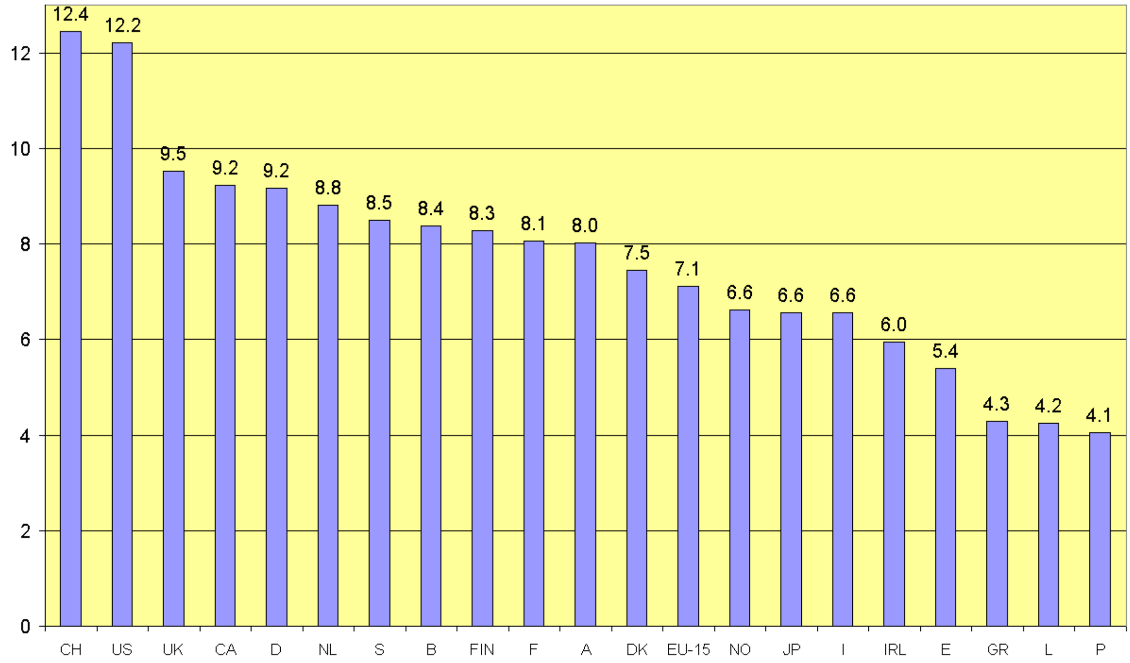
Graph C12. Government Biotechnology R&D Expenditures As Percentage of GDP (1994-1998)



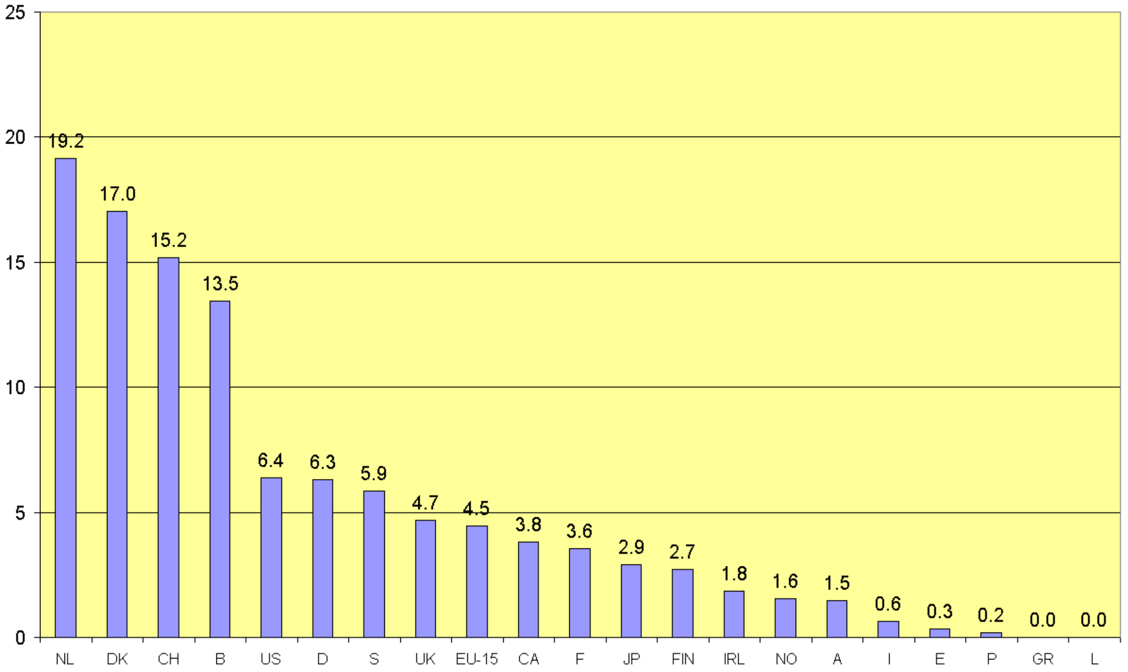
Graph C13. Biotechnology Publications pmC (2000)



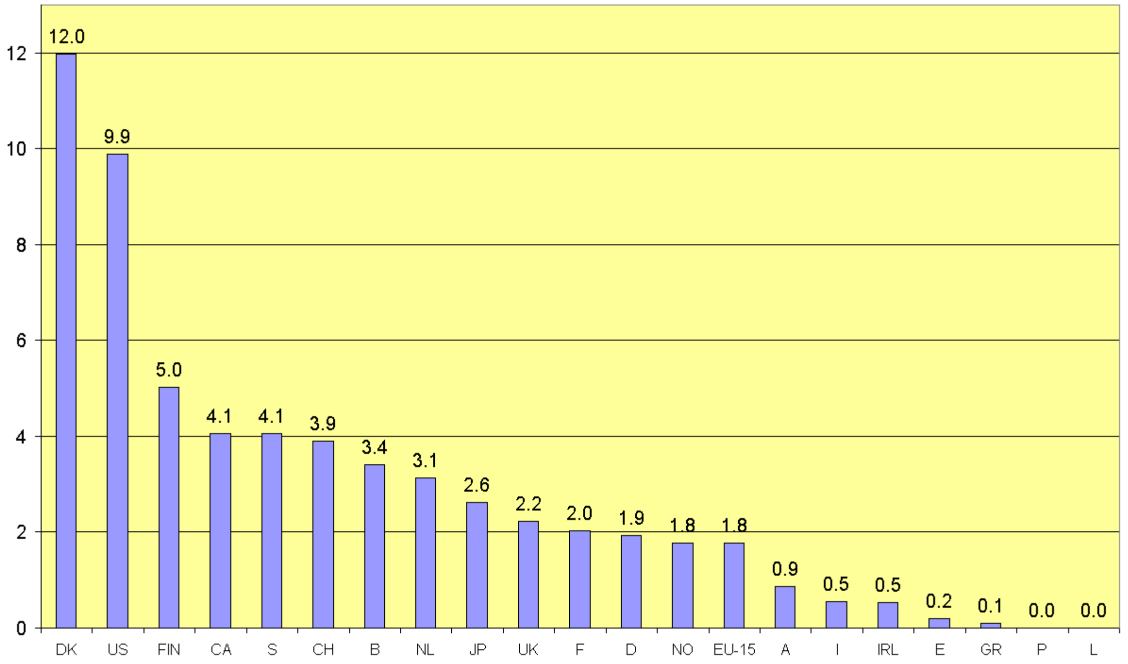
Graph C14. Citations Per Publication in Biotechnology (1996-2000)



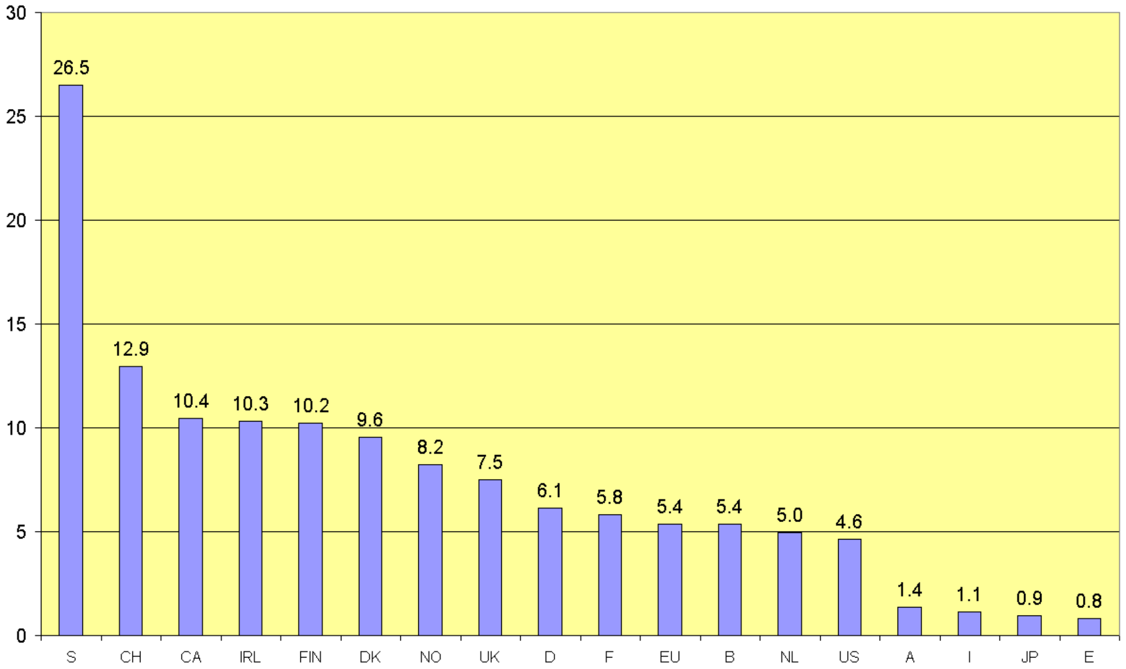
Graph C15. Biotechnology EPO Patent Applications pmC (2001)



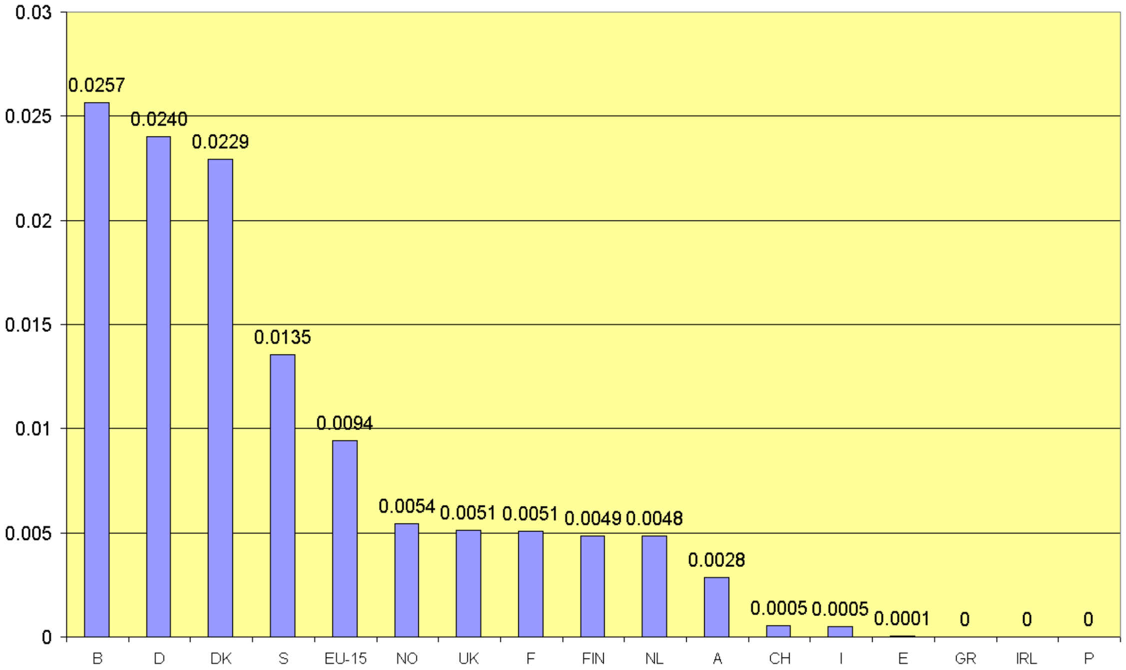
Graph C16. Biotechnology USPTO Patent pmC (2000)



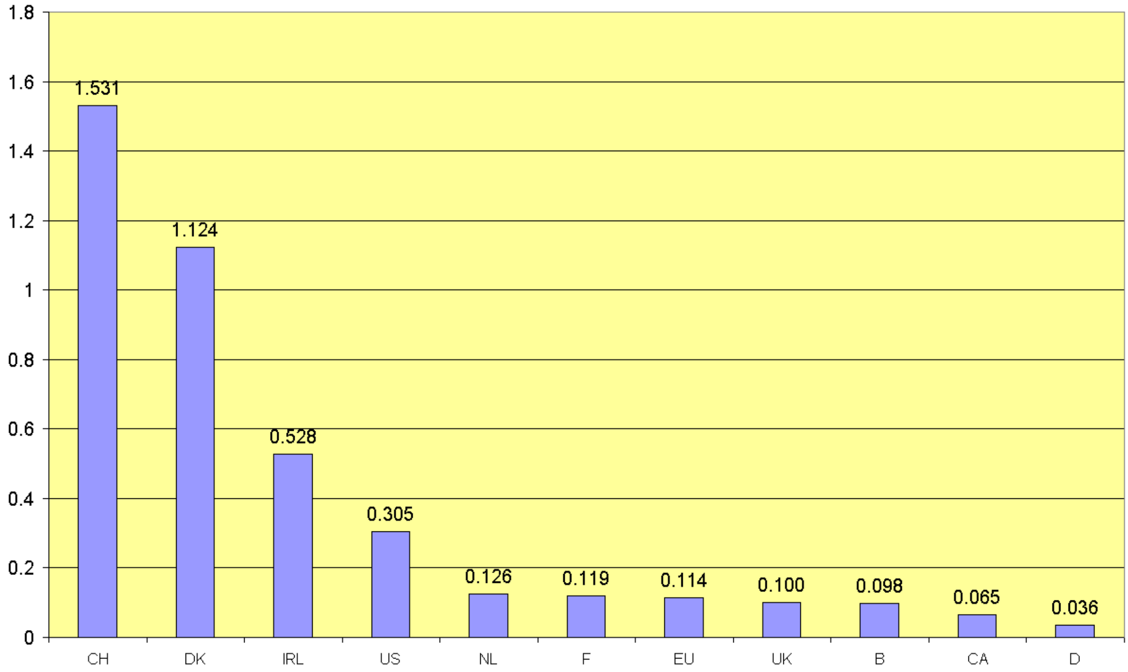
Graph C31. Number of dedicated Biotechnology Firms pmC (2000)



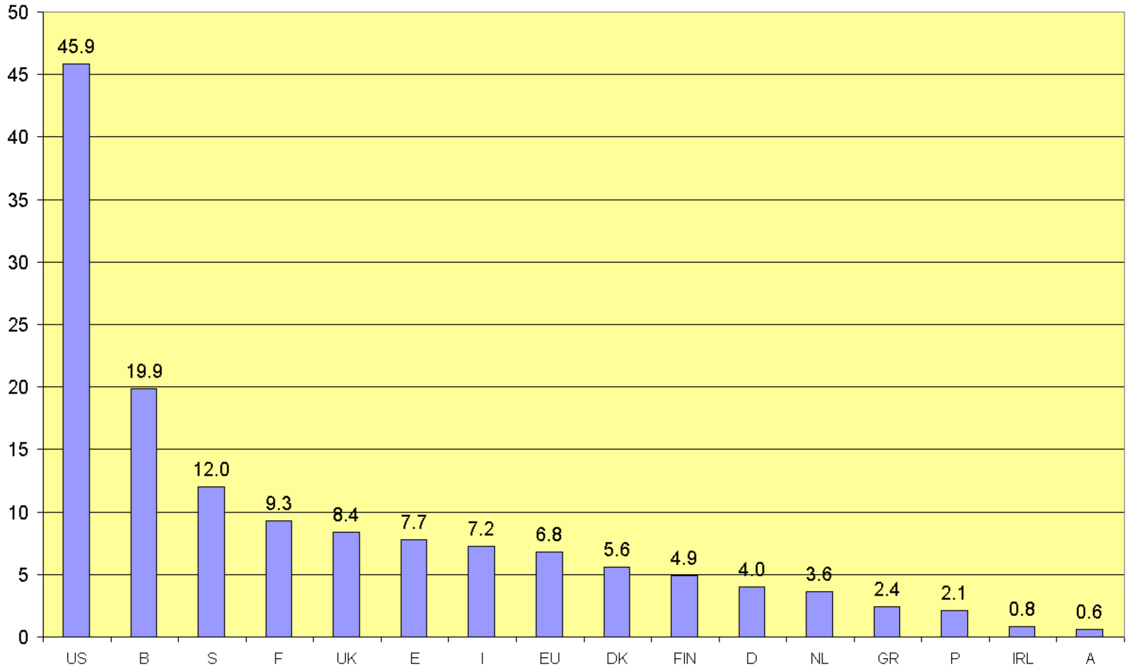
Graph C33. Biotechnology Venture Capital As Percentage of GDP (2001)



Graph C36. Number of Drug Approvals pmC (1980-02)



Graph C37. Number of Field Trials per Billion GDP in Agriculture (1996-01)



Graph C38. Average Score in Biotechnology Knowledge (2000)